Nebraska Water Resources Center

Annual Technical Report

FY 2000

Introduction

Welcome to the University of Nebraska Water Center's annual report for FY 2000. If you have any questions, please contact Kyle Hoagland at (402) 472-3305. Thank you.

Research Program

Basic Information

Title:	Determination of Aquifer and Aquitard Hydraulic Properties and Their Role in Streamflow Depletion
Project Number:	C88
Start Date:	9/1/1998
End Date:	8/31/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Models, Water Use
Descriptors:	Aquifer parameters, conjuntive use, groundwater modeling, surface-groundwater relationships, well hydraulics
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Xun-Hong Chen, James Goeke, Robert F. Diffendal

Publication

1. Chen, X. H. 2001. Migration of induced-infiltrated stream water into nearby aquifers due to seasonal groundwater withdrawal, Ground Water (in press).
2. Huang, Huihua, 2000. Evaluation of stream-aquifer interaction considering streambed sediment and stream partial penetration effects, M. S. thesis, University of Nebraska-Lincoln (partially supported).
3. Chen, X. H., 2000. Streamflow depletion due to groundwater irrigation: analysis of reduced baseflow and induced stream infiltration.Proceedings of the International Symposium on Hydrogeology and the Environment, October 17-21, 2000, Wuhan, China.

RESEARCH

Project Number: C-88 Start: 09/01/98
End: 08/31/2001

Title:
Determination of Aquifer and Aquitard Hydraulic Properties and Their Role in Streamflow Depletion

Investigators:
Dr. Xun-Hong Chen, Professor Jim Goeke, and Dr. Robert Diffendal, Jr.
University of Nebraska-Lincoln

Congressional District: NE 1

Focus Category: GW

Descriptors: Aquifer parameters, Conjunctive use, Groundwater modeling, Surface-groundwater Relationships, Well hydraulics

Problem and research objectives:
Problem: Streamflow depletion caused by groundwater withdrawal.
Objectives: 1) to apply new methodologies for collecting high quality pumping and recovery test data and for determination of reliable hydraulic properties of aquifers and aquitards; and 2) to analyze the role of aquifer and aquitard hydraulic conductivity in streamflow depletion due to groundwater pumpage for irrigation.

Methodology:
Design and construction of monitoring wells in alluvial aquifers, which connects to streams; Long-term groundwater level monitoring for determination of recharge and the responses of aquifer to groundwater pumping; Conducting pumping tests in an unconfined aquifer and in a multi-layered aquifer-aquitard system; Determination of aquifer and aquitard hydraulic properties; Analysis of the role of aquifer and aquitard hydraulic properties in streamflow depletion using numerical modeling analysis; Determination of the stream depletion processes: baseflow reduction and induced stream infiltration.

Principal findings and significance:

1. The aquifer test data from the Wood River site have been analyzed, and the results have been used to support our methodology regarding an optimal design of aquifer tests in unconfined aquifers. A manuscript describing this methodology has been submitted to Ground Water for review.
2. The roles of aquifer and aquitard hydraulic properties in stream depletion have been analyzed and we find that baseflow reduction is a major component in the

total stream depletion for many irrigation wells. A manuscript has been submitted to Ground Water for review.

3. In the analysis of the deep-well and shallow-well aquifer tests and long-term groundwater monitoring data at the second test site (Shelton, Nebraska), we found that the alluvial aquifer at this site, which is traditionally considered as unconfined aquifer, shows a hydrologic behavior of a confined aquifer. A manuscript is in preparation for this finding and will be submitted to Ground Water.
4. A numerical model of the stream-aquifer systems (the Platte River, the alluvial aquifer and the Ogallala Group) in the central Nebraska has been designed using MODFLOW. The interactions among the hydrologic processes (recharge, evapotranspiration, groundwater pumpage, stream gaining, stream losing, and boundary flows) for the study area have been analyzed to understand the hydrologic cycle in this area.

Basic Information

Title:	Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal
Project Number:	C66
Start Date:	9/1/1998
End Date:	8/31/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Methods, Water Quantity
Descriptors:	Surface-Groundwater Relationships, Groundwater Movement, Streams, Groundwater Hydrology
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Vitaly A. Zlotnik, Xun-Hong Chen, James Goeke, James J. Butler, Marios Sophocleous, Carl McElwee

Publication

1. Butler, J.J., Jr., Zlotnik, V.A., and M.-S. Tsou, , 2001, Drawdown and stream depletion produced by pumping in the vicinity of a partially penetrating stream, Ground Water, 39(5), in press.
2. Huang, Huihua, 2000, M.S. Evaluation of stream-aquifer interaction considering streambed sediments and stream partial penetration effects. University of Nebraska, Lincoln.
3. Kollet, S., and V.A. Zlotnik, 2000, Field approach to stream-aquifer interactions under pumping and non-pumping conditions: Prarie Creek, Nebraska, GSA Abstracts with Programs, Reno, Nevada, Nov. 9-18, p. A60
4. Cardenas, M.B., and V.A. Zlotnik, 2000, Mapping modern hetrogeneous streambed deposits through hydraulic testing, GSA Abstracts with Programs, Reno, Nevada, Nov. 9-18, p. A360.
5. Tsou, M.-S., and J.J. Butler, Jr., 2000, An analytical solution to assess the influence of anisotropy and stream-channel characteristics on aquifer response to stream-stage fluctuations (abstract), EOS, v. 81, no. 48, p. F422.
6. Butler, J.J., Jr., and M.-S. Tsou, 2000, Mathematical derivation of drawdown and stream depletion produced by pumping in the vicinity of a finite-width stream of shallow penetration, Kansas Geological Sruvey Open-File Rept. 2000-8.
7. Butler, J.J., Jr., and M.-S. Tsou, 2000, Aquifer response to stream-state fluctuations in a partially penetrating stream (abstract), EOS, v. 81, no. 19, p. S218.

1. RESEARCH

PROJECT NUMBER: **Start: 9/1/98**
End: 8/31/01

TITLE: HYDRAULIC CHARACTERIZATION OF THE STREAM-AQUIFER INTERFACE: THEORY, FIELD IMPLEMENTATION, AND PRACTICAL RAMIFICATIONS - A MULTI-STATE PROPOSAL.

INVESTIGATORS:
PI: Vitaly A. Zlotnik, Dept. of Geology, University of Nebraska-Lincoln
James J. Butler, Jr., Kansas Geological Survey, University of Kansas
Co-PI: Xunhong Chen, Conservation and Survey Division, Univ. of Nebraska-Lincoln
Jim Goeke, Conservation and Survey Division, University of Nebraska-Lincoln
Marios Sophocleous, Kansas Geological Survey, University of Kansas
Carl McElwee, Kansas Geological Survey, University of Kansas

CONGRESSIONAL DISTRICT OF UNIVERSITY:
University of Nebraska-Lincoln - Nebraska District # 1
University of Kansas - Kansas District # 3

FOCUS CATEGORY: GW, MET, WQN

DESCRIPTORS: Surface-Groundwater Relationships, Groundwater Movement, Streams, Groundwater Hydrology

PROBLEM AND RESEARCH OBJECTIVES: Surface-ground water interactions are often a key component of the hydrologic budgets of aquifers and streams. In Nebraska and Kansas, as well as many other areas in the Great Plains and elsewhere in the United States, these interactions have significant socio-economic and political ramifications. As illustrated by the numerous interstate conflicts that have arisen from disagreements concerning the impact of groundwater pumping on stream flow, there is a critical need to quantify the volumes involved in water exchanges between streams and aquifers. A key element of efforts to quantify stream-aquifer interactions is the estimation of the impact of pumping from alluvial aquifers on stream flows. Although several theoretical methods for estimation of pumping-induced water transfers have been developed over the last 50 years, these methods are based on mathematical models of hypothetical flow systems that often bear little resemblance to stream-aquifer systems in the Great Plains. Recent work has shown that these simplistic models can introduce significant errors into estimates of the impact of groundwater pumping on stream flows as a result of their neglect of critical aspects of the stream-aquifer interface, specifically the near-stream channel.

The three major objectives of this research are:

(1) develop transient models of stream-aquifer interactions that are suitable for estimation of stream depletion in conditions typically found in the Great Plains, i.e. shallow stream penetration, large stream width-to-depth ratios, and imperfect hydraulic connection between the stream and aquifer. As much as possible, emphasis will be placed on the development of analytical models that can serve as convenient-to-use alternatives to present approaches;

(2) develop field methodology for evaluation of the hydraulic characteristics of the stream-aquifer interface. Particular emphasis will be placed on passive and active monitoring approaches that use aquifer head responses to stream-stage fluctuations and pumping for estimation of the hydraulic parameters of the near-stream portions of the aquifer. The methodology will be assessed at representative sites in Nebraska and Kansas;

(3) develop a Atool set@ of field and modeling procedures that will allow a more realistic depiction of the stream-aquifer interface to be incorporated into the technical basis of stream-aquifer related administrative decisions.

<u>METHODOLOGY</u>: Theoretical investigations emphasized the development of accurate two-dimensional models of bank storage effects, stream depletion, and drawdown near the shallow, partially penetrating streams of a finite width. These models explicitly consider conditions of the shallow penetration, low-permeable streambed sediments, and narrow alluvial valleys common to the Great Plains and many other areas of the United States. Three major results include: (1) aquifer response to stream stage fluctuations, (2) stream depletion, and (3) head drawdown under pumping conditions near partially penetrating streams. Results were compared to the previously known models of stream depletion. In addition, these models were verified by comparing to three-dimensional finite-difference numerical models that consider aquifer anisotropy and various degrees of penetration.

Field studies in Nebraska on Prairie Creek watershed (Platte River tributary) emphasized both passive (without pumping) and active (with pumping) methods of investigation. Over period 1999-2001, head data were collected in numerous piezometers continuously. Due to the extremely dry summer of 2000, Prarie Creek did not have a runoff in July. Two pumping tests with pumping rate 1200 gpm B with water in the stream and without - were performed in June and July, 2000. Developed theoretical models were applied to interpretation of obtained data using least square based identification algorithms to assess their advantages and limitations.

Field studies in Kansas emphasized use of direct-push methodology to characterize the hydrostratigraphy in the vicinity of a stream. A direct-push electrical conductivity sensor was calibrated using cores, water samples, and conventional geophysical logging. Approach was then applied at two stream-aquifer sites.

<u>PROGRESS REPORT:</u> Field studies on the Prairie Creek watershed, Nebraska (Platte River tributary) indicate that parameters obtained from applications of the developed passive methods (bank storage effects) and active methods (pumping tests) using two-dimensional models are consistent. Weather conditions on the watershed were found to be a significant factor in groundwater-surface water interactions. Interpretation of three-dimensional field data involves consideration of water table conditions and positions of piezometers. The introduced leakance parameter can be used for streambed characterization in different

hydrogeological conditions. If this parameter is available from active or passive methods, the accurate evaluation of stream depletion is possible.

In Kansas, the field component of the research was concentrated on the search for appropriates sites and exploring the potential of "direct-push" methodology. Five field areas were investigated: the Neosho River at Emporia, and the Arkansas River at Dodge City, Kinsley, Larned, and Great Bend. As part of an extension of this project, field sites are being set up at the Kinsley, Larned, and Great Bend sites in the summer of 2001. Direct-push electrical conductivity logging was shown to be a powerful tool for hydrostratigraphic characterization. This methodology will replace conventional drilling for installation of near-stream piezometers and should greatly improve characterization approaches in the near-stream portions of the aquifer. Direct-push surveys were performed at the Dodge City and Emporia sites during this study.

Further progress has been made in the development and applications of analytical models of stream-aquifer interaction. These models explicitly consider conditions of shallow penetration and low-permeable streambed sediments common to the Great Plains and many other areas of the United States. Three major results include: (1) aquifer response to stream stage fluctuations, (2) stream depletion, and (3) head drawdown under pumping conditions near partially penetrating streams. This work has a significant element of novelty and resulted in peer-reviewed publications and conference presentations.

Basic Information

Title:	Reducing Atrazine Contamination of Interstate Surface Water
Project Number:	C55
Start Date:	9/1/1997
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Water Quality, Agriculture
Descriptors:	Atrazine, economics, modeling, runoff, water quality
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Thomas George Franti, Brian Benham, Dean E. Eisenhauer, Roger A Selley, Philip Barnes, Dan Devlin

Publication

1. Gorneau, W.S., T.G. Franti, and B.L. Benham. 1998. Evaluation of Tillage and Herbicide Application Practices Using a Calibrated GLEAMS Model. Presented at Mid-Central ASAE Meeting, St. Joseph, MO, April 24-25, 1998. Paper No. MC98-184.
2. Gorneau, W.S., T.G. Franti, and B.L. Benham. 1998. Evaluation of Best Management Practices for Reducing Herbicide Loading to Interstate Waters NE-KS. Presented at ASAE International Meeting, Orlando, FL, July 11-16, Paper No. 98-2223.

SYNOPSIS

Project Number:_C55____________ Start: 9/96 End: 12/98

Title: Reducing Atrazine Contamination of Interstate Surface Water

Principal Investigators:

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Collaborators:

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Brian Benham, Biological Systems Engineering
Dean Eisenhauer, Biological Systems Engineering
Bill Miller, Agricultural Economics
Roger Selley, Agricultural Economics

Kansas State University
Dan Devlin, Agronomy

Congressional District of University: Nebraska, District 1

Focus Category: WQL, ECON, AG

Descriptors: Atrazine, economics, modeling, runoff, water quality

Statement of Critical Regional and State Water Problem

Throughout the U.S., herbicides are appearing in surface water at concentrations greater than established standards, or maximum contaminant levels (US EPA, 1992; Snow and Spalding, 1993; Goolsby and Battaglin, 1993). Concentrations of herbicides in surface water in the Midwest are highest after heavy spring and summer runoff events that carry large quantities of runoff into rivers and lakes (Stamer, 1993). The U.S. Geological Survey's National Water Quality Assessment (NAQWA) program has documented that atrazine concentrations in surface water in northeast Kansas and southeast Nebraska often exceed the maximum contaminant level (mcl) of 3.0 *ug/L* (micrograms per liter) established by the U.S. Environmental Protection Agency under the Safe Drinking Water Act of 1986 (Fallon and McChesney, 1993).

The Blue River Basins comprise a 7,200 square mile agricultural watershed in Kansas and Nebraska, and includes the Big Blue River and Little Blue River in Nebraska and Tuttle Creek Reservoir in Kansas. Currently, elevated atrazine concentrations in surface water in the Blue River Basins are of concern to some Kansas municipalities, and are a common problem throughout the Midwest wherever surface water is used for drinking water. Atrazine was the herbicide most frequently detected in samples of surface water collected and analyzed by the

U.S. Geological Survey from March 1989 to February 1990 in the lower Kansas River Basin, which includes the Blue River Basins. Atrazine concentrations in Tuttle Creek Reservoir have on occasion exceeded the maximum contaminant level for drinking water (3 ppb). Water from Tuttle Creek Reservoir is used for drinking water by Topeka and Kansas City, Kansas (combined population greater than 275,000). Atrazine is a special problem for public drinking water supplies because it is not removed by conventional water treatment.

Objectives of Research

This project is part of a larger three Phase project that is being implemented in the Blue River Basins by the University of Nebraska-Lincoln (UNL) and Kansas State University (KSU). The project phases are: I) determine atrazine concentrations in surface water runoff from targeted Blue River Basin watersheds in Nebraska and Kansas; II) evaluate the economic and water quality impact of proposed management practices for atrazine; and, III) transfer knowledge gained into atrazine practice changes in targeted subwatersheds.

Objectives

The objectives of this project are:

1. Obtain atrazine runoff data from replicated field plots to evaluate several atrazine management practices for dryland and irrigated agriculture.

2. Use modeling to evaluate the economic and surface water quality impact of atrazine management alternatives.

Methodology

This project will build on current field research in both Kansas and Nebraska. Kansas has conducted research for several years on the runoff of atrazine and alachlor at the Foster Research/Demonstration site near Rossville, Kansas. Herbicides have been applied to three fields under established ridge-till and no-till conditions. In Nebraska, atrazine runoff from three fields, each under different tillage/herbicide management practices has been monitored for the past two years. Evaluating the impact of management practices on atrazine losses has been the primary focus of these field studies. Through modeling, this proposed project will provide additional insight into the economic dimension and the long-term water quality impact of atrazine management practices, and provide the information needed to recommend effective best management practices that are technically sound and economically viable for dryland and irrigated producers.

Project Locations:

The 10-acre KSU Foster Research/Demonstration site is located in northeast Kansas, near Rossville and consists of three fields in row crop. The soil is a Wabash silty-clay loam with a slope ranging from 5% to less than 1%, which is representative of northeast Kansas. In 1990, the site was designed and developed; terraces and berms were built; and sampling equipment was installed. Sampling equipment includes a gage house, automated samplers, data loggers, and a weather station.

The south part of the field is terraced with underground outlets. Each terrace is drained by a separate pipe, allowing measurement and sampling of the individual terraces if desired. The north field is separated from the terraced side by a grassed berm, preventing runoff from mixing. A berm across the top of the slope prevents any runoff from entering from outside the fields. A second grassed berm on the north side of the grass filter strips field guides runoff to the sampling point. After the 1991 harvest the site was modified to implement planting the fields on the contour.

In the fall of 1991, a third field was established just north and adjacent to the nonterraced field. This third field was designed to have similar slope and size as the existing fields and was set up to examine the effect of ridge-till cultivation on herbicide transport. The KSU site will be used to evaluate the runoff of atrazine from non-irrigated no-till and ridge-till treatments, planted to continuous corn.

The UNL study site is located at the South Central Research and Extension Center (SCREC) research farm near Clay Center, Nebraska. This field is 392 m long and 392 m wide, and is furrow irrigated with a gated pipe source. Soils at the study site are Hastings silt loam (Udic Argiustoll). The soils are moderately well drained on uplands, fine, montmorillonitic, and mesic. This site will be used to evaluate atrazine runoff from three replicates of the following tillage treatments, which have been in place since 1976: disk and surface plant (conventional), ridge till, and slot plant (no-till with cultivation). The treatments are arranged in a randomized complete block design. Continuous corn is grown on the plots and the field slope is 0.5%. The plot width is 10 m and length is 392 m.

Facilities and Equipment:

The KSU field site is completely instrumented and has been in full operation for two years. Farming and sampling equipment and hydrologic instrumentation used to implement and evaluate agricultural practices are available onsite or at the Kansas River Valley Experiment Field; no new equipment expenditures are anticipated during the duration of the study.

At the UNL field site, each plot will be instrumented with a 2-inch Parshall flume. Two replications will be equipped with water stage recorders while the other replication will be equipped with pressure transducers for head measurement. Each flume will be equipped with two single stage samplers (Brakensiek et al., 1979) to sample the first flows at each selected stage. The UNL field location is equipped with a weather station to collect on-site weather data for use in data evaluation and model calibration.

In Kansas, atrazine is broadcast sprayed on the no-till treatments prior to planting, and is banded at planting on the ridge-till treatments. In Nebraska, atrazine is broadcast sprayed immediately after planting on each treatment, and planting, chemical application, and irrigation will occur on the same dates for each treatment.

Data on soils, including organic matter content and residue cover, field operations, atrazine application rate, land slope and drainage area will be gathered for each plot. Also, runoff rate and amount, and atrazine concentration will be determined from each plot for the first four rainfall runoff events after atrazine application, up to the first irrigation event of each year in Nebraska (usually about July 1). Two water samples collected from each plot will be evaluated for atrazine concentration using gas chromatography and the results will be used to determine atrazine runoff from each treatment.

Water Quality Modeling:

The objective of the water quality modeling will be to determine the long-term impacts of tillage and atrazine management practices on atrazine losses using computer simulation modeling. The GLEAMS model (Leonard et al., 1987), or other appropriate models will be used for the simulation study. The model will be calibrated for the Kansas dryland scenario and the Nebraska irrigated scenario using the field data discussed above. The parameters that may be adjusted during calibration include the runoff curve number, the C-value in the USLE, and the soil parameters.

Following the modeling calibration, the model will be used to determine the long-term effects of tillage and atrazine management on atrazine loading from agricultural fields to first order streams. Long-term weather data will be generated for the two sites of interest. Frequency distributions of annual peak concentrations and annual atrazine loading will be determined from simulation.

The scenarios for simulation will include the following:

Dryland: Silty clay loam soil, moderate land slope. Tillage will include no-till and ridge till.

Irrigated: Silt loam soil, low land slope, furrow irrigation. Tillage will include slot plant, ridge till and disk till.

The **herbicide treatments** to be evaluated for each scenario include broadcast spray at label rates, broadcast spray at reduced rates, banding, incorporation with tillage and split application (early pre-plant/ post-plant).

Economic Modeling

The objective of the economic modeling study will be to determine the impact of alternative tillage/atrazine management practices on net revenue. To model the economic impact of the alternative atrazine management practices it is necessary to include the impact on the timeliness of the operations performed by the producer. A whole farm model will be used because many complex economic interrelationships are altered by a change in atrazine management practices.

The economic model inputs will be the same as for the water quality model so the many similar external driving factors (e.g. soil type, weather, machinery options) are taken into consideration in evaluating the economic performance of the farm operation. The economic model will include the working field days available each week based upon historical weather patterns. Weather influences the date of tillage, planting, cultivation and herbicide application. The economic model will include the machinery complement and labor available for several operations typical of those found in the watershed. Crop yields will be influenced by the alternative dates of tillage, planting, cultivation, and herbicide application. Model results for alternative cases will permit comparisons of net revenue among the different atrazine management practices.

Principal Findings and Significance

Field experiments were performed by measuring edge-of-field atrazine and water loss from disk-till, ridge-till, and slot plant (no-till) management systems. Runoff measurements in south central Nebraska were conducted with 0.12 ha plots on a silt loam soil with 0.5% slope. Results indicated less water runoff from no-till (34% less) and ridge-till (36%) than disk-till. Similarly, atrazine loss was also less; 24% less for no-till and 17% less for ridge-till than disk-till. GLEAMS simulations were calibrated using field-measured inputs and verified against observed data form two independent sites in south central Nebraska. Simulations were performed using 50 yr of rainfall data and 15 different combinations of herbicide application and tillage practices. Compared to pre-emergent broadcast + post application on corn with disk-till, annual reductions in atrazine loss for the alternative practices ranged from 17 to 77% in south central Nebraska and from 4 to 66 % in northeast Kansas. The percent of total atrazine lost ranged from 0.57 to 1.2 % in south central Nebraska and 3.7 to 7.1% in northeast Kansas. By evaluating the annual losses occurring during the 50 yr simulation, we found that for broadcast and banded applications, annual losses from 7 to 10 years constituted >50% of the total 50-year loss. Based on recurrence interval evaluation, pre-emergent incorporation and pre-emergent banding were most effective at reducing long-term atrazine losses at both locations.

Project Accomplishments

One Masters degree candidate graduated with thesis completed.

Two years of field data collected.

Project is continued and expanded through a USDA Fund For Rural America grant and two additional years of field data collected.
Project sites used for annual field demonstrations and for 1998 Blued River Basins Water Quality Tour.

Results of research shared at Extension meetings and presentations.

Continuation of Project

Economic evaluation was not conducted.

Project is completed.

Basic Information

Title:	A Test of Permeable Zero-valent Iron Barriers for In-Situ Containment and Remediation of Pesticide Contamination in Unsaturated Soils
Project Number:	C34
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Water Quality, Toxic Substances, Solute Transport
Descriptors:	Remediation, Zerovalent Iron, Chemical Reduction, Pesticides, Permeable Reactive Barrier, Soils
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	PATRICK JOHN SHEA, Steve Comfort

Publication

1. Comfort, S.D. P.J. Shea, T.A. Machacek, H. Gaber, and B.-T. Oh. 2001. Field-scale remediation of a metolachlor-contaminated spill site using zerovalent iron. J. Environ. Qual. 30:(in press).
2. Satapanajaru, T., C.L. Gibb, P.J. Shea, S.D. Comfort, and T.A. Machacek. 2000. Aluminum and ferrous sulfate catalyzed destruction of metolachlor by zerovalent iron. Abstr. Am. Soc. Agron. 92:411.
3. Shea, P.J., and S.D. Comfort. 2000. Iron-mediated remediation of contaminated soil and water. Proc. Int'l Symp. Korean Soc. Agric. Chem. Biochem. Oct. 27-28, Chonan, Korea.

Problem and Research Objectives

Problem. Zerovalent iron [Fe(0)] barriers have become an established technology for remediating ground water contaminated with halogenated hydrocarbons (Wilson, 1995). Metallic iron is an avid electron donor and its oxidation [standard reduction potential (Eh) = -0.409 V] can drive the reduction of many redox-sensitive contaminants. While oxygen is the normal electron acceptor during iron corrosion in aerobic environments, under anaerobic conditions such as those encountered in ground water, waterlogged soils or artificial impoundments (e.g., runoff ponds), electron transfer-mediated reactions of many chlorinated contaminants can occur. Permeable reactive barriers (PBR) are particularly attractive for in-situ remediation because they provide long-term solutions with low operating costs and are less expensive than conventional cleanup methods (O'Hannesin and Gillham, 1998). Although in situ PRBs have been successfully used to remediate chlorinated solvents in ground water, this technology has yet to be applied in unsaturated soils. A natural obstacle to this practice is the accelerated aging of iron and loss of reactivity resulting from oxygen in the soil atmosphere. Despite this apparent limitation, situations could arise where soil and site characteristics (i.e., depth to ground water) would allow horizontal placement of a PRB below the source of contamination. One potential application for this approach is the numerous point-sources of contamination caused by pesticide spills. In practice, contaminated soils would be excavated, a permeable iron barrier palced in the pit, and the soil replaced. Theoretically, as the pesticide desorbs from the soil matrix and migrates through the iron barrier it would be transformed and further degraded in the subsoil.

This study was conducted in conjunction with a larger field-scale demonstration project where contaminated soil from a metolachlor spill site was treated with zerovalent iron in large windrows (Comfort et al., 2001). Results from this field trial showed that metolachlor concentrations were decreased by 72 to 99% within 90 days following treatment with various combinations of Fe(0), acetic acid and aluminum sulfate. Although the metolachlor concentrations were dramatically reduced, the potential for leaching from the treated soil remained, especially if the soil was returned to the original runoff pit. To counrteract this potential problem, it was proposed that a permeable iron barrier be placed n the bottom of the excavated pit before returning the treated soil.

Objectives.

1. Determine the effects of iron sources, aluminum and iron salts on the efficiency of zerovalent iron as a remedial treatment for metolachlor-contaminated soil.

2. Conduct a series of soil column experiments to determine the capacity of Fe(0) to transform metolachlor under unsaturated flow.

References.

O'Hannesin, S., and R. Gillham. 1998. Long-term performance of an in-situ iron wall for remediation of VOCs. Ground Water 36:164-170.

Wilson, E.K. 1995. Zero-valent metals provide possible solution to groundwater problems. Chem Eng. News 73:19-22.

Methodology.

Batch Experiments. Batch experiments were conducted to determine the capacity of Fe(0) to transform metolachlor. Aqueous solutions of metolachlor (0.91 mM) were prepared from the commercial product Dual 8E (Syngenta, Greensboro, NC) and spiked with C-14 radiolabelled metolachlor. The metolachlor solutions were treated with 12.5 g annealed Fe(0) (indirectly heated under a hydrogen/nitrogen atmosphere). At preselected times, multiple aliquots were removed and analyzed by high performance liquid chromatography (HPLC) and liquid scintillation counting (LSC). In one experiment, the optimum aluminum sulfate concentration required for efficient metolachlor destruction was determined.

Transport Experiments. Transport experiments were conducted in 20-cm (5-cm diameter) Plexiglass columns. Soil columns were prepared by uniformly packing washed silica sand into the columns to yield a bulk density of approximately 1.5 Mg/m3. The columns were equipped with two end caps secured with O-rings that fit closely inside the columns. The bottom cap supported a porous plastic plate with an air entry pressure of 100 KPa; the top end plate secured the eluent delivery tube. Eluent was applied with a perstaltic pump set to deliver approximately 1.8 mL/h. Columns were attached to vacuum chambers. The fraction collector contained multiple glass tubes that advanced beneath the columns after collecting approximately 13 mL of effluent. A vacuum pump connected to the chambers provided a constant matrix potential.

Soil columns were wetted from the bottom and attached to the vacuum chambers set to -30 kPa. Once the initial drainage had been collected, 3 mM calcium chloride was applied to the top of the columns. After steady flow was established, the eluent was switched to a pulse of C-14 metolachlor in tritiated water. The tritiated water served as a water-tracer for characterizing transport proceses. After the metolachlor pulse had passsed through the columns, the eluent solution was switched back to the calcium chloride solution. Effluent fractions were analyzed for C-14 and H-3 activity, metolachlor and dechlorinated metolachlor. Additional column experiments were conducted using 16 cm of metolachlor-contaminated soil in place of the sand.

Principal Findings and Significance

Batch Studies. Batch experiments indicated that metolachlor destruction was significantly enhanced by adding small amounts of aluminum sulfate (0.5 g) with the annealed iron (12.5 g), and stoichiometric recovery of chloride released from metolachlor was observed. Temporal changes in metolachlor concentration and C-14 activity indicated that two mechanisms were likely operative when the annealed iron was used alone. Initial loss of metolachlor mimicked loss of C-14 activity, indicating adsorption to the iron surface was the primary mechanism. After 24 hours, the solution became black due to the formation of magnetite (Fe_3O_4) and temporal changes in metolachlor concentration decreased beyond what could be explained by adsorption alone (based on C-14 data). This observation coupled with the release of chloride indicated that dechlorination was responsible for loss of metolachlor after 24 h.

When aluminum sulfate was added with the Fe(0), the rapid stoichiometric recovery of chloride and less C-14 loss from solution indicated that dechlorination was the primary mechanism. The addition of aluminum sulfate during Fe(0) corrosion facilitated Fe(II) release and favored green rust formation. Green rusts are double-layered Fe(OH)2 sheets that contain varying amounts of Fe(III) and interlayers of anions and water molecules (Loyaux-Lawniczak et al., 2000). When Fe(II) is sornbed by the oxide surfaces, they can donate electrons and alter the electrical charge of the oxide-liquid interface and possibly facilitate electron release from the iron core. When ferrous sulfate or aluminum sulfate was added with the Fe(0), solutions turned green and transformation of metolachlor was rapid. Scanning electron microscopy indicated hexagonal crystals consistent with the formation of green rust.

Efforts were made to optimize the concentration of aluminum sulfate needed for efficient metolachlor destruction in the iron barrier. We found that the optimum concentration of aluminum sulfate for metolachlor destruction was between 1 and 4% (w/w) of the Fe(0) weight. At 1 and 2% aluminum sulfate, we observed near stoichiometric recovery of the dechlorinated metolachlor. At 4% aluminum sulfate, metolachlor as completely removed from solution but the concentration of the dechlorinated metolachlor did not account for a complete mass balance, indicating either further transformation of the dechlorinated product, formation of other products, and/or the dechlorinated product was adsorbed at the higher aluminum sulfate concentrations.

Transport Experiments. In the control column (no barrier), metolachlor and C-14 breakthrough curves (BTCs) were nearly identical, whereas the dechlorinated product and the C-14 BTC were supertimposed in the eluent of the column containing the 50:50 Fe(0)-sand barrier. These results inndicated that complete metolachlor destruction had occurred in the PRB and the dechlorinated product was the primary degradate in the leachate. Our observations demonstrate that Fe(0)-mediated dechlorination of metolachlor, previously observed in stirred batch reactors (Eykholt and Davenport, 1998; Comfort et al., 2000), can also occur during unsaturated transport.

Both annealed and unannealed iron sources were effective in reducing the concentration of metolachlor leaching through the columns, but considerably more C-14 was retained in the unannealed barrier. Less metolachlor leaching occurred and more dechlorinated metolachlor was produced when aluminum sulfate was added. More C-14 was adsorbed by the unannelaed iron than the annealed iron and less metolachlor leached through the barriers containing annealed iron than in those with unannealed iron. Differences in iron coatings between the iron sources distinctly influenced adsorption and corrosion rates. The surface of the unannealed iron was a mixture of hematite, maghemite and magnetite, whereas magnetite predominated on the annealed iron surface. When submerged in water and left open to the atmosphere for several months, we observed that annealed iron was much more resistant to rusting, maintained a lower dissolved oxygen concentration, and generated considerably more hydrogen gas bubbles at the iron surface. In contrast, the iron-water interface of the unannealed iron was passivated within a few days.

Subsequent experiments with metolachlor-contaminated soil indicated that the unannealed iron barrier was effective in decreasing metolachlor concentration in the leachate by approximately 50% compared to the untreated contaminated soi. It is notewothy that under our experimental conditions, the resident time of the solute in the barrier was <0.5 d and that longer times would likely occur in the field and result in more efficient destruction. This would ultimately depend on the thickness of the iron barrier and the pore water velocity.

Significance. The high cost of some soil remedial treatments has kept some fertilzer dealers and end-users from revealing spills that may be point-sources of ground and surface water contamination. Incineration costs for contaminated soil can range from $261 to 1961 per cu meter of soil (USEPA, 1990). These high costs have motivated researchers to seek straightforward and lower cost approaches to handling point-source of contamination. For a PRB to be effective in the vadose zone, several criteria must be met. The barrier must react with the target contaminants and not produce toxic effluent. Our current work demonstrates that Fe(0) sand barriers can dechlorinate metolachlor under unsaturated flow and that the dechlorinated metolachlor is more biodegradable than the parent compound (Comfort et al., 2001). It is essential that water continue to flow through the barrier with time. Thus barrier composition [Fe(0)-sand] must consider the hydraulic conductivity of the PRB relative to the surrounding soil. Despite important considerations that warrant further study and field testing, our initial observations indicate that iron barriers can function under unsaturated transport and may have a niche in containing solute leaching from point-sources of contamination.

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Basic Information

Title:	An Assessment of Factors Indicating Well Vulnerability in Nebraska
Project Number:	C24
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Groundwater, Water Quality, Water Supply
Descriptors:	Drinking Water
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Bruce Dvorak, Wayne E. Woldt

Publication

1. Fisher, J.L. (2000) An Assessment of Well Vulnerability to Viruses in Nebraska, presentation at the Annual Conference of the Nebraska Water Environment Federation in Kearney, NE, Nov. 3, 2000.
2. Fisher, J.L, and Dvorak, B.I. (2001) Assessment Of Viral Contamination In Nebraskas Small Community Wells, Proceedings of the 2001 American Water Works Annual Conference, Washington, DC. June.
3. Fisher, J.L. (2001) An Assessment of Well Vulnerability to Viruses in Nebraska, Thesis presented to the University of Nebraska at Lincoln for the degree of Master of Science in Environmental Engineering

Basic Project Information:

Title: **AN ASSESSMENT OF FACTORS INDICATING WELL VULNERABILITY IN NEBRASKA**

PROJECT No. C24
Start Date: 3/1/99
End Date: 2/28/01 (extended through 8/31/01)
Research Category: Drinking Water

Focus Category: Groundwater, Water Quality, Water Supply

Lead Institution: Nebraska Water Resources Center

Principle Investigators: Bruce I. Dvorak, Ph.D., Associate Professor
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RESEARCH

Problem and Research Objectives:

Most Nebraska communities rely on groundwater as a source of drinking water. Nebraska's groundwater aquifers typically have a non-Karstic hydrology: they are more or less typical aquifers in unconsolidated sands and gravels that do not initially appear to be at particular risk for microbial contamination. It has often been assumed that Nebraska's municipal groundwater supplies are free of pathogens due to natural filtration provided by the soil. Although there are few published studies on virus occurrence in groundwater, limited data available from some states seem to indicate that groundwaters may be vulnerable to contamination and may contain pathogens (e.g., Abbaszadegan et al.; 1998). The presence of human pathogens such as viruses in well waters has not been studied sufficiently, and no general consensus on the presence of viruses for regions like Nebraska.

To assess the vulnerability of Nebraska's drinking water wells from pathogen contamination, a study of well integrity factors or 'well vulnerability' was performed. In this study, only small (<10,000 population) Nebraska communities that do not currently disinfect or treat their drinking water were studied. There are 608 small community water systems in Nebraska. In addition there are 719 non-community water systems. Although few Nebraska community wells are in "vulnerable" (karst, fractured bedrock and gravel) formations, some wells are close to (or in violation) of setback distances to potential microbial contamination and/or have other water quality issues (e.g., high nitrates, total coliform detects in the distribution). Thus, the overall goal of this study was to assess the general frequency of pathogen (bacterial and viral) contamination in community water systems in Nebraska by monitoring wells that are among the most likely according to theory to be contaminated. In this project, a total of seven small community wells were studied intensively; the wells selected for study were believed to be among the most vulnerable to microbial contamination in Nebraska.

Methodology:

The general methodology of this study was to select seven community wells (located in the eastern half of Nebraska) that were perceived to be most vulnerable to being infected with viruses. Each of those seven wells was tested six times for viruses (using two methods, PCR and Cell Culture) as well as for bacteria and other water quality parameters. Six of the seven community wells were tested at least once before August 28, 2000. The seventh community well was not tested until September 11, 2000 because there was a severe drought during the summer and early falls of 2000. This drought has caused higher than normal pumping rates and possibly lower water table levels.

Selection of Community Wells

The only wells considered for this study were those serving small community water systems in Nebraska that rely on untreated groundwater (including no regular disinfection) for their public water supply. All communities considered had wells that were not under the influence of a surface water. An initial list of possible community wells were selected by placing a 200-mile radius around Lincoln, Nebraska. There were 32 candidates wells within Butler, Colfax, Dodge, Greeley, Lancaster, Merrick, Nance, Pawnee, Platte, Polk, Saunders, Seward, and York counties in Nebraska. The project team ranked the most vulnerable communities from the list of 32 in an extensive table listing important well characteristics related to the below criteria.

The first criteria concerned the well depth. All the selected community wells were shallow; for Nebraska communities. A relatively shallow well is one less than 250 feet. The depths of the selected wells are listed in Table 1. The seven community wells tested are listed in Table 1. The letters A-G in this paper refers to the wells. Each well is located in a different community.

Table 1. Community Wells Sampled.

Well:	A	B	C	D	E	F	G
Year Well Drilled[1]	1991	1987	1984	1937	1982	1985	1972
Well Depth[1]	205’	230’	214’	101’	116’	178’	276’
Nitrate/Nitrite[2] (mg/L)	6.2	N/A	1.3	5.1	5	7.2	7.4
Total Coliform Detections[2]	Yes	Yes	No	Yes	No	No	Yes
Sanitary Sewer Lines	>1500’	75’	50’	30’	200’	160’	30’
Sewer Lines Service Connection	>1500’	85’	50’	80’	245’	160’	78’
Wastewater Lagoon	>1500’	>3000’	700’	4500’	N/A	N/A	N/A
Sewer Manholes	>1500’	125’	150’	50’	545’	170’	156’
Septic Tanks	858’	N/A	N/A	300’	>1500’	>1500’	N/A

[Yellow highlight] Violation of Nebraska’s setback distance guideline

1 - From sources such as well logs (Nebraska Conservation and Survey), NDHHS files, and NDEQ files

2 – Reported on Community’s 1999 Customer Confidence Reports

The second criteria used for selecting the communities was Nitrate/Nitrite concentrations reported to the Nebraska Department of Health and Human Services (NDHHS) during 1998 and 1999. High Nitrate/Nitrite concentrations were considered to be a possible indication of a connection to the surface.

The third criteria was total coliform bacteria (TBC) detections in the distribution system reported to the Nebraska Department of Health and Human Services (NDHHS) during 1998 and 1999. Frequent TCB violations were considered to show the potential for microbial contamination of the well; although it is also possible that the TCB could have come from regrowth within the distribution system, backflow or intrusion into the distribution system, or poor maintenance.

The fourth type of criteria concerned the proximity of viral sources to the wells. The communities' setback distances from possible sources of contamination were used as a criterion (as listed in Table 1). If the community had a violation of Nebraska's current guidelines or was close to the setback distance considered a high probability for virus contamination. Nearly all wells selected were within each community's boundaries, and these would have a higher possibility of (human) virus contamination from leaky sewers, sewer connections or septic systems.

The last criterion was the willingness of each community to participate in this study. A total of eleven communities were approached in order to obtain seven that agreed to participate in the study. Overall, the communities selected were considered to be among the most vulnerable wells to microbial contamination within Nebraska. The selected data for the selected communities is listed in Table 1.

Information on the candidate communities was obtained from several sources. The Nebraska Natural Resources Commission Data Bank for registered groundwater well data were used to determine the well depth, pump depth, pump column diameter, pumping level, static level and pumping rate. The Nebraska Department of Environmental Quality (NDEQ) obtained data concerning the Well Head Protection Area. This data included current pumped water level, current non-pumped water level, average annual pumpage, storage facilities for the water, screen length, screen diameter, screen material, wastewater disposal, distance to the nearest water, and what is near the well. Nitrate-Nitrite and Total Coliform Bacteria data were obtained from the Nebraska Department of Health and Human Services (NDHHS). Aerial photos were gathered for each of the candidate communities from a USGS website. These aerial photos allowed a birds-eye view of what is near the wells in each of the communities to check for obvious sources of contamination. The Nebraska Department of Health and Human Services field staff assisted in confirming information related to the setback distances, pump rates and frequencies, and in obtaining community agreement to participate in the study.

Water Sampling

For each community, the water was sampled at a sample tap from the well of interest. Approximately 528 gallons (2000L) of water was filtered as part of the virus testing procedure. Samples were collected for the bacteriological parameters and other water quality parameters after virus testing filtration was completed.

A virus sampling apparatus was assembled. Then the groundwater was pumped from the well to the apparatus. Water flowed through the 25 micron pre-filter and the Virosorb filter at a flow rate between 1.5 and 1.0 gallons per minute for approximately 528 gallons (2000L). After completion of the filtration run, the virus filter was removed and then placed into a Ziploc bag along with the remaining water in the cartridge housing. The Ziploc was then placed into an insulated container and transferred to the University of Nebraska Medical Center Virology Laboratory for the virus testing within 18 hours after completion of the sampling.

The University of Nebraska Medical Center Virology Laboratory conducted the virus analyses. The Polymerase Chain Reaction PCR) and cell culture methods were both used for detecting enterovirus presence. The groundwater samples analyzed by the PCR method consist of a filter-adsorption and elution method. This method stereotypes all positives and sequences all polio positive as well as the lab controls. The cell culture method used inoculated the sample into MRC, PMK, and A-549 cell lines, which detects infectious enterviruses in the environment.

The sampling and analysis method used for enterovirus was verified by a four QA/QC field studies. This study consisted of running approximately 300-gallons of dechlorinated water spiked with 6.5 mL of CVB3 virus. The filter was analyzed by the PCR and the cell culture method. The results of all four studies were positive for enterovirus presence.

Other water quality parameters that were evaluated include: alkalinity, pH, dissolved oxygen, UV-254, E. Coli, and total coliform. These parameters were measured in samples taken at the point of collection for the virus samples. The samples for these parameters were collected immediately after collecting the virus samples. These water sampling and analysis techniques follow procedures in Standard Methods for the Examination of Water and Wastewater.

Groundwater Modeling

Ground water modeling was conducted with the computer program CANVAS (Version 2.1), which is a composite analytical-numerical model for viral transport simulations, distributed by International Ground Water Modeling Center in Golden Colorado (Park et al., 1995). This model is designed to predict the following: 1) Viral concentration at the water table from a viral source in the subsurface (unsaturated zone modeling). 2) The viral concentration at the wellhead from a source at the water table (saturated zone modeling). 3) The viral concentration at the wellhead from a source in the subsurface (both unsaturated and saturated zone modeling). The program simulates the transport and fate of virus particles with consideration for source strength, hydrogeologic conditions, advection, dispersion, adsorption/desorption, colloidal filtration, inactivation, and well operation.

Flow and transport through the unsaturated zone assumes a one-dimensional, vertical downward direction, under steady-state conditions (semi-analytical). Virus transport through the porous media was assumed to be based on a two-site kinetic modeling approach, which assumed the sorption was controlled by a rapid reaction with instantaneous equilibrium, or a reaction with a kinetic expression for a slower adsorption rate. It was assumed that the sorption is controlled by a rapid reaction with instantaneous equilibrium or a reaction with a kinetic expression for a slower adsorption rate. Virus flow and transport through saturated porous media was simulated using an areal two-dimensional, finite element-based steady-state modeling approach.

Site specific hydrogeologic and well construction information were gathered for all seven communities in this study. Only one site was selected for further exploration through computer-based modeling due to the established research timetable and associated time constraints. Well G was selected for the site application because it had the most available information for model development. In this case, the model was developed according to site conditions to assess the potential for viral contamination of the community well from a potential source (sewer line) near the well.

The modeling effort also explored the use of CANVAS for interpretive and generic modeling applications. Interpretive models provide a framework to gain an understanding of physical settings and the associated interrelationship with available data sets for the given physical setting. Generic modeling applications provide insights into highly complex, connected systems, under hypothetical conditions, which may be useful for establishing a baseline for policy review and formulation. The CANVAS model was used for two different modeling scenarios within the context of interpretive and generic applications. The first scenario looked at what soil types would allow virus to pass through the unsaturated zone and enter in the water table. This scenario involved a leakage source 15 feet below the subsurface and an unsaturated zone thickness of 75 feet. This configuration provides a geometry that is similar, on average, to the sites that were sampled. The second scenario explored the transport of virus from the water table to a given well under differing conditions. In this case, the model was run with variable strength sources located at three different spatial locations and distances from the well; which were 50 feet, 150 feet and outside the well capture zone.

Principle Findings and Significance

Out of the 47 samples tested, only one sample tested positive for enterovirus contamination using PCR; however no positives were detected for cell culture, as listed in Table 1. The sample that tested positive for viral contamination was Community B, which was positive on 8/7/00. Note the PCR method detects viral DNA and cell culture analysis only detects viable viruses.

Table 1. Virus Data.

	PCR		Cell Culture	
Well	**Positive**	**Negative**	**Positive**	**Negative**
A	0 (0%)	7 (100%)	0 (0%)	7 (100%)
B	1 (16.6%)	5 (83.4%)	0 (0%)	6 (100%)
C	0 (0%)	6 (100%)	0 (0%)	6 (100%)
D	0 (0%)	6 (100%)	0 (0%)	6 (100%)
E	0 (0%)	6 (100%)	0 (0%)	6 (100%)
F	0 (0%)	6 (100%)	0 (0%)	6 (100%)
G	0 (0%)	7 (100%)	0 (0%)	7 (100%)
Total	1 (2.3%)	44 (97.7%)	0 (0%)	44 (100%)

Throughout this study, no E. Coli samples (0 of 47 samples) were detected in any well. However two different sites tested positive for total coliform listed in Table 2. Note the Nebraska Health Department Total Coliform History data results from each community's distribution system is also provided in Table 2. The wells that were positive for total coliform did not have detects in the distribution systems. In addition, the two wells that tested positive for total coliform did not test positive for viral contamination using PCR or cell culture. The water quality for the water samples collected for this study was consistent throughout sampling and showed no direct relationship with the microbial data.

Table 2. Total Coliform Results.

	Collected Samples for Study *July of 2000 to Jan of 2001*			**NHHS Total Coliform History Data** *July of 2000 to Jan of 2001*		
Well	Number of Positive	Total Number Sampled	% Positive	Number of Positive	Total Number Sampled	% Positive
A	1	4	25%	0	7	0%
B	0	6	0%	11	59	19%
C	0	6	0%	0	8	0%
D	1	6	11%	0	16	0%
E	0	6	0%	0	8	0%
F	0	6	0%	0	15	0%
G	0	6	0%	11	62	18%

The results of this study have been compared to the Abbaszadegan et al. (1998) study mentioned previously. Abbaszadegan et al. (1998) sampled 174 sites that have sewage sources within 150 feet; for these wells, Abbaszadegan et al. showed that 17% were positive using PCR, 6% were positive for cell culture and 9% were positive for total coliform bacteria. Note that all of the Nebraska wells sampled in this study have similar geology; whereas in the Abbaszadegan study the geology was different at the 174 sites. The wells tested in this study were also within 200 feet of sewage sources but had lower positives for the PCR method (2.1%), cell culture (0%), E.Coli (0%), and total coliform (5%) than the Abbaszadegan study.

The first ground water modeling approach, simulation of well G, using the CANVAS program for both the unsaturated and saturated zone, predicted that the concentration of viruses reaching the water table directly below the viral source was below the detection limit. The concentration at the water table from a viral source of 10^7 PFU/liter was reduced to $0.11x10^{-6}$ PFU/Liter.

The first interpretive/generic modeling scenario involved modeling viral transport through the unsaturated zone using parameter specifications for four different soil types (approximately 75 feet). Table 3 shows the concentration at the water table given two source strengths of 10^3 PFU/liter to 10^7 PFU/liter.

Table 3. Concentration (PFU/liter) at the Water Table Given Different Soil Types.

Depth	Clay	Silty Loam	Silty Clay Loam	Sand
75'	$0.50x10^{-22}$ to $0.45x10^{-18}$	$0.48x10^{-21}$ to $0.48x10^{-17}$	$0.11x10^{-21}$ to $0.11x10^{-17}$	10^3 to 10^7

The second scenario modeled three different upgradient locations; 50 feet, 150 feet and outside the capture zone. It was assumed that the viral contamination had reached the water table. This modeling predicted that a source 50 feet from a well would present a risk if no die off and no retardation factors were considered. However if die-off and retardation were considered, the likelihood of viral contamination at the well was significantly reduced. Modeling results predict that a well located further downgradient from a source (i.e., 150 ft.) will have less risk of exposure, assuming no die-off and no retardation. Here again, if die-off and retardation were considered, the likelihood of viral contamination at the well was reduced significantly from a source located at 50 feet. The last location to be evaluated, outside the capture zone, showed that no viral contamination, regardless of the concentration source strength, would present a risk to the well.

The main conclusions from this study are:

- Only 2% of the public water supply samples were positive to viral contamination using the PCR method and, none of the samples were positive using the cell culture method.
- No obvious relationship exists between viral contamination in the supply wells and Total Coliform Bacteria contamination detected in the distribution system.
- The availability of well information and aquifer data was quite limited for older wells, which leads to a lack of understanding about the hydrogeologic conditions, and numerous assumptions about how the aquifer behaves.
- The CANVAS model predicted no viral contamination at well G, which is consistent with the sampling results.
- Modeling of viral transport through the unsaturated and saturated zones, for the site specific case and interpretive/generic cases, tends to indicate that the greatest risk to wells similar to the case study sites may be human induced types of factors, such as abandoned wells and improperly constructed wells that enhance the transport of virus to water supply aquifers.

Basic Information

Title:	Evaluating the Effects of Pesticide Mixtures to Freshwater Algae
Project Number:	C25
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Toxic Substances, Surface Water, Water Quality
Descriptors:	Algae, pesticides, pollutants, water quality
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Blair D. Siegfried, Kyle D. Hoagland

Publication

1. None

Project #: C25
Funding Period: March 1999 – February 28, 2001
Title: Evaluating the Effects of Pesticide Mixtures to Freshwater Algae
PIs: Blair Siegfried and Kyle Hoagland

Research: Most research that has been done in recent years on algal responses to pesticides has focused on response to a single pesticide. However, during spring rain events, many different pesticides can be measured in the same aquatic system. Algae and other aquatic organisms are therefore likely to be exposed to multiple contaminants. Research on individual pesticides is important to understanding an organism's response to these chemicals and to develop an understanding of mode of action. Additionally, it is important to conduct research on combinations of pesticides, because such exposure is more likely to mimic conditions of exposure under environmentally relevant conditions. The overall goal of this research is to determine the responses of two representative algal species to binary combinations of commonly used herbicides, including atrazine, alachlor, isoxaflutole, metolachlor and simazine.

The proposed project consists of several tasks including the isolation and culturing of representative algal tax from two algal Divisions, acute bioassays to determine relative toxicities of herbicides individually and in combination with a range of atrazine concentrations, and the determination of the resulting photosynthetic inhibition at the population level.

During the first 18 months of this project the following tasks have been accomplished: (1) a graduate research assistant (M.S. level) was recruited to conduct the research, (2) clonal cultures of two algal divisions are now in defined medium (a diatom and two species of green algae), (3) acute bioassays have been conducted on two of the species using the selected herbicides individually and bioassays have been done on the third species (a green) due to major toxicity differences using two of the herbicides (alachlor and metolachlor) compared with the primary green algal species. The primary species was unaffected during exposures to these two herbicides, even at very high concentrations (in excess of 1000 ppb). The secondary species was greatly affected at concentrations as low as 10-25 ppb, and (4) acute bioassays have been completed for binary combinations of 4 pesticides (alachlor, metolachlor, isoxaflutole, and simazine) with a range of atrazine concentrations. These acute combination bioassays have only been done for alachlor and metolachlor for the secondary green algal species. Preliminary results have shown a broad range in sensitivities of algal species to different herbicides even within the same division. This would indicate that herbicide mixtures in streams and lakes will likely reduce algal diversity and shift species composition to more tolerant species. Because algae form the base of the aquatic food web, inputs of herbicides to surface waters can also impact higher trophic levels.

Basic Information

Title:	Site Specific Management Strategies for Improving Nitrogen Use Efficiency Under Furrow Irrigation
Project Number:	C22
Start Date:	9/1/1997
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Irrigation, Methods
Descriptors:	irrigation management, nitrogen, fertilizers, leaching, water quality management, water use efficiency
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Gary W. Hergert, Brian Benham, Richard B. Ferguson, Charles A. Shapiro, William L. Kranz, C. Dean Yonts, Juerg M. Blumenthal

Publication

1. None

SYNOPSIS

Start: 9/1/97 (actual)

End: 2/28/01

PROJECT NUMBER: C22

TITLE: Site-Specific Management Strategies for Improving Nitrogen Use Efficiency Under Furrow Irrigation

INVESTIGATORS:

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CONGRESSIONAL DISTRICT: 03

FOCUS CATEGORIES: NC, IG, MET

DESCRIPTORS: irrigation management, nitrogen, fertilizers, leaching, water quality management, water use efficiency

PROBLEM AND RESEARCH OBJECTIVES:

Current best management practices (BMPs) for nitrogen and irrigation used by most producers and Natural Resource Districts in Nebraska have been developed primarily from University of Nebraska research. Additional research is required to provide next generation BMPs which will continue to reduce nitrate-N loss. Although there has been a transition to sprinkler irrigation during the past 25 years in the central Great Plains, large areas of cropland are still furrow irrigated (50% in Nebraska). Changing to sprinkler irrigation is expensive and offers no immediate economic returns other than labor savings for irrigated land in river valleys. Furrow irrigation will continue to be a major factor influencing N management and leaching although the impact of alternate row irrigation and N application has not been thoroughly investigated.

Increasing levels of nitrate in groundwater have been observed in some river valleys in Nebraska since the mid-1950's. In the most recent statewide evaluation of groundwater nitrate and pesticide levels, over half of the wells in the state testing higher that 10 ppm NO_3-N were in irrigated river valleys. A significant number of wells exceed 10 ppm NO_3-N in southern Phelps and southwestern Kearney counties, an irrigated corn producing area of fine-textured soils with depths to ground water between 15 and 30 m. Other research has shown that nitrate has moved down at least 18 m in 15 years under furrow-irrigated research plots on a silt loam soil. This situation may also be representative of most furrow irrigated areas from the arid west to the corn belt. A more recent concern about agriculture's impact is the hypoxia question in the Gulf of Mexico. Many sources of N contribute to increased stream flow nitrate, but crop land N management can have an influence. Improvements in N use efficiency in all parts of the Mississippi watershed will be required if agriculture is part of the hypoxia cause.

The objectives of the project were to:

1. Compare spatial nitrogen use efficiency and N balances for alternate row irrigation and alternate row N application versus every row N application and irrigation for variable rate and fixed rate side-dressed anhydrous ammonia across a range of precipitation regimes found in Nebraska at three locations, with a mean annual water balance ranging from 25 mm to –275 mm water (Figure 1).
2. Compare spatial nitrate-N movement of the four methods using a conservative (KBr) tracer.
3. Correlate spatial N leaching to crop and soil parameters including grain yield, N applied, field position and conservative tracer leaching.
4. Compare systematic soil sampling strategies for the 4 management schemes that will provide the best estimate of residual nitrate N that will be used in N recommendation algorithms for the next corn crop.

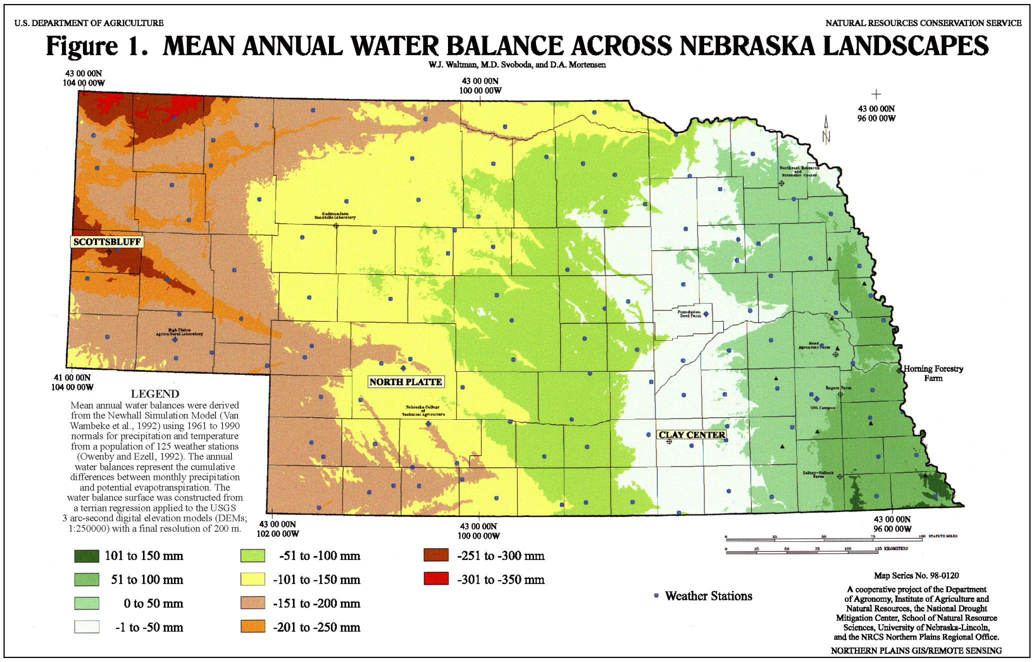

Figure 1. Mean annual water balance across Nebraska landscapes.

<u>METHODOLOGY</u>: This project was conducted across Nebraska at 2 locations in 1997 (Clay Center and North Platte) and 3 locations in 1998 and 1999 (Clay Center, North Platte, and Scottsbluff and at Scottsbluff in 2000 – Figure 1). Four management schemes were compared

1. Every furrow application of anhydrous ammonia (fixed rate based on average soil nitrate, organic matter, and field average expected yield) and every furrow irrigation. (**EFI-uniform**)

2. Every furrow application of anhydrous ammonia (variable rate based on spatial soil nitrate, organic matter, and field average expected yield) and every furrow irrigation. (**EFI-variable**)

3. Every other furrow application of anhydrous ammonia (fixed rate based on average soil nitrate, organic matter, and field average expected yield) and alternate row furrow irrigation in the non-N application furrows. (**AFI-uniform**)

4. Every other furrow application of anhydrous ammonia (variable rate based on spatial soil nitrate, organic matter, and field average expected yield) and alternate row furrow irrigation in the non-N application furrows. **(AFI-variable)**

Anhydrous ammonia was applied at the 4 to 8 leaf stage corresponding to current BMP suggestions. Treatments were replicated 4 to 5 times. Anhydrous ammonia application was made with a variable rate applicator (VRA) owned by the investigators. Grain yields were determined with a conventional 6 or 8 row combine equipped with a GPS and a yield monitoring system or a 3-row plot combine. Preplant soil nitrate samples were taken and logged with a GPS. During harvest, samples of grain were taken at the previously logged soil sampling locations and analyzed for N content. Post-harvest soil samples for nitrate were taken from the previous soil and grain sampling sites. The information on preseason nitrate, grain N removal, post season nitrate and N applied will be used to calculate a spatial N balance and apparent nitrogen use efficiency calculation for the management schemes.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Sites were sampled during the falls of 1997, 1998 and 1999 for residual nitrate and soil organic matter. Maps for these soil properties were the data used to develop spatial N rate recommendations using the University of Nebraska N recommendation algorithm for com. This data was kriged to develop N rate application maps. N was sidedressed in early to mid-June.

There was significant spatial variability in soil parameters (soil organic matter and residual nitrate-N) that influenced N dynamics at all three locations. Figure 3 illustrate these factors for the Clay Center site. At Clay Center, soil organic matter levels varied from about 10 g kg^{-1} (1%) in an area where topsoil had previously been removed to 30 g kg^{-1} (3%) in the better areas of the field.

Treatments within the four management schemes were either 6 or 8 rows for the length of the field; usually 300-400 m. There was also a no nitrogen control for each irrigation treatment. Treatments were replicated 4 to 5 times in a randomized complete block split plot design. The main plots were irrigation treatments (AFI and EFI) and the subplots were nitrogen treatments (no nitrogen, uniform and variable). Anhydrous ammonia was applied sidedress (4 to 8 leaf growth stage) with a modified Blu-Jet tool bar with a Dickey John flow controller and heat expansion chamber (Figure 2). The software that controlled the variable rate applicator was Falcon v. 1.9, AgChem, Inc. The software that created the application maps was SGIS v 2.4, AgChem, Inc. The sites were grid sampled on staggered 30 m intervals within each treatment strip for residual nitrate and soil organic matter during the fall or the spring before planting. Spatial data for organic matter and nitrate were used to develop spatial N rate recommendations using the University of Nebraska N recommendation algorithm (Hergert et al., 1995).

Figure 2. Variable rate anhydrous ammonia toolbar used

Surge irrigation was utilized at all locations for both irrigation treatments. Anticipating different advance rates for the hard (tire track) and soft (non tire-track) furrows, inflow rates were adjusted according to the furrow type. Soft furrows received greater flow rates and hard furrows reduced flow rates. Irrigation water was applied in sufficient quantity to maintain at least a 50% remaining available soil water balance. The EFI and AFI irrigation treatments were scheduled independently. Typically, four surge irrigation advance cycles were used. Advance-phase cycle times averaged 30, 50, 60 and 80 min for the 1st, 2nd, 3rd and 4th surges, respectively. Initial cutback cycle time averaged approximately 40 min.

RESULTS

There was significant spatial variability in soil parameters (soil organic matter and residual nitrate-N) that influenced N dynamics at all three locations. Figure 3 illustrate these factors for the Clay Center site. At Clay Center, soil organic matter levels varied from about 10 g kg^{-1} (1%) in an area where topsoil had previously been removed to 30 g kg^{-1} (3%) in the better areas of the field.

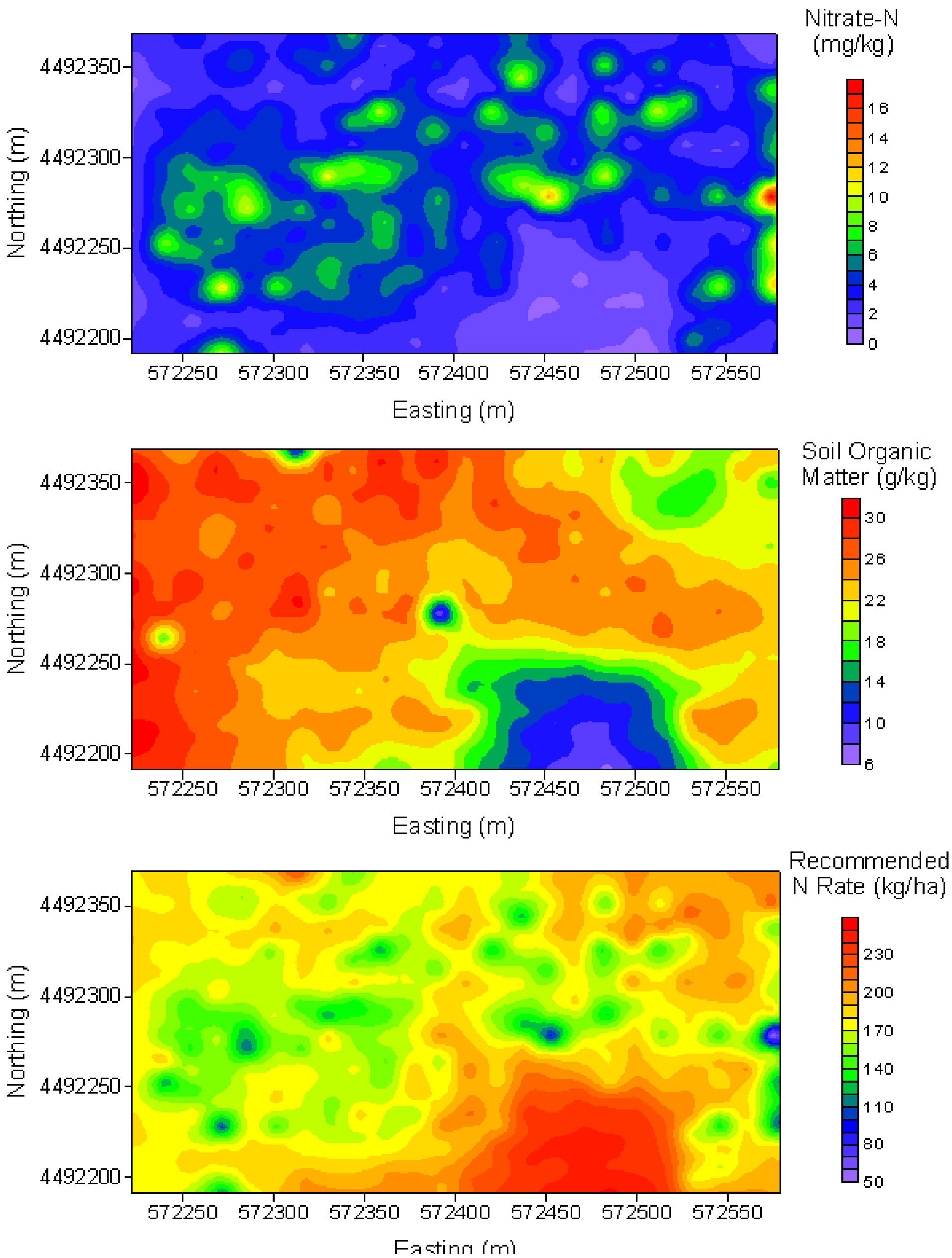

Figure 3. Soil residual nitrate-N, soil organic matter, and recommended N rate,

At all locations and in most years, yields from treatments that received no N

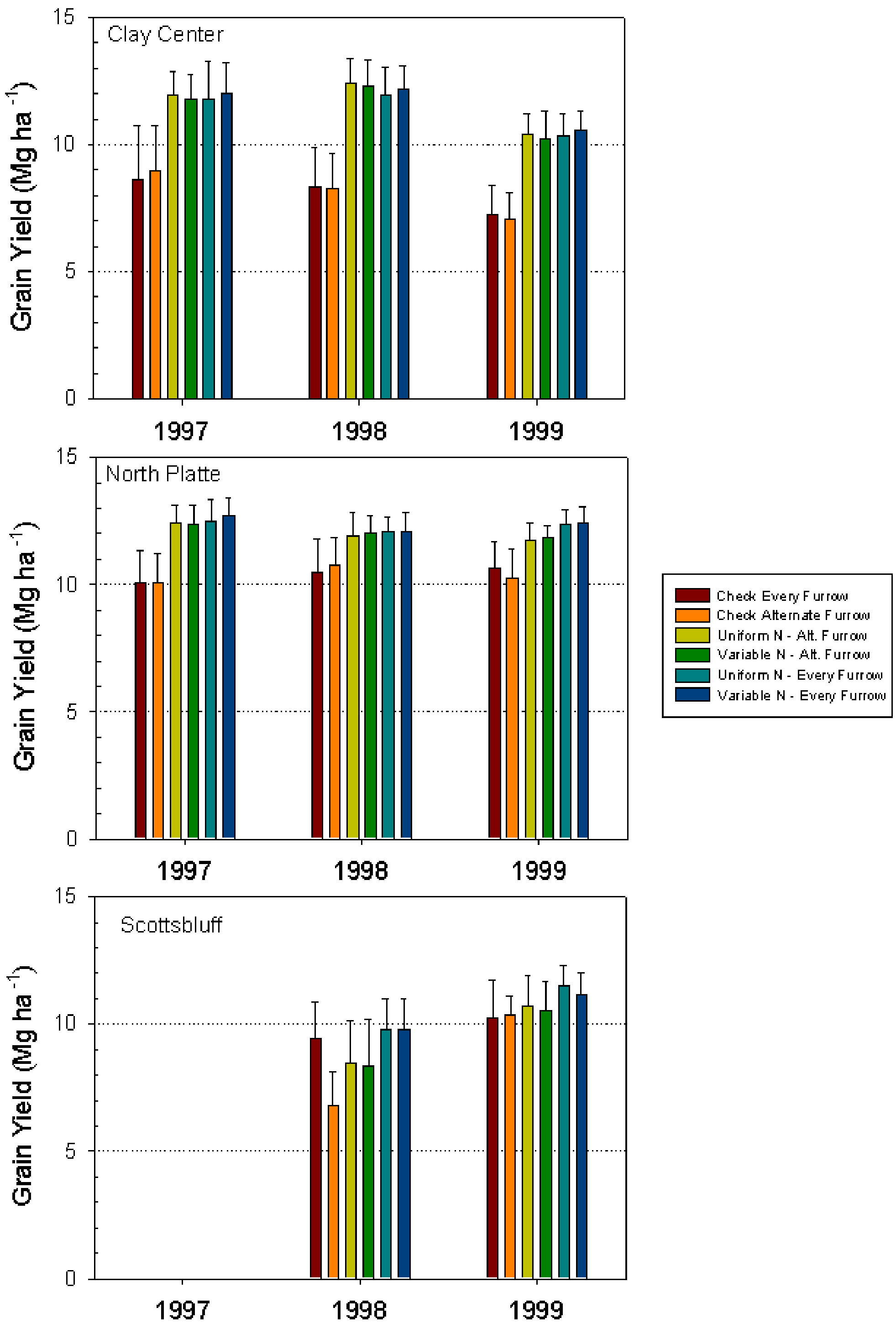

Figure 4. Grain yields for three sites, 1997 - 1999. Error bars are standard deviation.

fertilizer (control plots) were significantly lower than those that received N (Figure 4). Grain yield was not significantly affected by N application method (variable versus uniform rate.) These results are consistent across locations and with previous studies in Nebraska (Ferguson, et al., 1999) and show that variable rate N application provided no field-wide yield advantage compared to uniform N application. While rates varied within the variable rate application treatment, average treatment N rate was within 11 kg ha^{-1} of the uniform rate at each site. The lack of yield difference between the variable and uniform N rates indicates that organic matter and residual nitrate-N were not so variable that the uniform application significantly under-applied nitrogen to a large area of the field. This is consistent with the hypothesis that the University of Nebraska recommendations are near the maximum of the response function and the N response function is either quadratic or linear plateau.

Corn grain yields for both AFI and EFI were the same at Clay Center and North Platte. The AFI had an average of 72 mm less irrigation water applied per season at these locations. As was the case at Clay Center and North Platte, application of N fertilizer at the Scottsbluff location increased corn yield for both uniform and variable N applications. In contrast to the other two locations, grain yield at Scottsbluff was significantly lower for the AFI treatment compared to EFI in 1998 and 1999. Factors influencing the potential for AFI to reduce yield include soil water-holding capacity (which is lower at the Scottsbluff location due to coarser texture and lower soil organic matter relative to the North Platte and Clay Center locations), and mean annual water balance (Figure 1). With reduced precipitation the non-irrigated furrow may have insufficient moisture to allow either the N to move to the roots or the roots to adequately grow to the N.

End of season residual nitrate-N levels for each site are shown in Figure 5 (1998 values for Clay Center are missing due to laboratory error). In general, residual nitrate-N levels remaining after harvest are higher the farther west in the state, as mean annual precipitation decreases. At the Clay Center location, residual nitrate-N levels are generally unaffected by treatment other than the no-nitrogen checks. This is the case for the most part at North Platte as well, with the exception of 1998, when the variable N – alternate furrow irrigation treatment had a significantly lower residual nitrate-N level than the other fertilized treatments.

At the Scottsbluff location, the alternate furrow irrigation treatments tended to have significantly higher residual nitrate-N levels. This is consistent with the observed lower grain yield for these treatments and reduced nitrate uptake by the crop, as well as likely less nitrate-N leaching with the alternate furrow irrigation

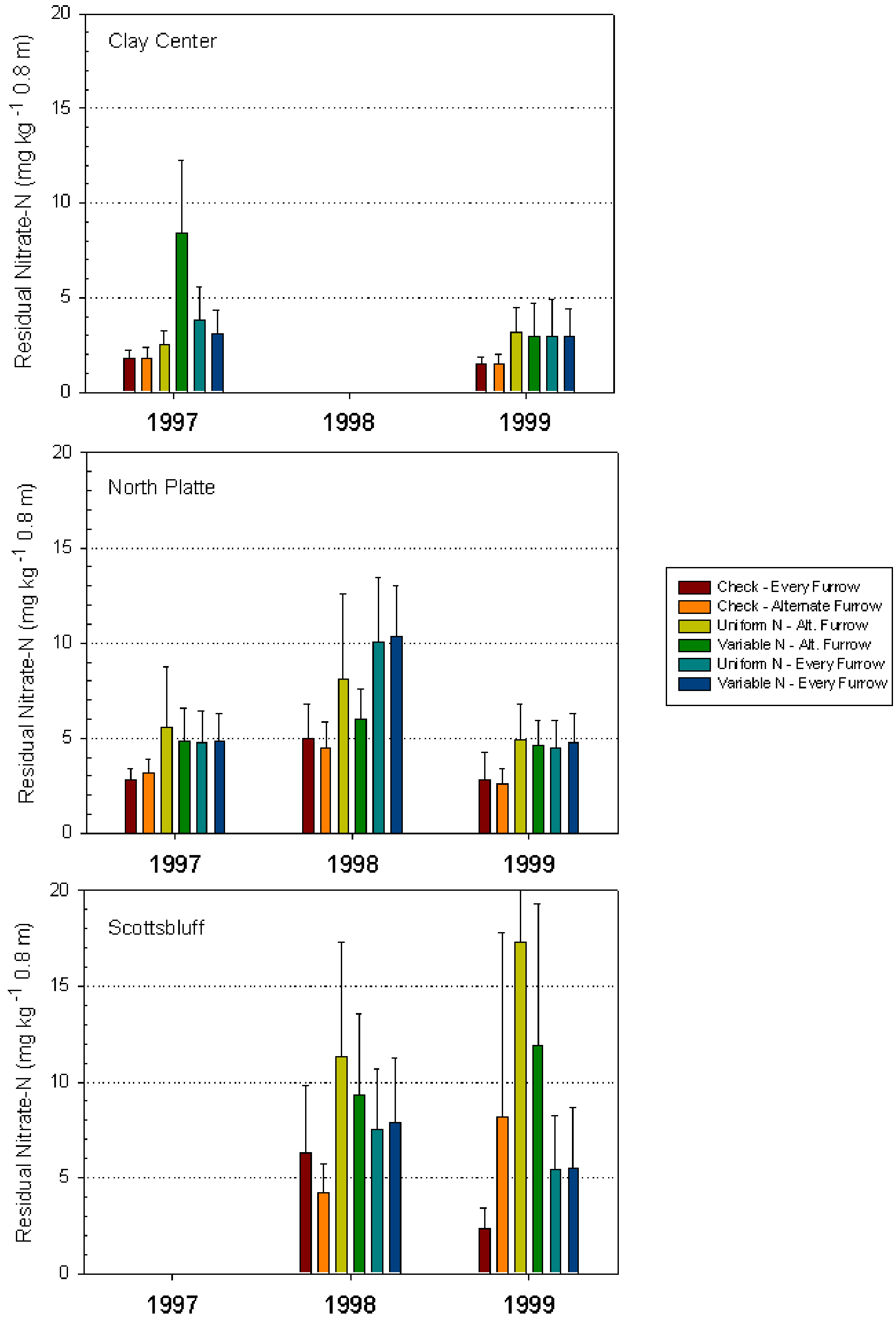

Figure 5. Average soil residual nitrate-N concentration to a depth of 0.8 m, 1997-1999.

treatment. At the Scottsbluff site, for the alternate furrow treatments, the uniform application had greater residual nitrate-N than the variable application (Figure 5).

ACKNOWLEDGEMENTS

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Basic Information

Title:	Advanced Assessment for Spot Spraying Plants to Reduce Chemical Input and Improve Water Qaulity
Project Number:	C77
Start Date:	9/1/1997
End Date:	9/30/2000
Research Category:	Not Applicable
Focus Category:	Water Quality, Non Point Pollution, Management and Planning
Descriptors:	Pesticides, Spot Spraying, Machine Vision, Spatial Variability, Water Quality Assessment
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	George E. Meyer, Thomas George Franti, David A. Mortensen

Publication

1. None

ANNUAL AND FINAL REPORT

June 25, 2001

Completion Date
9/30/00

PROJECT NUMBER: C77

TITLE: Advanced Assessment for Spot Spraying Plants to Reduce Chemical Input and Improve Water Quality

INVESTIGATORS: George Meyer (Principal), Tom Franti, Biological Systems Engineering. Dave Mortensen, Weed Science.

FOCUS CATEGORIES: WQL, NPP, M&P

CONGRESSIONAL DISTRICT: Nebraska --- First District

DESCRIPTORS: Pesticides, Spot Spraying, Machine Vision, Spatial Variability, Water Quality Assessment.

PROBLEM AND RESEARCH OBJECTIVES:

The premise of these studies was that reduction in the use of chemicals could be achieved by selectively and intermittently applying chemicals to the plants themselves and not the soil, thus reducing chemicals in runoff water and infiltration into the groundwater. Initial estimates were that 15-65% of current applications could be eliminated while maintaining crop yields. This premise was be tested by the following objectives:

1. Develop and test an advanced machine vision-based assessment and plant mapping system to evaluate optical sensor controlled spot sprayers under field conditions.

2. Analyze both plant spatial distributions and spot sprayer performance to evaluate the efficacy, efficiency, and economics of intermittent chemical applications.

3. Use the performance data from Objectives 1-2 to simulate and study the impact of spot spraying on surface water quality.

METHODOLOGY:

Objective 1. Machine Vision Assessment using electronic images of crop and weeds in the field provided location of plants, plant type, and chemical coverage of leaves. By using and testing various segmentation methods, plant regions were separated from backgrounds in these images. Once located, advanced image analysis resulted in plant size, shape and type (monocot or dicot), numbers of clusters, wetting of leaves by the chemical and plant distribution. Fuzzy logic and inductive textural algorithms assisted in plant identification.

Objectives 2. UNL has been a pioneer by building a field scale prototype optical sensor controlled spot sprayer as a research tool (Von Bargen, Meyer, Mortensen, and others). Weed threshold information for economic and environmental considerations assisted in describing the performance characteristics of spot spraying. These data were used to calculate (a) how much chemical application is reduced through spot spraying, (b) how effective was the chemical application control using spot spraying.

Objective 3. The plant distribution and chemical use reduction data collected were used in two water quality models, the Agricultural Nonpoint Source (AGNPS) surface water quality model and the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) pesticide runoff model. Simulations of runoff events were performed using synthetic rainfall data and with atrazine and alachlor as the subject pesticides. Typical corn production at a central Nebraska location was modeled on a field scale with GLEAMS and a typical 800-acre watershed in central Nebraska were used for the AGNPS modeling. Pesticide management alternatives evaluated included spray application using conventional spray (broadcast and banded), with and without incorporation versus intermittent sprayer technology, and timing of application, e.g. preemergent herbicide application (standard) versus postemergent with spot spraying.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Summary of Results

There are two approaches to controlling weeds using electro-optical sensors or machine vision and variable-rate application technology. The first real time method uses a sprayer mounted sensor which must detect and process weed information quickly followed by delivery of herbicide to the spotted location. Detection and processing speed depend on sprayer ground speed, background lighting, and roughness of the terrain. The second method uses aircraft overflight and digital photography over large field areas, followed by post flight processing of image data and development of a prescription map of the field. Coordination of weed locations is accomplished by a global positioning system on both the aircraft and the variable rate applicator using the prescription map. Image resolutions can achieve $\pm$ 1 cm per pixel with either method. Satellite imagery will probably not be to provide the needed resolution at this time.

Machine vision detection of weeds

Under objective 1, image analysis appeared to offer the best approach for discriminating between crop and weeds. Research efforts during this project focused on improving machine vision and software techniques for identifying, counting, and identifying weed types. Weed identification for potential spot spraying was based on weed seedlings of three weeks of age or less using post-emergence application of chemicals. It is during these growth periods, that the highest probability exists for identifying the species of weed according to basic botanical keying and imaging methods. The principal image analysis software packages used were Image-Pro and

Visual Basic with Windows. Image-Pro has built-in shape feature analysis under the menus. The textural feature analysis utility of Image-Pro was expanded with Visual Basic script. The combined use of these two software packages provided the image analysis tools needed for weed identification, based on canopy structure and individual leaf venation and shapes. However, the principal significant problem in color images was to find plant objects and distinguish them from the background. This process is called image segmentation. It depends primarily on image quality or tonal value. Unfortunately, traditional film photography and even modern digital photography can create highly variable tonal quality in images. Color (Red-Green-Blue) digital images were used to detect and identify weed plants.

Several manufacturers produce some very useful digital cameras. Kodak did produce an experimental color infrared camera which could be used to NIR spectral bands, but our hypothesis was that plants could also be detected with RGB. In most cases, digital cameras running under automatic exposure and focus produce superior images with the maximum tonal information needed. The only problem is that the color temperature and illuminance intensity of background lighting may change the RGB balance. Canopy lighting affects the degree of light and dark transitions, edginess, and feature detail. *Color temperature was measured concurrently with picture acquisition and varied from full shade / clear sky (12,000 K), full sun / clear sky (5700 K), cloudy sky (5900 K), and included incandescent lights at 2800 K.* Color temperature was the major source of segmentation error. A fuzzy logic model for this RGB balance was developed. The one megapixel Kodak DC 120 digital camera was the primary tool for obtaining electronic images of various plant species in this project. Plants were grown in the plant growth chamber, the greenhouse, and in field plots near the campus. The DC-120 camera was set to automatic exposure, but was zoomed manually and focused to include entire plants within the camera's field of view. Different natural and background lighting conditions were tested, forward lighting with soil background and back lighting without soil background. The DC 120 camera was found very versatile for most lighting conditions. It automatically adjusts for light quality within certain limits. We also tested the camera with manual settings with plants under different lighting sources, described by light intensity and color temperature, but could not achieve as good a result as with automatic settings..

Using the Kodak software provided with the digitized camera, digitized images were transferred to either a 400, 700 MHz, or 1.4 GHz Pentium computer with 128/256 megabytes memory, respectively for image and subsequent neural network fuzzy logic modeling analysis. Digital resolution is 25 dots/inch, with a width of 1280 pixels and height of 960. All electronic images were archived in a 24-bit color format (JPEG) on CD-ROM. It was found that one megapixel was too much data to handle in subsequent analyses. Digital pictures were resized during pre-processing to a width of *240 pixels and a height of 180 pixels,* sort of a television-like analysis. Figure 1 shows the overall image preprocessing and model development activities.

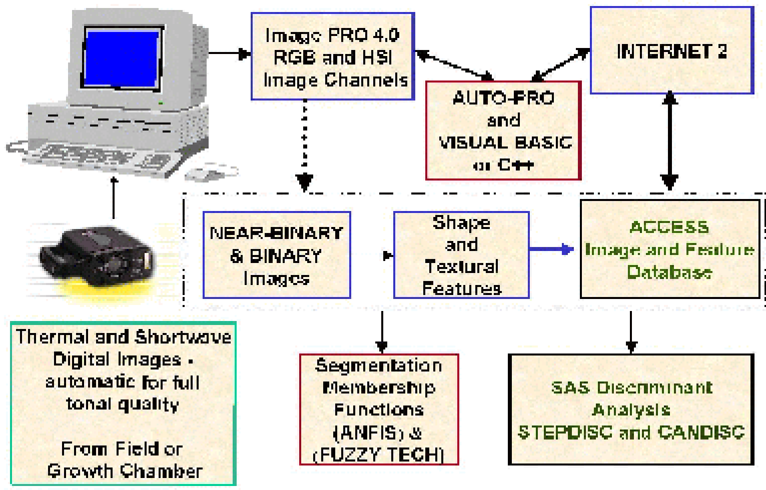

Figure 1. Plant and Weed Machine Vision, Fuzzy Neural and Statistical Analysis.

As previously mentioned, the most critical processing step is the identification or segmentation of plant regions from background regions. If this step is not done correctly, subsequent shape and textural feature analysis will not work. Several approaches to segmenting the plant from the soil background were tested. The simplest method was to use a threshold value such that all pixels with greater value are selected as leaf (white) and all pixels with less value were taken as soil background (black). This was usually done after analyzing a histogram. However, the threshold method always brought in background errors (salt and pepper noise) that made subsequent shape and textural feature analysis of the plant difficult. Pixel intensity values at some places in the soil background image part may be at the same level as or higher than that of leaf. This causes errors in the computation of textural co-occurrence matrices since the algorithm will use those tonal areas as well. These errors show up on a grayscale as well as any color rasters of a red-green-blue (RGB) or hue-saturation intensity (HSI) image. We saw no advantage of using HSI as suggested by Shearer of Kentucky.

Another approach to segmenting plants from soil background was to use a variance-based object detection method. With this approach, graphical outlines of all candidate plant areas were identified. Generally, edge detection techniques will create a number of boundaries of objects found within an image. These boundaries are then investigated to determine which ones have the highest probability of being plant but must be confirmed by subsequent feature analyses. The selected plant outlines were then painted or filled (cleaned up) using application programming interface (API) graphics functions from Visual Basic. A comparison of the original and cleaned up binary files are shown in Figures 2a and b.

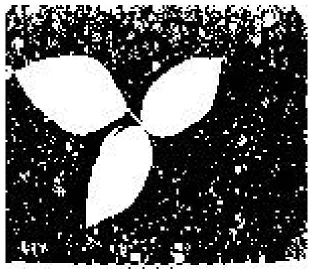

Figure 2a. Binary Image with Salt and Pepper Noise.

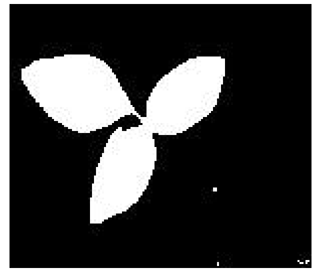

Figure 2b. Clean Binary Image.

Once a clean binary template image was developed, algorithms for plant feature analyses, counting or enumeration algorithms worked very well. Shape feature parameters such maximum ferret, minimum ferret, perimeter, area of the leaf, maximum length, maximum width, aspect ratio and roundness were used to calculate other complex shape factors were obtained from the template image. Dimensionless shape features independent of size and orientation, identified by Yonekawa et al. (1996) were investigated. Texture features of angular second moment, local homogeneity, inertia and entropy were computed, based on the co-occurrence matrices of the original gray scale images at all four directional nearest neighbor scan orientations. Feature data was currently stored in a Microsoft Access® database for further analysis. The binary template was shown to reduce the errors brought about by background segmentation noise, (Mehta, et. al, 1998). Statistical analyses and hypothesis testing are performed using SAS Canonical Discriminant Analysis. Results by Meyer et al. (1999) supported this methodology for identification of individual plant species based on leaf shape and textural analysis.

A third but very new segmentation approach tested was studied to integrate colors and textures into a sophisticated fuzzy logic rule-based model. Essentially, human vision uses color and texture together to separate natural and man made objects. The human visualization process is not easily modeled with ordinary mathematical methods. Fuzzy set theory is a mathematical system derived from basic set theory, with sets or classes of objects with unsharp boundaries and uncertainty. Fuzzy logic with neural networks on high speed computers allows approximate interpolation between uncertain observed input and output data with fundamental mathematical support (Ross, 1995). Fuzzy logic has already been applied to a variety of agricultural, biological, and environmental systems. This method simulates human decision-making processes based on imprecise criteria, using a set of linguistic variables to define a degree of membership for each object in a set. Fuzzy logic rules or fuzzy logic models are developed with the use of an artificial neural network (ANN).

Fuzzy logic plant segmentation and plant texture models were developed for a set of single-background images under a range of uniform illumination conditions. Target backgrounds included green turfgrass, bare soil, weathered corn stalks, and weathered wheat straw. Both natural and controlled artificial light sources, including fluorescent, incandescent, and halogen sources, were used. Average red, green, and blue (RGB) pixel values were calculated for each image. These average values, along with camera exposure time, light source illuminance, and apparent source color temperature, were used as inputs to train a Sugeno-type fuzzy logic inference system (FIS). These inference systems were developed as training and checking sets. They were found to be quite accurate, and in some cases better than traditional statistical methods.

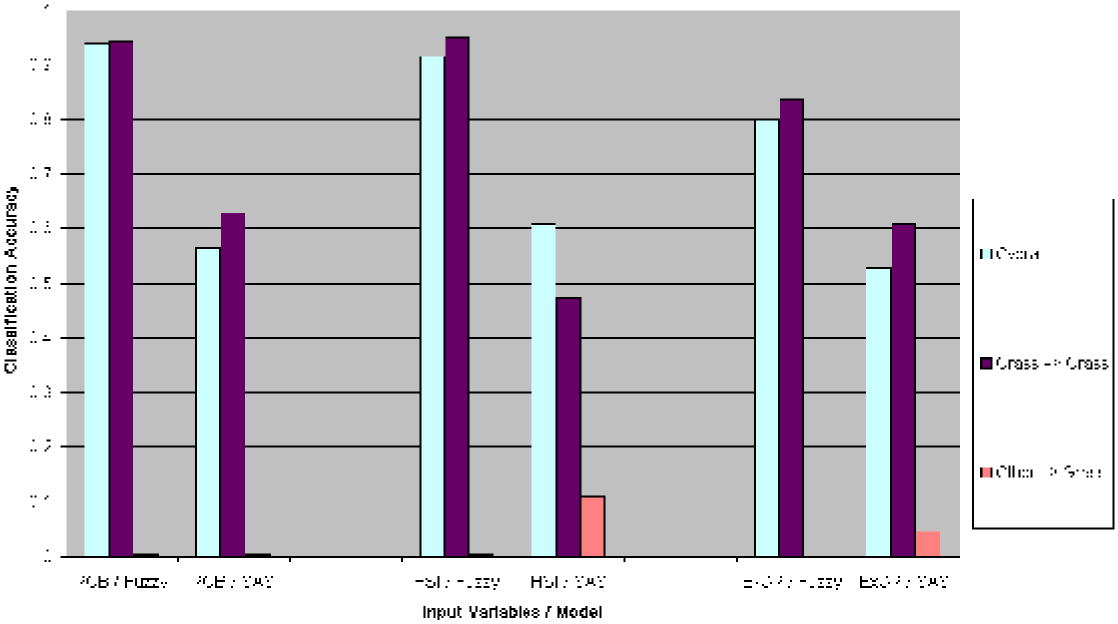

Figure 3. Fuzzy Logic Discrimination vs. SAS Discriminant Analysis.

A fuzzy logic plant segmentation model based on over 900 original images was developed and resulted in correct classification rates of up to 94%, compared to 56.3% for SAS discriminant analysis (Figure 3 and Tables 1 and 2). Similar results were obtained using hue, saturation, and intensity (HSI) values and calculated excess green and excess red plant segmentation indices. These inference systems were validated with independent sets of plant images against bare soil, corn stalk, and wheat straw backgrounds. The neural fuzzy method was found to be a very powerful system of correlating or mapping input and output data.

<u>Evaluation of electro-optical, single element sensor - prototype spot sprayer</u>

During the first years of the grant and with the assistance of Dr. Ken Von Bargen, a prototype electro-optical single element sensor - spot sprayer was developed prior to this project, but was not thoroughly tested at that time. Under objective 2, Raemakers, et al. reported a field test of the use of a single element plant (non-imaging) sensors using narrow spectral bandwidths of reflected natural red and near-infared (NIR light). These spectral bandwidths were combined into a Normalized Difference Index ratio (NDI). These sensors tended to work to detect weeds only under good lighting conditions. Moreover, the NDI method was only found capable of detecting small plants using a high level of operator supervision. The NDI plant detection threshold was found to be unstable over extended time periods (> 1 hour), resulting in the spray operator constantly needing to make gain and timing adjustments to the system to achieve a desired performance level.

There was a strong shadow effect with the NDI method, where shadows can occur during any period of high available light energy, as shown in Figure 4.

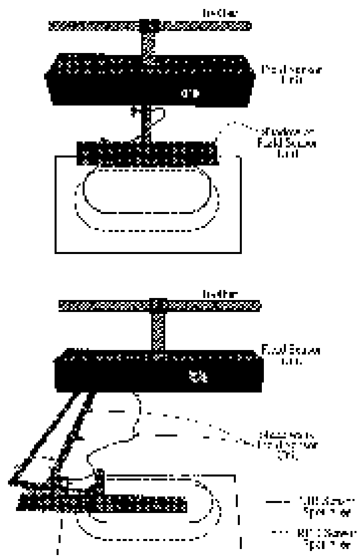

Figure 4. Shadows Generated by Sensing Head (Ramaekers, et al.)

Any weed detection sensor-control system that utilizes NDI will need a continuous readjustment of the threshold NDI. Table 3 shows experimentally obtained thresholds. These thresholds change with both plant and environmental conditions. In all probability, the single element optical detector system is too sensitive to reliably perform a real time spot spraying operation continuously over variable lighting conditions.

Under objective 3, Ramaeker's intermittent sprayer evaluation model was based upon one herbicide application to control weeds. Dividing the sensors spot area in half allows for greater resolution and a possible smaller spray area/weed. The smaller the spray area, the greater the herbicide reduction potential. This resolution, however has an increased cost associated with it. There is an optimal spray nozzle (row-unit) width which was not determined. Thus, there would also be a balance between chemical savings, crop value loss due to crop/weed interaction (if applicable), repeat applications, and additional herbicide costs.

The sprayer sizes chosen are based on popular row crop machinery sizes. The cost of retrofitting a conventional sprayer for intermittent sprayer approximately $1500/m ($455/ft). There is no large difference in sprayer per unit of width as size changes. The estimated field herbicide reduction for intermittent spraying was found to be 98.2%, 90.8%, and 83.5% (Table 4) respectively, for low, medium, and high weed densities shown in the weed maps in Figure 5a,b,c. One reason the estimated herbicide reductions were greater than Johnson et al. (1995) was the size of the area sprayed per individual weed. These reduction values were more optimistic than Hanson and Wick (1992). Repeated chemical application could be needed to control small undetected weeds and would reduce the overall herbicide savings.

Average herbicide cost reduction simulations ranged from $24.10/ha. ($9.75/a) for the high weed density field to $28.40/ha ($11.50/a) for the low weed density field. The 4.6 m (15 ft) wide sprayer would require 100 ha (250 acres) of annual use to recover the addition fixed costs). The 6.1m (20 ft) and 9.1 m (30 ft) wide sprayer would break even at 200 ha (500 acres) of annual use. At an annual use of 300 ha (750 acres) the 12.2 m (40 ft) sprayer would break even. All sprayers sizes would break-even at an annual use rate of less than 400 ha (1000 acres). The timeliness of the application operation at the sprayer beak-even points was not assessed.

Break-even usage for all sprayer sizes could be less. The high weed density field was used for analysis and would be a worse case scenario in terms of herbicide reduction in the simulation. Actual field weed densities would occur over a range from the low to high weed densities. The break-even annual usage would dependent upon a composite of numerous field weed densities in actual field usage. The lower the average weed density, the greater the chemical savings, and the lower the break-even usage.

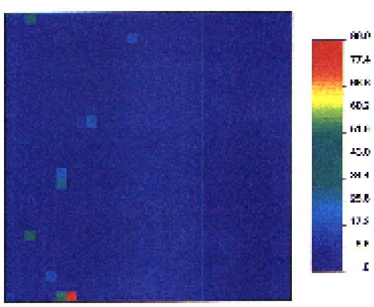

Figure 5a.
Low Weed Density

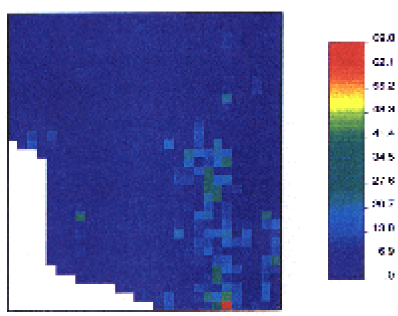

Figure 5b
Medium Weed Density

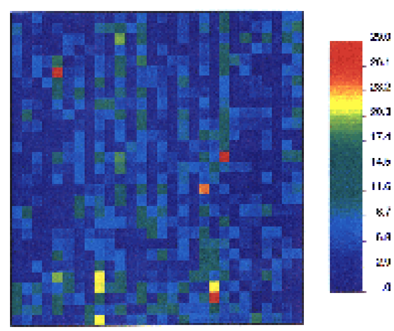

Figure 5c
High Weed Density

Impact of fixed and variable application dates on runoff losses of post-emergent herbicide

The use of spot-spraying techniques will require identification and herbicide application to emerged weeds. The dates at which the herbicide can be applied will depend on planting dates and weed growth rates. To assess the potential impact of spot-spraying on herbicide runoff, an assessment was conducted to determine the impact of fixed and variable application dates on runoff losses.

Whenever herbicides are used, a portion of the applied dose will reach the soil. An important aspect of the subsequent herbicide fate is loss to surface and subsurface water. Surface runoff is a dominant pathway for losses for moderately adsorbed herbicides commonly used with corn production. Some chemicals are lost more in subsurface flow. To make the fullest use of herbicide and reduce impacts on water quality, we should decrease the losses in runoff events.

In order to study the impact of application dates on runoff losses of post-emergent herbicide, we did computer simulations using GLEAMS (Groundwater Loading Effects of Agricultural Management Systems, 2.10) (Leonard et al., 1987) to test two methods to select application dates. The following methods were evaluated:

1. Application on five fixed dates each year for 50-year period.

2. Applications on different dates around the previous schedule every year.

Using the first method, we chose May 25, May 30, June 5, June 10, and June 15 as application dates. Using the second method, we checked the precipitation record first and then selected five dates each year around May 25, May 30, June 5, June 10, respectively, according to the criteria:
with De = Date application expected

1. If no rain on De and 1 day before, then apply on De.

2. If rain on De or one day before, then apply on first day following or 2 days without rain (ignore rainfall when it is less or equal 0.25 in.).

Four locations: York, Otoe, Dodge, Scotts Bluff County, Nebraska were used for this evaluation.

From Table 5 obvious differences can be seen between the two methods for Otoe and York County. The variable method resulted in loss for these two counties with difference in the mean loss ranging for 0.0% on June 15 York, to -21% on May 25 Otoe. But for Scotts Bluff County, it even increased the pesticide losses. The reason was because of the variable method's application date selection criteria. When it rained on the proposed day, that day was moved forward until no rain for two continuous days. For instance, the precipitation data of Scotts Bluff May 30 1954 and following days are: 0.48 in., 0.26 in., 0.00, and 0.00 in. An application was planned on day 1, with 0.48 inches rainfall, but because of the rain, we applied three days later. The result in the losses changed from 17.87 g/ha to 23.65 g/ha. Although it had rained on the expected day, it was not enough to make the soil saturated. If the application were applied on the following day, though there was no rain on that day, the previous two-day rainfall was enough to cause runoff.

After these simulations we conclude the following:

If the soil is unsaturated, the rain cannot run off. After the soil is saturated, the rain will cause runoff and it will result in potential significant pesticide losses depending on the amount of previous rainfall.

1. If an application date is chosen at the end of a long dry period, there are only little losses. If there is no rain, then there is no run off, resulting in no herbicide losses.

2. However, if the application date that is chosen after several wet days, it may cause great losses. For example, the loss of Otoe County May 25, 1956 is 130.8 g/ha. There were 0.17, 0.15, 0.34, 0.00, 0.07, 0.27 in. rainfall on the previous days respectively.

3. If significant rain is on the previous day, even if no rain on the day of application, there is still large losses. If only a little rain, the losses would not be great.

4. The variable method can make a big difference on herbicide losses, but it is only for the locations with a relatively large loss. If the location has small losses, such as Scotts Bluff, this method has less impact.

A statistical evaluation was performed. The herbicide losses data obtained by GLEAMS were not harmonious. For instance, the data for Dodge County May 30 (application date is May 30) came either from normal or gamma distribution; the data for Otoe County June 5 came only from gamma, but not normal distribution. There remains an unsolved problem: Is there a significant difference in mean losses for each location and each application date?

Personnel Support

Three graduate students were supported on the project: Mr. Tim Hindman started as an USDA National Needs Ph.D. Fellow. Mr. Lei Hua. a masters student worked fo a year before pursuing his mechanical engineering interests at South Carolina. Miss Yan Li, a civil engineering masters student worked on the surface water quality problem, but left after 6 months for personal reasons. Dr. Franti continues work on the environmental impact of spot spraying technology. Paul Woodward is a Sophomore Biological Systems Engineering also worked on the project. Brian Raemakers and Tarun Mehta provided data for the project but were supported by State assistantship. Mr. Hindman is defending his dissertation research this summer.

Project Impact

Widespread use of chemicals exemplifies both the success of the American agricultural system, but also presents potential tragedy to the environment. 8.2 metric tons (18,000 lbs.) per day of herbicide flow have been reported down the Mississippi River during peak spring runoff. 68,182 metric tons (150 million pounds) of five herbicides - atrazine, cyanazine, simazine, alachor, and metolachor are applied every spring across the corn belt. In Nebraska, approximately 15,000 metric tons (33 million pounds) of pesticides are applied annually (Baker, Peterson and Kamble, 1990), with a large percentage applied in the spring. Most herbicides are broadcast preemergence to the crop. While herbicides have been effective for weed control, water quality problems have also resulted. Spot sprayer operations in agricultural systems and road side or highway control of weeds can potentially reduce chemical usage, adverse environmental and health consequences, and improve surface water quality. The objective of this technology is to apply chemicals only in correct doses to individual or specific groups of plants and not to the soil or environment. However, simple optical plant sensor accuracy is currently only 60-70 percent. Better detection systems using machine vision will accurately detect and classify plants (80-95 percent) and subsequent chemical impact (hit, miss, and kill rate) during spot spraying using prescription maps.

The use of machine vision-spot spraying will reduce the amount of herbicides used under most conditions, and the water quality impacts are expected to be great. Post-applied products will be used for spot spraying, and preliminary research results indicate the use of post-emerge only applications of atrazine can reduce long-term atrazine runoff to surface waters greater than 50% compared to pre-emergent applications. One reason is that for a post application atrazine is applied at a lower rate and is applied after many runoff events have already occurred.

Table 1. SAS discriminant analysis results for RGB values (without low-intensity monochromatic light sources).

From TARGET	Number of Observations and Percent Classified into TARGET: Bare Soil	Corn Stalks	Grass	Wheat Straw	Total
Bare Soil	**125**	43	1	7	176
	71.02%	24.43%	0.57%	3.98%	100.00%
Corn Stalks	74	**46**	1	72	193
	38.34%	**23.83%**	0.52%	37.31%	100.00%
Grass	74	13	**154**	4	245
	30.20%	5.31%	**62.86%**	1.63%	100.00%
Wheat Straw	22	41	0	**129**	192
	11.46%	21.35%	0.00%	**67.19%**	100.00%
Total	295	143	156	212	806
Percent	36.60%	17.74%	19.35%	26.30%	100.00%

Error Count Estimates for TARGET:

	Bare Soil	Corn Stalks	Grass	Wheat Straw	Total
Rate	0.2898	0.7617	0.3714	0.3281	**0.4367**

NOTES: 806 observations

4 class levels
6 input variables

Class Means on Canonical Variables

TARGET	CAN1	CAN2	CAN3
Bare Soil	-0.19211	0.642758	-0.10629
Corn Stalks	-0.63698	0.234844	0.14733
Grass	1.739958	-0.2231	0.001119
Wheat Straw	-1.40386	-0.54058	-0.0521

Canonical Coefficients

	TARGET: Bare Soil	Corn Stalks	Grass	Wheat Straw
CONSTANT	-8.51143	-9.89051	-8.80934	-13.3508
Exposure	1.54153	-0.15079	0.84197	-0.03435
Illuminance	-0.0001	-0.00015	0.000265	-0.00022
Source Temp.	0.00271	0.00283	0.00247	0.0031
Red	0.3754	0.44897	0.15165	0.59382
Green	-0.35083	-0.40634	-0.06169	-0.50679
Blue	-0.01151	-0.02554	-0.07493	-0.07539

Table 2. Fuzzy logic model results for unclustered excess green (ExG) and excess red (ExR) test data set with 2 output classes.

ExGR ANFIS Fuzzy Logic Model

Class Level Information

TARGET	Frequency	Weight	Proportion
Plant	22986	22986	0.0599
Background	361017	361017	0.9401

Number of Observations and Percent Classified into TARGET:

From TARGET	Plant	Background	Other	Total
Plant	**18641**	4344	1	22986
	81.10	18.90	0.00	100.00
Background	436	**360549**	29	361014
	0.12	**99.87**	0.01	100.00
Total	19077	364893	30	384000
Percent	4.97	95.02	0.01	100.00

Error Count Estimates for TARGET:

	Plant	Background	Total
Rate	0.1890	0.0013	**0.0125**

NOTES:
Clustered training data set 24,000 epochs
2 class levels
4 input variables
Gaussian membership functions

Table 3. Plant characteristics and detection thresholds for Normalized Difference Index for a non-imaging sensor.

Days after Emergence	Weed Type		Weed Crown Area cm^2	Crown Minor Axis cm	Crown Major Axis cm	Field of View Covered by Weed %	NDI Threshold Value to Trigger Sprayer
6 days	Cocklebur	a	6.1	2.1	6.3	5.7	0.28
		b	4.8	0.5	7.0	4.5	0.25
		c	5.0	1.5	6.8	4.7	0.29
	Shattercane	a	6.2	2.2	8.3	5.8	0.27
		b	1.0	--	3.0	1.0	0.24
		c	4.5	2.0	7.5	4.2	0.26
	Corn	a	18.7	7.1	12.2	17.5	0.36
		b	25.8	5.8	17.8	24.1	0.34
	Velvetleaf	a	2.9	2.9	1.5	2.7	0.27
		b	1.8	2.2	1.5	1.7	0.28
		c	2.6	0.8	2.6	2.5	0.24
8 days	Cocklebur	a	9.4	5.2	5.8	8.8	0.30
		b	12.1	4.8	9.6	11.3	0.31
		c	9.7	5.2	7.5	9.1	–

Days after Emergence	Weed Type		Weed Crown Area cm^2	Crown Minor Axis cm	Crown Major Axis cm	Field of View Covered by Weed %	NDI Threshold Value to Trigger Sprayer
	Multiple Species	a	7.6	2.3	4.1	7.1	0.28
		b	10.2	4.7	4.9	9.5	0.29
		c	5.2	2.9	3.2	4.9	--
	Shattercane	a	14.6	--	8.9	13.7	--
		b	1.5	--	3.5	1.4	0.22
		c	7.4	-	9.8	6.9	0.26
	Corn	a	28.8	--	18.9	27.0	0.39
		b	30.4	--	20.4	28.4	0.41
	Velvetleaf	a	5.7	3.0	3.74	5.3	--
		b	3.7	1.9	2.9	3.5	0.25
		c	3.7	1.8	3.4	3.5	0.23
11 days	Cocklebur	a	19.6	7.6	7.7	18.4	0.40
		b	24.2	9.3	10.1	22.6	0.44
		c	26.2	9.7	10.0	24.5	0.40
	Multiple Species	a	7.6	4.0	3.9	7.12	0.28
		b	16.8	6.4	6.4	15.7	0.35
		c	12.2	4.6	7.2	11.5	0.30
	Shattercane	a	23.2	--	23.0	21.7	0.35
		b	3.95	--	6.6	3.7	0.26

Days after Emergence	Weed Type		Weed Crown Area cm^2	Crown Minor Axis cm	Crown Major Axis cm	Field of View Covered by Weed %	NDI Threshold Value to Trigger Sprayer
		c	17.1	7.4	20.1	16.0	0.34
	Velvet leaf	a	13.4	5.3	5.7	12.5	0.34
		b	5.9	2.7	3.4	5.6	0.26
		c	4.4	2.5	3.0	4.1	0.27

* - NDI threshold value above which the plant would not be detected

Table 4. Simulated Field level herbicide reduction using a non-imaging, sensor controlled spot sprayer.

Weeds / sensor detection cell	Theoretical Herbicide Savings (R_i) (%)	Portion (%) of Field Area (A_i)			Herbicide Reduced - %		
		low density	med density	high density	low density	med density	high density
0	100.00	81.51	45.92	8.50	0.00	0.00	0.00
1	96.25	10.46	14.86	11.08	0.43	0.61	0.46
2	92.50	2.93	8.89	14.29	0.24	0.72	1.15
3	88.75	2.04	4.63	10.71	0.23	0.53	1.23
4	85.88	0.77	4.26	12.32	0.11	0.64	1.84
5	83.00	0.38	3.41	8.87	0.07	0.61	1.60
6	80.25	0.38	2.56	5.54	0.08	0.54	1.17
7	77.63	0.13	1.95	5.91	0.03	0.46	1.39
8	74.88	0.00	1.58	5.42	0.00	0.41	1.42
9	72.00	0.00	1.34	3.08	0.00	0.38	0.87
10	68.38	0.26	1.46	2.34	0.08	0.45	0.72
11	64.88	0.00	0.97	3.45	0.00	0.32	1.14
12	63.88	0.00	1.22	1.85	0.00	0.43	0.65

Weeds / sensor detection cell	Theoretical Herbicide Savings (R_i) (%)	Portion (%) of Field Area (A_i)			Herbicide Reduced - %		
		low density	med density	high density	low density	med density	high density
13	62.25	0.13	1.22	1.48	0.05	0.45	0.55
14	60.25	0.13	0.37	0.86	0.05	0.14	0.34
15	58.00	0.13	0.49	1.35	0.05	0.20	0.55
16	55.63	0.00	0.61	0.86	0.00	0.27	0.38
17	53.75	0.00	0.61	0.12	0.00	0.27	0.06
18	51.63	0.13	0.37	0.62	0.06	0.17	0.28
20	47.13	0.00	0.73	0.25	0.00	0.36	0.12
21	46.38	0.00	0.37	0.25	0.00	0.18	0.12
22	45.13	0.00	0.12	0.25	0.00	0.06	0.13
23	44.13	0.00	0.24	0.00	0.00	0.13	0.00
24	42.25	0.00	0.12	0.12	0.00	0.07	0.07
25	39.88	0.00	0.24	0.00	0.00	0.14	0.00
26	38.13	0.00	0.24	0.00	0.00	0.14	0.00
27	36.00	0.00	0.12	0.25	0.00	0.07	0.14

Weeds / sensor detection cell	Theoretical Herbicide Savings (R_i) (%)	Portion (%) of Field Area (A_i)			Herbicide Reduced - %		
		low density	med density	high density	low density	med density	high density
28	33.88	0.00	0.12	0.12	0.00	0.07	0.07
29	32.50	0.13	0.12	0.00	0.08	0.07	0.00
30	30.50	0.00	0.00	0.00	0.00	0.00	0.00
more than 30	0.00	0.51	0.73	0.00	0.20	0.29	0.00
Total area sprayed					1.76	9.25	16.51
Total Herbicide Reduction -%					**98.24**	**90.75**	**83.49**

Table 5. Application date evaluation results. V= variable date application, F= fixed-date application.

Pst losses (g/ha)		25-May	30-May	5-June	10-June	15-June
Otoe	Mean V	37.3	40.1	41.0	43.4	35.7
	F	47.4	42.0	45.6	45.3	38.3
	Difference	-21%	-4.6%	-10.0%	-4.2%	-6.8%
	Max V	131	124	147	204	141
	F	540	165	267	204	141
	Difference	-76%	-24%	-45%	0.0%	0.0%
	Min V	1.55	2.15	2.53	2.68	2.83
	F	4	2.16	2.53	2.68	2.83
	Difference	-61%	-0.5%	0.0%	0.0%	0.0%
York	Mean V	28.7	30.5	28.7	28.9	26.2
	F	29.6	30.9	29.6	30.8	26.2
	Difference	-2.9%	-1.3%	-3.1%	-6.0%	0.0%
	Max V	106	135	110	100	126
	F	106	135	110	142	126
	Difference	0.0%	0.0%	0.0%	29%	0.0%
	Min V	4.60	2.21	1.98	1.64	1.74
	F	4.60	2.21	1.98	1.64	1.74
	Difference	0.0%	0.0%	0.0%	0.0%	0.0%
Dodge	Mean V	11.0	11.0	11.2	11.5	11.0
	F	11.1	11.4	11.4	11.8	11.5
	Difference	-1.4%	-3.8%	-1.2%	-2.2%	-4.5%
	Max V	43.2	42.5	45.5	48.8	52.0
	F	43.0	42.5	45.4	48.7	52.0
	Difference	0.4%	0.0%	0.2%	0.0%	0.0%
	Min V	0.61	0.64	0.76	0.81	0.86
	F	0.61	0.64	0.76	0.81	0.86
	Difference	0.0%	0.0%	0.0%	0.0%	0.0%
Scoffs Bluff	Mean V	2.29	2.88	2.21	2.79	2.23
	F	2.42	2.65	1.89	2.66	2.58
	Difference	-5.5%	8.8%	17%	4.7%	-14%
	Max V	19.3	23.7	15.0	16.1	19.7
	F	14.8	22.4	8.7	15.2	19.3
	Difference	30%	5.7%	72%	5.7%	2.2%
	Min V	0.06	0.07	0.08	0.12	0.10
	F	0.06	0.07	0.08	0.08	0.09
	Difference	0.0%	0.0%	4.0%	46%	6.7%

Basic Information

Title:	Program Administration/Management Description
Project Number:	B01
Start Date:	9/1/1997
End Date:	2/28/2000
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Kyle D. Hoagland

Publication

1. NOTE: see individual annual reports
2. See individual annual reports

RESEARCH:

Project C22 (Hergert et al.): Nitrogen Use Efficiency (complete) - Approximately half of all irrigated acres in Nebraska utilize furrow irrigation, thus nitrogen management practices must continue to improve in these areas to reduce the prevalence of nitrate contamination of ground water. The results of this study demonstrated that soil organic nitrogen and residual nitrate-N are spatially highly variable. Nevertheless, grain yields between variable (alternate row) versus uniform application treatments were not significantly different, indicating that there is no advantage to variable rate fertilizer applicatioins.

Project C24 (Dvorak and Woldt): Well Vulnerability to Viral Pathogens (complete) - Seven rural community wells were tested six times for the presence of viruses using PCR and cell culture techniques, and viral transport in ground water was modeled using CANVAS. Only 2% of the public water supplies tested positive for viral contamination, which was consistent with model predictions. Human induced factors such as abandoned wells and improperly constructed wells are likely to enhance viral transport to public water supplies.

Project C25 (Siegfried and Hoagland): Effects of Pesticide Mixtures on Algae (complete) - Individual and binary combinations of herbicides (atrazine, metolachlor, simazine, alachlor, and isoxaflutole) that either commonly occur in agricultural streams and/or are commonly used in agricultural fields were exposed to the green algae *Chlorella vulgaris* and *Ankistrodesmus falcatus,* and the diatom *Cyclotella meneghiniana*. The algae bioassayed exhibited a broad range of sensitivities to these pesticides, even within the same division (e.g., green algae). Combinations of these toxicants acted additively rather than synergistically or antagonistically for these species, despite their different modes of action.

Project C34 (Shea et al.): Use of Zerovalent Iron to Treat Metolachlor-Contaminated Soil (complete) - Aqueous batch experiments and transport column studies were performed to determine the efficacy of using zerovalent iron barriers to treat herbicide-contaminated soil. With 1-4% aluminum sulfate additions to Fe(0) in solution, nearly complete removal of metolachlor occurred. Significant Fe(0)-mediated dechlorination of metolachlor also occurred using a 50:50 Fe(0)-sand barrier during unsaturated transport in columns, indicating that this lower cost approach to soil decontamination is extremely effective.

Project C55 (Franti et al.): Reducing Atrazine Contamination (complete) - Surface water runoff from field plots were used to evaluate several atrazine management practices for dryland and irrigated farming and the economic impact of these atrazine management alternatives were analyzed via modeling. Results indicated less water and atrazine runoff from no-till and ridge-till than disk-till, with annual reductions in atrazine loss for alternative practices ranging from 17 to 77% in south-central NE to 4 to 66% in northeast KS. Pre-emergent incorporation and pre-emergent banding were most effective at reducing long-term atrazine loss.

Project C66 (Zlotnik et al.): Hydraulic Characterization of Stream-Aquifer Interfaces (ongoing) - A multi-state study was conducted to develop convenient to use, alternative models of stream-aquifer interactions for the Midwest. Modeling efforts to date have focused on aquifer response to stream stage fluctuations, stream depletion, and head drawdown under pumping conditions near partially penetrating streams, resulting in models which are highly relevant to particularly Nebraska and Kansas. These models address conditions common to the Great Plains and many other areas of the U.S.

Project C77 (Meyer et al.): Reducing Pesticide Inputs to Ground and Surface Water (complete) - Machine vision-based assessment using electronic images of crop plants and weeds in fields was developed to evaluate optical sensor-controlled spot sprayers to optimize and minimize herbicide applications. Comparisons of this approach were made with variable-rate application technology. Results indicate that machine vision spot spraying reduces the amount of herbicide used under most conditions, thus water quality impacts are expected. The use of post-emerge only applications of atrazine can reduce long-term runoff to surface waters by more than 50%.

Project C88 (Chen et al.): Determining Aquifer and Aquitard Properties (ongoing) - The aim of this study has been to develop new methods for measuring the hydraulic properties of aquifers and aquitards, focusing on stream-flow depletion caused by ground water withdrawals. Data obtained from Wood River, NE demonstrated the efficacy of this new method for unconfined aquifers. Baseflow reduction is a major component in total stream depletion for many irrigation wells. A numerical model of the stream-aquifer system has also been developed for central Nebraska using MODFLOW.

Information Transfer Program

Basic Information

Title:	INFORMATION TRANSFER PROGRAM
Start Date:	3/1/1999
End Date:	1/28/2001
Descriptors:	Education
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Steven W. Ress, Kyle D. Hoagland

Publication

INFORMATION TRANSFER PROGRAM:

2001 USGS ANNUAL REPORT INPUT
UNL WATER CENTER

NEWSLETTER:

The *Water Current* newsletter is in it's 33rd year of continuos publication. Published six times per year (February, April, June, August, October and December). An annual reader survey is published in the April edition. The newsletter was completely overhauled for general appearance, flag and certain content directions in October, 2000. A new logo and second highlight color were added. Water-related research faculty are featured on a regular basis. Guest columns are being solicited and published from area water-related professionals on a regular basis. Individual issues rotate between eight and 12 pages in length. Research briefs, research progress reports and RFPs are frequently published. Subscriptions are provided at no charge to the public and there are approximately 2,400 subscribers. A major thrust this year was revising and "culling" the mailing list for reasons of economy and efficiency. Plans for the coming year include publication of color photographs and graphics.

Virtual copies of the newsletter are now available on-line at the Water Center's web site.

OTHER PRINT RESOURCES:

"How To Access Water Resources Information," a public guide to local and internet resources on a variety of water and water-related issues. Distributed free and available on-line.

Water Center informational brochures. Updated and produced annually to provide overawes of the mission and programming of the UNL Water Center. Distributed free.

Water Center Pocket Directory (being developed) will be a pocket-size brochure listing key NU, federal, state and local water resource agencies and points of contact.

Sixteen-page newspaper tabloids on wetlands and drinking water issues, respectively published in 1997 and 1999 continue to be used by a variety of university programs, 4-H, FFA, state agencies and the public schools in natural science curriculums and educational programs on these issues. Distributed free (in quantity).

A range of publications produced outside the UNL Water Center are also made available in print and/or electronic versions, most at no charge, through the Water Center's web site.

NEWS RELEASES:

The Water Center produces about 25 press releases annually based on research, cooperative extension, teaching and public outreach programming sponsored or co-sponsored by the UNL Water Center. They are used to announce conferences, seminars, summer festivals, tours, waste pesticide collections and other activities as well as to publicize recent research results. These are widely published in state newspapers, as well as in organizational, trade and professional journals. The releases support a wide variety of UNL water-related research and programming that crosses department lines and is interdisciplinary in nature.

ELECTRONIC RESOURCES:

Electronic versions of newsletters and other print materials, RFPs, information about the Water Center and its research faculty, information about the Water Sciences Laboratory and course information for graduate and undergraduate students in water-related fields of study are available at http://watercenter.unl.edu. The Water Center co-sponsors four additional sites: the UNL Water Sciences Laboratory, the Platte Watershed Program, the UNL Department of Agronomy and Horticulture's Festival of Color and the UNL-based Cooperative Eco-Systems Study Unit (CESU). Each of these is program specific. Many free water-related publications and other resources are available through these sites. They can be found at:

***Water Sciences Laboratory*:** http://www.ianr.unl.edu/waterscience/wsl.html

***Platte Watershed Program*:** http://ianrwww.unl.edu/ianr/pwp/pwp.html

***Fall Festival of Color*:** http://hort.unl.edu/fallfest/

***Cooperative Eco-Systems Studies Unit (CESU)* -** under construction/not yet on-line.

The Water Center's web site was extensively revamped in November and December, 2000. Faculty members now have their own web page and there are links to current research, academic programs for undergraduate and graduate students, extension and outreach programming, water-related links, and much more. Vastly increased use of color and graphics was used in the site redesign.

CONFERENCES, SEMINARS AND TOURS:

Nebraska Water Conference conducted each March and co-sponsored by the Water Center, Nebraska Water Conference Council and other academic, commercial and non-profit organizations. The conference attracts about 200 speakers and participants. News releases, brochures and a program are produced for this event. This year's event was a one-day affair dedicated to groundwater well monitoring and featured state educational credits for well drillers.

Water Resources Seminar Series is a series of 12 to 14 public lectures held from January to April each year and co-sponsored by the Water Center and other NU departments and concerns. The series may be taken for graduate or undergraduate student credit or as a free public series. News releases, mailings and brochures are produced in conjunction with this event. This year's seminar was held in conjunction with the Department of Political Science and it's venue was moved to make it more accessible to a wider range of UNL faculty and students..

Festival of Color is a bi-annual fall lawn and garden open house co-sponsored by the Water Center, UNL's Department of Agronomy and Horticulture and other NU departments and organizations. Water quality issues are part of it's primary focus. The one-day event attracts great media interest and is attended by 8,000 to 10,000. News releases, newspaper advertisements, flyers and a brochure are produced in conjunction with this event.

Platte Watershed Program Symposium is co-sponsored by the Water Center and other NU departments and centers, as well as from the U.S. Environmental Protection Agency, Region VII and the U.S. Fish and Wildlife Service. The symposium explores research and educational programming related to the ecology of the Central Platte River Basin area of Nebraska. Approximately 200 attend this event each winter. News releases and brochures are produced in conjunction with this event.

Summer Water and Natural Resources Tour co-sponsored by the Water Center, Nebraska Water Conference Council and other NU, public, private and commercial entities. The annual three-day tour is conducted in June and is used to educate on current water and natural resource issues effecting Nebraskans. About 100 water users, legislators, ag producers and members of the public attend. News releases, mailings and a brochure are produced in conjunction with this event.

EDUCATIONAL DISPLAYS:

The Water Center makes frequent public displays in association with conferences, symposiums, water-related trade shows, educational open houses and water and environmental festivals. These average about 8-10 per year.

Staff participate in such educational festivals as The Groundwater Foundation's "Children's Groundwater Festival," NU's "Earth Wellness Festival," "Husker Harvest Days" and others.

PROMOTIONAL ITEMS:

Inexpensive promotional items such as coffee mugs, key chains, lanyards, etc. imprinted with the Water Center's new bi-color logo and web address and telephone numbers are produced for distribution in conjunction with educational programs/displays, student recruitment seminars, conferences and tours as funds are available.

PESTICIDE EDUCATION OFFICE:

The Water Center helps with publicity, promotion and press relations for programs conducted by the UNL Pesticide Education Office, which is part of the UNL Department of Agronomy and Horticulture. These efforts include press releases supporting statewide programs supporting pesticide container recycling and waste pesticide collections. The UNL Pest. Ed. office was formerly part of the Water Center until a recent administrative reorganization.

Basic Information

Title:	Program Administration/Management Description
Start Date:	3/1/1997
End Date:	2/28/2000
Descriptors:	
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Kyle D. Hoagland

Publication

Project C02 (Ress): This project number encompasses all of the primary information transfer activities for the Water Center at the University of Nebraska, including publication of the bimonthly newsletter *Water Current* and a total revision of our web site this year. Printed publications have included a public guide to local and Internet resources on water-related issues, a pocket directory of key state federal and local water resources agencies, and newspaper tabloids published statewide on wetlands and drinking water issues. Additional products included regular news releases on water resource research, education and outreach activities, and partial sponsorship of the annual water conference, water resource seminar series, and the highly successful annual water tour. This is a model program for similar efforts university-wide.

Significantly less funds were allocated to the Director's budget this year (44% reduction). Operating expenses were used for basic program administration, including development of the Water Center's new web site, which is now complete. The web site is critical for information transfer, communication with water science faculty, graduate and undergraduate student recruitment and training, and linkages to other programs. Travel funds for the Director and Associate Director were used for participation in the annual NIWR and to generate additional water research funding. These are critical needs to effectively oversee and coordinate research programs supported by USGS funds administered through the UNL Water Center and to foster additional research in the water sciences through a wide variety of agencies (including EPA, NASA, ACOE, and USDA).

Basic Information

Title:	Determination of Aquifer and Aquitard Hydraulic Properties and Their Role in Streamflow Depletion
Start Date:	9/1/1998
End Date:	2/28/2000
Descriptors:	Aquifer parameters, conjunctive use, groundwater modeling, surface-groundwater relationships, well hydraulics
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Xun-Hong Chen, James Goeke, Robert F. Diffendal

Publication

INFORMATION TRANSFER PROGRAM

Pumping test results from Wood River site and description of the procedures for design of a high-quality aquifer test in unconfined aquifers were sent to the Central Platte Natural Resource District in Grand Island, Nebraska.

Basic Information

Title:	An Assessment of Factors Indicating Well Vulnerability in Nebraska
Start Date:	3/1/1999
End Date:	2/28/2000
Descriptors:	
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Bruce Dvorak, Wayne E. Woldt

Publication

Information Transfer Program

The results of this study are being disseminated _ ways. The results of this work are being shared with the communities that participated in the study by sending a summary of the results to the communities. The results are being shared with the state regulatory agency by sharing a copy of the student's masters thesis and providing the regulatory agency with a seminar presentation (June 2001). The results have been presented at a National Conference (2001 American Water Works Association Annual Conference) and will be condensed into a journal article in order to include the results of this study in the archival literature.

Basic Information

Title:	Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multistate Proposal
Start Date:	9/1/1998
End Date:	2/28/2000
Descriptors:	Surface-groundwater relationships, groundwater movement, streams, groundwater hydrology
Lead Institute:	University of Nebraska - Lincoln
Principal Investigators:	Vitaly A. Zlotnik, Xun-Hong Chen, James Goeke, James J. Butler, Marios Sophocleous, Carl McElwee

Publication

INFORMATION TRANSFER

Results were presented at several national meetings (American Geophysical Union, Spring 2000, Washington, D.C., Fall 2000, San Francisco; Geological Society of America, 2000, Reno, November 9-18, 2000).

Results were also presented to the state users: Central Platte Natural Resources District, Nebraska in 2000, and at the 17th and 18th Annual Water and the Future of Kansas Conference, March 2000, Manhattan, Kansas.

The web site was set up in Kansas Geological Survey - www.kgs.ukans.edu/StreamAq - for rapid and direct dissemination of information. Downloading of reports and computer program is available on the Internet.

The materials were taught at the seminar "Modern Problems of Hydrogeology", Spring 2001, University of Nebraska-Lincoln.

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	3	0	0	4
Masters	2	6	0	0	8
Ph.D.	1	2	0	0	3
Post-Doc.	0	2	0	0	2
Total	4	13	0	0	17

Notable Awards and Achievements

Bruce Dvorak - Nebraska C24 Project

A poster titled "Assessment of Viral Contamination in Nebraska's Small Community Wells," won 2nd place in the poster competition at the 2001 American Water Works Annual Conference in Washington, DC. June, 2001. The poster was presented by Julie Fisher.

Publications from Prior Projects