

# **Nebraska Water Resources Center Annual Technical Report FY 2002**

## **Introduction**

During the past 12 months, unfilled vacancies at the University of Nebraska resulted in Water Center Director Kyle Hoagland temporarily vacating the post and serving as Acting Director of the School of Natural Resources Sciences (SNRS). In Hoagland's absence, Michael Jess, Associate Director of the Conservation & Survey Division (CSD), served as Acting Director of the Water Center. The temporary assignments for Hoagland and Jess began in December 2001.

In late 2002 a five-member team of reviewers ranked 14 applications submitted for Sec. 104b grants. Ultimately, approval for funding went to three applications.

Reorganization and redirection of the Water Center's affiliated Water Science Laboratory was completed in the second half of 2002. A new Laboratory manager also was named. With so-called "ear mark" funds made available through the efforts of Congressman Douglas Bereuter (R., Neb.), additional laboratory equipment was acquired and was finally installed in spring 2003. The new equipment expands the lab's analysis capabilities and permits faster turn-around.

## **Research Program**

# Relating landscape scale characteristics with phosphorus loss potential to surface waters

## Basic Information

<b>Title:</b>	Relating landscape scale characteristics with phosphorus loss potential to surface waters
<b>Project Number:</b>	2002NE1B
<b>Start Date:</b>	5/1/2002
<b>End Date:</b>	2/28/2003
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	Nebraska 1
<b>Research Category:</b>	Water Quality
<b>Focus Category:</b>	Agriculture, Models, Sediments
<b>Descriptors:</b>	manure, Phosphorus, surface runoff, GLEAMS Model
<b>Principal Investigators:</b>	Martha Mamo, Daniel Ginting, Martha Mamo, Dennis L. McCallister, C. William Zanner

## Publication

1. M. Mamo, D. Ginting, D. McCallister, and W. Zanner. 2003. GLEAMS simulations of P loss from manured watersheds under various management scenarios. American Society of Agronomy Meeting. Denver, Colorado, Nov. 2-6.
2. M. Mamo, D. Ginting, D. McCallister, and W. Zanner. 2003. GLEAMS simulations of P loss from manured watersheds under various management scenarios. American Society of Agronomy Meeting. Denver, Colorado, Nov. 2-6.

**Title:** Relating landscape scale characteristics with phosphorus loss potential to surface waters

**Project Number:** 2002 NEB1

**Start date:** March 1, 2002

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**Funding source:** 104B

**Congressional District:** Nebraska 1<sup>st</sup>

**Research Category:** Water Quality

**Focus categories:** NPP, WQL, AG, SED, MOD

**Keywords:** phosphorus loss, water, manure, soil management, surface runoff, modeling

**Primary PI:** Martha Mamo

**Other PIs:** Dennis McCallister, Daniel Ginting, William Zanner.

### **PROBLEM AND RESEARCH OBJECTIVES**

Runoff from agricultural land is a major source of nutrient loading into rivers in Nebraska (NE Department of Environment Control, 1991). Agricultural runoff and leaching contributed about 11 % of the total nutrient loading into the Gulf of Mexico (Maede, 1995). Part of the problem is manure produced by dairy, beef, and swine operations. In Nebraska over 5.1 million Mg of feedlot beef cattle manure are produced annually (Eghball and Power, 1994). Application of manure of this magnitude often only on agricultural lands close to the concentrated animal farm operation results in concentrated and stratified P levels on the soil surface.

The effects of manure on soil P available to crops are commonly evaluated with standard soil P testing such as Bray-P, Olsen-P, Mechlich-3 P depending on soil characteristics (Olsen and Sommers, 1982, Mechlich, 1984). Extensive research has studied the relationship between standard soil P test with P runoff (Sharpley, 1995; Sharpley et al., 1981, McDowell and Sharpley, 2001). Some techniques of runoff analyses (e.g. sodium hydroxide extraction, iron oxide-impregnated filter paper strips, and ion exchange resins or capsules) have also been correlated with runoff P bioavailability (Pote et al., 1996, 1999). These research were done on controlled experimental treatments, conditions, and environmental setting and scale, with limited use for other conditions, and environmental settings and/or require extensive testing under conditions involving a range of manure management approaches (Oberle and Keeney, 1994; Sharpley et al., 1995). While better

soil tests are part of the solution in estimating the effects of manure managements on soil nutrient status, it is necessary to extend these sample-scale analyses to a landscape scale if the information is to be most useful for assessment of future impacts of manure managements on water quality. The key to this is a modeling approach that integrates the soil analysis for biologically available P (BAP) with other available soil databases.

The modeling approach requires mathematical models constructed to represent physical processes and mechanisms. Examples of models that are made to represent the impact of management practice on major physical processes are the “erosion-productivity impact calculator, EPIC” (Sharpley and William, 1990), the “chemicals, runoff, erosion from agricultural management system, CREAMS” (Knisel, 1980), and the “groundwater loading effects of agricultural management system, GLEAMS” (Knisel et al., 1993). These models simultaneously involve hydrology, erosion processes, runoff and sediment N and P loading, soil nutrient dynamics, and fate of applied pesticide. Despite uncertainties inherent in the modeling approach, the approach provides flexibility to evaluate and compare a wide range of existing and potential manure management practices.

The *objective* of this study was to evaluate the effects of manure on soil P level and soil P stratification at the first 15 cm depth and to predict soil P dynamics over a range of manure and soil managements using a modeling approach. Our specific objectives were: 1) To measure BAP of soils which have or have not received animal manure, using a group of standard agronomic and environmental tests, and, 2) To use a simulation model, GLEAMS, to predict the dynamics of soil P status and P stratification, and its effects on runoff water quality of different landscape settings upon imposing various manure and soil management scenarios.

## METHODS

### Field Site Selection

Three sites having the same soil type, Moody silty clay loam (fine-silty, mixed, mesic Udic Haplustolls), were selected to represent the range of soils present in areas of Nebraska with heaviest concentrations of livestock (primarily the northeast). For identification the sites were named as Haskell, Nebuda, and Roeppert. All three sites are in dryland corn-soybean production.

The Haskell site is located on a toposequence of a rolling landscape having convex shape from summit to shoulder, rectilinear backslope, and concave footslope (Fig. 1). This site was delineated from a larger area used for manure study from 1999-2001 at the Haskell Agricultural Laboratory, Concord, NE. Details of this study are presented in detail by (Ginting et al., 2003). During this study the area were divided into 18 strips allocated in a randomized complete block design with three replications of site specific and uniform application of cattle feed-lot manure (CAM) treatment, site specific and uniform application swine manure (SWM) treatment, uniform application of commercial N fertilizer treatment, or control (CTL) check (no treatment). Since our concern was on

manure effects on soil P dynamics, only soil from strips with uniform application of CAM, SWM, and CTL were sampled. The manures were applied annually (before planting) in 31 March 1999, 15 Nov. 1999, and 19 April 2001 for corn growing in 1999, 2000, and 2001, respectively. Manure was incorporated into 15-cm topsoil by disking within 24 hours after application. Rate of application was based on corn N needs, adjusted with soil nitrate test. Rate of manures application and corresponding P applied is presented in Table 1.

The Nebuda site is near West Point, NE ( $96^{\circ}66'$  W long.,  $41^{\circ}89'$  N lat.). The field site is approximately 4 ha and has received feedlot beef manure for at least the last five years. Manure has been surface applied and incorporated by shallow disking. The field landscape is convex with an eroded intermittent channel that occurs in the middle extending from upland to bottomland of the field (Fig. 2). The Roeffert site is also near West Point, NE ( $96^{\circ}67'$  W long.,  $41^{\circ}88'$  N lat.). The field site is approximately 5 ha and has no manure history with landscape form similar to the Nebuda site.

### **Soil Sampling**

In May 2002, soil samples were collected in three transects (at summit and shoulder, backslope, footslope and toeslope positions) across the field. At the Haskell site, samples were taken from strips treated with uniform applied CAM, SWM, and CTL. At each of the three position, 8 to 10 soil cores (each 1.8 cm diameter) were collected at 0-5-, 5-10-, and 10-15 cm depths, and then composited by each depth. All soil samples were air dried and ground to pass 2 mm sieves and analyzed for total P, Bray and Kurtz-1 P, iron strip P, and water extractable P. On selected samples soil clay, silt and sand content were also measured.

### **GLEAMS Model Description**

GLEAMS is an extension of CREAMS that considers vertical pathways of pesticide and nutrient cycling and transformation, and estimates pesticide and nutrient loadings at edge-of-field and bottom of root zone loadings. GLEAMS includes four components, i.e. hydrology, erosion, pesticide, and plant nutrients. Field operations that modify the response of each component to climate (updateable parameters) could be represented. Examples are dates of planting, harvest and crop rotation, date- rate-method of application of fertilizers, manure, and pesticide, irrigation, fertigation, chemigation, tillage systems and implements, terracing, contour tillage, residue management. Because P dynamics and loadings in runoff water and sediment were the focus of our study, only hydrology, erosion, and nutrient components were considered. The hydrology and erosion components have been described in detail by Knisel et al., 1989, Leonard et al., 1987; Leonard et al., 1990.

### **Model Parameterization**

The main concern of any model-whether it is realistic, able to portray the functioning and the emergent properties of the system-depends greatly on parameterization. For this purposes model first needs sensitivity analysis and calibration against a measured properties/behavior of a system and then used the calibrated model parameters in the prediction of future properties/behavior of the same system (and other resembling

system). For this purpose two-step approach was taken. First calibrate model parameters using the manure treatment of the detailed experiment at Haskell site. General or non-site specific parameters (constants that controls the effects of climatic variables on hydrology, erosion, and nutrient components, constants that partitioning P flows among P pools and decomposition) are left unchanged. During the sensitivity analysis and model parameter calibration, parameters that caused deviation (between the simulated and measured P) of less than 10% were taken as the best fit. Second, the calibrated parameters are used to predict the P dynamics and its effects on runoff P losses from the field at Haskell and Nebuda sites. Site-specific parameters and initial conditions were either measured or estimated using readily available database.

### **Hydrology Component**

Drainage area, hydraulic slopes, field length:width ratio, and other topography-related information were derived from topographic measurements (Figs. 1 and 2). Effective saturated conductivity immediately below the root zone and effective rooting depth were estimated from Dixon and Cuming County Soil Surveys. Runoff curve number of 78 was selected for row crops with straight rows and good hydrologic condition. The elevation and latitude of the sites were estimated to be the same with those of the closest weather station, where the daily climatic parameters from 1 Jan 1982-31 Dec. 2002 were obtained. Monthly maximum and minimum air temperature, solar radiation, wind speed, and dew point for each year were derived from the daily records. These monthly values for each year were used for yearly updates. Daily dew point was estimated from the relative humidity and the mean daily temperature.

Preliminary GLEAMS simulation indicated that P loss was responsive to P stratification. Therefore each soil P sampling depths (0-5, 5-10, and 10-15 cm) was regarded as a horizon, identified as  $A_{P1}$ ,  $A_{P2}$ ,  $A_{P3}$ , respectively. The rest of the depth of AP and A horizons was regrouped as A, and all the B ( $B_1$ ,  $B_2$ , and  $B_3$ ) horizons were made as B-horizon. This scenario results in total of 5 horizons representing the soil profile.

Physical property measured for the first 3 top horizons was texture (clay and silt). Other mean soil physical properties (porosity, bulk density, field capacity, and wilting point, and evaporation constant) for all horizons were estimated using the textural information. Soil chemical properties (pH, base saturation, and  $CaCO_3$ ) were estimated using available sources.

Crop and tillage data (Table 1) was used for updateable parameters (e.g. crop rotation cycles, crop and irrigation management data, and potential crop productivity). Based on Table 1, continuous corn with no irrigation management was simulated. Default GLEAMS leaf area data of corn for grain were used and not adjusted in the simulation.

### **Erosion Component**

For the Haskell site execution sequence of erosion was “overland”. The overland profile was represented by 5 points, each having distance (from the upper end of overland profile) and slope information derived from the overland profile transect (Fig. 1). In this simulation soil erodibility value of 0.29 was fixed for all parts of overland profile. The crop and tillage data (Table 1) was used for the number and dates of parameter (crop

factors, management factors, and hydraulic roughness factor) updates. The updateable parameters were applied uniformly for all parts of the overland profile. The practice factor was set as one (no contouring factor) because practices were done up-and-down the slope. The crop factor ranged from 0.3 (after harvest with corn residue on surface) to 0.7 (after autumn moldboard plow and field cultivation prior to planting when soil residue was minimum). The hydraulic roughness factor, Manning's "n" value, ranged from 0.14 (smooth after field cultivation) to 0.046 (rough, after moldboard plowing).

For the Nebuda site execution sequence of erosion was "overland-channel" (Fig. 2). The overland profile was represented by 5 points with distance and slope information derived from Fig. 2. Derivation of overland profile parameters and overland updateable parameters were done with the same procedure as the Haskell site. Channel profile was divided into 3 segments based on the slope of the channel and channel top-width parameter. The channel top-width parameter is one of the channel updateable parameters. However, to represent the increase of channel top-width in up and down stream direction, the channel top-width was used to divide the channel into three segments. In this case channel top-widths do not change during field operations (same value for all the updates) and during simulation period. Other updateable channel parameters are Manning's "n" and depth to non-erodible layer.

### **Nutrient Components**

Soil profile horizons scenario follows that in hydrology component. Initial crop residue was estimated to be  $5000 \text{ kg ha}^{-1}$ . For each horizon, initial N values (total N concentration, nitrate-N concentration, potentially mineralizable nitrogen, organic N from animal waste in plow horizon) were estimated. The P values from control treatment at Haskell site was used as the initial P values for the  $A_{p1}$ ,  $A_{p2}$ , and  $A_{p3}$  horizons of the cattle treatment because no soil-P analysis was performed at the initiation of experiment in April 1999. This is based on assumption that the P values of control in 2002 would be pretty similar to that when the experiment started. Nitrogen concentration,  $2.3 \text{ mg L}^{-1}$ , in rainfall was adapted from Chapin and Uttomark (1983). No N and P in irrigation because no irrigation was applied.

Updateable plant nutrient parameter changed with management practices (animal waste application and any tillage to incorporate and mixed manure with soil). Number of manure application every year (one), number of tillage operations, and date of harvest every year is derived from Table 1. Potential corn grain yield was  $15 \text{ Mg ha}^{-1}$ . Dry matter ratio (ratio of total dry matter production to grain), C:N ratio, and N:P ratio was estimated to be 2.0, 40, and 5, respectively based on a continuous corn experiments in eastern Nebraska. Rate of manure application, and parameters for manure N, P and organic matter are based on managements (Table 1) and manure analysis (Table 2). Manure is incorporated into top 15 cm depth. Depth of tillage by disking and field cultivation is 15 cm, and depth filled cultivation followed by ridging is assumed to be 20 cm. Mixing efficiency of tillage equipment uses GLEAMS default value.

## PRINCIPAL FINDINGS AND SIGNIFICANCE

### Extractable P

Extraction showed a high stratification of both water and Bray extractable P levels. The highest level of extractable P was found in the 0-5 cm (Figs. 3 to 5). This is expected because of manure surface application and shallow incorporation as well as plant residue accumulation overtime. The 5-10 cm had lower P levels compared to the surface 0-5 cm.

For the Nebuda site, the extractable P levels were high at all transects at the 0.5 cm depth compared to the other two lower depths (Fig. 3). The level of P in the channel of the Nebuda site (transect 3) was high at all positions, except for the lowest elevation level. At the lowest point of the channel, the extractable P level was as low as what would be found in unmanured soil. We postulate that rapid and accelerated flow occurring close to the exit of the field resulting in high soil erosion. This high erosion resulted in deep cuts that possibly eroded the P enriched soil out of the field.

The Roeppert site has no manure history except of inorganic starter P application. The levels of both water and Bray extractable P were much lower in comparison to the Nebuda site. The water extractable P was lower than  $5 \text{ mg kg}^{-1}$  at all depths, while the Bray P levels reached only  $35 \text{ mg kg}^{-1}$  at the 0-5 cm depth (Fig. 4).

The Haskell site surface 0-5 cm depth was enriched with P due to swine and cattle manure additions (Fig. 5). In comparison to the Nebuda site, the P levels due to manure application were much lower. This can be explained by the short manure application history of the Haskell site compared to the Nebuda site. In addition, manure at the Haskell site was applied at agronomic rate for the last three years while the Nebuda site probably utilized manure for disposal of cattle manure from near by animal feedlot. The 5-10 cm depth soil P levels were also higher compared to the control (check) at the Haskell site, indicating some vertical mobility of the applied P to lower depths.

The significance of the results is that soil is enriched with P within few years after manure application. In landscapes that are susceptible to erosion, the P enriched soil can be a significant source of P in runoff from fields. Based on the soil test and climate factors, the expected level of erosion is reported below in preliminary GLEAMS modeling.

### Preliminary model prediction

The GLEAMS simulation for the Haskell and Nebuda sites were done for 20 years. The model simulation was responsive to the P stratification, indicating that the model was sensitive to soil P stratification of the top 5 cm. The model assumes the top 1 cm as the active erosion layer, where P and water interactions occurs the most. However the depth of sampling for this study was surface 5 cm of active layer where most of the P was present and erosion occurred. The simulation was done for ortho P in runoff, sediment ortho P, and sediment organic P. The simulation was then compared to the check or control at the Haskell site and for the Nebuda site compared to the unmanured Roeppert site.



For the Haskell site, runoff ortho P, sediment ortho P, and sediment organic P were high compared to the unmanured check (Fig. 6). However, the most significant loss from the Haskell site was the sediment associated organic P. Although the organic P is not immediately available for the growth of biological organisms in surface water, it is a potentially available source in the short and long-terms. Cattle manure also resulted in higher runoff ortho P and sediment ortho P compared to swine manure. This is associated with inherently high level of P in cattle manure compared to swine manure (Table 2). The results at the Nebuda site were similar to the Haskell site. Compared to the unmanured Roeppert site, there was larger loss of runoff ortho P, sediment ortho P, and especially sediment organic P (Fig. 7).

Following this preliminary simulation, sensitivity analyses will be done on the Haskell site to assess the reliability of model predictions. Additionally, various management scenarios will be used to assess the magnitude of P loss or the reduction of P losses.

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Table 1. Major field operations at Haskell Site, Concord, NE

Activities	DOY	Date and Description
<b><u>1999</u></b>		
Spring manure and tillage	90	31 Mar -1 Apr; swine 56 m <sup>3</sup> ha <sup>-1</sup> ; Cattle 78.4 Mg ha <sup>-1</sup> , disked
Field cultivate and planting	120	30 Apr., 54000 seeds ha <sup>-1</sup>
Field cultivation	165	14 June; field cultivation on all plots
Harvesting	277	4 Oct.; corn residue left in the field
Autumn manure applied	319	15-16 Nov.; Swine 12 m <sup>3</sup> ha <sup>-1</sup> ; Cattle 78 Mg ha <sup>-1</sup>
Autumn tillage	320	16-17 Nov.; Disked the manure plots
<b><u>2000</u></b>		
Spring tillage	110	26 Apr.; Pre-plant cultivation on all field
Corn planting	122	1 May; 54000 seeds ha <sup>-1</sup>
Corn harvest	251	7 Sep.
<b><u>2001</u></b>		
Cattle manure and tillage	109	19 - 20 Apr.; Manure application followed by disking
Swine manure and tillage	117	27 and 28 Apr.; Manure application followed by disking
Field cultivation	129	9 May; pre-plant cultivation on all plots
Corn planting	130	10 May; 54000 seeds kg ha <sup>-1</sup>
Corn harvest	263	20 Sep.
Cattle manure and tillage	312	8 Nov, 76 Mg ha <sup>-1</sup> , disked
Swine manure and tillage	319	15-16 Nov, 43 m <sup>3</sup> ha <sup>-1</sup> , disked
<b><u>2002</u></b>		
Spring tillage & Planting	136	16 May, Disking
Soil Sampling	137	17 May, needed for model calibration
Harvest	254	11 September

Table 2. Analysis of beef cattle and swine manure applied annually at the Haskell site.

Element†	Cattle manure‡			Swine manure		
	1999	2000	2001	1999	2000	2001
Organic N (g kg <sup>-1</sup> or g L <sup>-1</sup> )	8.53 ± 0.61	7.10 ± 0.82	5.8 ± 0.28	4.20 ± 0.34	3.46 ± 0.05	1.32 ± 0.02
NH <sub>4</sub> -N (g kg <sup>-1</sup> or g L <sup>-1</sup> )	2.18 ± 0.30	0.22 ± 0.03	0.49 ± 0.11	3.08 ± 0.03	3.22 ± 0.17	2.53 ± 0.01
NO <sub>3</sub> -N (g kg <sup>-1</sup> or g L <sup>-1</sup> )	8.58 ± 1.17	409 ± 120	323 ± 87	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.61
Total N (g kg <sup>-1</sup> or g L <sup>-1</sup> )	10.7 ± 0.87	7.72 ± 0.76	6.61 ± 0.43	7.29 ± 0.38	6.69 ± 0.20	3.86 ± 0.02
P (g kg <sup>-1</sup> or g L <sup>-1</sup> )	3.69 ± 0.33	3.62 ± 0.33	3.47 ± 0.62	1.47 ± 0.16	1.39 ± 0.70	0.66 ± 0.02

†the unit is mass for beef cattle manure, and mass per volume for the swine manure.

‡Manure applied in Mar. 1999, Nov. 1999, and Apr. 2001 for the growing season of 199, 2000, and 2001, respectively. Values following + are standard errors.

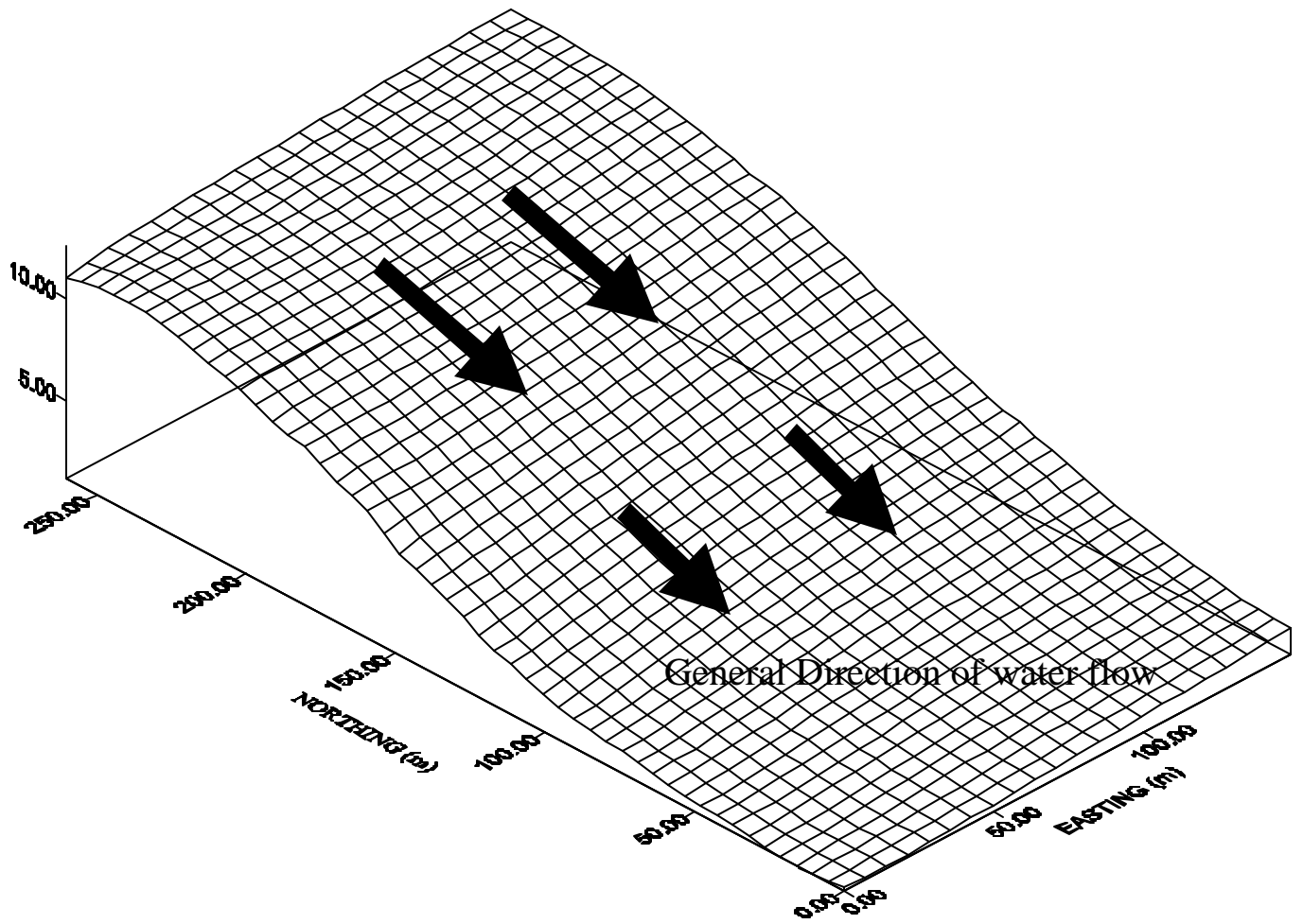


Fig. 1- Haskell field site landscape.



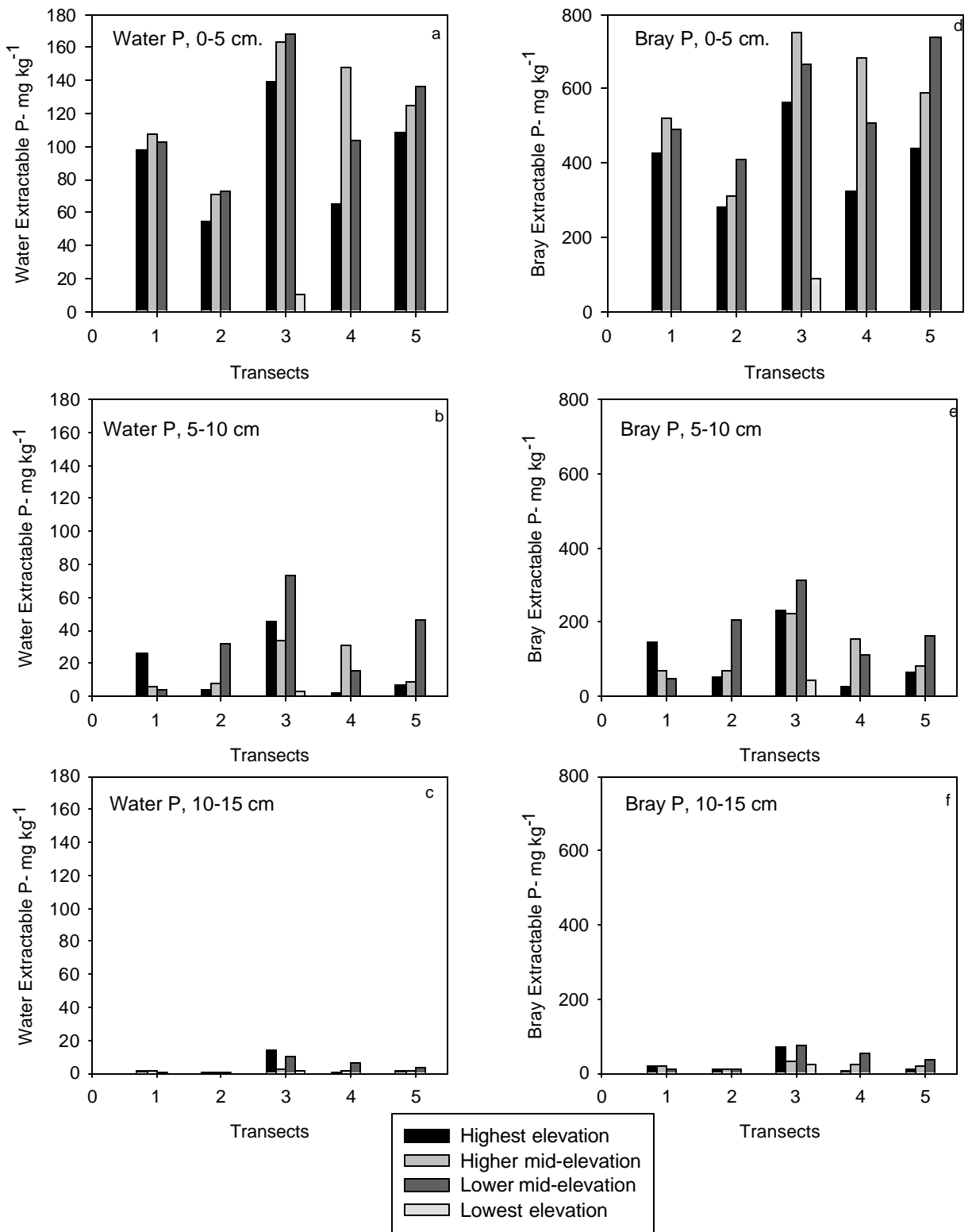


Fig. 3 Water and Bray Extractable P at the Nebuda site at depths of 0-5 cm, 5-10 cm, and 10-15 cm.

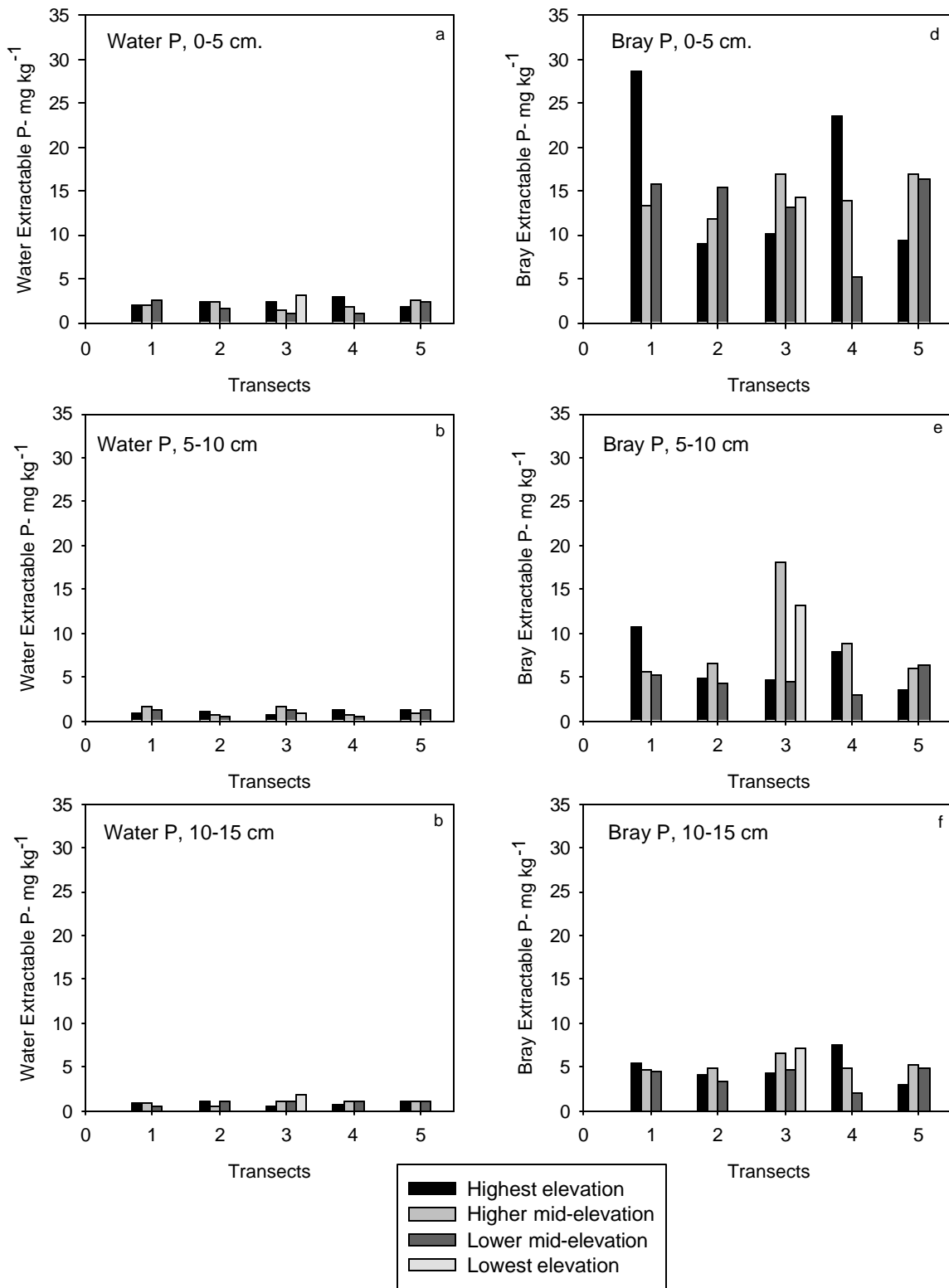


Fig. 4 Water and Bray Extractable P at the Roeppert site at depths of 0-5 cm, 5-10 cm, and 10-15 cm.



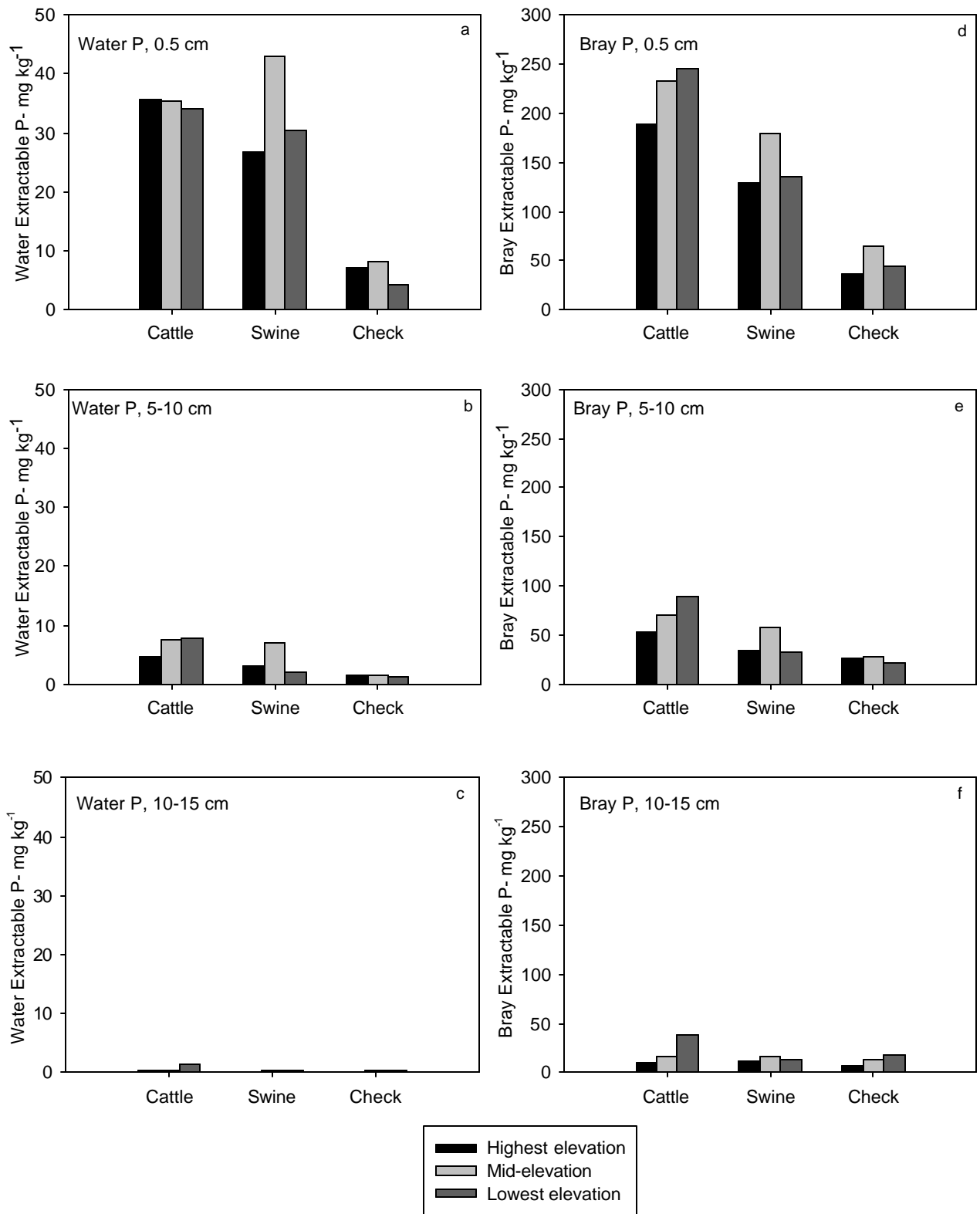


Fig. 5 Water and Bray Extractable P at the Haskell site at depths of 0-5 cm, 5-10 cm, and 10-15 cm.

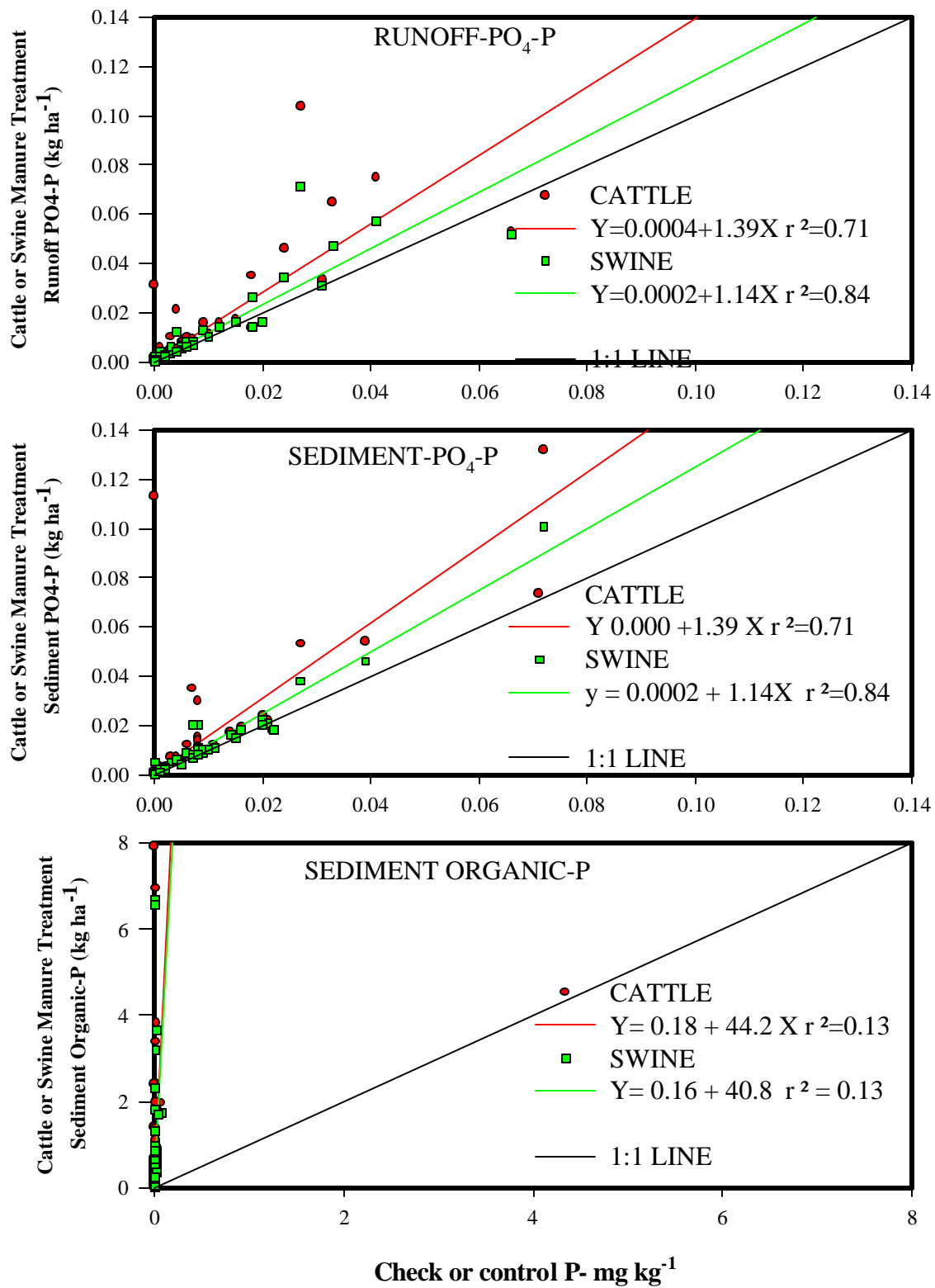


Fig. 6 GLEAMS simulations of runoff ortho P, sediment ortho P, and sediment organic P of manure and check plots over a twenty year period at Haskell.

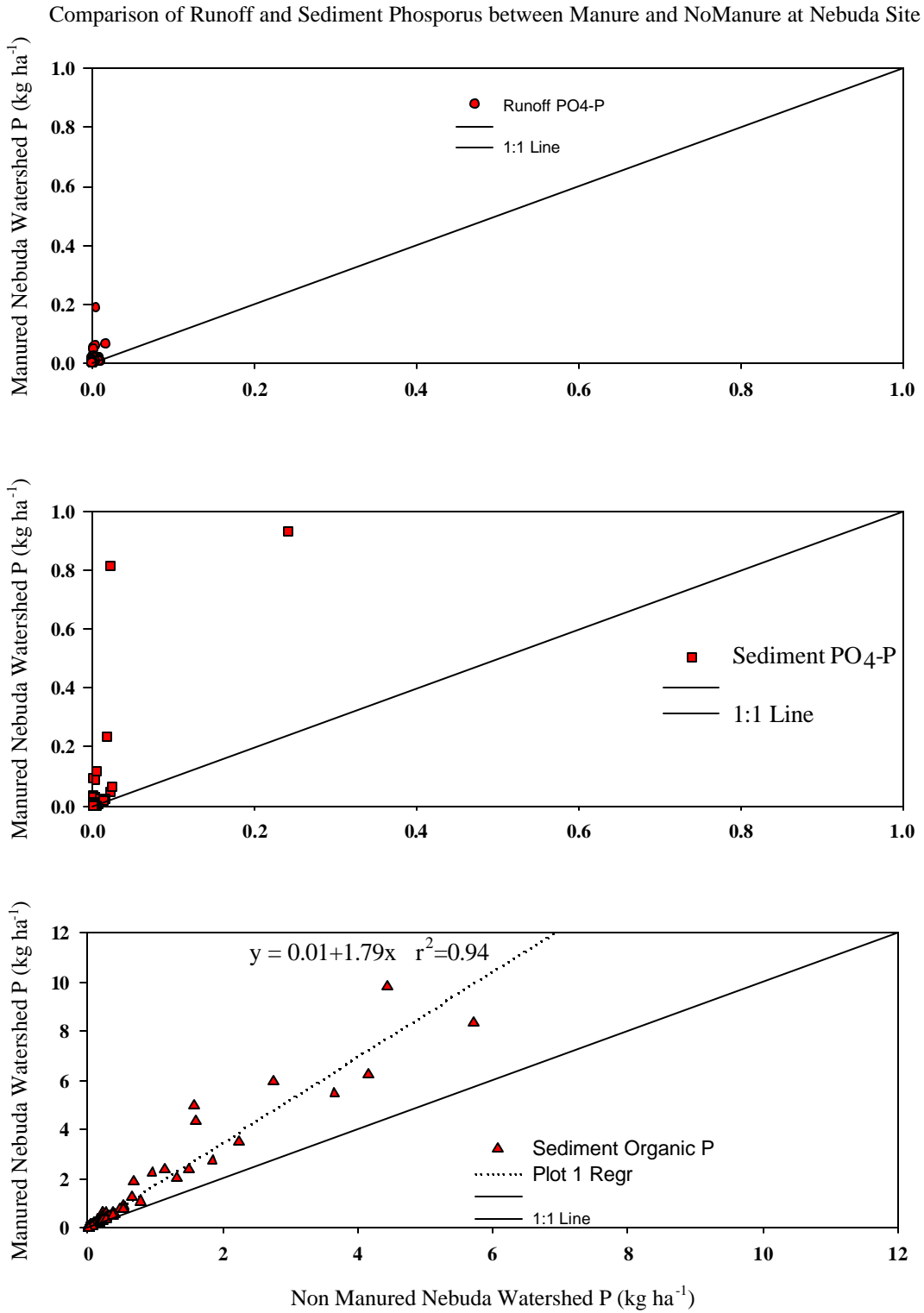


Fig. 7 GLEAMS simulations of runoff ortho P, sediment ortho P, and sediment organic P of manured Nebuda and unmanured Roeffert sites over a twenty year period.

# ASSESSMENT OF THERMAL-INFRARED IMAGING AS A TOOL FOR EVALUATION OF GROUNDWATER-LAKE INTERACTIONS IN THE NEBRASKA SAND HILLS

## Basic Information

<b>Title:</b>	ASSESSMENT OF THERMAL-INFRARED IMAGING AS A TOOL FOR EVALUATION OF GROUNDWATER-LAKE INTERACTIONS IN THE NEBRASKA SAND HILLS
<b>Project Number:</b>	2002NE9B
<b>Start Date:</b>	4/1/2002
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<b>Funding Source:</b>	104B
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<b>Research Category:</b>	Climate and Hydrologic Processes
<b>Focus Category:</b>	Methods, Surface Water, Groundwater
<b>Descriptors:</b>	remote sensing, thermal infrared (TIR) techniques,, lakes, surface water-groundwater interactions, recharge
<b>Principal Investigators:</b>	Vitaly A. Zlotnik, David C. Gosselin, Geoffrey M. Henebry, Donald C. Rundquist

## Publication

1. Tcherepanov, E.N., and V.A. Zlotnik, 2002. Applications of remote sensing for hydrological studies in the Nebraska Sandhills, in GSA Abstracts with Program, Denver, Colorado, October 27-31, 2002, p. 88.

## **ASSESSMENT OF THERMAL-INFRARED IMAGING AS A TOOL FOR EVALUATION OF GROUNDWATER-LAKE INTERACTIONS IN THE NEBRASKA SAND HILLS**

**Statement of Critical Regional or State Water Problem.** Many studies dealt with the Sand Hills lakes hydrology over the last decade. However, little is known about water exchange between the lakes and the aquifer in the context of the complete hydrologic system. Therefore, it is critical to investigate and expand the potential of innovative large-scale methodologies for studies of the Sand Hills hydrologic system.

**Nature, Scope, and Objectives of the Project.** There is a large body of theoretical and field investigations that indicates that localities of the groundwater recharge zones in lakes may be relatively conservative in space and in time. To a large degree the water-table configuration determines the presence of near-shore zones of this recharge (Winter, 1986). Previously, detection of such zones was based on inference of the hydraulic head gradients from network of observation wells in the vicinity of individual lake(s) (LaBaugh, 1986). This approach assumes availability of vast network of piezometer clusters that provide a fine resolution of head distribution in vertical and horizontal directions. In the Sand Hills, a very sparse network of wells is available, and potential of delineation of the water-exchange zones is limited.

The project exploited an idea of using temperature differences between groundwater and surface water in the Sand Hills lakes to delineate zones of extensive groundwater-surface water exchanges. The groundwater temperature is relatively stable, while the temperatures of the surface water are affected by diurnal and seasonal fluctuations due to several mechanisms. Analysis of the areal temperature patterns of the surface water is based on a search of anomalies that include zones of elevated or reduced temperatures compared with the ambient temperature. Groundwater discharge to the Sand Hills lakes may be manifested by zones of reduced temperatures in summer months, while zones of warmer temperatures are expected in winter months.

The general objective of this study was to evaluate thermal-infrared imaging as a tool for characterizing groundwater-surface water interactions between the lakes and the shallow aquifer of the Nebraska Sand Hills. The specific objectives were as follows:

- Collect and process data on surface temperatures for several lakes using TIR imaging to identify zones of active groundwater-surface water exchange and their orientation with respect to the regional flow;
- Collect data on the distribution of lake surface temperatures using ground methods and compare with remotely sensed TIR data;
- Compare results with previously collected remote sensing TIR data from several lakes;
- Assess the potential of the technique for upscaling data of groundwater-surface water interactions to a larger numbers of lakes and areas in the Nebraska Sand Hills

**Related Research.** In case of lakes that are strongly interconnected with the groundwater, the localized temperature anomalies of the surface water body may be affected by the water and heat exchange with the groundwater. Factors that affect this balance can be divided into water mixing (currents, wind speed and consistency, surface body depth) and heat transfer (solar radiation etc.). In addition, these factors may vary with seasonally and diurnally. For example, in case of rapid water currents, the insufficient contrast between the temperatures of the groundwater and surface water coupled with intensive mixing can obscure inflow of warmer or cooler water into the recharge zone that makes detection of groundwater recharge unfeasible. More quantitative approach can be affected by heat conduction, wind effects, thermal boundary layer effects and stratification during different seasons and times of day (LeDrew and Franklin, 1985; Torgersen et al., 2001).

Rundquist et al. (1985) pioneered the idea of using the TIR remote sensing for qualitative analysis of hydrology of flow-through lakes. They singled out four lakes in the Sand Hills with greater potential for inference of the zones of intensive groundwater seepage. Data from thermal-infrared multi-spectral (TIMS) airborne scanner in 8.2-12.2 micron range were obtained in 1983 and 1984 from NASA National

Space Technology Laboratory (NSTL) missions in Nebraska. Using channel with 8.2-8.6 micron, Rundquist et al. (1985) detected the thermal variability and possible groundwater discharge zones to these lakes. This study demonstrated feasibility of hydrologic inference from remote sensing data. Later TIR remote sensing was used in freshwater lakes to map surface temperature and circulation patterns (LeDrew and Franklin, 1985; Anderson et al., 1995; Garrett and Hayes, 1997).

Over the last decade, new technological capabilities of TIR remote sensing emerged that permit applications commonly available airborne platforms (small commercial planes and helicopters) instead of special NASA missions. These capabilities include commercially available TIR cameras (e.g., Thermacam™) operating in ranges 3-5 and 8-12 micron. Data collection of approximately 250 linear kilometers of continuous imaging can be accomplished with a budget of approximately \$20/km when and where the appropriate infrastructure is available (McKenna, 2000).

The latest applications of TIR techniques include delineation of groundwater recharge to estuaries, stream temperatures due to groundwater recharge, surface temperatures and circulation patterns in lakes, land environmental effects of urban development in various climatic zones.

McKenna et al. (2001) applied TIR technique combining the ground-, aerial-, and satellite (LANDSAT 7, thermal band) imagery for delineation of groundwater discharge to the Rehoboth and Indian River bays, Delaware. Roseen et al. (2001) assessed the nutrient loading in the Great Bay estuary, New Hampshire using comparison of aerial methods with hydrogeological field measurements (piezometric mapping).

Recently, extensive studies of stream temperatures were carried out in Oregon (Torgersen et al., 2001) and Washington (Naveh et al., 2001, Handcock et al., 2001). Unlike in estuaries, lakes, or on the land surface, the length of surveyed areas (tens of kilometers) greatly exceeded the width (100 m) of the surveyed corridors along the streams. Therefore, the TIR remote sensing on the stream temperatures became the only feasible approach.

However, lake studies in the Sand Hills have seen limited applications of TIR techniques recently, and potential of these techniques needs assessment of these conditions.

**Methods and Results.** In search of large-scale approaches, we investigated if methods of satellite data collection and analysis have the potential for detection of groundwater discharge to the lakes in the Sand Hills area. This pilot study had a qualitative nature and attempted to find any manifestations of this discharge and to explore techniques that are valid for the Sand Hills conditions.

*Direct temperature measurements.* Lake temperatures were measured in three Sand Hills lakes (Crescent, Island, and Blue lakes) during four field surveys in summer 2002 using digital thermometer. Data were collected at 20-60 locations at each lake, depending on lake area. Measurements were made from the lake surface to the bottom with 20-cm depth increments. Resulting three-dimensional temperature distributions in the lakes allowed to locate zones of anomalously cooler water during summer season. These zones were considered as potential zones of groundwater discharge.

Relationship between thermal lake regime and weather conditions (air temperature and wind speed) was studied using submersible data loggers over several weeks with 30-minute measurement interval. Weather data (air temperature and wind speed) were obtained from online data bank of High Plains Regional Climate Center (HPRCC). Data loggers were installed in different parts of the lakes with different suspected magnitude and direction of fluxes between lake and aquifer.

Three types of temperature distribution in the Sand Hills lakes were found: 1) lake mixing as a result of strong wind, when water in a lake is thermally uniform in vertical direction from lake surface to bottom; 2) lake stratification as a result of higher air temperature compared to lake temperature when lake temperature is the highest in the upper layer and becomes lower with depth; 3) isothermal distribution when lake temperature is uniform in vertical direction in the absence of strong wind; this occurs primarily during night-time in summer when the air temperature is lower than lake temperature, and there is no groundwater discharge. Ground-based data allowed to locate zones where groundwater discharge can potentially occur and to study their thermal regime.

*Remote sensing and GIS.* Due to unavailability of the airborne TIR system, we utilized commercially available Landsat data. Satellite imagery was obtained from UNL Center of Advanced Land Management Information Technologies (CALMIT) imagery archive and from the USGS EROS data center. Available 21 Landsat images (satellites Landsat 4, 5, and 7) were taken from 1989 to 2002 in different seasons, mostly in the summer, but also in the fall, spring and winter time. All images were georeferenced. Only the Landsat thermal infrared band (10.40-12.50 microns) was processed and analyzed. Special algorithm was used in ERDAS Imagine software for recalculation of lake surface temperatures from pixel values (digital numbers). Atmospheric conditions were not taken into account, therefore, calculated temperatures were considered as uncorrected. Resulting uncorrected lake temperatures were used to identify patterns of surface temperature distributions in the studied lakes. Spatial resolution of the sensors on the Landsat satellites (60 and 120 m) and also thermal resolution of these sensors (0.4-0.6 °C) allowed to distinguish patterns of relatively cooler water on summer and fall images and patterns of relatively warmer water on winter and spring images. These anomalous zones can be considered as indicators of potential groundwater discharge in the lakes.

To locate zones with consistently anomalous surface temperature, the following technique was applied. All available Landsat images were classified into two groups. The first group included 16 images with “warm season patterns” when groundwater temperature is supposed to be lower than the lake temperature (late spring, summer, and early fall seasons). Zones with cooler water on these images can be considered as the zones of potential groundwater discharge. The second group of 5 images included the “cold season patterns” when groundwater temperature is supposed to be higher than the lake temperature (late fall, winter and early spring seasons). Zones with warmer water on these images can be considered as the zones of potential groundwater discharge.

Each group was analyzed in ArcGIS 8.1 software. The Landsat images were taken in different weather conditions and lake temperatures ranges. Therefore, lake temperatures were normalized as follows:  $T_N = (T - T_{MIN}) / (T_{MAX} - T_{MIN})$ , where  $T_N$  – normalized temperature;  $T$  – uncorrected temperature, calculated for each pixel;  $T_{MIN}$  – minimal uncorrected temperature in the lakes on the image;  $T_{MAX}$  – maximal uncorrected temperature in the lakes. These normalized temperatures ranged from 0 to 1 that made possible to analyze spatially all images together. Different statistics (mean, standard deviation and minimum) were calculated for each pixel location for warm and cold season images. This resulted in finding of several anomalous zones in each lake that can be considered as the potential zones of groundwater discharge. Future studies should include direct measurements of groundwater-lake water exchange across the lakebeds.

**Major Findings.** Thermal infrared imaging was assessed for evaluation of groundwater-surface water interactions by comparing satellite (Landsat) images with ground-based temperature data. Detailed three-dimensional temperature distributions for several Sand Hills lakes were obtained from ground-based studies for summer time and anomalous thermal zones were located. In these zones lake water is generally cooler and they can be considered as groundwater discharge zones. Dependence of thermal regime of the lakes on weather conditions was studied and three principal types of thermal distributions in the Sand Hills lakes were distinguished (lake mixing, lake stratification and isothermal vertical distribution). Numerous Landsat thermal infrared images were processed and analyzed, and lake temperature patterns were studied. Spatial analysis of thermal infrared images in ArcGIS allowed to identify zones in the lakes where lake water was consistently cooler during warm season. These zones which are considered as the potential zones of groundwater discharge are generally located in the same parts of the lakes as the zones which were found after field-based surveys. These data refined findings from TIMS surveys of the summer thermal lakes patterns obtained in 1983-1984. Therefore, thermal infrared remote sensing has a potential for identification of the groundwater discharge zones in the shallow groundwater-fed Sand Hills lakes.

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# Assessment of Source of Variation in Copper Concentrations in Nebraska Drinking Water Systems

## Basic Information

<b>Title:</b>	Assessment of Source of Variation in Copper Concentrations in Nebraska Drinking Water Systems
<b>Project Number:</b>	2002NE12B
<b>Start Date:</b>	3/1/2002
<b>End Date:</b>	2/28/2003
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	1
<b>Research Category:</b>	Not Applicable
<b>Focus Category:</b>	Water Quality, Treatment, Water Supply
<b>Descriptors:</b>	
<b>Principal Investigators:</b>	Bruce I Dvorak, Matthew C Morley

## Publication

# Title: Assessment of Source of Variation in Copper Concentrations in Nebraska Drinking Water Systems

## **RESEARCH**

### **Problem and Research Objectives:**

Copper is a commonly used material for water distribution piping. Although it is fairly resistant to corrosion, copper piping may corrode under some conditions, resulting in elevated copper concentrations in drinking water. In response to potential for adverse health effects at high concentrations, the EPA has established an action level of 1.3 mg/L for copper in drinking water (USEPA, 2000). The action level is the 90% percentile value for the samples collected. Because the primary source of copper in drinking water is corrosion of plumbing materials, the EPA requires treatment for corrosion control as a method for reducing copper concentrations. As of August 2001, a total of 49 drinking water systems in Nebraska exceeded the U.S. EPA's action level for copper in drinking water (NDHHS, 2001). A total of 19 of the systems in violation of the copper standard were below the copper action level in several rounds of samples between 1992 and 1999, but exceeded the action level in a round of testing in the past year. Implementation of the EPA-mandated corrosion control methods will be a significant financial impact on many of these communities.

Many of Nebraska water systems that have excessive copper levels utilize groundwater that has high alkalinity, neutral pH, and low dissolved oxygen. There is little scientific information concerning corrosion of copper by this type of water chemistry (Edwards, 2001; Schock, 2001).

For many waters, a protective scale will form on copper pipe (which significantly reduces copper corrosion) in between 1 day and 50 years, depending on a range of factors (water chemistry, temperature, water use pattern, etc.). In a few cases, a protective scale will never form. If a protective scale layer has not formed on the copper pipes, then a common method of reducing copper corrosion is to add food grade ortho- and polyphosphate inhibitors to the water at the water source. Past research has shown that orthophosphates will help form a protective  $\text{CuPO}_4$  scale layer on the pipe. In all cases found in the literature, orthophosphates reduced copper dissolution. On the other hand, polyphosphates have been found to make copper corrosion worse.

The reason polyphosphates are often added to drinking waters is to sequester dissolved iron and manganese. In Nebraska this occurs with some high alkalinity, neutral pH, high TDS waters. Dissolved iron and manganese (in anoxic ground waters) can be oxidized in the home or distribution system by dissolved oxygen and/or chlorine and form precipitates that are observed as red or black water (and lead to staining of fixtures). The sequestering agents, such as ortho and polyphosphates, can change the iron and manganese precipitates so they form smaller, more stable particles, that result in less observed color and staining of fixtures. Past research has shown that polyphosphates are better sequestering agents than orthophosphates, but high orthophosphate concentrations can also be effective for sequestering. Also, polyphosphate will convert over time to orthophosphates in the water distribution system.

Edwards of Virginia Tech suggested in a 1999 publication a conceptual model of impact of polyphosphates on copper corrosion concentrations:  $Cu \text{ increase} = [\text{Poly PO}_4] / ([\text{total PO}_4])$   
Too much polyphosphates in a phosphate blend negate ability of orthophosphates to form a protective  $CuPO_4$  film.

Although some phosphate vendors are very knowledgeable, many vendors are not very knowledgeable and Nebraska communities have been sold phosphate blends that are not optimal for their water chemistry. This project is focused on providing scientific data and a conceptual model to help water utilities better select phosphate blends for copper corrosion control.

Based on the initial findings of this project related to scale layers and interactions with small community water suppliers, this study has slightly redirected focus toward impact of phosphate inhibitors on variations in copper concentrations.

This study is funded by funds from three sources: USGS 104 program, Nebraska Section of the American Water Works Association (AWWA), and the Nebraska Department of Health and Human Services System (NE HHSS). Not all of the non-USGS funds are listed as an official match to the USGS 104 grant. The USGS funds have been used to pay for the initial portions of the project and the AWWA and NE HHSS funds will be used to complete the project.

The basic research objectives are to:

1. Study a range of pipe scales from Nebraska public water supplies using a scanning electron microscope to characterize the copper corrosion phenomenon.
2. Identify the minimum ortho- and polyphosphate concentrations required to sequester iron and manganese in waters typically of Nebraska ground waters.
3. Examine the rate of polyphosphate conversion to orthophosphate in waters typically of Nebraska ground waters.
4. Study the impact of different mixtures of ortho- and polyphosphate concentration on copper dissolution in waters typically of Nebraska ground waters.
5. Develop a model to suggest the impact of ortho- and polyphosphate on copper corrosion in real drinking waters with high alkalinity and a neutral pH.

## **Methodology:**

The basic methods for this project are listed below for the three portions.

### **Phase I. Understanding implications of different PO<sub>4</sub> mixtures on Fe and Mn sequestering.**

Collect copper pipe samples from at least three public water supplies in Nebraska and study these using a scanning electron microscope.

### **Phase II. Understanding implications of different PO<sub>4</sub> mixtures on Fe and Mn sequestering.**

Objective: perform “jar” tests to determine for three to four Nebraska waters the effect of different concentrations sequestering agents (different polyphosphates, orthophosphate, no treatment) on sequestering dissolved Fe & Mn. This information is useful to help utilities determine an approximate minimum polyphosphate dose required for sequestering.

Assumptions: Free Cl residual of 0.5 mg/L required at end of test period and test period of 24 hours.

Data collected: Basic water quality information, Fe, Mn (before and after sequestering agents), and free chlorine.

Values to Water Science: Information concerning reasonable trends concerning minimum sequestering agent concentrations for use in phosphate blends. Field confirmation of Darren Lytle’s theoretical work related to phosphate concentrations required for sequestering

### **Phase III. Impact of different Phosphate blends on typical Nebraska water chemistries.**

Objective: perform pipe rig study on two communities, each for three months, to test six different phosphate mixtures. These studies will test the blends only on new copper pipes. The results from Phase II were used to select the blend concentrations. Orthophosphate and polyphosphate chemicals were used that were purchased from chemical suppliers and are not proprietary blends.

Data collected: Basic water quality information, free chlorine, copper (both particulate and dissolved), PO<sub>4</sub> concentrations. Analysis of pipe scales at end of study.

Values to Water Science: Information concerning reasonable copper trends concerning results from typical phosphate blends. Field confirmation of Marc Edward’s conceptual phosphate model and experimental work on synthetic waters.

#### **Basic Work Plan:**

1. A bench-scale apparatus has been constructed for the copper corrosion method testing. The apparatus allows six phosphate blends and the untreated water to be tested on a side-by-side basis. Chlorine was added to the water since state regulations require chlorination when phosphates are added to a drinking water since phosphates can accelerate microbial regrowth in a water distribution system. The concentrations are listed below; the phosphate concentrations are in mg/L as phosphate and the chlorine is mg/L total chlorine.

Pipe Number	Orthophosphate	Polyphosphate	Chlorine
1	0	0	0
2	2.0	0	0.6
3	0.7	0	0.6
4	0.3	0.3	0.6
5	0.7	0.7	0.6
6	1.3	0.3	0.6
7	1.3	0.7	0.6

For each corrosion control method, the drinking water has the corrosion control chemicals added to the water and then will flow through the apparatus (including the new copper pipe). Approximately 200 gallons of water will flow through each circuit each day. A flow rate of 1 gallon per minute will be passed through each pipe.

2. The apparatus is monitored for a total of 3 months for each of the two studies. The first study is occurring in Waverly, NE from May 6 to August 6, 2003. Negations are on-going to have the second study at Mahoney State Park in August through October 2003.
3. The source water for the apparatus is also monitoring and sampling on a regular basis. Water samples will be analyzed for copper and other common water quality parameters related to copper corrosion in order to determine the best method for copper corrosion control.

### Proposed Project Timeline

Task	June	July	Aug.	Sept.	Oct.	Nov/Dec
<b>Pipe Scale Analysis</b>						
Analyze scale on pipes from other communities (Finished)						
Analyze scale on pipes from apparatus						
<b>Jar Tests to evaluate Fe/Mn Sequestering Abilities</b>						
Communities: Sequestering Study to determine reasonable min. Polyphosphate. Dose for Fe / Mn						
<b>Copper Pipe Rig Studies at Two Communities near Lincoln</b>						
Operate Pipe Rig Apparatus in Waverly for 3 months						
Operate Pipe Rig Apparatus on nearby water supply with higher Fe/Mn						
Analyze scale on pipes (before PO <sub>4</sub> used and 6 mo. after)						

<b>Reporting and Dissemination of Information</b>						
Data Analysis						
Final Report						

## **Principle Findings and Significance**

This project is schedule to be completed in December of 2003. There are six preliminary findings at time are as follows.

1. Polyphosphates increase copper corrosion in high alkalinity, neutral pH water found in Nebraska. Polyphosphates are added to the water to sequester iron and manganese.
2. Polyphosphates aggressively remove existing scale layers and can actually increase copper corrosion.
3. Orthophosphates decrease copper corrosion in high alkalinity, neutral pH water found in Nebraska.
4. Orthophosphate concentrations often used for copper corrosion are sufficiently high to provide iron and manganese sequestering for the needs of many communities.
5. Polyphosphates convert to orthophosphates rapidly in high alkalinity, neutral pH water found in Nebraska.
6. Most communities will want to just use orthophosphates without polyphosphates to control copper corrosion.

## **Publications**

None

## **Information Transfer Program**

The results of this study will be disseminated three ways. The results of this work are scheduled to be presented at two regional conferences (Nebraska Section of the American Water Works Association and the Nebraska Rural Water Association). The result will be presented a National Conference (such as the 2004 American Water Works Association Annual Conference) and will be condensed into a journal article in order to include the results of this study in the archival literature.

## **Student Support**

This project was an excellent opportunity for students with a technical background to expand their understanding of social and regulatory issues associated with the drinking water industry. In contrast to many research projects which provide students with an in-depth knowledge of an obscure technical process or model, this project required students to work with regulatory and community water system personnel, and to integrate their technical background into a broader experience with small communities. At the same time, the required data collection and analysis, and the laboratory work associated with the water analyses dictated that the student maintain and further develop strong technical and analytical skills.

Two students were employed on this project, a graduate research assistant (Ms. Junling Qiu) and an under-graduate research assistant (Ms. Gina Rust). Ms. Qiu was a graduate student in the

Environmental Engineering program and Ms. Rust was an undergraduate in Civil Engineering. This project was the basis of a Master of Science thesis for Ms. Qiu.

Section 104			
	Base Grant	RCGP Awards	TOTAL
Undergrad	1		1
Masters	1		1
Total	2		2

**Notable Achievements**

# Evaluation of Conductive Properties of the Surficial Aquifer in the Nebraska Sand Hills

## Basic Information

<b>Title:</b>	Evaluation of Conductive Properties of the Surficial Aquifer in the Nebraska Sand Hills
<b>Project Number:</b>	2001NE2461B
<b>Start Date:</b>	3/1/2001
<b>End Date:</b>	8/30/2002
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	1
<b>Research Category:</b>	Ground-water Flow and Transport
<b>Focus Category:</b>	Groundwater, Methods, Geomorphological Processes
<b>Descriptors:</b>	hydraulic, conductivity, air, permeameter, eolian, sediments, Dunes
<b>Principal Investigators:</b>	Vitaly A. Zlotnik, David B. Loope, Joseph A. Mason

## Publication

1. Goss, D., and V.A. Zlotnik, 2000, Field investigations of portable air permeameters for subsurface measurements, in GSA Abstracts with Programs, Reno, Nevada, Nov. 9-18, p. A360



# EVALUATION OF CONDUCTIVE PROPERTIES OF THE SURFICIAL AQUIFER IN THE NEBRASKA SAND HILLS

## Problem and Research Objectives

Hydraulic properties of the aquifer underlying the Nebraska Sand Hills control water availability and quality in an area of 50,000 km<sup>2</sup> (Figure 1). The Sand Hills is one of the largest grass-stabilized dune fields in the world (Ahlbrandt et al., 1980, Loope and Swinehart, 2000). Deposited by eolian processes, this dune field serves as a water buffer that preserves precipitation and conveys a part of it to the underlying alluvial sand, gravel, and silt, and further to the High Plains aquifer (Ogallala formation). Hydraulic conductivity is the major property of this buffer that controls groundwater recharge. However, surprisingly little is known about the hydraulic conductivity of this area (Keen, 1992, Gosselin et al., 1999) in spite of the significance for water resources of Nebraska, the High Plains aquifer, and wetlands protection.

Therefore, it is important to develop a field methodology for measurements of hydraulic conductivity in the Sand Hills in unsaturated conditions and to provide the field data needed for evaluation of water resources and water quality of the region. The scope of this work is three-fold:

1. Development of new methodology for estimation of permeability by air injection (equipment, procedures, and data interpretation)
2. Evaluation of hydraulic conductivity in characteristic dune areas and analysis of spatial patterns of eolian sediments (shallow aquifer) of the Nebraska Sand Hills
3. Validation of the methodology by comparing data with previously collected data in the area.

## General Approach

Measurements of hydraulic conductivity  $K$  in unconsolidated sediments for aquifer characterization are based commonly on a range of methods (Zlotnik et al., 2000). The most common group of methods - hydraulic testing – involves water injection into or withdrawal from the aquifers below the water table. Difficulty of this approach in the dune environment of the Nebraska Sand Hills lies in several factors: large depth to the water table, high variability of this depth due to the dune relief, significant quantities of water required for injection in a relatively highly permeable formation, and inaccessibility of the area for standard drilling and testing equipment.

Analysis of permeability for assessment of hydraulic conductivity was used for older consolidated sediments of eolian origin (Goggin et al., 1988a) or alluvial sands (Dreyer et al., 1990). Evaluation of permeability as a proxy for hydraulic conductivity has many advantages for unconsolidated sand of the modern sand dunes and surficial aquifers in the Nebraska Sand Hills. Use of the air injection eliminates difficulties of operating with large volumes of water in difficult terrain conditions. This approach requires development of several components: instruments, field methodology, and data interpretation. Use of air received significant attention mainly in laboratory (Sharp et al., 1994, Tidwell and Wilson, 1997) and in some field investigations (Davis et al., 1994). However, the instruments were designed for use in outcrops of the aquifers with different degrees of consolidation or with laboratory rock slabs only that limited spatial analysis of  $k$  heterogeneity.

Evaluation of permeability by air injection avoided the drilling or use of subsurface probes at depths from the surface. In contrast, recent developments in remediation methodology address the subsurface testing (when measurements are performed at depth from the surface), but the methodology requires installation of permanent wells (Baer and Hult, 1991). The direct push method for delivery of the screen to different depths became common in aquifer hydraulic testing (Butler et al., 2001), however its applications for air testing has not been reported yet.

We also took advantage of an important sedimentary feature of eolian dunes, i.e. relative vertical consistency of the dune lithology. The grain size characteristics of dune sediments vary only slightly over large thickness. After investigation of the hydraulic properties of sand dunes one can extrapolate data collected in the unsaturated zone (above the water table) to the larger depth (including saturated conditions). In this approach, one measures permeability  $k$  of formation, which is in a relatively simple relationship to the hydraulic conductivity  $K$ .

## Methods and Procedures

The laboratory studies lead to a development of the air permeameter that could be applied at depths ranging from few cm to 1.5 m. All previously proposed air permeameters are based on developing a steady-state air mass flow rates and pressure head. Use of previously published design (Davis et al., 1994, Sharp et al., 1994) was not robust enough in field conditions due to a significant size needed to store and supply the steady air flow and necessity of relatively prolonged injection. To provide sufficient air supply and accurate interpretation of relationship between the air mass flux relationship, a new design was proposed. Schematic diagram of the air permeameter is shown in Figure 2. This permeameter includes the subsurface and the ground components. The subsurface component consists of a steel pipe of 2.8 cm diameter fitted with a short screen (8.8 cm long). This pipe can be driven to the tested depth. The ground component involves the air mass flowmeter for measurements of the mass flow rate  $Q$ , pressure transducer for measurements of the injected air pressure  $P$ , and thermometer. Together with the screen depth, these characteristics are used for estimation of permeability of the formation zone that is adjacent to the screen.

Theoretical studies included derivation of the formula for permeability estimates. In steady-state regime, the permeability  $k$  can be estimated from a simple equation

$$k=fQ/P,$$

where  $f$  is a shape factor for the particular configuration of the device (Goss and Zlotnik, 2000). Shape factor for this instrument was derived by generalization of previous studies of the air permeameter (Tartakovsky et al., 2000, Goggin et al., 1988 b, Zlotnik, 1994). Analysis of the quasi-linear airflow in the system was reduced to a solution of the boundary value problem for the Laplace equation in uniform media. Hydraulic conductivity  $K$  is related to the formation permeability by relationship  $K = k\rho g / \mu$ , where  $\rho$  is water density,  $\mu$  is dynamic viscosity, and  $g=9.81 \text{ m/s}^2$  (Freeze and Cherry, 1979). The parameter  $\mu$  is temperature dependent; and this was taken into account in the process of field data collection (see Ronan et al., 1998) and calculation of the factor  $f$ . The viscosity of water in the conversion of  $k$  to  $K$  was taken to have the value characteristic of the mean annual temperature (20 °C) of the ground at the latitude of the site. The pressure sensor was calibrated in the laboratory by direct comparison with water manometer.

At the stage of field studies, the characteristic site locations for air permeameter applications were identified. Considering limited resources, these studies emphasized the

collection of permeability data at morphologically different locations at one representative dune (schematic cross section on Figure 3).

### Summary

Two modifications of the device (air permeameter) were designed and constructed for use in the near subsurface (at depths up to 1.5 m from ground surface) for use in poorly consolidated sediments. These devices supply air at known pressure and mass flow rate to the subsurface. After selecting the optimal configuration, the guidelines for instrument operation and data interpretation for evaluation of the permeability in the vicinity of the probe were developed.

The permeability  $k$  was estimated by measuring the flow rate  $Q$  and the applied pressure  $P$  for a given geometric configuration. Geometric effects were incorporated by calculation of a shape factor  $f$ . In each test, this pressure was measured using linear relationship  $V$  between voltage across a pressure sensor and pressure  $P$  for a given geometric configuration. The correlation coefficient  $r$  for each site and depth location had a range  $r=0.915-1.00$ , with the most values greater than 0.99.

Systematic measurements were made upon a selected dune location (Gudmundsen Sandhills Lab, University of Nebraska - Lincoln) approximately  $N42^{\circ}4.9'$  and  $W101^{\circ}28.3'$  with a history of episodic vegetative covering in characteristic locations. Measurements of the permeability were performed at five depths between 0.1 m and 1.3 m at 34 distinct locations.

The depth-averaged permeability values of  $k$  and hydraulic conductivity  $K$  may be sorted into distinct ranges according to the dune features at different site locations. The five highest values of  $k = (61.9-72.4)10^{-12} \text{ m}^2$  or  $K=(60.3-70.6) 10^{-5} \text{ m/s}$ , were associated with a step in the dune profile; the 22 lowest values of  $k= (3.3-11.9) 10^{-12} \text{ m}^2$  or  $K=(3.2-11.6) 10^{-5} \text{ m/s}$  were associated primarily with the stoss slope and the compacted steep face of the dune; most of the seven intermediate values of  $k= (12.7-25.5)10^{-12} \text{ m}^2$  or  $K=(12.4-24.9) 10^{-5} \text{ m/s}$  were associated with alluvial fans.

For modern unvegetated dunes, the permeability followed qualitative expectations of being greatest for grainflow and grainfall regions, and smaller for stoss slope ripple strata. For vegetated dunes, there were two sets of permeability found that differed by an order of magnitude; these were located at different identifiable locations and may be related to the form of the dune. Permeability and hydraulic conductivity values obtained were consistent with a few earlier hydraulic conductivity measurements by Sweeney (1999). The later were performed using steady-state water injection in unsaturated zone. More direct investigations of hydraulic conductivity were unavailable due to unavailability of piezometers for well testing.

The permeability of the vegetated dunes is strongly influenced by the existence of vegetation and herbivores. For example, the intermediate to low permeability values on the steep face appear to be the result of compaction of soil in the process of formation of climbing cow trails (catwalks). Low spots on the dune surface are seasonally covered with loose sand ejected from ground squirrel burrows; this fluffy material seems to have a higher permeability than the surroundings.

Sand features due to erosion, transport, and deposition by running water showed systematic variations in permeability according to features. Clay bands (lamellae) decrease the permeability locally and cause it to be anisotropic and moisture dependent. This was verified by

coring a sand location where the permeability was unreasonably low, and finding lamellae at the depth where the permeability was unmeasurable.

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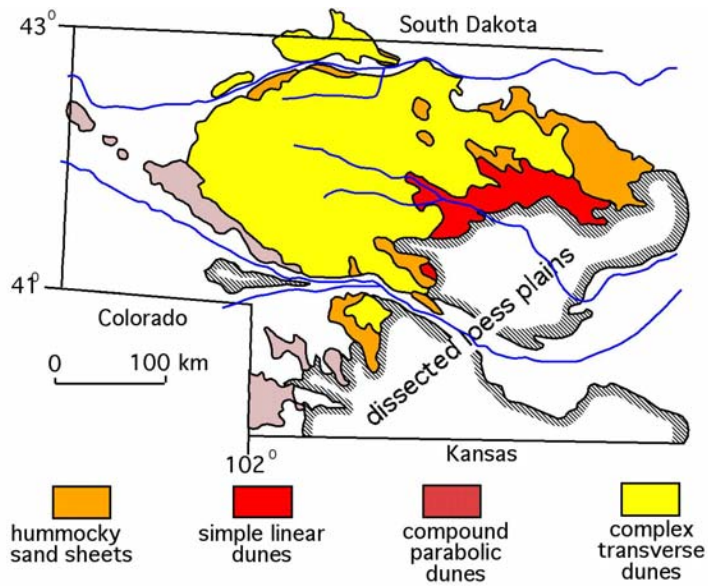


Figure 1. Distribution of wind-blown sediment and dune types in the Nebraska Sand Hills.

Figure 2. Air permeameter for use in sandy aquifer materials.

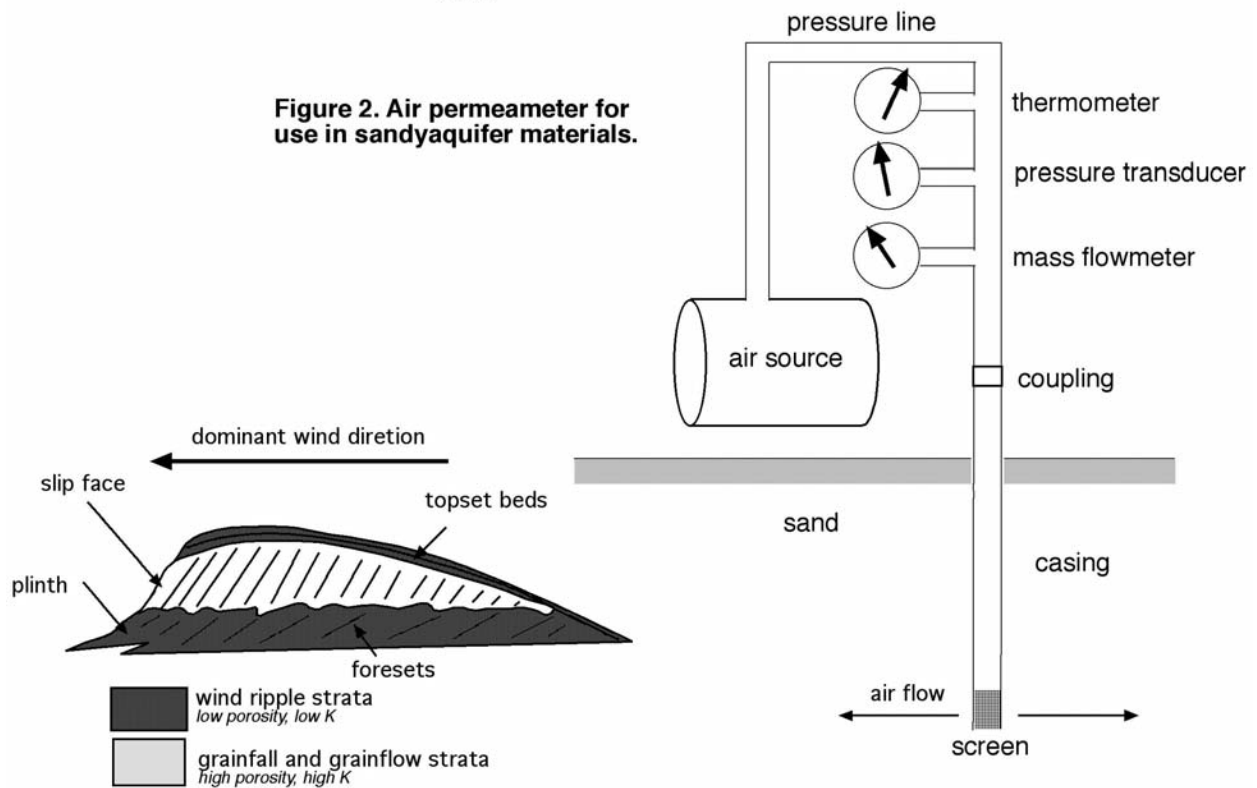


Figure 3. Cross-section of wind-blown sand dune showing distribution of different stratification types

# Investigation of Directional Hydraulic Conductivities of Streambeds and Their Roles in Stream-aquifer Interactions

## Basic Information

<b>Title:</b>	Investigation of Directional Hydraulic Conductivities of Streambeds and Their Roles in Stream-aquifer Interactions
<b>Project Number:</b>	2002NE28B
<b>Start Date:</b>	3/1/2002
<b>End Date:</b>	2/28/2003
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	1
<b>Research Category:</b>	Ground-water Flow and Transport
<b>Focus Category:</b>	Groundwater, Surface Water, Hydrology
<b>Descriptors:</b>	Streambed, Hydraulic Conductivity, Stream-aquifer Interactions
<b>Principal Investigators:</b>	Xun-Hong Chen, James Goeke

## Publication

1. Chen, X.H., 2002. Determination of streambed hydraulic conductivity using extended permeameter methods. American Water Resources Association Annual Summer Conference Ground Water/Surface Water Interactions, July 1-3, 2002, Keystone, Colorado, p. 529-534. Chen, X. H., and Xi. Chen, 2002. Analysis of infiltrated stream water to a pumping well. American Water Resources Association Annual Summer Conference Ground Water/Surface Water Interactions, July 1-3, 2002, Keystone, Colorado, p. 511-516.
2. Chen, X. H., 2003. Analysis of pumping-induced infiltration in gaining streams. *Journal of Hydrology* 275 (1-2), 1-11. Chen, X.H., and X. Chen, 2003. Effects of aquifer anisotropy on the migration of infiltrated stream water to a pumping well. *Journal of Hydrologic Engineering* (in press). Chen, X.H., and Y. Yin, 2003. Semi-analytical solutions for stream depletion in partially penetrating streams. *Ground Water* (in press). Chen, X., and X. H. Chen, 2003. Stream water infiltration, bank storage, and storage zone due to flood stages in channels. *Journal of Hydrology* (in press). Chen, X. H., and L. C. Shu 2003. Streambed hydraulic conductivity for rivers in south-central Nebraska. *Journal of the American Water Resource Association* (in review). Chen, X.H., and X. Chen, 2003. Sensitivity Analysis and Determination of Streambed Leakage and Aquifer Hydraulic Properties. *Journal of Hydrology* (in second review).

### Problem and research objectives:

Problem: Streambed hydraulic conductivities and their roles in stream-aquifer interactions.

Objectives: 1) utilization of permeameter methods for determination of in-situ streambed hydraulic conductivities in Nebraska's key rivers and their tributaries; 2) collection of streambed hydraulic gradients (their upward or downward directions and magnitude) in various river reaches for determination of the losing/gaining river segments; and 3) development of a stream-aquifer model to evaluate the role of streambed hydraulic conductivity in stream-aquifer interactions.

### Methodology:

We developed standpipe methods for measurement of streambed hydraulic conductivities directly in river channels. The standpipes were used to measure streambed hydraulic conductivities along a number of directions over vertical profiles of stream sediments, including vertical, horizontal, and oblique directions. Measurements were conducted in the Platte, Republican, and Little Blues rivers of Nebraska, including 20 transects across the river channels and 198 tests.

This study also includes a modeling activity to analyze the role of streambed hydraulic conductivities in stream-aquifer interactions, particularly the streamflow depletion due to groundwater extraction during irrigation seasons. Semianalytical solutions were developed and MODFLOW and MODPATH of USGS were used for the analysis of stream depletion, bank storage, and the migration of infiltrated stream water to a pumping well.

### Principal findings:

Sandy streambeds commonly occur in the Little Blue River, the Republican River, and the Platte River in south-central Nebraska. Low-permeability silt and clay layers locally occur in the river channels. The vertical hydraulic conductivity ( $K_v$ ) for the top 40-cm sediment of sandy streambeds is usually greater than 20 m/day, and the most common range is from 30 to 40 m/day. It can reach as large as 98 m/day. In contrast, the average  $K_v$  for the silt and mud layer is about 1.5 m/day. Statistical analyses indicated that the  $K_v$  values of sand and gravel in the Platte and Republican rivers have the same mean but the  $K_v$  values from the Little Blue River have a different mean compared to those from the other two rivers.

The sediment of the top 40-cm sand and gravel layers seems to be relatively uniform in grain size by field observation. Nevertheless, anisotropy of streambed conductivity is still determined in it. The ratio of the horizontal to vertical hydraulic conductivity is about 4; this ratio is as large as 7.6 for sand and gravel that contain small shale fragments. These thin and flat fragments have apparently reduced the vertical hydraulic conductivity of the streambed.

The horizontal hydraulic conductivity ( $K_h$ ) values of the alluvial aquifers in the Republican and Platte River valleys determined using pumping tests are similar to the  $K_h$  values of sandy streambed determined using permeameter tests. However, the  $K_v$  values of the alluvial aquifers are much lower than those of the top sandy streambed. This is interpreted as the layers of silt and mud in the sand and gravel sediments leading to a stronger anisotropy than a single layer. The  $K_v$  values of the sandy and silty streambeds determined in this study provide essential information in the analysis of the anisotropy of interbedded sediment layers. Because the



sediments in the rivers are essentially the same materials as the alluvial aquifer, the  $K_v$  values of the alluvial aquifer that have been determined by aquifer tests are probably good references for the  $K_v$  values of the entire thickness of streambed materials.

Simulation results using stream-aquifer models indicate that in a partially penetrating river, the pumping-induced stream infiltration moves downward beneath the streambed. Thus, the vertical hydraulic conductivity of the sediments in river channels has a significant role in controlling the interactions between groundwater and stream water. Migration of infiltrated stream water in the aquifer is often very slow and it requires a long time for the water to get at the pumping well.

# **Information Transfer Program**

# Water Center Educational Materials

## Basic Information

<b>Title:</b>	Water Center Educational Materials
<b>Project Number:</b>	2002NE33B
<b>Start Date:</b>	3/1/2001
<b>End Date:</b>	2/28/2002
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	1
<b>Research Category:</b>	Not Applicable
<b>Focus Category:</b>	Education, None, None
<b>Descriptors:</b>	
<b>Principal Investigators:</b>	Steven W. Ress, Kyle D. Hoagland

## Publication

Information Transfer Program:

2002 USGS Annual Report  
UNL Water Center

Newsletter:

The *Water Current* newsletter is in its 34th year of continuous publication (dating to 1968). It is published in February, April, June, August, October and December and has a free distribution of more than 2,800 copies, more than 95 percent of which represent requested subscriptions. An annual reader survey is published each April.

Full color photographs and graphics were added to the *Water Current* this year.

A 16-page special issue was published in October, recognizing the U.S. Bureau of Reclamation's centennial.

Water-related research and extension faculty are featured in each issue.

Guest columns are published in each issue. Area water-related professionals and educators write these on a wide variety of topics and opinions.

Individual issues are normally 12 pages in length.

Editorial content is geared both toward a general audience and toward water professionals, researchers and academicians.

Virtual copies of the newsletter are available on-line and archived at <http://watercenter.unl.edu>

Other Print Resources:

*Water Center* informational brochures. Updated and produced annually. Overviews of the mission and programming of the UNL Water Center, Great Plains CESU, EEAI unit and other centers and units affiliated with the Water Center. Distributed free.

*Water Center Pocket Directory*. A pocket-size brochure listing key NU, federal, state and local water resource agencies and points of contact.

Newspaper tabloids on wetlands and drinking water issues respectively published in 1997 and 1999. These continue in use by a variety of university programs, 4-H, FFA, state agencies and the public schools within natural science curriculums and educational programs. 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 from the USGS, are also made available in print and/or electronic versions, through the Water Center's web site.

News Releases:

The Water Center produces about 25 press releases annually. Most of these are based on research, cooperative extension, teaching and public outreach programming involving the Water Center. They are also used to announce conferences, seminars, tours, pesticide collections and other activities. These are widely published in state newspapers, as well as in organizational, trade and professional journals. The

releases support a wide variety of UNL water-related research and programming that crosses department lines and is interdisciplinary.

Electronic Resources:

Electronic versions of newsletters, print materials, information about the Water Center and Water Sciences Laboratory and course information for graduate and undergraduate students enrolling in water-related courses of study 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/>

The Water Center's web site was redesigned in December 2000 and will be redesigned again in 2003.

Conferences, Seminars and Tours:

**Nebraska Water Conference** normally conducted each March. Co-sponsored by the Nebraska Water Conference Council and other academic, commercial and non-profit organizations. The conference attracts about 200 participants. News releases, brochures and a program are produced for this event.

**Water Resources Seminar Series.** A series of 12 to 14 public lectures from January to April each year. Co-sponsored by other NU departments and units. The series may be taken for student credit or as a free public lecture series. News releases, mailings and brochures are produced in conjunction with this event.

**Platte Watershed Symposium** is co-sponsored by the Water Center and other NU departments and centers, as well as from the U.S. Environmental Protection Agency, Region VII and the U.S. Fish and Wildlife Service. The 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 and brochures are produced in conjunction with this event.

**Summer Water and Natural Resources Tour.** Co-sponsored by the Nebraska Water Conference Council and other NU, 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.** A new event held in conjunction with UNL's School of Natural Resource Sciences. Brings water and natural resource researchers and students together for a one-day symposium to share research results and progress. This year's event attracted about 75 faculty members and students.

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

Promotional Items:

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

UNL Pesticide Education Office:

The Water Center helps 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.

# **USGS Summer Intern Program**

## 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	3	0	0	0	3
Ph.D.	0	0	0	0	0
Post-Doc.	2	0	0	0	2
<b>Total</b>	7	0	0	0	7

## Notable Awards and Achievements

Tcherepanov, E.N., Student Grant, Geological Society of America, 2003, \$1,800

## Publications from Prior Projects

- 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Cardenas, M.B.R., and V.A. Zlotnik, Constant-head injection tests: a simple method for streambed permeability estimation, *Ground Water*, in press.
- 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Kollet, S. and V.A. Zlotnik, 2003, Stream depletion predictions using data of pumping tests in heterogeneous stream-aquifer system in the Great Plains, USA, *J. Hydrology*, in press.
- 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Cardenas, M. B., and V. A. Zlotnik, Three-dimensional model of modern channel bend deposits, *Water Resour. Res.*, 39(6), 1141, doi:10.1029/2002WR001383, 2003
- 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Kollet, S.J., V.A. Zlotnik, and G. Ledder, 2002, Discussion of Papers: A stream depletion field experiment by Bruce Hunt, Julian Weir, and Bente Clausen, March-April 2001 issue, v. 39, no. 2: 283-289., *Ground Water*, 40(4), 448-449.
- 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Rus, D.L., V.L. McGuire, B.R. Zurbuchen, and V.A. Zlotnik, 2001, Vertical Profiles of Streambed Hydraulic Conductivity Determined Using Slug Tests in Central and Western Nebraska, U.S. Geological Survey, Water-Resources Investigations Report 01-4212, 32 p.
- 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Butler,



- J.J., Jr., V.A. Zlotnik, M.-S. Tsou, 2001, Drawdown and stream depletion produced by pumping in the vicinity of a partially penetrating stream, *Ground Water*, 39(5), 651-659.
7. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Kollet, S.J., V.A. Zlotnik, D. Woodward, 2002, A field and theoretical study on stream-aquifer interactions under pumping conditions in the Great Plains, Nebraska, In Proceedings of AWRA 2002 Summer Specialty Conference Ground Water/Surface Water Interactions, July 1-3, Keystone, Colorado, p. 29-34.
  8. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Cardenas, B.R., and V.A. Zlotnik, 2002, Assessment of bend topography models via calibration to a ground-penetrating radar profile and permeability data, 83(47), F592.
  9. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Zlotnik, V.A., S.J. Kollet, M.B.R. Cardenas, and D. Woodward, Study of stream-aquifer interactions in the Platte River watershed using methods of aquifer hydraulics, sedimentology, geophysics, and geostatistics. GSA Abstracts with Program, Denver, Colorado, October 27-31, 2002, p. 98.
  10. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Rus, D.L., C.P. Carney, F.E. Harvey, M.K. Landon, C.M. McCormick, V.L. McGuire, S.M. Peterson, V.A. Zlotnik, B.R. Zurbuchen, 2002. Streambed Hydraulic Conductivity in Central and Western Nebraska. GSA Abstracts with Program, Denver, Colorado, October 27-31, 2002, p. 234.
  11. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Woodward, D., S.J. Kollet, and V.A. Zlotnik, 2002, A field and theoretical study on stream-aquifer interactions under pumping conditions in the Great Plains, Nebraska. In Program of AWRA 2002 Summer Specialty Conference Ground Water/Surface Water Interactions, July 1-3, 2002, Keystone, Colorado, p. 3.
  12. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - McGuire, V.L., D.L. Rus, V.A. Zlotnik, and B.R. Zurbuchen, 2002, Vertical profiles of streambed hydraulic conductivity determined using slug tests in Central and Western Nebraska, In Program of AWRA 2002 Summer Specialty Conference Ground Water/Surface Water Interactions, July 1-3, Keystone, Colorado, p.6.
  13. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Cardenas, M. B., and V.A. Zlotnik, 2001, Hydrogeological model of active meander deposits based on three-dimensional hydraulic characterization, 7th International Conference on Fluvial Sedimentology, Program with abstracts, Unl, USA, August 6-10, 2001, p. 71
  14. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Cardenas, M.B., and V.A. Zlotnik, 2001, Three-dimensional structure of modern river bend deposits: development and its implications on hydrogeologic models. GSA Abstracts with Program, Boston, Massachusetts, Nov. 1-10, p. A 45.
  15. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Kollet, S., and V.A. Zlotnik, 2001, Stream-aquifer interactions: pumping tests near a stream with and without stream discharge. GSA Abstracts with Programs, Boston, Massachusetts, Nov. 1-10, p. A279.

16. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - : Kollet, S. and V.A. Zlotnik, 2001, Interpretation of pumping tests in unconfined aquifers: heterogeneity vs. drainage processes above the declining water table. EOS Transactions, American Geophysical Union, AGU Fall Meeting, San-Francisco, Abstracts, 82(47), F359.
17. 2000NE3B ("Hydraulic Characterization of the Stream-Aquifer Interface: Theory, Field Implementation, and Practical Ramifications - A Multi-State Proposal") - Other Publications - Halihan, T., and V.A. Zlotnik, 2001, Asymmetric dipole flow test in a fractured carbonate aquifer, EOS Transactions, American Geophysical Union, AGU Fall Meeting, San-Francisco, Abstracts, 82(47), F360.
18. 2000NE1B ("Determination of Aquifer and Aquitard Hydraulic Properties and Their Role in Streamflow Depletion") - Articles in Refereed Scientific Journals - Chen, X.H., Y. Yin, J.W. Goeke, and R.F. Diffendal, Jr. 2003. Estimation of Aquifer-Aquitard Hydraulic Properties for a High Plains Aquifer in Central Nebraska. Journal of Hydrologic Engineering (in review).