Nebraska Water Resources Center
Annual Technical Report
FY 2004

Introduction

Dr. Kyle D. Hoagland served as director of the University of Nebraska Water Center this year, with Michael Jess as associate director and Dr. John Holz as the new assistant director. Steven Ress and Tricia Liedle continued as communications specialist and office supervisor, respectively. The Water Center is currently making plans to move into the newly renovated natural resources building, scheduled for completion in November 2005.

The campus-wide Water Resources Research Initiative (WRRI) continued into its second year. To date, six new faculty members have been hired in a variety of water-related fields including, water law, aquatic chemistry, surface hydrology, climate modeling, water economics, and stream ecology. The second annual Water Law, Policy and Science Conference was hosted at the University of Nebraska-Lincoln on April 7-8, with Water Management and Policy in the Great Plains: Implications of Drought and Climate Change as its theme. This ongoing conference series is aimed at better integrating water science and its societal dimensions, while focusing on themes of immediate relevance to this region yet of international importance as well.

Research Program

In 2004, an outside panel of state and federal agency representatives reviewed seven USGS 104(b) proposals and recommended two for full funding. Fortunately, we were able to obtain 1:1 matching funds for two projects and thus were able to fund the third-ranked project this year. Areas funded included (a) quantification of stream-aquifer connectivity, (b) detection and toxicity of androgenic growth promoters on non-target vertebrates, and (c) impacts of beaver on stream stability and restoration in agriculturally dominated ecosystems.

Also as part of the WRRI, additional equipment was added to the Water Sciences Laboratory (e.g., an ICP/MS and Auto-analyzer) to further enhance its analytical capabilities, particularly in the area of trace organics. Use of this core facility by water science faculty has continued to increase both in breadth of analyses and the number of faculty taking advantage of this cutting-edge facility. Analyses are conducted for other universities, state and federal agencies, as well as private companies and individuals. Analyses include munitions, antibiotics, pesticides (incl. herbicide metabolites), nutrients, and stable isotopes (e.g., N15).

Remediation of PCB-Contaminated Soils and Sediment using Zerovalent Iron and Surfactants

Basic Information

Title:	Remediation of PCB-Contaminated Soils and Sediment using Zerovalent Iron and Surfactants
Project Number:	2004NE72B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	North Central Region
Research Category:	Not Applicable
Focus Category:	Toxic Substances, Sediments, Treatment
Descriptors:	
Principal Investigators:	Steve Douglas Comfort

Publication

1. None at present

Remediation of PCB-Contaminated Soils and Sediment using Zerovalent Iron and Surfactants

Steve Comfort

School of Natural Resources, University of Nebraska

Abstract

Polychlorinated biphenyls (PCBs) contaminated sediments remain a significant threat to humans and aquatic ecosystems. PCBs had been used as coolants and lubricants in transformers, capacitors, and other electrical equipment because they do not burn easily and are good insulators. The traditional methods of excavation or dredging followed by landfill disposal or incineration of PCB-contaminated soil and lake sediments involve high costs. An alternative ex-situ treatment of PCB-laden sediments is by abiotically treating the dewatered sediment with zerovalent iron (Fe^0), surfactants and additional catalysts in static unsaturated windrows. Experiments show that solubility of PCBs in water can be increased by addition of surfactants. Solubility experiments revealed that apparent solubility of PCB congeners 2,2',5 Trichlorobiphenyl and 2,4' Dichlorobiphenyl could be increased with the increasing Didecyl concentrations (up to 1%). Low concentrations of Didecyl (0.25%) also increased the mass of Aroclor 1260 (commercial mixture) that dissolved in water (30 mg out of 50 mg placed in 100 mL water). Experiments with Aroclor1260 and Fe^0 alone in a surfactant matrix indicate adsorption of Aroclor1260. Experiments with Aroclor1260, Fe^0, didecyl, and catalyst ($Al_2(SO_4)_3$) indicates rapid removal of PCBs from solution but most of this loss is a result of adsorption. Increased removal rates were obtained when Pd was used as catalyst. Ongoing experiments are now combining zerovalent iron reduction with a secondary treatment involving peroxide or permanganate to oxidize adsorbed PCB from iron surface.

Objectives

- Increase aqueous solubility of different PCBs with surfactant and quantify optimum concentration needed.
- Determine effectiveness of zero-valent iron (Fe0) to degrade/adsorb PCBs in the presence of surfactant and catalyst.

Results

Results showed that aluminum sulfate can accelerate removal of PCBs by zerovalent iron from solution (Figure 1) containing a cationic surfactant matrix.

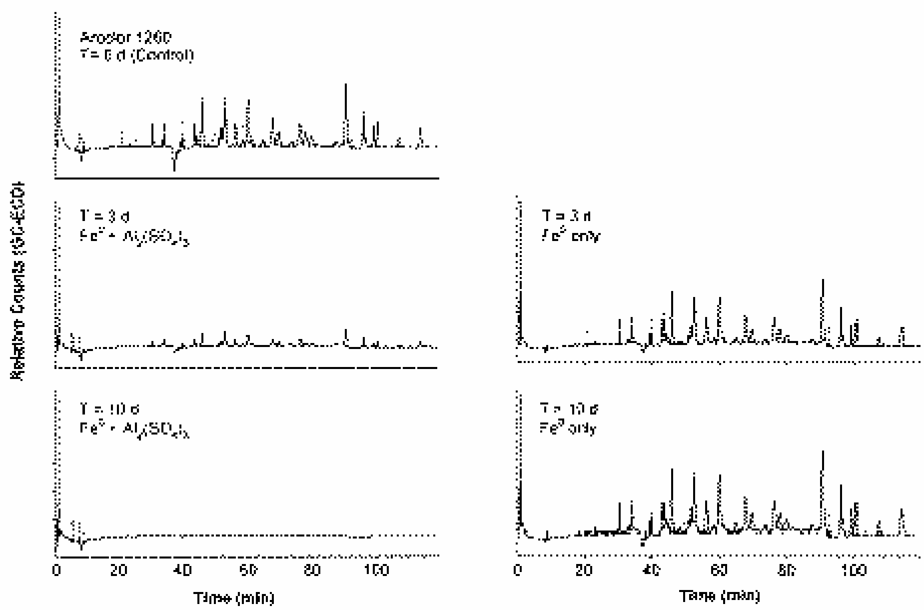

Figure 1. Effects of aluminum sulfate on PCB (Aroclor 1260) destruction by zerovalent iron in cationic surfactant matrix. Chromatographs were generated with GC-ECD.

Solubility experiments revealed that apparent solubility of various PCB congeners could be increased with the increasing didecyl concentrations (up to 1%) (Fig. 2).

Low concentrations of didecyl (0.25%) also increased the mass of Aroclor 1260 (commercial mixture) that dissolved in water (30 mg out of 50 mg placed in 100 mL H_2O**).**

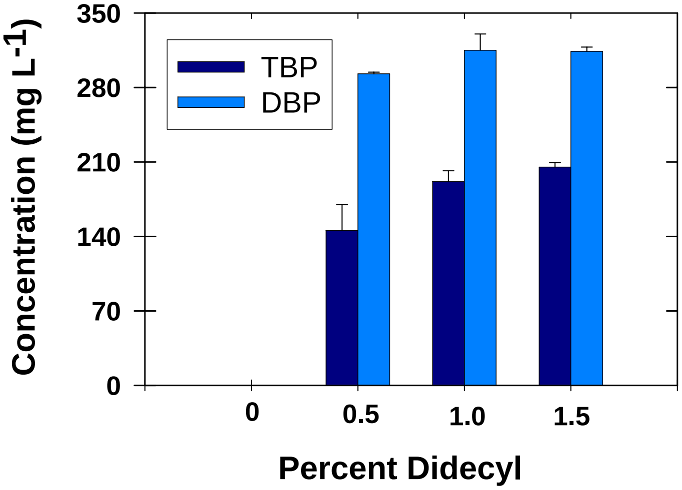

Figure 2. Increase in PCB concentration with increasing didecyl concentrations.

Very rapid removal of PCB mixture occurred with 0.05% Pd was used with iron (Fig. 3).

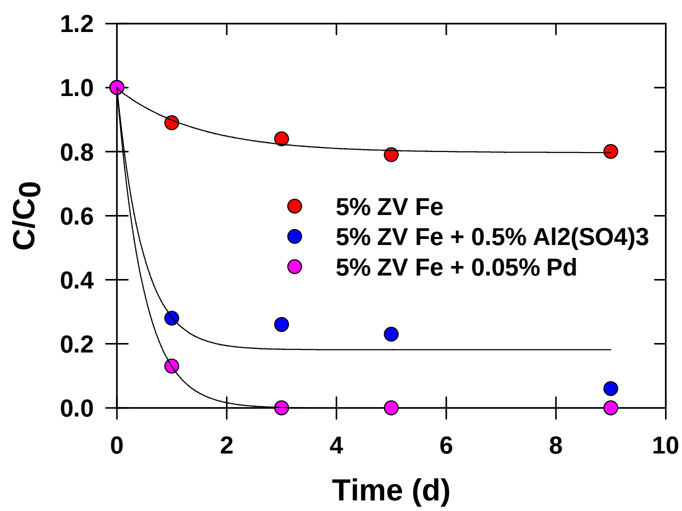

Figure 3. Destruction kinetics of PCBs with zerovalent iron with and without aluminum sulfate or palladium.

Extraction of iron surface revealed that most of the removal occurring was a result of adsorption and not dechlorination. Subsequent ongoing experiments are using a secondary treatment of peroxide or permanganate to oxidize adsorbed PCBs.

Initial Conclusion from First Years Work

- An optimum value of 1% didecyl was observed for increasing PCB congeners solubility. However, dissolution of solid-phase Aroclor 1260 was observed with only 0.25% didecyl.
- Experiments with Aroclor1260 and Fe^0 alone in a surfactant matrix indicate adsorption is occurring.
- Experiments with Aroclor1260, Fe^0, didecyl, and catalyst ($Al_2(SO_4)_3$) indicates rapid removal of PCBs from solution but most of this loss is a result of adsorption. Increased removal rates were obtained when Pd was used. Using a secondary treatment of iron plus peroxide appears to remove adsorbed PCBs. This treatment train will be pursued in future proposals.

Investigation of Groundwater Interactions with Surface Hydrologic Systems in River Valleys -- Using Modeling and Field Approaches

Basic Information

Title:	Investigation of Groundwater Interactions with Surface Hydrologic Systems in River Valleys -- Using Modeling and Field Approaches
Project Number:	2004NE73B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	First District
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	Groundwater monitoring, Evapotranspiration, Diurnal Fluctuation, Streamflow
Principal Investigators:	Xun-Hong Chen, James W. Goeke

Publication

1. Chen, X.H., Y. Yin, J.W. Goeke, and R.F. Diffendal, Jr. 2005. Vertical movement of water in a high plains aquifer induced by a pumping well. Environmental Geology 47(7): 931-941 (DOI: 10.1007/s00254-005-1223-4).
2. Chen, X. H., 2005. Statistical and geostatistical features of streambed hydraulic conductivities in the Platte River, Nebraska. Environmental Geology (accepted for publication).
3. Wen, F. J. and X. H. Chen, 2004. Evaluation of the impact of groundwater irrigation on streamflow depletion in Nebraska. Journal of Hydrology (in review).

COVERAGE

Project Number:	2004NE73B
Funding Period:	March 1, 2004 – February 28, 2005
Title:	Investigation of Groundwater Interactions with Surface Hydrologic Systems in River Valleys – Using Modeling and Field Approaches
PI:	Xun-Hong Chen
CO-PI:	James Goeke and Robert Caldwell

RESEARCH SYNOPSIS

Title: Investigation of Groundwater Interactions with Surface Hydrologic Systems in River Valleys – Using Modeling and Field Approaches

Project Number: 2004NE73B

Start Date: 03/01/2004

End Date: 02/28/2005

Funding Source: 104(b)

Congressional District: NE 1

Research Category: Groundwater flow and transport

Focus Categories: GW, HYDROL, MOD

Descriptors: Streambed hydraulic conductivity, Evapotranspiration, Groundwater modeling, Diurnal fluctuation of the water table, Parameter Estimation

Primary PI: Xun-Hong Chen

Other PIs: James Goeke and Robert Caldwell

Project Class: Research

Summary

This project is part of an on-going water resources investigation in Nebraska with a current focus on the interaction of groundwater with surface water. Surface water and groundwater are recognized to be hydrologicaly connected in Nebraska, and thus efficient management of surface water and groundwater requires a better understanding of their hydrologic relations. The goal of this project is to determine the groundwater evapotranspiration rate in riparian zones of selected river valleys of Nebraska, which is a key parameter in the development of water resources management tools

Objectives

This project has three specific objectives: 1) Install groundwater observation wells in the Platte River valley to observe groundwater level fluctuations in response to evapotranspiration and changes in stream stages; 2) Develop a cross-sectional numerical model for simulation of groundwater interactions with surface hydrologic components; 3) Develop an inverse method that calculates the rate of groundwater evapotranspiration, as well as streambed conductance, using the observed water level data.

Results

Objective 1 **–** The Platte River valley between Grand Island and Kearney was selected as the study area for this project. Two groundwater wells were constructed. One is co-located with the USGS stream gauge on the Platte River near Kearney; the other is co-located with a weather station of the High Plains Regional Climate Center (HPRCC) at the Kearney Airport. Hourly groundwater level and temperatures have been collected from the two wells since May 2004. In the study area, we also constructed several groundwater monitoring wells from previous projects and we collaborated with the Central Platte Natural Resources District for long-term groundwater monitoring from additional seven wells. One of these wells is co-located with the USGS stream gauge on the Platte River near Grand Island; several other wells are under trees in the riparian zone. Nine groundwater wells, three weather stations (HPRCC), and two streamflow and two rain gauges (USGS) form a monitoring system of surface water and groundwater within the study area.

Long-term groundwater monitoring data from the Republican River valley were analyzed to determine the evapotranspiration rate. Figure 1 shows the diurnal fluctuations of the water table from two observation wells. Figure 2 shows daily evapotranspiration rate of groundwater at the two observation locations.

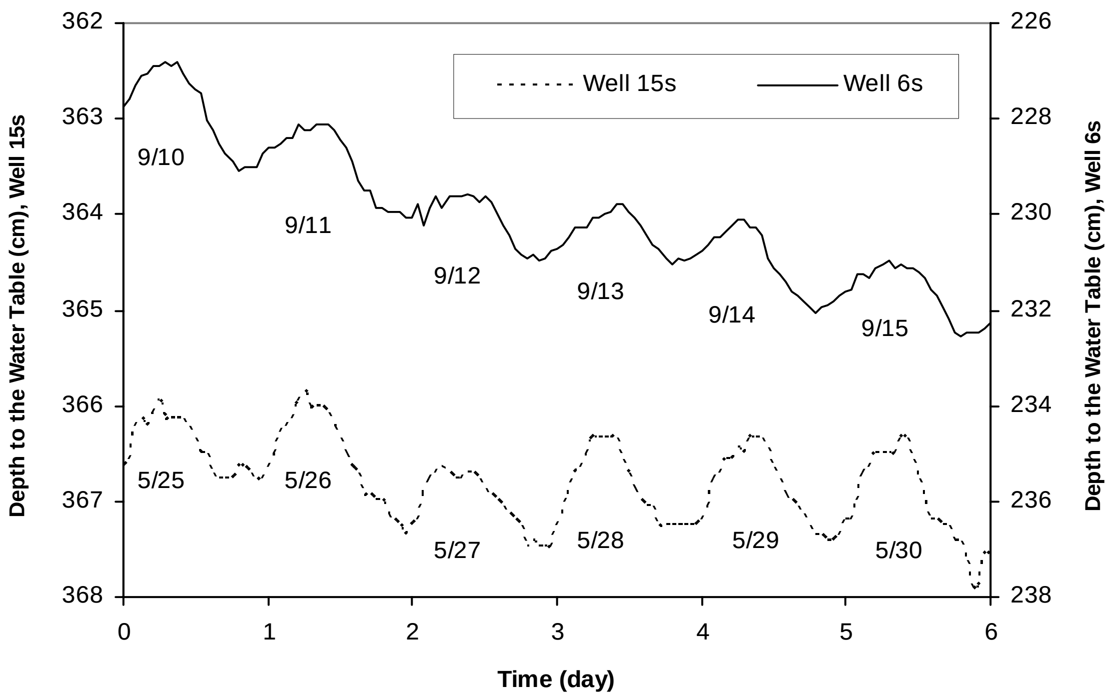

Fig. 1. Diurnal fluctuation of the water table (depth below the ground surface) with time (1999) observed at well 6s near the Republican River, Nebraska, USA and at well 15s near the Red Willow Creek, a tributary of the Republican River.

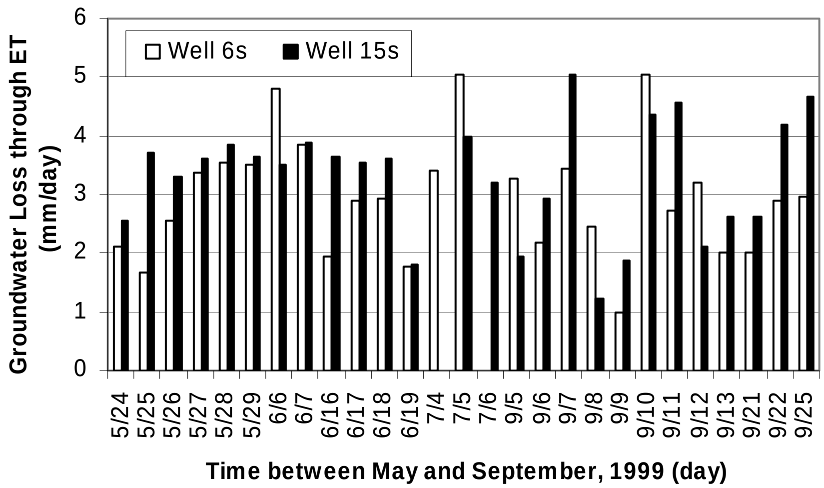

Fig. 2. Daily groundwater loss through evapotranspiration (ET) of the riparian vegetation in the Red Willow Creek and the Republican River valley, Nebraska.

Diurnal fluctuation of the water table was also observed from two monitoring wells in the riparian zone of the Platte River. The evapotranspiration rate was also estimated for the two locations.

Objective 2 **–** A groundwater flow model was developed to simulate the interactions between groundwater and surface water (stream stage, ET, and recharge). The model was developed based on the Garlerkin finite-element method and is able to model detailed flow systems over a vertical profile. This model has been used to simulate the stream-aquifer interactions based on the long-term monitoring data of groundwater levels and stream stages at the USGS gauge station near Kearney (station number 06770200) and Grand Island (station number 06770500).

Objective 3 **–** The cross-sectional groundwater model was coupled with the least squares methods for inverse calculation of aquifer and streambed hydraulic parameters. This method uses both stream stage and groundwater level data and inversely calculates several hydraulic parameters: vertical and horizontal hydraulic conductivities in the nearby aquifer, specific yield, and vertical hydraulic conductivity of streambed. We also conducted permeameter tests to determine vertical hydraulic conductivity of the shallow part of the channel sediments on the Platte River. The tests were conducted along two transects across the Platte River, one near Kearney and the other near Grand Island. The values of vertical hydraulic conductivity range from about 8 to 136 m/d across the river channel.

Student support

The grant has supported one Ph.D. student in hydrogeology.

Low-Cost Flow Estimation for Storm Water Quality BMP Monitoring

Basic Information

Title:	Low-Cost Flow Estimation for Storm Water Quality BMP Monitoring
Project Number:	2004NE77B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Non Point Pollution, Hydrology, Water Quality
Descriptors:	
Principal Investigators:	David Mark Admiraal, Bruce Irvin Dvorak, John S Stansbury

Publication

lCurrent Status:
The graduate student initially assigned to this study recently left the program, so we are currently securing a replacement and intend to be back on schedule soon.

Summary of Progress:
Thus far, the project has focused primarily on a preliminary literature review. The literature reviewed thus far has included a review of weirs, culverts, and stage measurement devices. These three topics are very relevant for establishing criteria for flow measurement. Culverts appear to be the only control that is likely to be found in most small watersheds, weirs can occasionally be found, but not in an ideal form (e.g., v-notch weirs are not common in urban watersheds). Several promising low-cost stage measurement devices have been discovered in the literature, including ultrasonic techniques and displacement methods. Our next step will be to construct laboratory experiments that will allow us to determine the performance criteria of culverts for stage-discharge rating curve measurements. We will test a variety of flows, including non-uniform flows and possibly unsteady flows.

Additional Funding:
The Nebraska Department of Environmental Quality has agreed to help fund this project.

Hydrogeological Controls of Salinity Patterns in the Sand Hills Lakes, NE

Basic Information

Title:	Hydrogeological Controls of Salinity Patterns in the Sand Hills Lakes, NE
Project Number:	2004NE78B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	#1
Research Category:	Not Applicable
Focus Category:	Surface Water, Groundwater, Solute Transport
Descriptors:	
Principal Investigators:	Vitaly A. Zlotnik, Sherilyn C Fritz, David B Loope, James B Swinehart

Publication

1. Tcherepanov, E.N., V.A. Zlotnik, G.M. Henebry, Using Landsat Thermal Imagery and GIS for Identification of Groundwater Discharge into Shallow Groundwater - Dominated Lakes, 2005, Int. J. Remote Sensing, in press.
2. Zlotnik, V.A., M. Burbach, J. Swinehart, D. Bennett, S. Fritz, D. Loope, 2005, A case study of direct push methods for aquifer characterization in dune-lake environments, Ground Water, in revision
3. Goss, D., and V.A. Zlotnik, 2004, Studies of permeability in shallow eolian sediments in the Nebraska Sand Hills and Great Sand Dunes National Monument, Colorado, GSA Abstracts with Programs, Denver, Colorado, November 7-10, 2004, Vol. 36, No. 5, p. 125.

Summary

This project is a part of a program of studies of the Sand Hills and Nebraska lakes to forecast their water chemistry under various scenarios of climate change. The long-term goal of our research is to develop a methodology of simulating lake salinity and salinity dynamics. The specific goal of this project is to collect background data for understanding lake-groundwater interactions in the Sand Hills area. This topic is important for sustainability of water resources of the Sand Hills.

Specific Objectives: The objectives of this study include characterization of the chemistry of the aquifer and adjacent lakes across a broad range of salinity (from freshwater to hypersaline) in a restricted area of the Sand Hills. These lakes were located in the vicinity of Crescent Lake National Wildlife Refuge. The specific objectives included 5 tasks: 1) Collection of Salinity Data; Map; 2) Preliminary Characterization of Aquifer; 3) Evaluation of Basic Groundwater Chemistry; 4) Core Collection; 5) Hydraulic Conductivity Evaluation.

Results – Task 1: Collection of data for mapping spatial patterns of lake salinity including water samples and field data on TDS, Secchi depth, temperature, pH, conductivity, total alkalinity, $\delta^{18}O$ and $\delta^{2}H$ in 37 "wet" lakes in the area of approximately 15 km by 15 km. Eleven lake samples have been analyzed for water chemistry (in the Water Sciences Lab for anions and in the Groundwater Chemistry Lab for cations).

Results – Task 2: Aquifer and groundwater have been characterized in eleven locations (low areas in the vicinity of the sampled lakes). These locations were arranged in three transects in a southwest-to-northeast direction. A Geoprobe Systems® direct push system (model DT6610DT) with soil electrical conductivity probe (model SC400) was used at distances from 5 to 100 m from the lake strandlines. In each location, continuous vertical EC profiles were collected to depths up to 15 m. An expected contact of eolian sand with Ogallala, or buried valley, or organic sediments was not found in soil electrical conductivity logs, =which show relatively uniform lithological conditions in the vicinity of the lakes.

Results – Task 3: Evaluation of basic groundwater chemistry indicates that lake water varied in TDS between 318 mg L^{-1} and 121,000 mg L^{-1} with a mean of 2,950 mg L^{-1} and standard deviation 16,735 mg L^{-1}, pH varied between 8.7 and 10.57. TDS for groundwater samples varied from 127 mg l^{-1} at a site 2 to 1727 mg l^{-1} at a site 3, with a mean of 477 mg l^{-1} and a standard deviation of 439 mg l^{-1}. Currently, these data are being analysed and interpreted.

Results - Task 4: Collection of 4-foot cores was performed in eleven locations for better delineation of stratigraphy following EC profiling, slug test, and water chemistry collection. Short cores (12-28 cm) were also collected from 2 lakes of contrasting water chemistry (Reno, Whitehead) to assess the stability of water chemistry based on diatom analysis. Both cores are undated but likely span one to two centuries. The diatom stratigraphy at both sites suggests alterations in surface water salinity and alkalinity over recent time.

Results – Task 5: Hydraulic conductivity (*K*) evaluation using pneumatic slug tests, a Geoprobe Systems® direct push system (model DT6610DT), and the Screen Point 16 (SP-16) showed that the lake beds are underlain primarily by fine sands of eolian origin (*K* ranges from 0.3 m/day to 15 m/day with mean K=4.8±4.6 m/day). Rare exceptions are more characteristic of coarser sands (possibly of fluvial origin). These data correspond well to previously obtained results from air injection tests by Goss and Zlotnik (2000) and constant-head infiltration tests by Sweeney and Loope (2001).

Preliminary Conclusions.

Mapping lake water chemistry data, finalizing water chemistry and stable isotope analyses of ground water and lakes, and core analyses are in progress.

Groundwater is significantly less saline than the lake water. This strongly suggests the evaporative nature of lake salinity, because sources of saline groundwater have not been detected directly in neither of eleven cases.

Differences in lake salinity cannot be explained by hydraulic or aqueous properties of the surficial aquifer. Existing groundwater-lake water gradients suggest that mass exchange can be strongly controlled by the force balance of density-driven and regional topography-driven flow.

Information Dissemination:

A manuscript " A case study of direct push methods for aquifer characterizating in dune-lake environments" (V.A. Zlotnik, M. Burbach, J. Swinehart, D. Bennett, S. Fritz, D. Loope has been prepared for submission to Ground Water or Groundwater Monitoring Review and Remediation

Contributing materials and a short narrative for Nebraska Educational Television Network program "Statewide" on Sandhills lake research (shown in December 2004, February 2005)

General information was disseminated among representatives of the rancher community in the Garden County (J. Cooper, G. deWitt, M. Eldred, and J. Parker)

Additional Funding

This project made use of additional funding from two sources:

NSF “Sand Hills biocomplexity: Integrating biogeophysical processes across space and time”, Co-PI, with D. Wedin, UNL, G. Henebry and D .Loope, PIs, and S. Fritz, C. Rowe, and 9 other CO-PIs, 9/03-8/07, total $1,800,000

USEPA project on Classification of Lakes in Agricultural Landscapes, J. Holz (PI) (200-STAR-G1), total $1,400,000

Defining Dynamic Crop-Water-Stress-Index Baselines to Schedule Irrigation Using Infrared Thermometers

Basic Information

Title:	Defining Dynamic Crop-Water-Stress-Index Baselines to Schedule Irrigation Using Infrared Thermometers
Project Number:	2003NE34B
Start Date:	4/1/2003
End Date:	10/31/2004
Funding Source:	104B
Congressional District:	3
Research Category:	Biological Sciences
Focus Category:	Irrigation, Agriculture, Water Use
Descriptors:	
Principal Investigators:	Jose Oscar Payero, Jose Oscar Payero

Publication

Dynamic Crop-Water-Stress-Index Baselines to Schedule Irrigation for Corn and Soybean Using Infrared Thermometers

José O. Payero

Abstract. *In this study, canopy temperature, meteorological, and other supporting variables were measured from corn and soybean plots at North Platte, Nebraska, during the 2004 growing season. The objectives were: (1) to develop transferable upper and lower crop water stress index (CWSI) baselines, and (2) to develop relationships between soil water depletion in the crop root zone and CWSI. Equations to estimate the upper and lower CWSI baseline were developed in this study for corn and soybean (R^2 = 0.76 to 0.94). The lower baselines for both crops were a function of several variables, including plant canopy height, vapor pressure deficit, solar radiation, and wind speed. The lower baselines were only a function of solar radiation for soybean, and solar radiation and plant canopy height for corn. By taking into account all the variables that affect the baselines, it should be possible to apply them at different times of the day and at different locations. The attempt to develop relationships between CWSI and soil water depletion in the crop root zone in this study was not successful. The relationships between the two variables always resulted in very low R^2 values. The new baselines developed in this study should facilitate the application of the CWSI method for irrigation scheduling of corn and soybean, although there is still a need for additional validation of the equations by repeating the experiment in other environments and in other growing seasons.*

Keywords. Crop water stress index, canopy temperature, infrared thermometers, irrigation scheduling, corn, soybean.

A contribution of the University of Nebraska Agricultural Research Division, Lincoln, NE 68583. Partial funding for this project was provided by the USGS.

José O. Payero, Assistant Professor, Department of Biological Systems Engineering, University of Nebraska-Lincoln, West Central Research and Extension Center, 461 West University Drive, North Platte, NE 69101, USA; tel. 308-696-6707; fax 308-532-3823.

Introduction

Irrigated agriculture is a major component in Nebraska's economy, producing an annual income of about $5 billion. Around 33% of Nebraska's cropland is irrigated (Johnson, 2001), which is above the national average of only 11% (Postel, 1999). Irrigated land area in Nebraska is about 8.1 million acres, which ranks second in the nation following California. The most important irrigated crop in the state is corn, with close to 5 million acres, followed by soybeans, with around 1.5 million acres. Sources of irrigation water include both surface and groundwater. Groundwater is mainly extracted from the Ogallala formation of the High Plains Aquifer, a large aquifer underlying parts of 8 states.

Nebraska is currently facing water quantity and quality challenges. First, in 1998 Kansas filed a lawsuit against Nebraska demanding more water from the Republican River basin. As a result of this lawsuit, the two States have recently agreed upon a settlement in which Nebraska is required, among other things, to establish a moratorium in new irrigation wells. Second, to comply with requirements of the Endangered Species Act, Nebraska is required to transfer considerable amounts of irrigation water from the Platte River to maintain wildlife habitats. At the same time, although Nebraska is rich in groundwater, studies have shown that in some areas, groundwater levels are declining. Alarmingly, high levels of nitrate and pesticides have been detected in groundwater, as a result of excessive applications of nitrogen and pesticides, combined with excessive irrigation. Because of these problems, many farmers in Nebraska are now under a water allocation system in which they are only allowed to pump a fixed amount of groundwater during a given period. Finally, high cost of energy and low commodity prices are imposing economic incentives for farmers to make efficient use of irrigation water. Current conditions require farmers to improve irrigation management practices to conserve water, protect the environment, and increase profitability.

Despite increasing pressure for farmers to use irrigation water more efficiently, most farmers in Nebraska still schedule irrigation empirically, due to tradition, and to the lack of easily applicable and scientifically-based irrigation scheduling methods. A potentially simple way to schedule irrigation is by measuring crop canopy temperature using a portable infrared thermometer. *It is known* that the difference between canopy and air temperatures (Tc-Ta) increases when crops are under water stress. This happens as a response to decreased evapotranspiration, which serves as a cooling mechanism for the crop. It is also known that (Tc-Ta) is lineally related to air vapor pressure deficit (VPD). Although the slope of the line stays nearly constant, its position also changes with soil moisture deficit and solar energy available at the time of measurement. For a crop, a lower and an upper baseline of [(Tc-Ta) versus VPD] can therefore be obtained, which represent non-stressed and maximum water stress conditions, respectively. Based on these baselines, and using actual (Tc-Ta) and VPD for a given day, an index can be calculated, usually known as the Crop Water Stress Index (CWSI), which has been shown to increase with soil moisture depletion and can be used to schedule irrigation. This method of scheduling irrigation, however, is not practical at present because of a few *gaps in the knowledge base*. The most important gap is that it is usually assumed that the solar energy available at the time of measurement is constant if measurements are taken near noon and under clear-sky conditions. This assumption makes this method site-specific, since it is well known that solar radiation changes with location, time of day, and day of year, even under clear-sky conditions. Because of this assumption, different researchers have found different lower and upper baselines for the same crop. *This is an important problem* since as solar radiation has not been considered to define the baselines, no universal baselines that can be applied from place to place exist. Therefore, to apply this method for a given crop and location, first it is necessary to empirically determine the lower and upper baselines.

Technically sound ways of scheduling irrigation include measuring soil moisture with one of many devices commercially available and /or keeping track of soil moisture budget using crop water use information. Farmers have been slow in adopting these scheduling techniques, mainly because they are labor intensive or require knowledge or tools they do not have. The potential for using infrared thermometers as an easy method for irrigation scheduling has been recognized for a long time, but this potential has not been realized yet because this method is not practical in the present state of knowledge.

Wolpert (1962) was among the first to study the factors affecting canopy temperature, using a theoretical mathematical representation of all the variables important to the heat balance of a plant leaf. Gates (1964) and Linacre (1964) recognized that transpiration was an important factor controlling leaf temperature, as it acts as a cooling mechanism. At that time, canopy temperature was measured using thermocouples embedded in the leaves, which was not very practical for general use. The use of infrared thermometers to measure canopy temperature, however, was becoming feasible (Conaway and van Bavel, 1967; Fuchs and Tanner, 1966). Calson et al. (1972) recognized that canopy temperature provided a measure of the plant response to its environment and suggested that the factors affecting canopy temperature were the same affecting evapotranspiration. These factors included wind speed, solar radiation, air temperature, and vapor pressure deficit, and soil moisture. Linking canopy temperature to soil moisture was particularly important since the potential of using canopy temperature as an indicator of crop water stress and as a tool for irrigation scheduling was then recognized. The basic assumption was that transpiration cools the leaves and as available soil moisture decreases, transpiration is reduced and, therefore, the temperature of the leaves increases. A lot of research followed trying to use canopy temperature as a tool for irrigation scheduling, and many indexes were developed relating canopy temperature to soil moisture depletion (Idso et al. 1977; Jackson et al. 1977; Blad et al. 1981, Ehrler, 1973; Ehrler et al. 1978).

Idso et al (1981). made the seminal observation that canopy minus air temperature (Tc-Ta) was lineally related to air vapor pressure deficit (VPD) and that lower and upper baselines could be established empirically for both non-water-stressed and for non-transpiring crop conditions, respectively. They used these baselines to calculate what they called the Crop Water Stress Index (CWSI), as a measure of crop water stress. This empirical CWSI is calculated as (Idso et al. 1981):

$$\mathbf{CWSI = [(Tc\text{-}Ta)_{\mathit{m}}-(Tc\text{-}Ta)_{\mathit{LB}}]/[(Tc\text{-}Ta)_{\mathit{UB}}-(Tc\text{-}Ta)_{\mathit{LB}}]} \quad \ldots\ldots\ldots(1)$$

where the subscripts *m, LB,* and *UB* refer to the (Tc-Ta) values for the measured, lower baseline, and upper baseline, respectively.

Jackson et al. (1981) and Jackson (1982), followed this work by establishing the theoretical basis for the Crop Water Stress Index (CWSI). They showed that the lower baseline is a function of net radiation, crop resistances (both aerodynamic and surface) and vapor pressure deficit, while the upper baseline is a horizontal line that depends on available energy and crop aerodynamic properties. This theoretical approach then required knowledge of crop resistance properties and net radiation, in addition to measured (Tc –Ta) and VPD, which made it difficult to apply in practice. For this reason, most researchers have preferred to use the empirical approach of Idso et al (1981), which have been shown to work well for a given location as long as you have locally calibrated baselines. To establish the lower and upper baselines, however, most researchers have assumed that both the available energy and the wind speed are constant if the required measurements are made close to noon and under clear sky conditions. This assumption, however, is problematic because it is well known that both the available energy and wind speed change, among other things, with location, time of day and day of the year. Because of this, empirical baselines for the same crop will be different under different solar radiation and wind speed conditions as shown by Zolnier et al. (2001) and Jensen et al. (1990). Researchers from different places have used this method for scheduling irrigation, using different baselines. For instance, fig. 1 shows the different lower baselines (non-water-stressed) that researchers have used for corn.

The same type of disagreement is found in defining the upper baseline. For instance, for corn, Shanahan and Nielsen (1987) and Nielsen and Gardner (1987) used a maximum value of (Tc-Ta) = 3ºC as the upper baseline. Steele et al. (1994), however, used 5 ºC, and Irmak et al.(2000) used an average value of 4.6ºC. Sadler et al. (2000), however, reported values of (Tc-Ta) > 10 ºC and Jensen et al (1990), found (Tc-Ta) values for several crops as high as 8 ºC for high levels of solar radiation and values approaching zero or even negative at low levels of solar radiation.

The lack of transferability of the baselines, together with the restriction of having to make required measurements close to noon and under clear sky conditions, are recognized as the major drawbacks of using the CWSI for irrigation scheduling. These problems have prevented farmers for decades from using this method for irrigation scheduling. Transferable baselines that could be used in different locations and using measurements at any time of day can however be developed. All that is needed is to take into account the effect of both available energy and wind speed, which have been identified as the main factors affecting the baselines. However, since it can be assumed that for a given day during the daytime hours, available energy is linearly related to solar radiation, then baselines that change with solar radiation can be developed. An attempt to developed transferable baselines have recently been made by Alves and Pereira (2000), who provided a new definition of the lower baseline based on the difference between the canopy temperature and the wet bulb temperature, instead of the air temperature. This new concept, however, requires almost as much information as the theoretical approach of Jackson et al. (1981), and also requires crop-specific calibration.

The body of work reviewed in this section makes it clear that there is a need to define lower and upper baselines that are transferable to other locations and that will allow measurements to be taken at different times of day. This will make it possible for the CWSI method to be used for irrigation scheduling by farmers without the need to perform site-specific calibration, which has prevented its use for decades. The objectives of this study were: (1) to develop transferable upper and lower [(Tc-Ta) versus VPD] baselines**,** and (2) to develop relationships between soil water depletion in the crop root zone and crop water stress index (CWSI).

Methods

Site Description

Field data for this study were collected from corn and soybean plots during 2004 at North Platte (41.1˚ N, 100.8˚ W, 861 m above sea level), Nebraska. The field experiment was conducted at the University of Nebraska-Lincoln West Central Research and Extension Center. The soil at North Platte was a Cozad silt loam (*Fluventic Haplustolls*) with field capacity of 0.29 m^3 m^{-3} and permanent wilting point of 0.11 m^3 m^{-3} (Klocke et al. 1999). The corn variety Renze 9363 Bt RR was planted at 0.76-m row spacing. Corn was planted on May 10 and harvested on November 15. The soybean variety Renze 2600 RR, which is in the maturity group 2, was also planted at 0.76-m row spacing and at a depth of approximately 2.5 cm. The soybean was planted on May 21 and harvested on October 5. Both crops were irrigated using a solid-set sprinkler system, which was arranged in a 12.2 m x 12.2 m grid. In each of its four sites, each experimental plot was surrounded by a "border" plot of the same size. The inclusion of "border" plots precluded water from different contiguous irrigation treatments from overlapping within a given experimental plot. Sprinkler heads were installed at the four corners of each plot on 3.35-m risers.

Field Measurements

For each crop, data were collected from four different plots, which received different irrigation treatments, including a dry-land treatment. Measurements included canopy temperature, air temperature, relative humidity, wind speed and direction, solar radiation, and plant canopy height. Daily average canopy heights for each crop were estimated from weekly measurements. For each crop, canopy temperatures were measured from four plots receiving different irrigation treatments. The irrigation treatments were part of a larger experiment that included 9 treatments for corn and 8 for soybean. The four plots were located at the same distance from a center "border" plot (shaded plots in fig. 2).

A tripod was installed at the center of the "border" plot (its location is indicated by and "x" in fig. 2). The tripod supported an environmental enclosure that housed a datalogger and a multiplexer. It also supported an anemometer , a pyranometer, and an air temperature/relative humidity sensor. Power to the system was supplied by a 12-volts car battery. Wind speed and direction were measured using a R.M. Young wind sentry 03101-5 system (Campbell Scientific, Logan, UT). The anemometer was installed at a height of 3.7 m above ground in the corn plots and at a height of 2 m in the soybean plots. Solar radiation was measured using a solar pyranometer (Apogee Instruments, Inc., Logan, UT) that was leveled and installed on the tripod above all other instruments to make sure it was never shaded. Air temperature and relative humidity were measured with a HMP45C sensor (Campbell Scientific, Logan, UT) installed at the same height as the anemometer. The air temperature and relative humidity measurements were used to calculate the vapour pressure Deficit (VPD) of the air as (Allen et al., 1998):

$$e_s = 0.6108*Exp[17.27T/(T + 237.3)] \quad (2)$$
$$e_a = e_s*(RH/100) \quad (3)$$
$$VPD = e_s - e_a \quad (4)$$

where, e_s = saturation vapour pressure (kPa), T = mean air temperature (^oC), RH = relative humidity of the air (%), and VPD = vapour pressure deficit (kPa).

Canopy temperature measurements started on July 15, when the crops had reached full cover, to avoid measuring the temperature of the soil background. For each crop, canopy temperature from each of the four plots was measured using two infrared thermometers per plot (model IRTS-P, Apogee Instruments, Inc., Logan, UT). The infrared thermometers were installed approximately one meter above the maximum plant canopy height at a 45 degree angle, one pointing East and the other pointing West. The average of the two sensors was used for analysis. A mount made of 1.9 cm PVC tubing and fittings was constructed to house the two infrared thermometers in each plot and to be able to install them above the canopy (fig. 3). The mount was shaped in form of a "T" and a steel pipe was used as a riser. The riser was supported by a T-post that was driven in the ground. The infrared thermometers were placed inside the PVC tubing for protection and to reduce temperature variations of the body of the sensors, which could affect their accuracy, as reported by Bugbee et al. (1998).

The infrared thermometers were sampled using a 21X datalogger (Campbell Scientific, Logan, UT). The thermometers were connected to the datalogger via an AM16/32 multiplexer (Campbell Scientific, Logan, UT). Both the temperature of the target and that of the body of the sensor were measured from each infrared thermometer using Type K (Chromel-Alumel) thermocouple wires. The temperature from each thermocouple was sampled every minute by measuring the differential voltage between the two thermocouple wires. Data from the infrared thermometers and from all the other instruments were averaged and stored every ten minutes. Data were downloaded from the datalogger to a laptop computer approximately twice a week.

Daily soil water depletion in the crop root zone was estimated using a soil water balance approach. A computer program was written in Microsoft Visual Basic® to model the daily soil water status. Input to the program included daily weather data, rainfall, irrigation, the water content in the soil profile at crop emergence, and crop-specific and site-specific information such as planting date, maturity date, soil parameters, maximum rooting depth, etc. Based on these inputs, the water balance in the crop root zone was calculated daily. The water content in the soil profile at crop emergence was measured using the neutron scattering method. Soil water readings were taken from 50-mm diameter aluminum access tubes installed at the center of the plot in each irrigation treatment. Readings were taken at 0.3-m depth increments to a depth of 1.8 m. Daily crop evapotranspiration was calculated using the procedure presented in FAO-56 (Allen et al. 1998; Wright, 1982). Since this is a very long procedure, readers are referred to the original sources for details. According to this procedure, crop evapotranspiration can be obtained as the product of the evapotranspiration of a reference crop (ET_o) (a grass reference was used in this study) and a crop coefficient (K_c). ET_o is calculated using the weather data as input to the Penman-Monteith equation and the K_c is used to adjust the estimated ET_o for the reference crop to that of other crops at different growth stages and growing environments. In this study, the dual crop coefficient approach was used to separate the two components of evapotranspiration, namely evapotation (E) and transpiration (T). This procedure also linearly reduced crop evapotranspiration when the available soil moisture in the crop root zone was below 50%, which was used to quantify the effect of water stress on crop water use. The dual crop coefficient procedure also accounts for the sharp increases of the evaporation component due to a wet soil surface following rain or irrigation. Weather data used as input to the program was obtained from an automatic weather stations located near the research plots. The weather station was part of the High Plains Regional Climate Center (HPRCC) weather network. Daily weather data were downloaded from the HPRCC web site (*http://www.hprcc.unl.edu/home.html*), including daily maximum and minimum air temperature, relative humidity, wind speed, rainfall, and solar radiation. The computer program calculated the daily soil water balance for each 0.30 m soil layer and then calculated the daily % root zone depletion on day i ($\%Dep_i$) as:

$$\%Dep_i = (Dep_i/TAW_i)*100 \qquad (5)$$

where, Dep_i = soil water depletion in the crop root zone on day i (mm), TAW_i = total available water in the crop root zone on day i (mm).

Calibration of infrared thermometers

The manufacturer of the type of infrared thermometers used in this study recommends correcting the temperatures measured by the infrared sensors to account for differences in sensor body temperature using the procedure proposed by Bugbee et al. (1998) as:

$$CTT = (ATT\text{-}SEC) \qquad (6)$$

$$SEC = (0.25/P_{sb})*[((ATT - H_{sb})^2)\text{-}K_{sb}] \qquad (7)$$

where, CTT = corrected target temperature (^oC), ATT = apparent target temperature (^oC), SEC = sensor error correction (^oC), and P_{sb}, H_{sb} and K_{sb} are generic (sensor independent) calibration coefficients that can be calculated as a function of sensor body temperature (SB) (^oC) using second degree polynomials as:

$$P_{sb} = 26.168 + 2.8291(SB) - 0.03329(SB^2) \qquad (8)$$
$$H_{sb} = 5.8075 - 0.08016(SB) + 8.49e^{-3}(SB^2) \qquad (9)$$
$$K_{sb} = -85.943 + 11.740(SB) + 0.08477(SB^2) \qquad (10)$$

In this study, however, to improve accuracy a calibration function was developed for each infrared thermometer. Calibration of the infrared thermometers was performed using a model 1000 calibration source (Everest Interscience Inc., Tucson, AZ). The Blackbody surface of the calibration source had been prepared using high emissivity aluminum oxide, with a configuration that uses re-entrant concentric rings. The calibration was conducted inside a laboratory hood (fig. 4). The temperature inside the hood and that of the blackbody were increased using a portable electric heater. For temperatures below ambient temperature, the calibration source was placed inside a refrigerator until its temperature was just above freezing. The temperature of temperature of the blackbody was then allowed to decrease or increase and readings with the infrared thermometers were taken at different temperatures, ranging between approximately 5 to

45°C, which included the temperatures that would normally occur in the field during the study. Temperatures of the blackbody, and the infrared thermometer readings, including the temperature of the body of the sensors, were recorded. A total of 21 temperature readings were recorded for each infrared thermometer, taking at least 3 readings for each temperature. The same wiring, cable length, and datalogger program actually used in the field was used during the calibration. During the calibration, however, the sampling interval in the datalogger program was changed from one minute to ten seconds, to be able to record the rapid temperature changes of the calibration source.

Statistical Analyses

The statistical analyses, which included summary statistics and regression analysis were conducted using the SAS System for Windows® statistical software (SAS Institute, Inc., Cary, NC).

Data Quality Control

Before analysis, data were validated by identifying and excluding unreasonable values. For instance, data obtained during times when irrigation or rainfall was occurring were excluded. Solar radiation values of less than 100 W m^{-2} were filtered out, which excluded data collected during nighttime, early morning, late afternoon, and severely overcast conditions. Considerable differences between the canopy temperatures measured by the infrared thermometer looking East and that looking West on the same plot were detected during this study (fig. 5). These differences could be due differences in shading of the crop canopy, and differential cooling of the canopy as a result of changes in wind direction. They, however, could also be due to problems with one or both sensors, such as shifts in calibration, improper installation, improper wiring and/or programming, etc. To be conservative, in this study only data with an absolute difference of ≤ 2°C between the canopy temperatures measured by the two sensors in each plot were retained for further analysis. Also values collected after the crops started to mature were excluded.

Additional limits on the data were imposed to exclude data that would be unreasonable or abnormal for the area during the period of the study. These limits include the following arbitrary criteria:

- 5% ≤ Relative Humidity ≤100 %
- 0 °C ≤ Air Temperature ≤ 50 °C
- 0 °C ≤ Canopy Temperature ≤ 50 °C
- 0 W m^{-2} ≤ Solar Radiation ≤ 1300 W m^{-2}
- 0.2 m s^{-1} ≤ Wind Speed ≤ 12 m s^{-1}
- 0% ≤ % Soil Water Depletion in the crop root zone ≤100 %

These criteria would not apply to every situation, but were expected to help filter out most of the unreasonable data during this study. These criteria were included in a computer program that was used to validate the data and to make further calculations based on the validated data.

Results

Calibration of infrared thermometers

Results of calibration for each of the infrared thermometers used in this study are shown in figs 6 and 7. Very good correlations were found between the temperature measured by the infrared sensors and the temperature of the blackbody calibration source as indicated by the R^2 values of 1.0 or very close to 1.0 shown in figs 6 and 7. The relationships, however, were better explained by a second order polynomial function rather than a linear function. The good agreement is also indicated by the fact that readings from almost all of the sensors followed the 1:1 lines in figs 6 and 7. There were only three sensors that significantly deviated from the 1:1 line [232(T1)E, 232(T1)W, and 331(T7)E]. The temperatures measured by these three sensors, however, were well-correlated to the temperatures of the calibration source and it was possible to adjust their readings using the calibration equation developed for each of the sensors.

Weather conditions

Daily averages of several weather variables during the 2004 growing season at North Platte, NE, are shown in table 1. It shows considerable variations in weather variables during the growing season. For instance, solar radiation (R_s) was similar during the months of May to September, but decreased considerably during October. Weather variables are also affected by significant diurnal changes. For example, Rs during a clear day in the summer at North Platte can vary between 0 W m^{-2}, just before sunrise or just after sunset, to more than 1000 W m^{-2} during midday. Considerable diurnal variations also occur with the other meteorological variables. These variations could significantly affect the CWSI baselines.

Amounts and timings of rainfall events during the 2004 growing season at North Platte are shown in table 2. A total of 39 rainfall events occurred during the growing season, supplying a total of 414 mm of water, which was enough to meet more than half (54.5%) of the calculated seasonal crop water requirements. These conditions were wetter than normal for the area, but irrigation was still required to match crop water requirements for both crops.

Irrigation

Amounts and timings of irrigation events applied to the different irrigation treatments included in this study are shown in table 3. For corn, seasonal irrigation depths for the irrigated treatments ranged from 39 to 161 mm, enough to meet between 5.1 to 21.2 % of the seasonal crop evapotranspiration calculated assuming that water stress did not limit evapotranspiration (ET_w). For soybean, between 19 and 162 mm of irrigation were applied to the different treatments during the season. These irrigation amounts were enough to meet 3 to 28% of ET_w. The dryland treatments for both crops received no irrigation. Because of considerable rainfall early in the season, it was possible to delay irrigation until early August. The last irrigation to both crops was applied in early September.

Root Zone Depletion

The daily % soil water depletions in the crop root zone for each irrigation treatment during the 2004 growing season for both crops are shown in fig. 8. For soybean, considerable differences in depletion among treatments started in August, while for corn, differences among treatments started much earlier in the season. The difference between the two crops was due to differences in water contents in the soil profile at the beginning of the season, especially for depths greater than the rooting depth of soybean. Figure 8 also shows that a variety of soil water depletion levels were observed for both crops during the study. For both crops, the wetter treatment was T1 and the driest was the dryland treatment (T8 for soybean and T9 for corn). Figure 8 also reflects the fact that soybean started maturing sooner than corn. In 2004 corn maturity was delayed by approximately a month due to weather conditions that were cooler than normal for North Platte.

Upper and Lower CWSI baselines

After validating data using the filtering criteria described above, a total of 9468 and 3315 data points (10-min averages) were retained for corn and soybean, respectively. Summary statistics for the data retained for further analysis are shown in table 4. Statistics include the mean, standard deviation, minimum, and maximum values for nine variables used in the analyses. After data were validated, equations for the upper and lower CWSI baselines were then developed using multiple regression analysis. The equation for the upper baseline was developed by only including data when the % root zone depletion was greater than 85%, which indicated that the crops were under severe water stress. To develop the equation for the lower baseline, only data collected when the % root zone depletion was less than 50%, which is commonly considered as no-water-stress conditions, were included in the analysis. All variables that could have an effect on the baselines were originally included in the multiple regression analysis. However, only those variables that were statistically significant ($p < 0.01$) were included in the final multiple regression equations.

The multiple regression analyses for both crops and for the upper and lower baselines resulted in high R^2 values, which ranged from 0.76 to 0.94 (table 5). The resulting lower baselines were a function of several variables, including plant canopy height, vapor pressure deficit, solar radiation and wind speed. The upper baselines, however, were only a function of solar radiation for soybean, and solar radiation and plant canopy height for corn. The upper and lower baselines for corn and soybean calculated using the equations in table 5 assuming specific values for solar radiation, wind speed, and plant canopy height as a function of vapor pressure deficit are plotted in fig. 9. It shows that the baselines developed in this study are consistent with the theoretical approach of Jackson et al. (1981) and Jackson (1982), in the sense that the lower baseline has a negative slope when plotted as a function of VPD, while the slope of upper baseline is zero. Figure 10 shows the baselines calculated every ten minutes with the equations developed in this study for corn and soybean. It shows that the baselines had significant diurnal variations as a response to the changes in weather conditions that normally occur during the day and from day to day. It shows that for both baselines and crops, a diurnal change in (Tc-Ta) of approximately 5^{o}C was typical under the conditions of this study.

Relationship between CWSI and % Root Zone Depletion

The second objective of this study was to develop relationships between CWSI and % root zone depletion (%Dep_i) . To this end, CWSI values were calculated with equation (1) for every 10-minute interval using the measured (Tc-Ta) values and the baselines calculated using the equations developed in the previous section. Then, linear regression analyses were conducted between the CWSI and %Dep_i. The results were disappointing and always resulted in very low R^2 (< 0.15), indicating a poor relationship between these two variables. Part of the problem may have been that there was only one value of %Dep_i available for a given day, while there were many values of CWSI for the same day and the CWSI values varied considerably during the day. Future work should also automatically collect soil moisture data at the same times as the CWSI data to be able to explain the relationships between these two variables, especially at different times during the diurnal cycle.

Conclusions

In this study equations to estimate the upper and lower CWSI were developed for corn and soybean. The lower baseline was a function of several variables, including plant canopy height, vapor pressure deficit, solar radiation, and wind speed. The lower baseline was only a function of solar radiation for soybean, and solar radiation and plant canopy height for corn. By taking into account all the variables that affect the baselines, it should be possible to apply them at different times of the day and at different locations for these crops. The attempt to develop relationships between crop water stress index and soil water depletion in the crop root zone in this study was unsuccessful. The relationships between the two variables always resulted in very low R^2 values. The new baselines developed in this study, however, should facilitate the application of the CWSI method for irrigation scheduling of corn and soybean, although there is still a need for additional validation of the equations by repeating the experiment in other environments and in other growing seasons. There is also a need for further studies to investigate the relationships between CWSI and soil water depletion in the crop root zone in more detail, especially focusing on the diurnal variations of these two variables.

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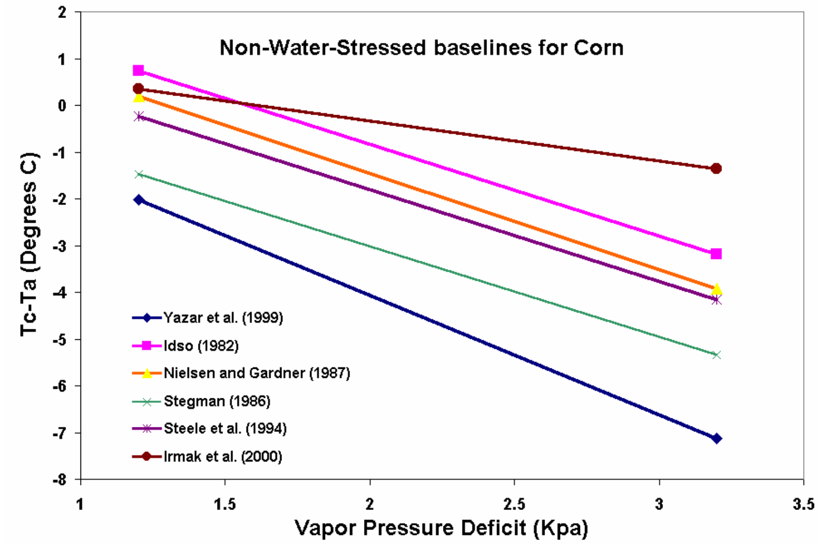

Figure 1. Non-water-stressed baselines reported by several researchers for corn.

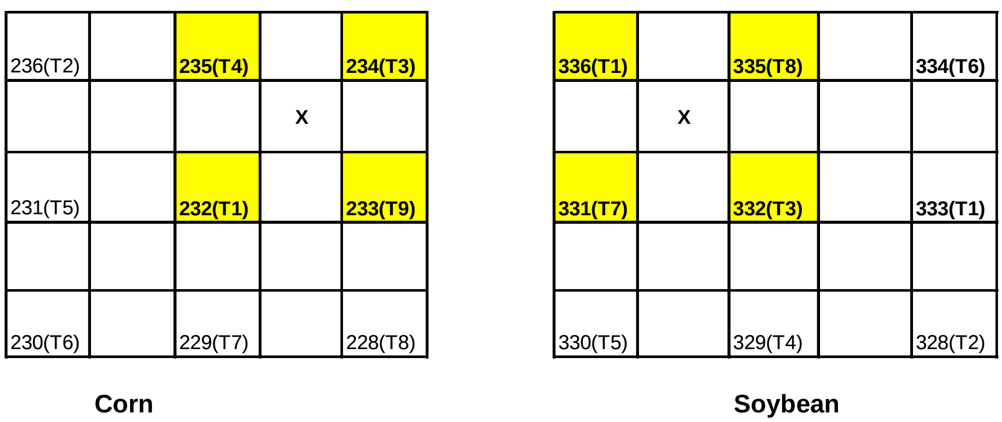

Figure 2. Plot layout of field experiment at North Platte. Canopy temperature data for each crop were collected from the shaded plots. The number indicates the plot number and the irrigation treatment is indicated in parenthesis. The plots with no numbers are the "border" plots. The "x" indicates the location of the tripod with the datalogger, multiplexer, and meteorological sensors.

Figure 3. Setup used to install two infrared thermometers above the crop canopy.

Figure 4. Calibration of infrared thermometers.

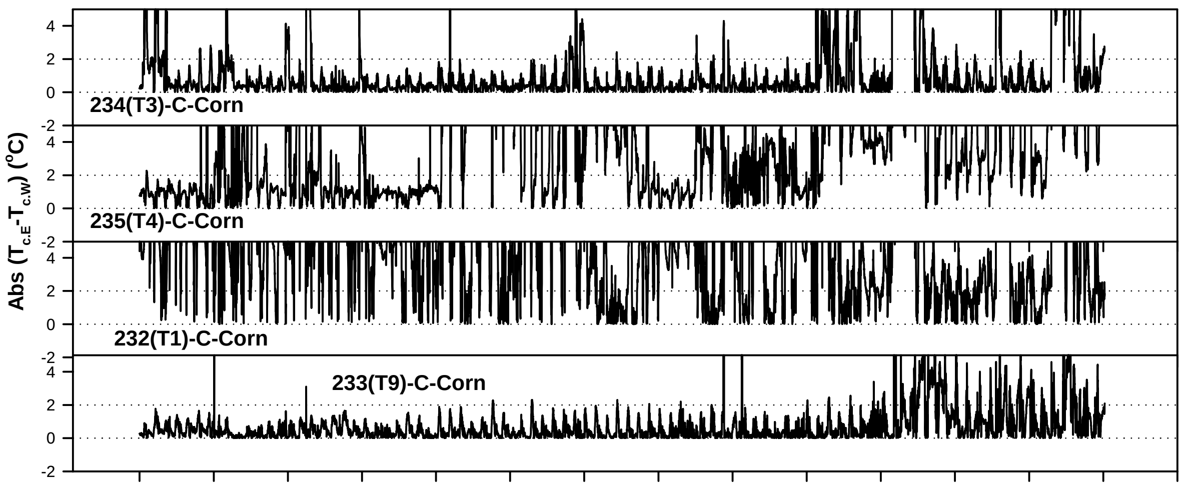

Figure 5. Absolute values of the difference between the canopy temperatures measured with the infrared thermometer looking East ($T_{c.E}$) and West ($T_{c.W}$) over four corn plots at North Platte. The X axis represents time from mid July to mid October. Each data point is a 10-minute average. 234(T3)-C-Corn indicates the plot number (234), the irrigation treatment (T3), "C" means that the readings were corrected using the calibration function developed for each sensor, and "Corn" is the crop.

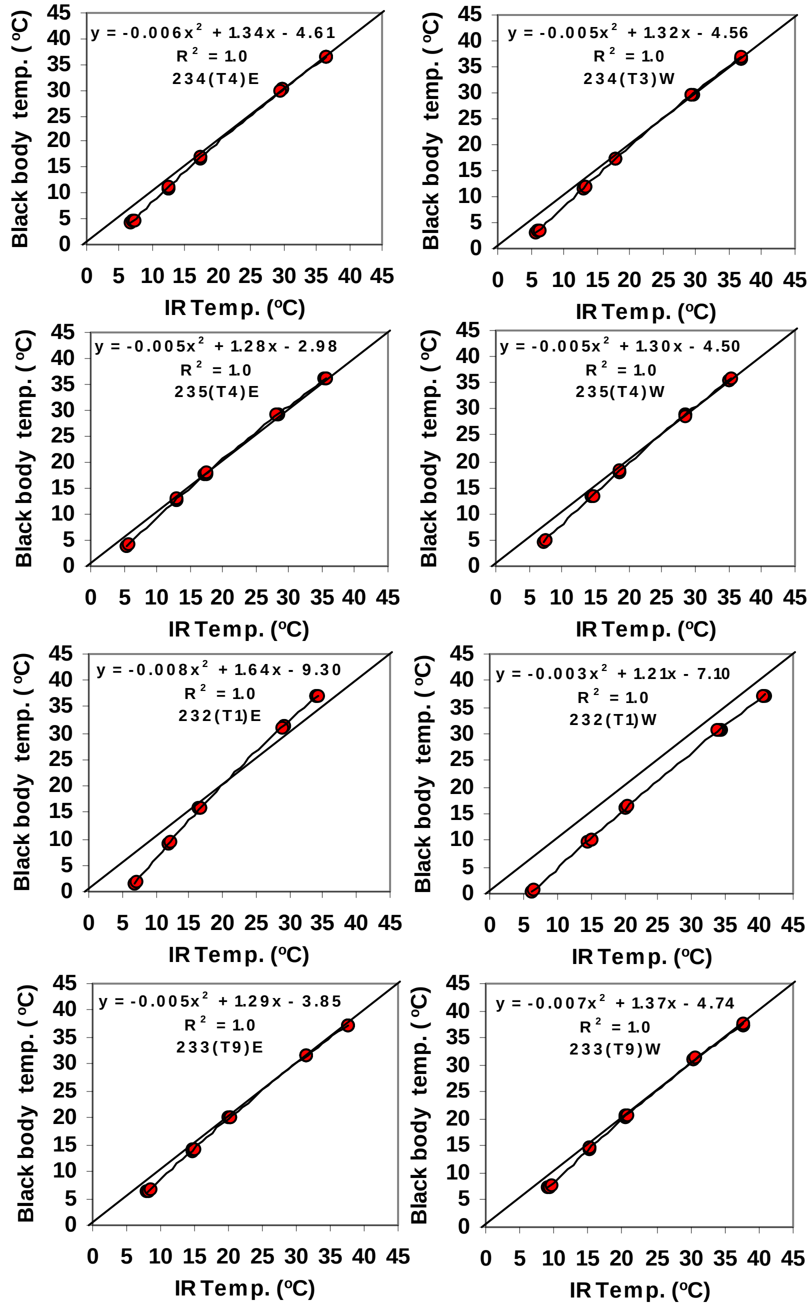

Figure 6. Calibration functions developed for each infrared thermometers used to measured canopy temperature over the corn plots. IR temp is the temperature measured by the infrared thermometer. In “233(T9)E” the number “233” is the plot number, “T9” is the irrigation treatment, and “E” and “W” indicate if the IR sensor was pointing towards the East or West. The straight line is the 1:1 line.

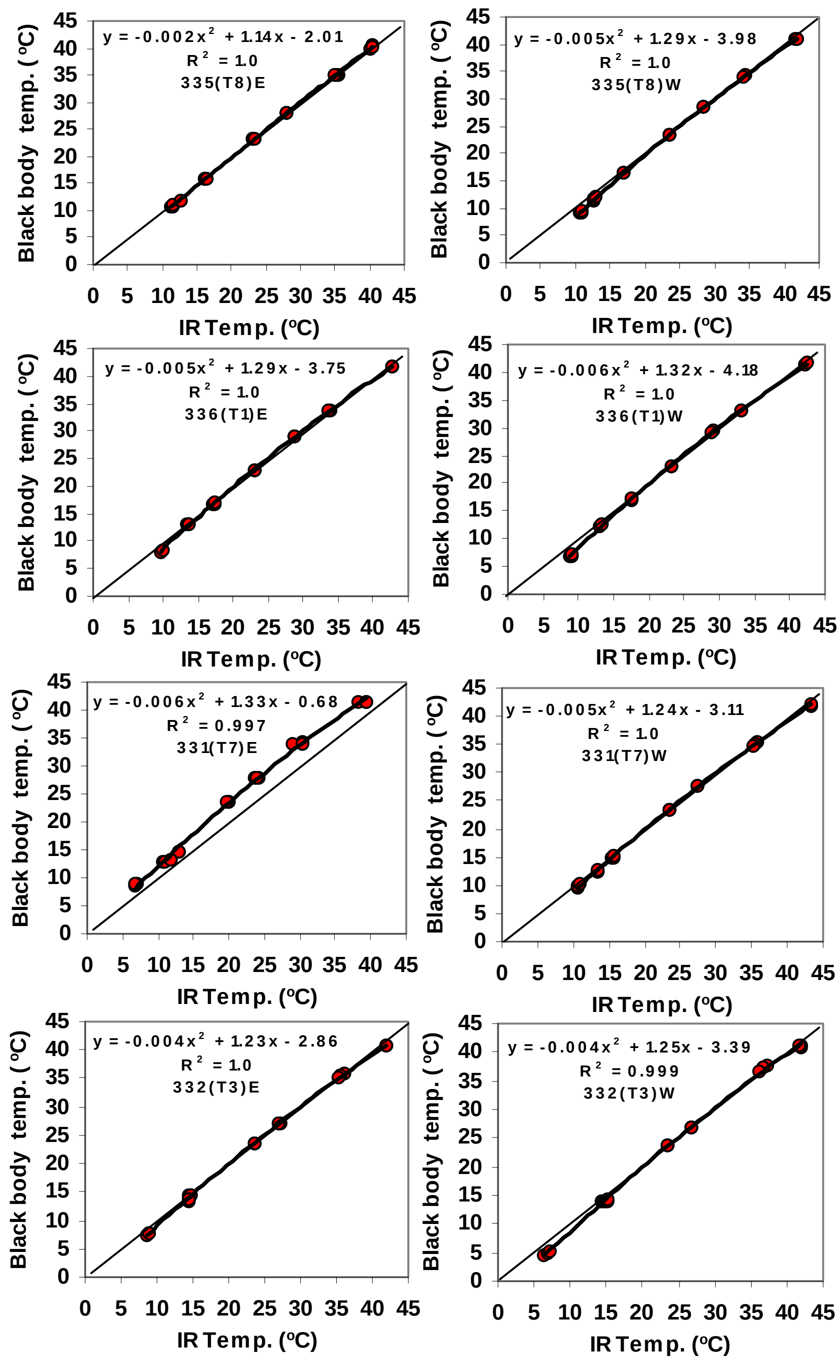

Figure 7. Calibration functions developed for each infrared thermometers used to measured canopy temperature over the soybean plots. IR temp is the temperature measured by the infrared thermometer. In "335(T8)E" the number "335" is the plot number, "T8" is the irrigation treatment, and "E" and "W" indicate if the IR sensor was pointing towards the East or West. The straight line is the 1:1 line.

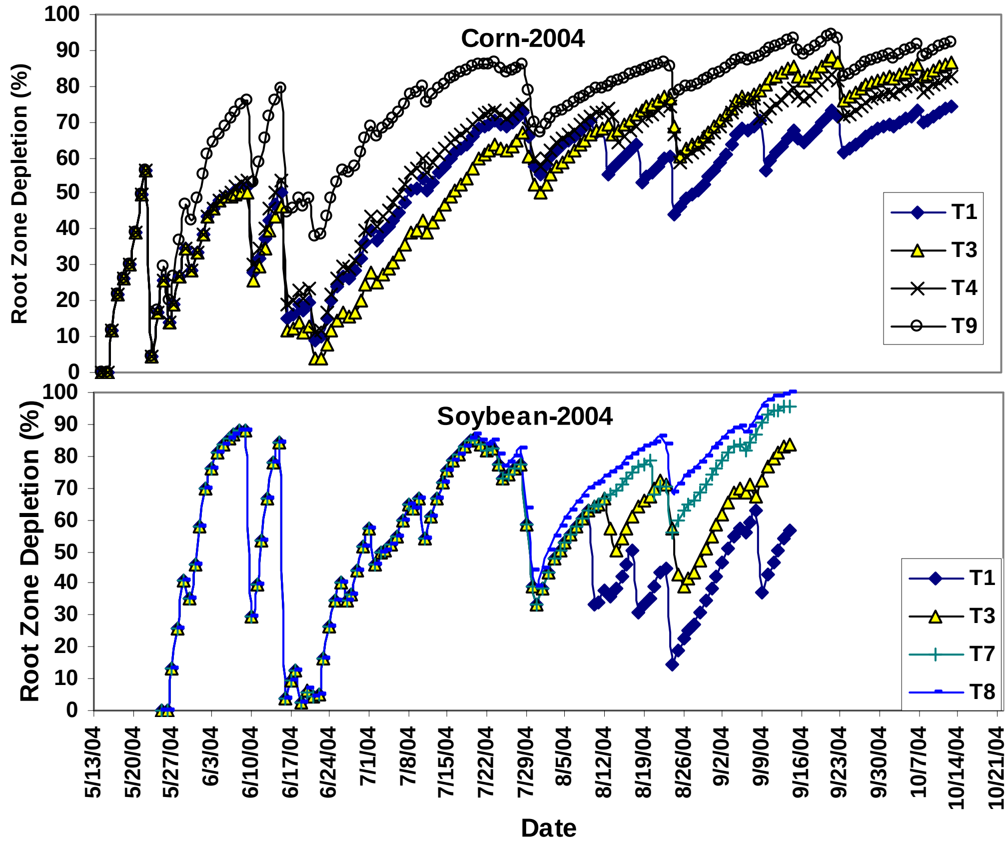

Figure 8. Daily soil water depletion in the crop root zone for different irrigation treatments (T1 toT9) for corn and soybean during the 2004 growing season at North Platte, NE.

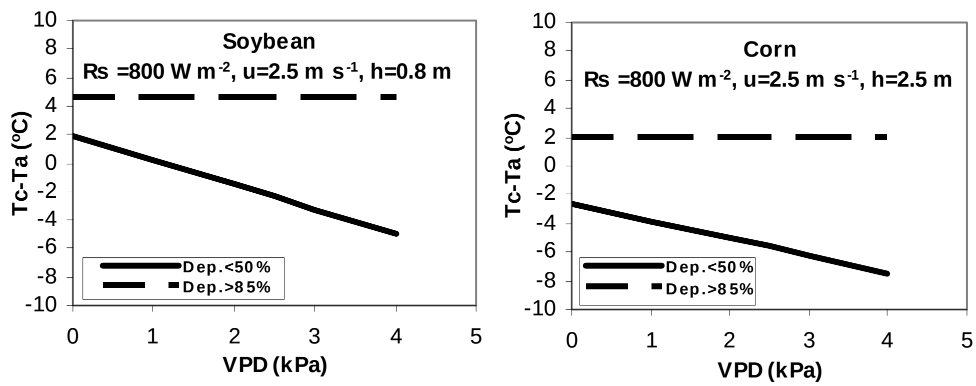

Figure 9. Upper and lower baselines for corn and soybean for the conditions shown, calculated using equations in table 5. Rs = solar radiation, u = wind speed, h= plant canopy height, Dep= % soil water depletion in the crop root zone.

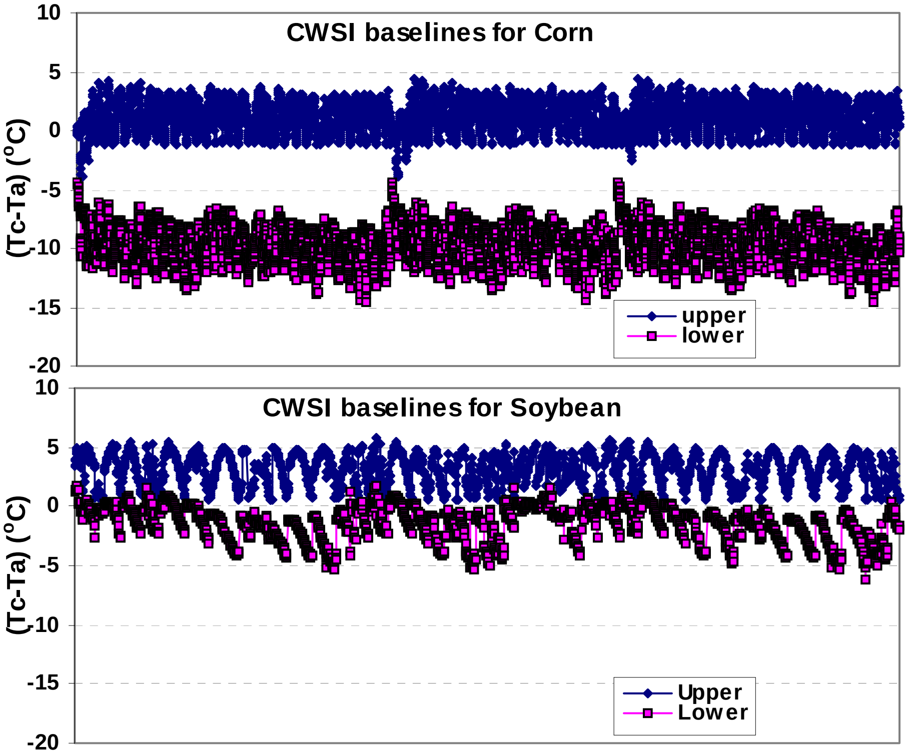

Figure 10. Calculated lower and upper crop water stress index (CWSI) baselines for corn and soybean at North Platte. The X axis represents time from day of year (DOY) 201 to 240 for corn and from DOY 220 to 240 for soybean. During that period, plant canopy height (h) for corn ranged from 2.36-2.74 m, and 0.76-0.84 m for soybean. Each point represents a 10-min average collected during the daytime.

Table 1. Average of daily values of maximum air temperature (T_{max}), minimum air temperature (T_{min}), average air temperature (T_a), solar radiation (R_s), relative humidity (RH), wind speed at 2-m height (u_2), and grass reference evapotranspiration (ET_o) for the month of May to October at North Platte, NE during 2004.

Month	T_{max} (°C)	T_{min} (°C)	T_a (°C)	R_s (MJ m^{-2} d^{-1})	RH (%)	u_2 (m s^{-1})	ET_o (mm d^{-1})
May	24.9	8.6	16.7	23.7	58.3	2.9	4.9
June	26.0	11.0	18.5	21.8	64.2	2.5	4.7
July	29.8	14.8	22.3	22.6	69.3	2.1	4.9
Aug.	27.9	11.8	19.9	21.0	65.9	1.9	4.2
Sept.	30.9	12.9	21.9	20.5	50.1	3.1	5.5
Oct.	18.5	4.1	11.3	11.0	71.7	2.1	1.8
Average	**26.3**	**10.5**	**18.4**	**20.1**	**63.3**	**2.4**	**4.3**

Table 2. Rainfall events during the growing season at North Platte during 2004.

Date	Rain (mm)
5/14/04	1
5/15/04	2
5/22/04	40
5/25/04	10
5/26/04	3
5/29/04	8
6/9/04	30
6/10/04	1
6/15/04	56
6/16/04	5
6/18/04	7
6/20/04	26
6/21/04	5
6/26/04	4
7/1/04	9
7/2/04	1
7/3/04	4
7/4/04	3
7/5/04	1
7/8/04	4
7/9/04	1
7/10/04	15
7/20/04	3
7/21/04	3
7/23/04	5
7/24/04	5
7/28/04	23
7/29/04	28
7/30/04	12
8/22/04	6
8/23/04	25
8/26/04	1
9/5/04	4
9/14/04	9
9/15/04	6
9/21/04	4
9/22/04	31
10/1/04	3
10/6/04	10
Total	**414**
% of ET_w§	**54.5**

(§) % of ET_w is the percent of seasonal crop evapotranspiration when soil water is not limiting that was supplied by in-season rainfall.

Table 3. Irrigation (mm) applied to soybean and corn at North Platte during 2004 for each irrigation treatment (T1 to T9).

Soybean				
Date	T1	T3	T7	T8
8/9/04	43.9	-	-	-
8/12/04	7.9	16.0	-	-
8/13/04	-	13.2	-	-
8/17/04	35.8	-	-	-
8/20/04	-	-	18.8	
8/23/04	26.7	-	-	-
8/24/04	-	27.7	-	-
8/25/04	-	11.2	-	-
9/7/04	-	11.2	-	-
9/8/04	47.8	-	-	-
Total	**162.1**	**79.2**	**18.8**	**0.0**
% of ETw[¢]	**28%**	**14%**	**3%**	**0%**
Corn				
Date	**T1**	**T3**	**T4**	**T9**
8/9/04	11.7	-	-	-
8/11/04	39.1	-	-	-
8/12/04	-	10.4	10.4	-
8/13/04	-	-	22.6	-
8/17/04	35.8	-	-	-
8/19/04	-	-	-	-
8/23/04	26.7	-	-	-
8/24/04	-	28.2	28.2	-
8/25/04	-	-	-	-
9/7/04	-	-	18.8	-
9/8/04	47.8	-	5.6	-
Total	**161.0**	**38.6**	**85.6**	**0.0**
% of ET_w[¢]	**21.2%**	**5.1%**	**11.3%**	**0.0%**

(¢) % of ET_w is the percent of seasonal crop evapotranspiration when soil water is not limiting that was supplied by irrigation.

Table 4. Summary statistics (n=9468 for corn and 3315 for soybean). Variables are canopy temperature (T_c), air temperature (T_a), vapor pressure deficit (VPD), canopy height (h), solar radiation (Rs), wind speed at 2-m height (u_2), and soil water depletion in the crop root zone (%Dep_i).

Corn					
Variable	**Units**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
T_c	°C	24.36	5.18	4.53	36.5
RH	%	56.99	16.65	22.71	98.3
VPD	kPa	1.5	0.91	0.03	4.45
h	m	2.65	0.23	1.77	2.74
Rs	W m^{-2}	531.14	257.21	100.1	1126
u_2	m s^{-1}	2.31	1.36	0.2	7.31
T_a	°C	24.59	5.31	7.95	36.69
%Dep_i	%	71.35	9.92	44	88
(T_c-T_a)	°C	-0.23	1.73	-7.63	7.8
Soybean					
Variable	**Units**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
T_c	°C	21.45	4.65	4.82	34.55
RH	%	57.76	16.38	29.98	97.4
VPD	kPa	1.25	0.73	0.04	3.22
h	m	0.81	0.03	0.74	0.84
Rs	W m^{-2}	524.83	254.08	100.1	1030
u_2	m s^{-1}	3.1	1.41	0.45	6.74
T_a	°C	22.07	4.84	7.61	31.79
%Dep_i	%	58.16	17.52	15	86
(T_c-T_a)	°C	-0.62	1.85	-5.1	10.19

Table 5. Upper and lower baselines for corn and soybean determined at North Platte during 2004. The baselines were determined by multiple regression analysis. Variables and units are canopy temperature (Tc, °C), air temperature (Ta, °C), vapor pressure deficit (VPD, kPa), canopy height (h, m), solar radiation (Rs, W m^{-2}), and wind speed (u, m s^{-1}). RMSE is the root mean square error, and n is the number of values used in the analysis.

Baselines	Depletion (%)	Equations for Corn	n	R^2	RMSE
Upper Baseline	>85	Tc-Ta = -22.42+7.56h+0.0055Rs	975	0.76	0.93
Lower Baseline	<50	Tc-Ta = 20.40-11.44h-1.21VPD+0.0059Rs-0.135u	50	0.94	0.34
		Equations for Soybean			
Upper Baseline	>85	Tc-Ta = 0.0056Rs	84	0.94	0.44
Lower Baseline	<50	Tc-Ta = 12.23-16.20h-1.73VPD+0.003Rs+0.108u	784	0.80	0.67

Assessing the occurrence of Arsenic in groundwater: Implications for Small Water Supply Systems in Nebraska

Basic Information

Title:	Assessing the occurrence of Arsenic in groundwater: Implications for Small Water Supply Systems in Nebraska
Project Number:	2003NE36B
Start Date:	4/1/2003
End Date:	9/30/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Water Quality, Groundwater, Geochemical Processes
Descriptors:	
Principal Investigators:	David C. Gosselin, F. Edwin Edwin Harvey, R. Matthew Joeckel

Publication

1. Gosselin, David , Lynne Klawer, R.M. Joeckel, F.Edwin Harvey, Angela Noe, and Kelli Warren, 2004, Arsenic in Rural Nebraska Public Water Supplies, Nebraska, U.S.A., Awwa Journal. (In Review)
2. Gosselin, David , Lynne Klawer, F.Edwin Harvey, and Kelli Warren, 2004, Arsenic in Nebraskas Groundwater and Public Water Supplies, "in" Geoscience in a Changing World Annual Meeting and Exposition in Denver, CO, Geological Society of America Abstracts, Denver, CO, p. 356.
3. Gosselin, Dave, Lynne Klawer, and Angela Noe, 2004, Arsenic in Nebraskas Groundwater and Public Water Supplies, Earth Science Notes No. 7, Conservation and Survey Division, School of Natural Resources, University of Nebraska-Lincoln, 8 pages.

COVER PAGE

Grant #: 2003NE36B
Funding Period: April 1, 2003 – September 30, 2004
Title: Assessing the Occurrence of Arsenic in Groundwater: Implications for Small Water Supply Systems in NE
Primary PI(s): David Gosselin
Other PIs: Matt Joeckel and Ed Harvey

SYNOPSIS

Title: Assessing the Occurrence of Arsenic in Groundwater: Implications for Small Water Supply Systems in NE

Project Number: 2003NE36B

Start Date: April 1, 2003

End Date: September 30, 2004

Funding Source: 104(b)

Research Category: Groundwater

Focus Categories: GW, HYDGEO, WQL

Descriptors: Arsenic (As), Arsenic Speciation, Arsenite (As^{3+}), Arsenate (As^{5+}), Public Water Supplies (PWS), Field Parameters, Quality Control/Quality Assurance (QA/QC), Sequential Extraction Method

Primary PI: David C. Gosselin, Ph.D.

Other PIs: F. Edwin Harvey, Ph.D. and Robert Matthew Joeckel, Ph.D.

Project Class: Research

Summary

This project is part of an on-going state-wide groundwater resource assessment that is currently focused on arsenic. The **long-term goal** of our research is to reduce the economic impact of arsenic regulations on public water supply systems by evaluating less costly options for achieving compliance with the 10 ug/L MCL. The **specific goal of this project** is to improve our understanding of As in Nebraska's groundwater and apply this knowledge to mitigating the impact of As on public water systems.

Specific Objectives

The specific objectives of this state-wide project are: 1. Determine the chemical form in which the arsenic occurs in groundwater; and 2. Determine the geological and geochemical factors that control the occurrence of arsenic.

Results - Objective 1

As part of our EPA-funded reconnaissance sampling of two wells from 10 public water supplies, we tested 20 wells two to five times for arsenate from April through August 2003. Data indicate that arsenate (As^{5+}) comprises between 70 and 90 percent of the arsenic in the following public water supplies: Anselmo, Broadwater, Cambridge, Elwood, Lodgepole, McCook, Oshkosh, and Stromsburg. The two wells at Benkelman had less than 40 percent arsenate. In Cambridge, there was about a 20 percent difference in arsenate concentration between the two wells tested. Our conclusions thus far are that Arsenic occurs primarily as As^{+5}. This form of arsenic is preferred for most treatment options. However, wells need to be evaluated on an individual basis.

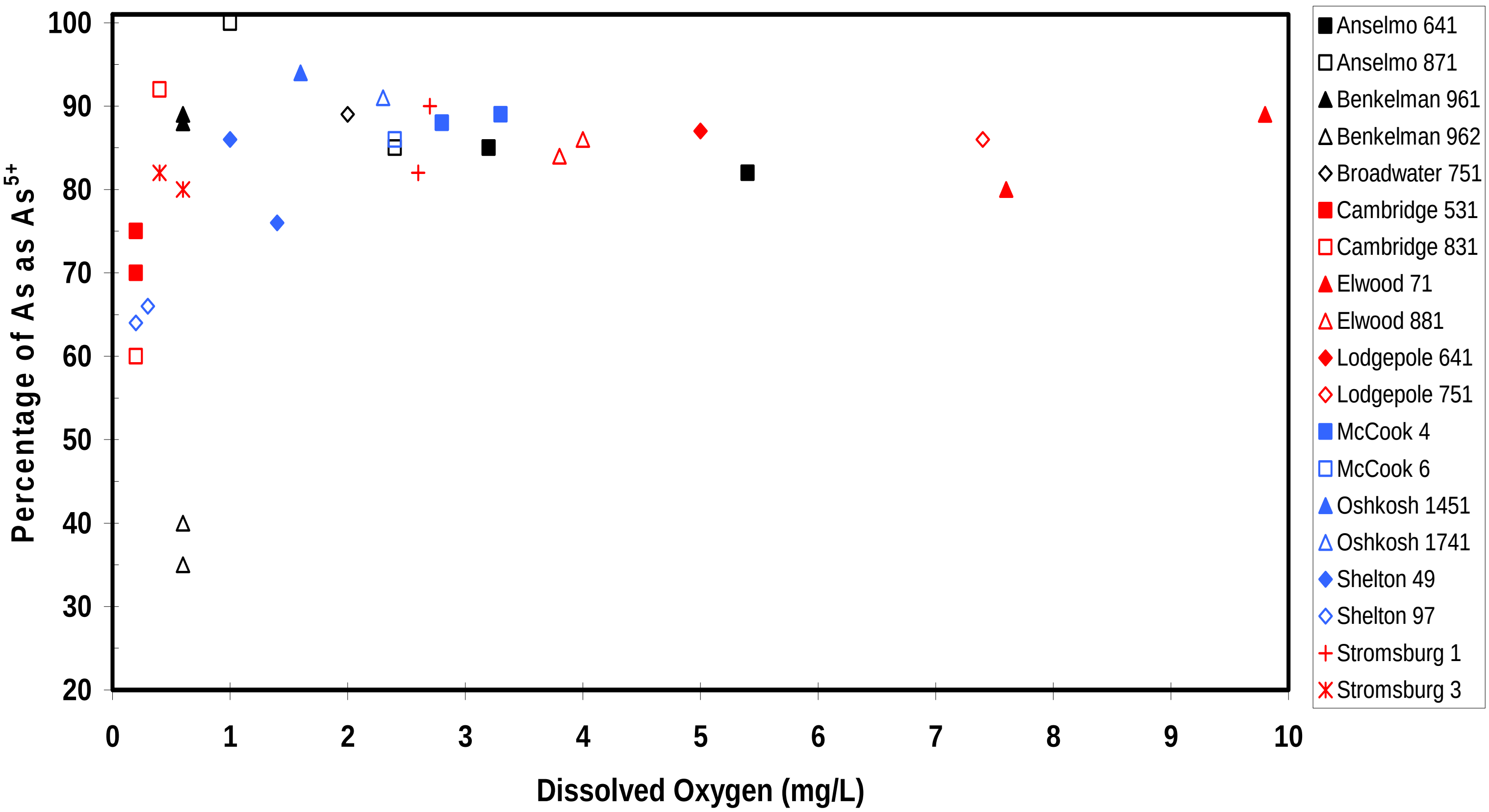

Fig 1. Public water supplies Arsenic5+ concentrations versus dissolved oxygen expressed as percentages.

Results - Objective 2

In Nebraska, arsenic in the groundwater is derived from the interaction between the water and geologic material through which it flows. Therefore, it is crucial to assess the availability of arsenic from the various geologic materials that comprise Nebraska's aquifers. We obtained two cores (~90 feet total) of unsaturated and saturated alluvial sand and gravel from Cambridge in the Republican River valley and from Oshkosh in the North Platte valley. Both of these valleys are recognized for their high arsenic levels. We have also acquired samples from the Conservation and Survey Division archive that includes: Quaternary sand and gravels, loess and glacial till, Cretaceous bedrock, and Tertiary Bedrock. To determine arsenic availability, sequential extraction procedures will be used on approximately 22 samples.

We conducted leaching experiments to assess the source of As in a variety of geologic units including cores specifically extracted for this project. Unfortunately, the results of the experiments were not definitive. The extraction method we used was developed by Keon et al. (2001). Based on data from our initial trial runs with this methodology that provided positive results on our Quality Assurance/Quality Control (QA/QC) samples and selected unknown study samples, we made the decision to use this method and go forward with the extraction process. Archived samples from the Conservation and Survey Division's geologic sample storage facility were obtained from known groups (White River) and formations (Carlile Shale) that should have high arsenic concentrations. These controls as well as a process blank and standard were placed in each extraction group for QA/QC. The results with this second submission did not repeat the trial run's success. The following are examples of the problems we had with the second group: several of the process blanks indicated arsenic contamination while the known standard (15.0 to 40.0 µg/L) indicated no detection or less than 50% recovery; or the standard would have 94% recovery while the blank and samples would test between 6.8 to 10.7 µg/L. In most cases the blank and samples were nearly identical. The laboratory performed an internal audit as our trial run or first submission was tested by a different analyst with very good results. The audit was able to determine that the samples had been diluted far too much by the second analyst especially in comparison to the first analysts work. They also discovered they mistakenly destroyed our samples and therefore were unable to do any retesting. The analyst who performed the second run is no longer with the lab so they will not be able to review with them if there may have been an error in factor multiplication and/or other problems. This investigation took several months and just concluded late winter 2005.

The laboratory has acknowledged their errors and has offered to run new samples at their expense. We plan to perform new extractions sometime this summer –early fall and then submit these samples to the laboratory's first analyst to ascertain if As is present in these samples. We anticipate a successful outcome as in the trial run and would like to add an addendum to this report at that time.

Results - Related EPA-funded Studies

The average concentrations for the 20 public water supplies range from 4.2 to 22.1 µg/L. Twelve of those wells have average As concentrations greater than the MCL. Only four of these (Stromsburg 1 and 3, Anselmo 871, Broadwater 551) have average As concentrations greater than 13 µg/L. An additional four wells (Benkelman 962, Cambridge 831, Lodgepole 751, Oshkosh 1741) have average concentrations between 9.3 and 9.8 µg/L, but they have values that, at times, exceed 10 µg/L. The two wells at Elwood and Shelton 49 have the lowest average As concentrations at 6.3, 5.5, and 4.2 µg/L, respectively. Wells from the same PWS which derive their water from similar geologic units can have comparable As concentrations (for example, McCook); or one well can have concentrations up to 60 percent higher than another (for example, Anselmo). Arsenics concentrations varied by as little as 1.5 µg/L to as much as 7.0 µg/L in individual wells over the one-year study. In some cases, the apparent variation in As concentrations brings the well into compliance with the MCL. Analytical variability may be responsible for up to at least +/- 10% of the observed variation among the samples.

Our conclusions thus far are as follows: 1. Arsenic concentrations are variable in individual wells on different time scales. 2. In some cases, monthly variability is large enough to bring the As concentrations into compliance with the MCL. However, this variability is not predictable. 3.

A well should be pumped for at least 30 minutes prior to sampling. Mitigating arsenic by well field management does not appear to be an adequate solution for PWS.

Recommendations for Water Quality Management

1. USGS and NURE data document a complex spatial and geologic distribution of As in ground water throughout Nebraska. The non-uniform occurrence of As reflects differences in the geology, ground-water flow systems, and associated geochemical environments throughout the state. The geologic, hydrogeological and geochemical factors make the prediction of As concentrations very difficult. It is recommended that assessing historical, quality controlled data and information can improve the likelihood of finding a new source of water that has lower arsenic concentrations.

2. Although our data were relatively constant, in some parts of the U.S. individual PWS wells show significant variability. We recommend four quarterly samples to assess the extent to which the drinking water public is exposed to As.

3. Short-term pumping tests indicate As concentrations can be variable during the first 30 to 60 minutes of pumping. It is recommended that a well be allowed to pump for at least 30 minutes prior to sampling. *(Current NHHSS protocol states "Allow the cold water tap to run approximately 3 minutes." NHHSS is now revising the sample protocol because of the 24-hour pump test results and this studies recommendation.*) An alternative sampling protocol that could be used is that the well should be sampled at the midpoint or average time that the pump typically runs if the primary purpose of the sampling is to assess the As concentrations to which the drinking water public is exposed.

4. Annual and short-term pumping test data indicate that mitigating As by pumping management is not an adequate solution for public water supplies.

5. Arsenic occurs primarily as arsenate, As^{+5}, in the public water supplies assessed in this study. This form of arsenic is preferred for most treatment options. Although our data indicates that arsenate predominates, it is recommended that wells need to be evaluated on an individual basis.

6. To address the arsenic issue, partnerships between local communities and the University of Nebraska's Public Policy Center, UNL Water Research Initiative, the UNL Rural Initiative and state regulatory agencies should be used to assist communities in their decision-making process regarding the various options to lower arsenic concentrations.

7. Continue outreach and information dissemination through the Arsenic Information Website: http://nesen.unl.edu/nearsenic.

Additionally, we have been funded from Region 7 of the U.S. Environmental Protection Agency (Federal Assistance Identifier MM-98749401-0) to continue our work with 13 additional Nebraska PWS. This study will run through October 31, 2005 and will include the appropriate recommendations discussed previously.

We are also working with the Nebraska Health and Human Services System on the following project: "Evaluation of Geologic Rehabilitation of Public Water Supply Wells Having High Arsenic and Uranium: A Collaborative project between NHHSS and UNL". Characterizing As concentrations at distinct intervals within a well will be important to determine the factors that influence the availability of As. This study will focus on the vertical distribution of As in Nebraska's alluvial sediments and document the extent to which it occurs in association with clay-bearing units. The project is scheduled to run through the summer (2005) with anticipated results by late summer early fall.

Information Dissemination

Project information has been disseminated through a variety of avenues including 18 newspaper articles, 14 arsenic study presentations, 11 Nebraska Public Policy Center Community Water and Development Project presentations, eight poster presentations, three educational outreach activities, two radio interviews, and one University of Nebraska-Lincoln Conservation and Survey Division Publication . The Arsenic Information System website (http://nesen.unl.edu/nearsenic/) was developed to inform not only the PWSs involved in the project, but also a wider audience such as educators, researchers, government agencies and the public in general.

Additional Funding

Funding from Region 7 of the U.S. Environmental Protection Agency (Federal Assistance Identifier MM-98720701-0, X6-98728301-0 and MM-98749401-0).

Sources of Information

Keon, N.E.; Swartz, C.H.; Brabander, D.J.; Harvey, C.; & Hemond, H.F., 2001. Validation of an arsenic sequential extraction method for evaluating mobility in sediments. *Environmental science & Technology* 35(13):2778.

Acknowledgments

Funding from the U.S. Geological Survey 104b program and Region 7 of the U.S. Environmental Protection Agency (Federal Assistance Identifier MM-98720701-0, X6-98728301-0 and MM-98749401-0) is gratefully acknowledged. The Nebraska Department of Health and Human Services provided financial support for analytical cost, which is appreciated. Financial support does not constitute an endorsement by the USEPA, USGS or NHHSS of the views expressed in this report. C. Flowerday and D. Ebbeka provided editorial and graphical support. We would also like to thank the operators of the public water supplies for their cooperation and hospitality during this study.

Biodegradation of Dual-Contaminant Mixtures in Groundwater: Chlorinated Solvents and High Explosives

Basic Information

Title:	Biodegradation of Dual-Contaminant Mixtures in Groundwater: Chlorinated Solvents and High Explosives
Project Number:	2003NE41B
Start Date:	3/1/2003
End Date:	12/31/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Groundwater, Toxic Substances, Treatment
Descriptors:	groundwater, remediation, high explosives, chlorinated solvents, biodegradation
Principal Investigators:	Matthew Morley, Daniel Davidson Snow

Publication

1. Young, T.S.M.; Morley, M.C.; Snow, D.D. Simultaneous biodegradation of trichloroethylene and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), tentatively accepted for publication in ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management; revised manuscript submitted May 2005.
2. Young, Travis S.M., 2004, Anaerobic Biodegradation of Hexahydro-1,3,5-Trinitro-1,3,5-Triazine (RDX) and Trichloroethylene (TCE): Single- And Dual-Contaminant Batch Tests, MS Thesis, Environmental Engineering, College of Engineering and Technology, University of Nebraska Lincoln, Lincoln, NE, 140 pages.

Title: Biodegradation to Dual-Contaminant Mixtures in Groundwater: Chlorinated Solvents and High Explosives

Project Number: 2003NE41B

Start Date: April 1, 2003

End Date: December 31, 2004

Funding Source: 104B

Research Category: Water Quality

Focus Categories: GW, TS, TRT

Descriptors: groundwater, remediation, high explosives, chlorinated solvents, biodegradation

Primary PI: Matthew C. Morley

Other PIs: Daniel D. Snow

Project Class: Research

RESEARCH: Due to its extensive use as an explosive, hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) is a common groundwater contaminant at many defense-related sites. Because of its wide spread use as an industrial degreasing compound, roughly fifty percent of the sites listed on the U.S. EPA National Priority List have groundwater contaminated with trichloroethylene (TCE). There are at least five sites in the U.S. that have groundwater contaminated with mixtures of high explosives and TCE. The current remediation approach is to extract this contaminated groundwater and treat it using granular activated carbon, which will be a long and costly process. Single contaminant biodegradation of TCE and RDX has been well studied and can be an effective treatment method. However, there has been no previous research examining the ability of mixed microbial consortia to biodegrade two contaminant mixtures of TCE and RDX. The intent of this research was to make an initial assessment of the feasibility of biodegrading aqueous mixtures of RDX and TCE under anaerobic conditions in laboratory microcosms. The major objectives of this research were to assess the ability of two different microbial consortia to biodegrade TCE and RDX as single contaminants and as mixtures under anaerobic conditions, and to determine the metabolites produced by each culture.

This research examined the ability of two microbial cultures (anaerobic sludge and a facultative enrichment culture) to biodegrade single- and dual-contaminant mixtures of trichloroethene (TCE) and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) under anaerobic conditions, using acetate as an electron donor and carbon source. In single component batch tests, both cultures degraded 0.6 – 1 mg RDX/L and its nitroso metabolites to below detection limits in <7 d. During initial 9-d TCE biodegradation tests, the anaerobic sludge did not transform TCE, whereas the facultative culture transformed approximately 10% of the initial 1.4 mg TCE/L. Prior to dual-contaminant batch tests, both cultures were grown in the presence of

TCE. Subsequently, both acclimated cultures rapidly biodegraded mixtures of RDX and TCE. Both cultures degraded RDX and RDX-nitroso compounds to below detection limits in <4 d. In the same tests, TCE-acclimated anaerobic sludge converted TCE primarily to *cis*-dichloroethene (*cis*-DCE), while the acclimated facultative culture produced *cis*-DCE and other chlorinated metabolites. These preliminary results demonstrate that anaerobic bioremediation may be part of a feasible groundwater remediation alternative for mixtures of TCE and RDX.

PUBLICATIONS:

1. Articles in Refereed Scientific Journals:

Young, T.S.M.; Morley, M.C.; Snow, D.D. "Simultaneous biodegradation of trichloroethylene and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)," tentatively accepted for publication in ASCE *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*; revised manuscript submitted May 2005.

2. Book Chapter: Not applicable.

3. Dissertations/Theses

Young, Travis S.M., 2004, Anaerobic Biodegradation of Hexahydro-1,3,5-Trinitro-1,3,5-Triazine (RDX) and Trichloroethylene (TCE): Single- And Dual-Contaminant Batch Tests, MS Thesis, Environmental Engineering, College of Engineering and Technology, University of Nebraska Lincoln, Lincoln, NE, 140 pages.

4. Water Resources Research Institute Reports: Not applicable.

5. Conference Proceedings: Not applicable.

6. Other Publications: Not applicable.

D. **INFORMATION TRANSFER PROGRAM:**

E. **STUDENT SUPPORT:** 1 MS student (Travis Young) was supported with USGS funding.

F. **NIWR-USGS STUDENT INTERNSHIP PROGRAM:** Not applicable.

G. **NOTABLE ACHIEVEMENTS AND AWARDS:** Not applicable.

Information Transfer Program

The University of Nebraska-Lincoln (UNL) Water Center continues to fine-tune and adapt a long and productive tradition of vigorous information transfer programming utilizing USGS funding assistance. The UNL Water Center, arguably, has one of the most comprehensive, aggressive and up-to-date information transfer programs of any of the more than 50 Water Resources Research Institutes nationwide.

Information supports a variety of research, extension, outreach and education programming sponsored or co-sponsored by the Water Center, the Water Resources Research Initiative and the UNL School of Natural Resources. Vehicles used to convey information, include print, electronic, broadcast and Internet, along with conferences, symposiums, tours and other public events. Information can be found in the from of newsletters, brochures, press releases, conference and symposium proceedings, several internet sites, radio and television, videotape and web streaming, to name a few.

Water Center Educational Materials

Basic Information

Title:	Water Center Educational Materials
Project Number:	2002NE33B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	None
Focus Category:	Education, None, None
Descriptors:	None
Principal Investigators:	Kyle D. Hoagland, Steven W. Ress

Publication

2004 USGS Report
Information Transfer Program:

Water Center,
University of Nebraska-Lincoln

Newsletter:

The *Water Current* newsletter is in its 36th year of continuous publication. The 12 to 16-page newsletter is published in full-color on coated paper in a magazine-type format and as a quarterly with January, April, July and October publication dates. It has a free distribution of approximately 3,000 copies per issue, more than 95 percent of which represent requested subscriptions. An annual reader survey is published in the spring issue. Water-related research, extension and outreach faculty and key staff members are featured in each issue. Guest columns are published as available. Individual issues are normally 16 pages in length. Virtual copies of the newsletter are available online in PDF format and are archived at http://watercenter.unl.edu.

The Water Current was redesigned to its present format and appearance several years ago and recently underwent a partial redesign, or freshening of the basic appearance, to bring it in line with new University "branding" guidelines. The new look debuted with the spring, 2005 edition of the newsletter.

The UNL Water Center is also a primary contributor to the UNL School of Natural Resources' *Resource Links* newsletter, also a quarterly, as well as the twice-annual NU Agricultural Research Division's *Research Nebraska!* Magazine and a quarterly newsletter published by UNL's "Nebraska Earth Science Education Network" or NESEN, among others.

Other Print Resources:

Water Center informational brochures. Updated and produced annually. These include, but are not limited to, the mission and programming of the UNL Water Center, Great Plains CESU, EEAI unit, Water Resources Research Initiative (WRRI), UNL School of Natural Resources, UNL Water Sciences Laboratory and others affiliated with the Water Center. Distributed free.

Water Center Pocket Resources Directory. A pocketsize brochure listing key NU, federal, state and local water resource agencies and points of contact (due for reprint in 2005).

Newspaper tabloids on wetlands and drinking water issues published in 1997 and 1999. These continue in use by a variety of university programs, 4-H, FFA, Projects WET/WILD, state agencies and the public schools. Distributed free (in quantity).

Pocket cards. Credit card-size. Explain commonly used terms such as "cubic feet per second (CFS)," acre-feet, gallons per minute, etc.

A range of publications produced outside the UNL Water Center, particularly fact sheets and other print materials from the USGS, Nebraska Department of Environmental Quality and University of Nebraska Cooperative Extension Division, are made available through the Water Center's web site.

News Releases:

The Water Center produces about 30 to 35 press releases annually. Most of these are based on research, cooperative extension, and public outreach programming involving the Water Center or its sponsored programs. They are also used to announce conferences, seminars, tours, collections of waste pesticides, pesticide container recycling and other activities. These are widely published in state and regional newspapers, as well as in organizational, trade and professional journals and have frequently been "picked-up" by national news networks such as the Associated Press and Brownfield Network. The releases support a wide variety of UNL water-related research and outreach that cross departmental and academic disciplines.

Electronic Resources:

Electronic versions of newsletters, news articles, press releases. print materials, information about the Water Center and Water Sciences Laboratory and curriculum information for graduate and undergraduate students enrolling in water science majors are available at **http://watercenter.unl.edu**. The Water Center co-sponsors these additional sites, each of which is program specific:

***Water Sciences Laboratory*:**
http://waterscience.unl.edu

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

Groundwater Chemistry Laboratory:
http://csd.unl.edu/csd/staff/harvey/lab.html

Great Plains Cooperative Eco-Systems Studies Unit (CESU):
http://greatplains.cesu.unl.edu/

Water Law, Policy and Science Conference:
http://snr.unl.edu/waterconference/

Water Resources Research Initiative (WRRI):
http://wrri.unl.edu/

The Water Center web site was redesigned to its present format and appearance in 2003 and is currently undergoing another redesign to bring it in line with new University "branding" guidelines. The new look should be online by summer 2005.

Conferences, Seminars and Tours:

Water Law, Policy and Science Conference. Conducted annually in March or April. Co-sponsored by various other UNL Schools, Colleges, departments and centers. Explores pertinent current issues related to Nebraska water law, policy and research. In its first two years, the conference has attracted from 175 to more than 250 participants and been headlined by noted national and regional experts on water issues. News releases, brochures, a printed program, radio spots and web-based information are produced for this event. This year's conference featured online registration and web streaming for the first time ever.

Water and Natural Resources Seminars. A series of 12 to 14 free weekly public lectures from January to April each year. Co-sponsored by the School of Natural Resources and other University departments and units. The series may be taken for student credit or as a free public lecture series. Each lecture typically attracts an audience of 60-100, as well as approximately a dozen for-credit students. News releases, mailings, brochures, posters and web-based information are produced in conjunction with this event. An increasing number of regional and national experts are being added to the seminar schedule each year.

Platte Watershed Symposium. Co-sponsored by the Water Center and other University departments and centers, as well as by the U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service. The bi-annual symposium explores research and educational programming related to the ecology of the Central Platte River Basin area of Nebraska. Approximately 200 attend. News releases, brochures and a printed program are produced in conjunction with this event, along with web-based information.

Summer Water and Natural Resources Tour. Co-sponsored by the Nebraska Water Conference Council, Kearney Area Chamber of Commerce and other University, public, private and commercial entities. The annual three-day tour is conducted in July and is used to educate and inform 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.

Fall Research Colloquium. Held in conjunction with UNL's School of Natural Resource Sciences. Brings water and natural resource researchers, cooperative extension programming heads, key staff and students together for a one-day symposium to share research results and progress.

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.

In addition, Water Center staff makes presentations and have seats on the organizational committees of such educational festivals as the Lincoln Public Schools' "Earth Wellness Festival," statewide "Husker Harvest Days"(one of the largest commercial agricultural expositions in the country), "Gateway Farm Expo" and others.

Promotional Items:

Promotional items for distribution include coffee mugs, key chains, pens, lanyards, signed copies of University-published books, etc. May are imprinted with the Water Center and University logos, web addresses and telephone numbers are produced for either general distribution or specific to individual conferences, tours, educational programs/displays, or student recruitment seminars.

UNL Pesticide Education Office:

The Water Center assists with publicity and press relations for programs conducted by the UNL Pesticide Education Office, which is part of the UNL Department of Agronomy and Horticulture. This includes press releases supporting pesticide container recycling and waste pesticide collection programs that are integral to state groundwater quality issues.

Primary Information Dissemination Clientele:

U.S. Department of Agriculture
U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Bureau of Reclamation
Nebraska Department of Natural Resources
Nebraska Department of Agriculture
Nebraska Department of Health and Human Services System
Nebraska Department of Environmental Quality
Nebraska Environmental Trust
Nebraska Association of Resources Districts (and the individual NRDs)
Nebraska Congressional delegation
Nebraska State Senators
Public and private power and irrigation districts
The Audubon Society
The Nature Conservancy
Nebraska Alliance for Environmental Education
Nebraska Earth Science Education Network
Other State Water Centers
University and College researchers and educators

NU students
Public and parochial science teachers
Farmers
Surface and groundwater irrigators and irrigation districts
Private citizens

Cooperating Entities:

In addition to primary support from the USGS, the following agencies and entities have helped fund information dissemination activities by the UNL Water Center during the past year.

U.S. Environmental Protection Agency
U.S. Department of Agriculture
Nebraska Department of Environmental Quality
Nebraska Research Initiative
Nebraska Game and Parks Commission
National Water Research Institute
Nebraska Water Conference Council
Nebraska Public Power District
Central Nebraska Public Power and Irrigation District
Farm Credit Services of America
Kearney Area Chamber of Commerce
Nebraska Association of Resources Districts
UNL Institute of Agriculture and Natural Resources
UNL Agricultural Research Division
UNL College of Agricultural Sciences and Natural Resources
UNL School of Natural Resources

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	2	0	0	0	2
Masters	2	0	0	0	2
Ph.D.	2	0	0	0	2
Post-Doc.	1	0	0	0	1
Total	7	0	0	0	7

Notable Awards and Achievements

Publications from Prior Projects