

**Nebraska Water Center
Annual Technical Report
FY 2014**

Introduction

Dr. Chittaranjan Ray, professor and professional engineer (PE) in the Department of Civil Engineering at the University of Nebraska-Lincoln, became permanent director of the Nebraska Water Center (NWC) on August 1, 2013. Steve Ress and Tricia Liedle serve respectively as NWC's communications coordinator and program specialist. NWC staff also includes Craig Eiting as web developer and graphic designer. The original "UNL Water Center" also underwent a name change in February 2012 becoming the Nebraska Water Center, a part of the Robert B. Daugherty Water for Food Institute (DWFI) at the University of Nebraska. Water Center marketing, promotion and education efforts are being conducted with the help of additional funding and personnel assistance from DWFI. The Nebraska Water Center is currently housed at Nebraska Innovation Campus (2021 Transformation Drive, Suite 3220, Lincoln NE 68588) along with DWFI.

NWC assisted DWFI with the sixth annual Global Water for Food Conference held in Seattle, Wash. in October 2014. Additionally, NWC hosted a day-long brainstorming session in fall 2014 in Nebraska City, Nebr. with faculty members from each of the University of Nebraska system campuses located in Omaha, Lincoln and Kearney to focus on key research objectives and available funding opportunities and strategies for those programs. In March 2015, NWC hosted a one- symposium showcasing water-related research and programming in Nebraska, with a focus on "Sustainability of the High Plains Ogallala Aquifer for Crop Production and Water Supply". This event was co-sponsored by the U.S. Geological Survey's Nebraska Water Sciences Center in Lincoln, Nebr. In addition to featuring research from University of Nebraska scientists, Kansas Geological Survey and Michigan State University, producers from Texas Alliance for Water Conservation and Nebraska Water Balance Alliance presented innovative work done directly with and for fellow producers to conserve water and to extend the life of the aquifer. The second event following the one-day symposium was a one-day water law conference, designed for practicing attorneys, but attended by many water policy makers and managers. It was co-sponsored by the University of Nebraska, College of Law. Continuing Legal Education (CLE) credits were offered as this event.

Research Program Introduction

During fiscal year 2013 two research seed grants received funding through the USGS 104(b) program. Areas chosen for funding were: (1) Development of an Affinity-Based Concentrator-Detection Kit for Monitoring Emerging Contaminants in Recycled Water; and (2) An Innovative Graphene Oxide Filter for Drinking Water Contaminants Removal; An additional three seed research grants were selected for possible funding during the 2014 fiscal year. The U. S. Army Corps of Engineers awarded a supplemental grant through the NWC and USGS to study Development of a National Database of Depreciated Structure Replacement Values for Inclusion with SimSuite/HAZUS and Flood Mitigation Reconnaissance Studies. Areas chosen for upcoming 2014 were: (1) Documenting Stream/Groundwater Interaction in the South Platte River; and (2) Hydroclimatic Controls on the Conjunctive Use of Surface and Ground Water in the Platte River Basin; and (3) Fate of Steroid Hormone Conjugates and E. coli From Manure in Soil: Potential Sources of Free Hormones and Pathogens in Forages and the Environment?

The Nebraska Water Sciences Laboratory (WSL), a core research and teaching facility and integral part of the NWC since 1990, is a state-of-the-art laboratory designed to provide technical services and expertise in analytical and isotopic methods. The facility provides specialized instrumentation and methods for organic, emerging contaminants, heavy metals, and for stable isotope mass spectrometry. Faculty, staff, and students have analyzed thousands of samples at the facility since it was established in 1990 and work to develop new analytical research methodologies as well as helping other University of Nebraska faculty with their core research.

The Nebraska Water Center is now a part of the global Robert B. Daugherty Water for Food Institute (DWFI) at the University of Nebraska and in this role the Center plays as a local repository of expertise in water research, education and programming for DWFI's research, education, and outreach activities that are largely aimed at helping to maximize global food production through efficient use of available water.

Development of an affinity-based concentrator-detection kit for monitoring emerging contaminants in recycled water

Basic Information

Title:	Development of an affinity-based concentrator-detection kit for monitoring emerging contaminants in recycled water
Project Number:	2013NE255B
Start Date:	3/1/2013
End Date:	8/31/2014
Funding Source:	104B
Congressional District:	NE-01
Research Category:	Water Quality
Focus Category:	Methods, Water Quality, None
Descriptors:	Emerging contaminants, water screening, analytical method development
Principal Investigators:	David Hage, Daniel Davidson Snow

Publications

1. Elliott Rodriguez, Ryan Matsuda, Christopher White II, Donald Jobe and David Hage*, “Development of a Displacement Assay for Screening Contaminants in Water”, 5th Annual Research Poster Session, Chemistry Dept., UNL, Lincoln, NE, August 2013.
2. Elliott Rodriguez, Ryan Matsuda, Christopher White II, Donald Jobe and David Hage*, “Development of a Displacement Assay for Screening Contaminants in Water”, Nebraska Summer Research Symposium, UNL, Lincoln, NE, August 2013.
3. Ryan Matsuda, So-Hwang Kye, Christopher White II, Elliott Rodriguez, Donald Jobe, Daniel Snow and David Hage*, “Detection of Emerging Contaminants in Water by a Displacement Assay through High-Performance Affinity Chromatography”, 2013 Nebraska Water Conference, Lincoln, NE, October 2013.
4. Elliott Rodriguez, Ryan Matsuda, Christopher White II, Donald Jobe and David Hage*, “Development of a Displacement Assay for Screening Contaminants in Water”, 5th Annual Research Poster Session, Chemistry Dept., UNL, Lincoln, NE, August 2013.
5. Elliott Rodriguez, Ryan Matsuda, Christopher White II, Donald Jobe and David Hage*, “Development of a Displacement Assay for Screening Contaminants in Water”, Nebraska Summer Research Symposium, UNL, Lincoln, NE, August 2013.
6. Ryan Matsuda, So-Hwang Kye, Christopher White II, Elliott Rodriguez, Donald Jobe, Daniel Snow and David Hage*, “Detection of Emerging Contaminants in Water by a Displacement Assay through High-Performance Affinity Chromatography”, 2013 Nebraska Water Conference, Lincoln, NE, October 2013.
7. Ryan Matsuda, So-Hwang Kye, Christopher White II, Elliott Rodriguez, Donald Jobe, Daniel Snow and David S. Hage*, “Detection of Emerging Contaminants in Water by a Displacement Assay Based on High-Performance Affinity Chromatography”, Pittcon 2014, Chicago, IL, March 2014.
8. Ryan Matsuda, So-Hwang Kye, Christopher White II, Elliott Rodriguez, Donald Jobe, Daniel Snow and David S. Hage*, “Detection of Emerging Contaminants in Water by a Displacement Assay Based on High-Performance Affinity Chromatography”, UNL Graduate Research Fair, Lincoln, NE, April 2014.

Development of an affinity-based concentrator-detection kit for monitoring emerging contaminants in recycled water

9. Ryan Matsuda, So-Hwang Kye, Christopher White II, Elliott Rodriguez, Donald Jobe, Daniel Snow and David S. Hage, "Development of Displacement Assay for Emerging Contaminants in Water using High-Performance Affinity Chromatography", HPLC 2014, New Orleans, LA, May 2014.
10. Ryan Matsuda, Ellis Kaufmann, Xiwei Zheng, So-Hwang Kye, Elliott Rodriguez, Christopher J. White, Donald Jobe, Daniel Snow and David S Hage, "Displacement Assay Based on High-Performance Affinity Chromatography for Detecting Emerging Contaminants and Drugs in Water and Biological Samples", Pittcon 2015, New Orleans, LA, March 2015.
11. Elli Kaufmann, Ryan Matsuda, Xiwei Zheng, and David S. Hage, "Free Fraction Analysis by a Displacement Assay Based on High Performance Affinity Chromatography", 135th Annual Meeting, Nebraska Academy of Sciences, Lincoln, NE, April 2015.
12. Ryan Matsuda, Ellis Kaufmann, Xiwei Zheng, and David S Hage, "Free Fraction Analysis by a Displacement Assay Based on High-Performance Affinity Chromatography", Molecular Mechanisms of Disease 2nd Annual Conference, Lincoln, NE, April 2015.

2014 Project Report: Development of a Displacement Assay for Emerging Contaminants in Water using High-Performance Affinity Chromatography

David S. Hage¹ (PI) and Daniel Snow²

¹ Department of Chemistry, University of Nebraska-Lincoln, Lincoln, NE

² Water Sciences Laboratory/Nebraska Water Center, Daugherty Water for Food Institute, University of Nebraska-Lincoln, Lincoln, NE

Project Summary: Problem & Research Objectives

Water reuse is becoming increasingly common in countries and regions with limited water resources. Even in regions with abundant water resources, irrigation with recycled water is relatively common. For example, Nebraska ranks 2nd in the U.S. after California in the number of farms that use recycled or reclaimed water.¹ Though obviously beneficial from a water conservation perspective, this trend is also creating a growing need to assess the sources, occurrence, and effects of biologically-active contaminants occurring in water. For instance, recent evidence indicates that traces of pharmaceuticals and steroid hormones are present in surface and groundwater, and may even be found in drinking water supplies. Because of current treatment technologies and design limitations, treated municipal wastewater releases traces of steroids, pharmaceuticals, illicit drugs, and other chemicals into receiving waters.²⁻³ Residues of antibiotics, other veterinary pharmaceuticals, and steroid hormones are also known to occur in livestock waste and wastewater.⁴⁻⁶ Municipal wastewater discharge, run-off from feedlots, and crops fertilized with manure are all potential routes for releasing these compounds into aquatic environments. Many questions remain as to the importance of contaminant sources, the feasibility and effectiveness of new treatment methods, and the potential health implications of increasing antibiotic resistance or direct toxicological effects of these compounds in reused water and resulting crops. The observed concentrations of these chemicals in water are typically quite low (i.e., ng/L- μ g/L range) and these contaminants are often present in complex matrices. These factors have created a pressing demand for improved sampling and detection technologies for these biologically-active emerging contaminants in water.

Recent preliminary studies to develop new analytical approaches for examining these contaminants have been conducted by a multidisciplinary group in analytical and environmental chemistry at the University of Nebraska–Lincoln (UNL). This team has combined efforts to achieve a common goal of developing and testing innovative approaches for sampling and detecting emerging contaminants in environmental matrices. This initial work has led to the discovery that low-cost binding agents such as bovine serum albumin (BSA) can be used as affinity sorbents for the extraction of various pharmaceutical agents and steroid hormones in water. It has also been shown that these affinity sorbents can be used for the selective extraction of these contaminants and related compounds prior to identification and measurement by laboratory methods such as liquid chromatography-tandem mass spectrometry (LC/MS/MS). Continued refinement and expansion of these sorbents into new formats can lead to methods and technologies for both *in situ* contaminant detection and improved sample collection for emerging contaminants.

The overall goal of this proposal has been to explore the development of novel, low-cost affinity sorbents for use in screening and concentrating indicator compounds for emerging contaminants in water. This work is expected to lead to the development of innovative, inexpensive, and rapid screening techniques for monitoring irrigation water quality and to help evaluate risk from water reuse. These techniques, in turn, should provide data that will lead to further studies to better tools for managing water quality for both human and animal consumption. The specific objectives are to 1) explore the development and use of general binding agents such as BSA in low-cost, affinity-based assays for screening water samples for

indicator compounds of biologically-active emerging contaminants and 2) examine such devices for collection of the same contaminants for analysis by LC/MS/MS.

Project Results: Methodology & Principal Findings

This study has explored the use of affinity sorbents and high-performance affinity chromatography (HPAC) as a tool for rapidly screening for common emerging contaminants found in water. HPAC is chromatographic technique that utilizes a biologically-related binding agent as the stationary phase to retain chemicals. A displacement assay based on HPAC was constructed by using a fluorescent labeled analog of the drug phenytoin and an affinity column containing immobilized bovine serum albumin (BSA). BSA is a serum transport protein found in cattle that has a series of sites that are capable of binding to various pharmaceuticals and hormones, as well as some pesticides (as shown in **Figure 1**).

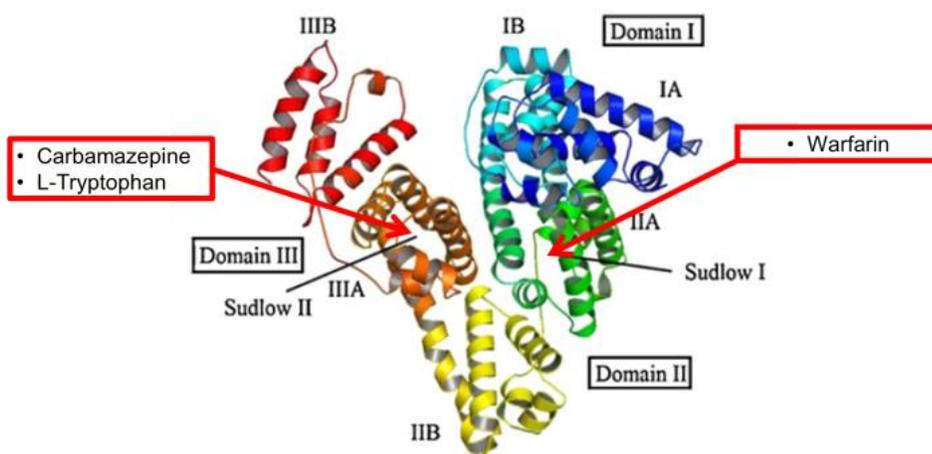


Figure 1. BSA and the binding sites to which carbamazepine, L-tryptophan and warfarin are bound during a displacement assay; phenytoin also interacts at each of these sites

Warfarin, carbamazepine (widely found in wastewater), and L-tryptophan were used as the model chemicals and binding probes to develop and test this assay. All of these compounds were found to displace labeled phenytoin when applied to the BSA column and provided a signal within a few minutes of sample application. This approach was examined in this study as a possible a screening tool that could be used for detection of emerging contaminants in reclaimed and recycled water.

Labeled phenytoin was synthesized by combining 20 μmol 3-amino-5,5-diphenylimidazolidine-2,4-dione (ADPH) with 9 μmol *N*-hydroxysuccinimide-fluorescein (NHS-fluorescein) in dimethyl sulfoxide (DMSO) and triethylamine. This reaction is shown in **Figure 2**. The mixture was allowed to react in the dark and in an ice bath for 4 hours. DMSO and triethylamine were then removed from the final product by using a vacuum oven at 60 $^{\circ}\text{C}$ and 25 mm Hg.

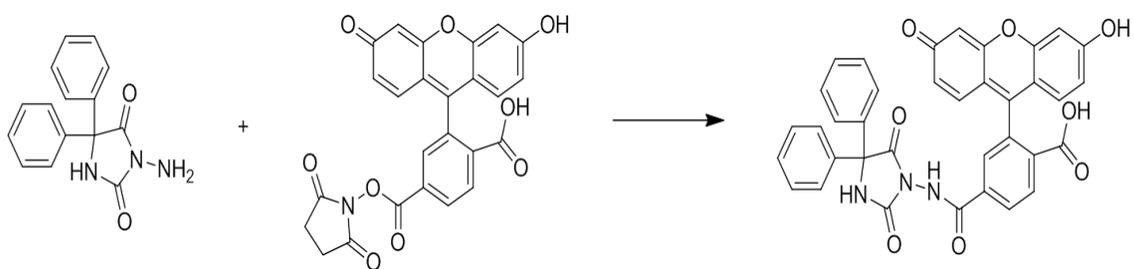


Figure 2. Reaction involved in synthesis of fluorescein labeled phenytoin.

Labeled phenytoin was first applied to a column containing immobilized BSA and allowed to bind to the BSA, as depicted in step 1 of **Figure 3**. Following the injection of the labeled phenytoin, the various model analytes were injected onto the column. This resulted in displacement of some of the labeled phenytoin, as depicted in step 2. Changes in the displaced peak area were found to be correlated with the concentration of the applied analyte, as shown in **Figure 4**.

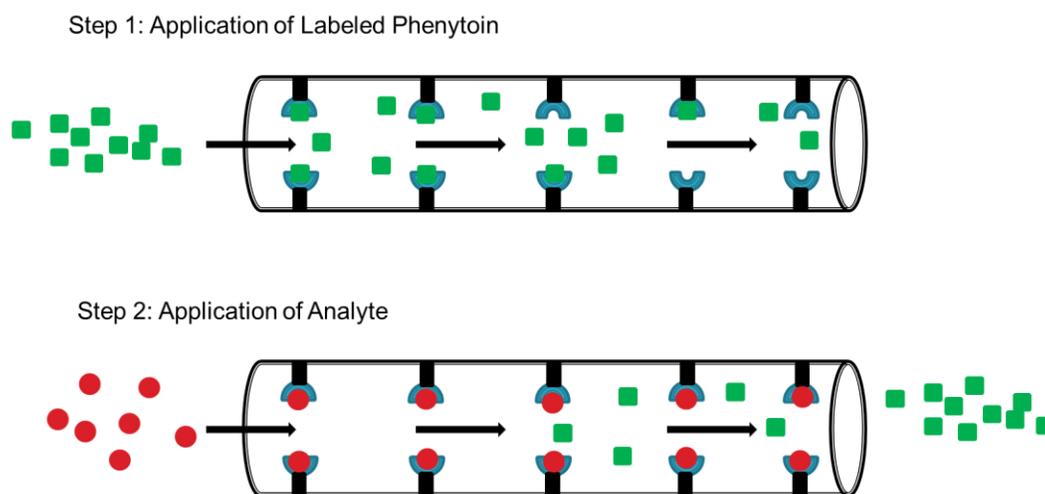


Figure 3. Scheme for displacement assay based on HPAC

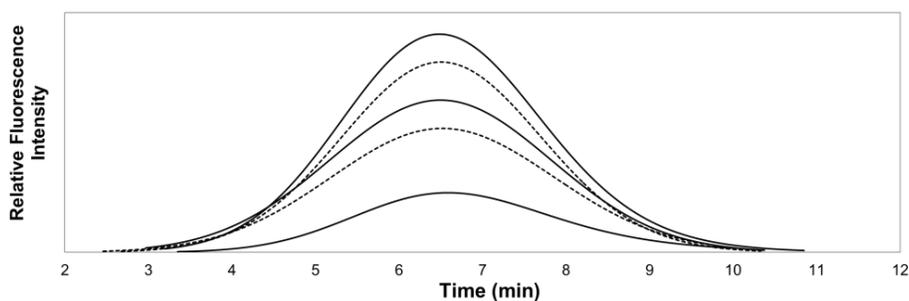


Figure 4. Example of a displacement assay using a BSA column (1 cm x 2.1 mm i.d.) and labeled phenytoin. These results were obtained for warfarin sample concentrations of 0-50 μ M using a 20 μ L sample injection at a flow rate of 0.25 mL/min.

Calibration curves were obtained for the displacement assay by using a set of standards ranging from 0.01-1 μM for warfarin and carbamazepine, as shown in **Figure 5**. The linear ranges for the calibration curves are shown in the insets of these figures. A similar calibration curve was obtained for L-tryptophan. The estimated limits of detection for carbamazepine and warfarin were 11 nM and 6 nM respectively.

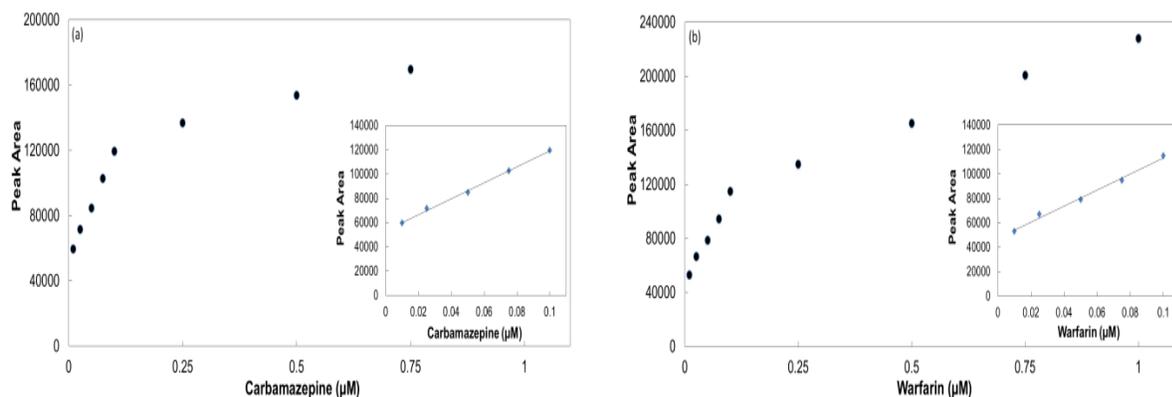


Figure 5. Calibration curves obtained for (a) carbamazepine and (b) warfarin

Spiked samples were also prepared by adding in a known concentration of either carbamazepine or warfarin to a 20 mL sample of tap water. The samples were then injected onto the BSA column containing the labeled phenytoin. The displayed peak area was used with the linear calibration plots to determine the concentration of the spiked samples, as shown in **Table 1**. There was a good correlation between the actual and detected concentration for both analytes.

Table 1. Results from spiked recovery experiments for carbamazepine and warfarin

Actual Conc. (μM)	Detected Carbamazepine Conc. (μM)	Detected Warfarin Conc. (μM)
0.10	0.10 (± 0.03)	0.08 (± 0.06)
0.25	0.25 (± 0.08)	0.24 (± 0.07)
0.49	0.49 (± 0.15)	0.49 (± 0.02)
0.73	0.75 (± 0.21)	0.73 (± 0.12)
1.0	1.04 (± 0.12)	1.12 (± 0.04)

Another portion of our work has begun to examine the use of BSA Columns to capture emerging contaminant indicators. This was tested by using a 1 cm x 2.1 mm i.d. BSA column that contained 71 (± 5) mg BSA/g silica, or 1.1 mg BSA per column. The application of warfarin to this column indicated that this column had a binding capacity for such contaminants of 17 (± 1) nmol (or 5.2 μg for warfarin). A 5 cm x 4.6 mm i.d. BSA column of the same design was also been coupled with LC/MS/MS, in preliminary work with NSF/EPSCoR and Teledyne-ISCO, and used to detect carbamazepine in water, giving a signal of 24 ng or 0.1 nmol.

Additional studies were conducted in which fluorescein-labeled thyroxine was considered for use in place of phenytoin as the displaced agent. A method for synthesizing this

labeled agent was developed and the use of this agent in the displacement assay format was evaluated. In addition, the displacement assay using labeled phenytoin has been tested over a broader range of flow rates and column sizes and has been adapted for use in looking at the non-bound, or “free”, fractions of drugs and hormones in water or in complex samples that may contain soluble binding agents for these same compounds. Work in which the displacement assay was used as part of a microchip-based device was also begun and indicated that this assay could be used in such a format.

Project Summary & Significance

This study examined the development of a displacement assay for the detection of pharmaceutical agents and other chemicals contaminants in water samples. The detection range for the different analytes was in the nM to μ M range, with detection limits in the low nM range. The displacement assay also demonstrated comparable results to actual concentrations for spiked samples containing either warfarin or carbamazepine. Although this particular study looked at carbamazepine, warfarin and L-tryptophan as model analytes, the same approach could be extended to other compounds that bind to BSA. It was also found that this affinity-based method could be combined with LC/MS/MS for capturing and screening drugs and other agents in water samples. The information that has been provided by this study indicates that this approach can be used as a potential screening tool to detect emerging contaminants in water and may thus be developed into a screening tool for irrigation water quality. Future studies will continue to explore the use of this method in miniaturized systems, with other types of displacement labels, and in field-portable kits that can be used alone or in combination with LC/MS/MS.

References Cited

1. USDA, Census of Agriculture: Farm and Ranch Irrigation Survey, Vol. 3, Special Studies, Part 1, AC-07-SS-1, (2009).
2. Kolpin, DW, Skopec, M, Meyer, MT, Furlong, ET, Zaugg, SD. Urban contribution of pharmaceuticals and other organic wastewater contaminants to streams during differing flow conditions. *Sci Total Environ* 328 (2004) 119-130.
3. Stackelberg, PE, Furlong, ET, Meyer, MT, Zaugg, SD, Henderson, AK, Reissman, DB. Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water-treatment plant. *Sci Total Environ* 329 (2004) 99-113.4.
Burkholder, J, Libra, B, Weyer, P, Heathcote, S, Kolpin, D, Thorne, PS, Wichman, M. Impacts of waste from concentrated animal feeding operations on water quality. *Environ Health Perspect* 115 (2007) 308-12.
5. Dolliver, HAS, Gupta, SC. Antibiotic losses from unprotected manure stockpiles. *J Environ Qual* 37 (2008) 1238-1244.
6. Shappell, NW, Billey, LO, Forbes, D, Matheny, TA, Poach, ME, Reddy, GB, Hunt, PG. Estrogenic activity and steroid hormones in swine wastewater through a lagoon constructed-wetland system. *Environ Sci Technol* 41 (2007) 444-450.

An Innovative Graphene Oxide Filter for Drinking Water Contaminants Removal

Basic Information

Title:	An Innovative Graphene Oxide Filter for Drinking Water Contaminants Removal
Project Number:	2013NE256B
Start Date:	3/1/2013
End Date:	12/31/2014
Funding Source:	104B
Congressional District:	1
Research Category:	Engineering
Focus Category:	Water Quality, Treatment, Methods
Descriptors:	
Principal Investigators:	Yusong Li, Yongfeng Lu, Daniel Davidson Snow

Publications

1. [1] Stefan Schaepe, 2015, Engineering Graphene Oxide Membranes For Contaminant Removal and Bacterial Inactivation, "MS Thesis", Civil Engineering Department, University of Nebraska-Lincoln, Lincoln, NE.
2. [2] Hillary Stoll, 2015, The Biocidal Capabilities of Graphene Oxide-Coated Filters for Treating Drinking Water , 'Undergraduate Honor Thesis', Civil Engineering Department, University of Nebraska-Lincoln, Lincoln, NE.
3. [3] Stefan Schaepe, Julia Burchell, Yusong Li, Xu Li, 2015, Graphene Oxide (GO) Membranes for Contaminant Removal in Drinking Water, University of Nebraska-Lincoln Research Fair.
4. [4] Stefan Schaepe, Julia Burchell, Yusong Li, Xu Li, Graphene Oxide (GO) Membranes for Contaminant Removal in Drinking Water, Nebraska Water Environment Association (NWEA) Fall Conference, 2014

2014 Project Report: An Innovative Graphene Oxide Filter for Drinking Water Contaminants Removal

Yusong Li¹, Daniel Snow² and Yongfeng Lu³

¹ Department of Civil Engineering, ² School of Natural Resources, ³ Department of Electrical Engineering, University of Nebraska-Lincoln

PROJECT SUMMARY

According to a World Bank estimate, nearly 1.1 billion individuals lack access to safe drinking water, resulting in millions of deaths annually by waterborne disease in developing countries. In agricultural areas such as Nebraska, nitrate and pesticide contamination of drinking water supplies is also a concern, as are contaminants such as uranium and arsenic that may be mobilized by pumping. In the rural or remote areas, portable water purification devices, or point-of-use water treatment systems, can be extremely helpful for people to obtain drinking water from untreated or natural sources. Only a few point-of-use technologies are available providing economical and efficient removal of a wide range of contaminants. Therefore, there is a critical need to develop technologies for effective, practical and robust treatment of drinking water.

Dr. Andre Geim, the winner of 2010 Nobel Prize in Physics, recently (January 2012) published in *Science* an innovative membrane made from graphene oxide (GO) nanomaterials, which possess extremely rapid permeation of water, but can be completely impermeable to liquids, vapors, and gases, including helium one of the most difficult to contain elements in nature. The article reported that water permeates through the membranes 10^{10} times faster than helium gas. This unusual property was explained by the unique structure of GO sheets, which arrange in such a way that between them there is room for exactly one layer of water molecules. A low friction flow of a monolayer of water is possible through two-dimensional capillaries. When a solution is exposed to a GO membrane, water molecules will rush into the capillaries and form a highly ordered monolayer. As such, pore space will be clogged with water molecules so that other chemicals cannot get through.

The overall goal of this research is to evaluate the possibility to apply GO nanomaterial membrane for use in water purification. Objectives of this proposal include:

- Fabricate and characterize GO membranes suitable for water purification.
- Produce preliminary data to assess the ability of GO membranes to remove contaminants in drinking water.

PROJECT RESULTS

1. Fabrication of GO membrane

Two different methods were evaluated to develop GO membrane. The first method is based on vacuum filtration approach, and the second one is based on a layer by layer deposition approach.

Vacuum Filtration Method:

As purchased GO need to be modified to make it more hydrophobic. The modified GO suspension will then be vacuum filtered to make GO film membrane. Steps are as illustrated in Figure 1.

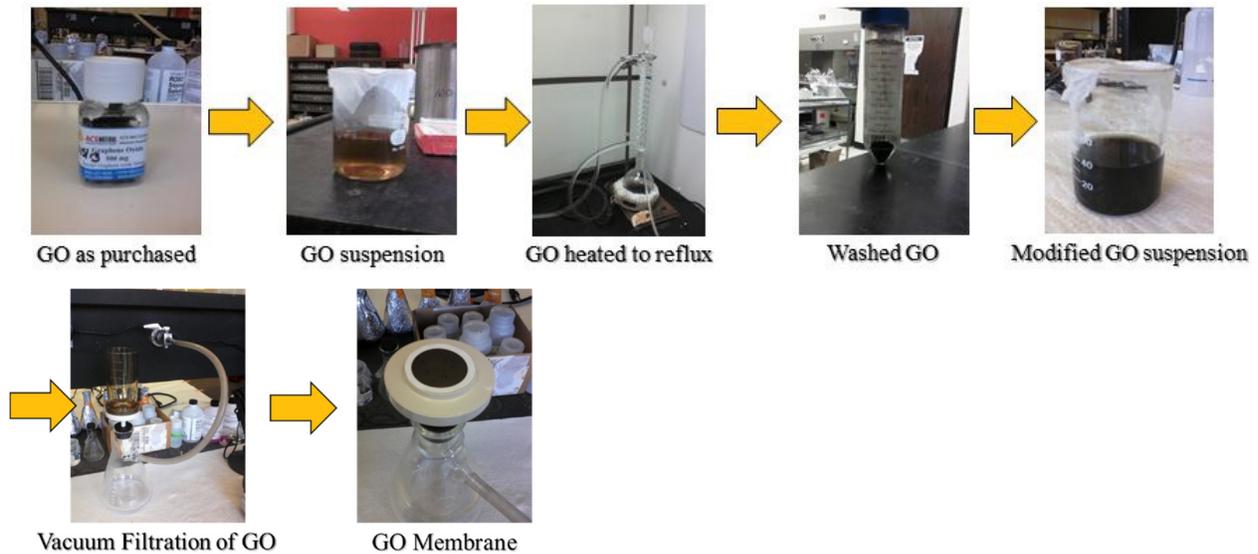


Figure 1 Procedure of making GO membrane

- ▶ Graphene Oxide single layered flakes were sonicated in ultrapure water and subsequently centrifuged
- ▶ The sediment obtained following the centrifuging process was re-dispersed in ultrapure water and the process was repeated four more times
- ▶ Sodium hydroxide was added to the suspension in order to create a more hydrophobic membrane
- ▶ The suspension was then stirred under the flow of nitrogen
- ▶ The suspension was heated to reflux for one hour
- ▶ The suspension was centrifuged again and the sediment was re-dispersed in ultrapure water and repeated 3 times in order to wash the GO

- ▶ Small amounts of the modified GO suspension were sonicated in ultrapure water and then vacuum filtrated onto a polyethersulfone membrane

Layer by Layer Deposition Method:

- ▶ Membrane soaked in GO solution that was sonicated in Isopar
- ▶ Membrane then rinsed with Isopar to remove excessive GOs
- ▶ Membrane then dipped in TMC and GO solutions a designated amount of times
- ▶ The synthesized GO membrane was boiled in a 95 °C water bath for 2h to remove residual Isopar

2. Characterization of GO membrane

We have characterized the GO suspension and GO membrane produced using the vacuum filtration method. Zeta Potential of modified GO suspension is measured around -38mV for pH varied from 3 to 10. A negative zeta potential indicates that the modified GO suspension is very stable. GO flakes vary greatly in size, ranged from 500nm-2 μ m.

Contact angle was measured to evaluate the hydrophobicity of the GO. As shown in Figure 2. The contact angle of unmodified GO suspension was 28°, and the contact angle of modified GO was 59°. The increase of contact angle is a direct indicator that the modified GO was more hydrophobic.

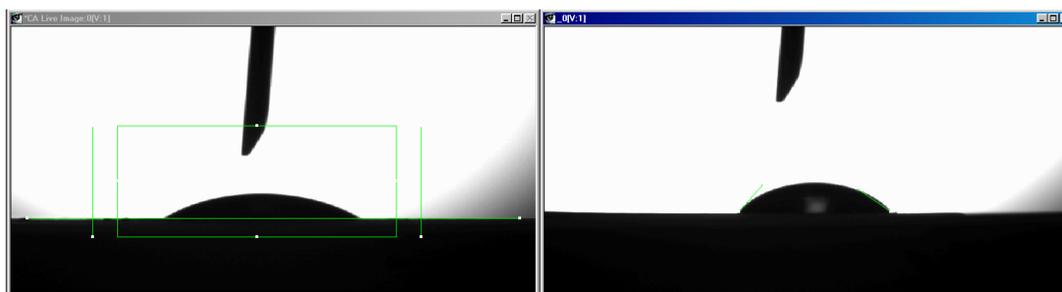


Figure 2. Contact angle measurement for GO suspension before (left) and after (right) modification

Figure 3 is an AFM image of the GO suspension. AFM shows height profiles on the left and the surface roughness on the right. The thickness of GO flakes in the suspension was determined as 1 nm per flack.

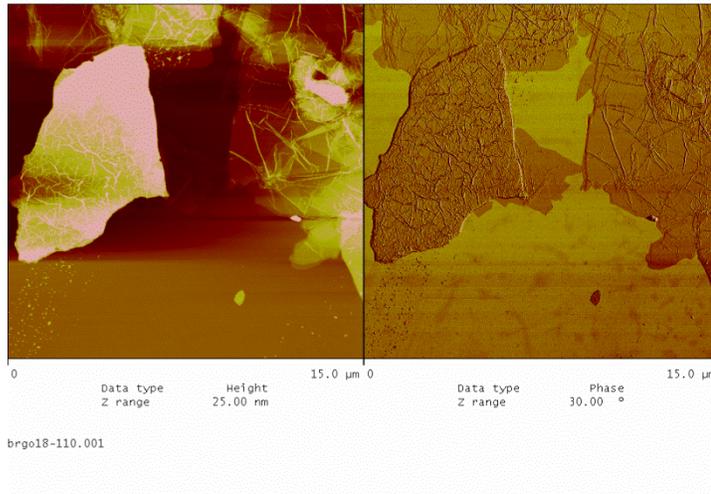


Figure 3. AFM image of GO suspension

Figure 4 presents a SEM image of the GO coated membranes produced using vacuum filtration method. The coatings for the images shown using vacuum filtration method were taken of a GO membrane with a loading rate of 50mg/m² which is the thinnest membrane used in the study. As shown, the support membrane is completely covered. SEM images (not shown) indicated that layer by layer deposition method was not able to provide a good coverage of GO on the surface of membranes. Therefore, GO coated membrane produced by vacuum filtration method was the focus of study for the work.

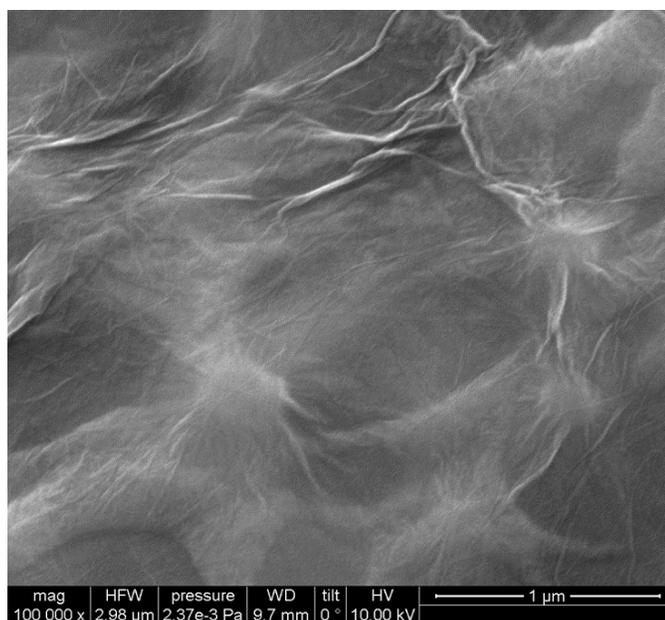


Figure 4: SEM image of polyethersulfone membrane with GO coating produced using vacuum filtration method.

Fourier Transform Infrared Spectrometry (FTIR) measurements were conducted for GO coated membranes from vacuum filtration method (Figure 5). The peaks in the figure represent various chemical bonds taking place within the membranes. Measurements were taken for a polyethersulfone membrane, and two membranes of varying GO thickness. There are two major takeaways from the FTIR results. First the peak on the left hand side of the figure reveals the presence of water within the sample. The membrane with no GO coating has no peak and therefore no water in the sample. The membrane consisting of the GO loading of 50mg/m² contained a small amount of water while the thicker 150mg/m² GO coated membrane revealed an even higher amount of water. The extra content of water found in the FTIR measurement is likely contributed by excess water contained within the GO sheets. Secondly the variations in the percent transmittance are an indicator of the thickness of the GO coating. The polyethersulfone membrane stays consistently around the 100% transmittance. Similarly the thinner GO coated membrane also stays around the 100% transmittance mark which reveals that there is only a thin coating of GO present on the surface. The drop in transmittance for the thicker GO coated membrane ensures what was also confirmed with the SEM images that full coverage is in fact present on the polyethersulfone filter. The loading rate of 50mg/m² was the lowest amount that provided complete coverage of GO over the polyethersulfone membrane (revealed by the SEM images).

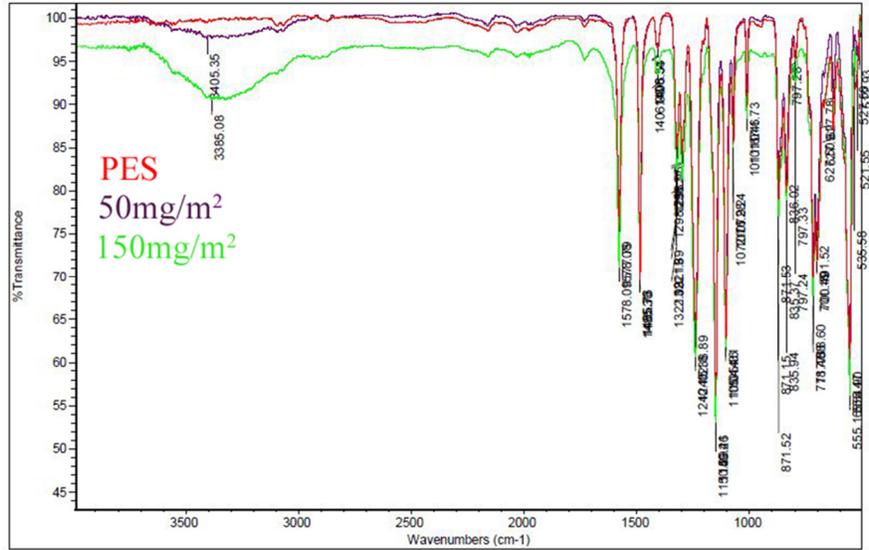


Figure 5: FTIR measurements

3. Evaluate the Water Flux of GO membrane

We investigated water flux of the GO membrane using a dead end membrane filtration system (Figure 6).



Figure 6 Dead-end Filtration System

This system consists of a feed tank pressurized with a nitrogen cylinder, a stirred cell from Millipore (Billerica, MA), and a digital balance to monitor the permeate of water flux. DI water was used to test the pure water flux of the membrane. The membranes was placed in a stirred cell filter holder. The cell was connected to a pressure tank where water (clean or contaminated) was stored in order to pass through the GO membrane. Figure 7 is a typical water flux curve under a pressure of 1 bar. The steady state water flux at the end of the curve was recorded as water flux for GO membrane. Pure water flux values dropping quickly immediately is common in filters.

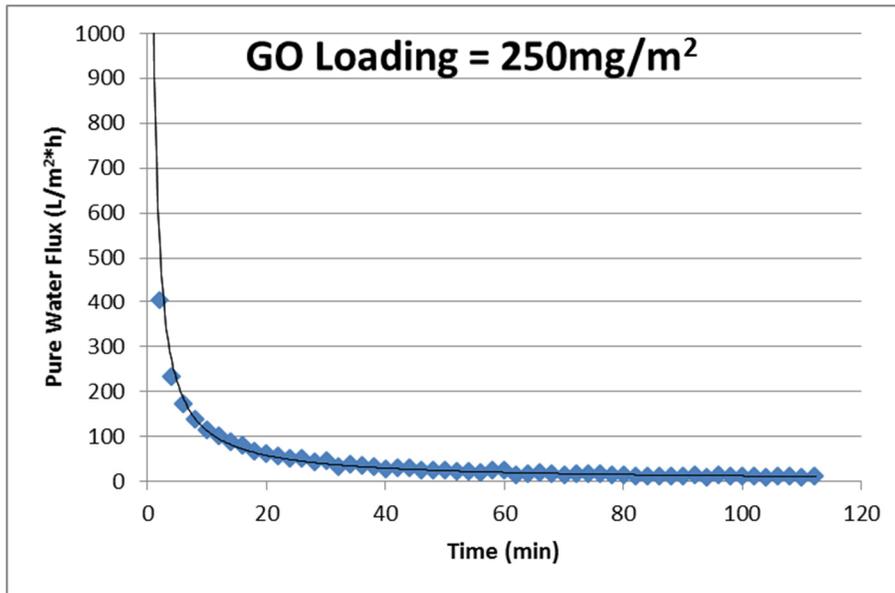


Figure 7 Pure water flux measurement curve for a GO membrane with load of 250 mg/m².

Water flux was tested for GO membrane with GO loading ranged from 100 to 300 mg/m². Figure 6 presents the influence of GO loading on the membrane water flux. In general, water flux of GO membrane is in the decreasing with the increase of GO loading. The water flux was about 275 L/m² h for a GO loading of 100 mg/m², and can be as low as about 25 mg/m². Typical values for nano-filtration are between 20-50 L/m² h. Flux decreasing with increasing loading rate makes sense, however one similar study found no trend between thickness and flux through the GO membrane.

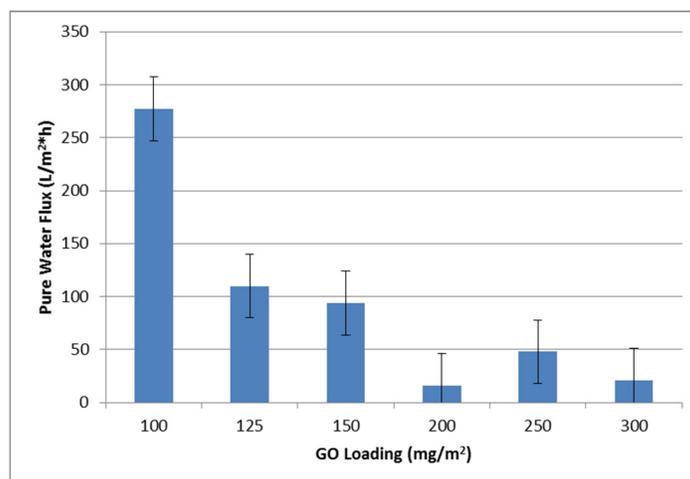


Figure 7 Measured water flux with different GO loading

4. Contaminant Removal

In order to test the ability of GO membranes to remove dissolved salts from water 0.1mM NaCl and 0.1mM Na₂SO₄ solutions were used. The concentration of salt allowed for a high enough conductivity reading so that any reduction in concentration that occurred after passing through the GO would be significant enough to provide accurate results. Insignificant salt rejection was observed. Various loading rates of GO were tested, but no trend was found indicating that the thickness of the GO coating improved the salt rejection values.

Both Methyl Blue and Rhodamine-WT organic dyes were used in order to measure how well the membranes were able to reject dissolved organic contaminants. The 50 μ L of dye per 1L of ultrapure water used as the starting concentration allowed for a high enough concentration in order to accurately measure influent and effluent values. A relationship between measured UV-Vis absorbance and concentration was developed as standard curve to estimate concentration. A limited amount of organic dye rejection was observed for membranes formed using both methods.

A 2014 study by Joshi et al. found that smaller ions were able to permeate through GO coated membranes thousands of times quicker than was expected. They attributed the behavior to nanocapillaries that open up when in a hydrated state. GO coated membranes produced using vacuum filtration method was based off of a study by Han et al. in 2013. The GO coated membranes from their study were also run under a hydrated state, but produced salt rejection as high as 60%. The same method was attempted to be duplicated by another study group (Hu & Mi), which found that the vacuum filtration process resulted in a pasty GO coating that was unusable for filtration

purposes. For organic dye rejection, the 2013 study by Han et al. reported over 99% rejection of similar dyes. Negligible rejection was measured in our experiments. The varying results reported from different studies are likely linked to how the GO was produced. For our study the purchased GO was produced using the modified Hummer's method. While the same method was reportedly used for both other studies, slight modifications in the preparation of the GO could contribute to the varying results from each of the studies.

5. Bacterial inactivation

Bacterial inactivation tests were conducted for the membranes formed from vacuum filtration method. The GO coated membranes were compared against the base polyethersulfone membranes for all of the tests, and it was assumed that no inactivation of bacteria took place on the polyethersulfone membranes.

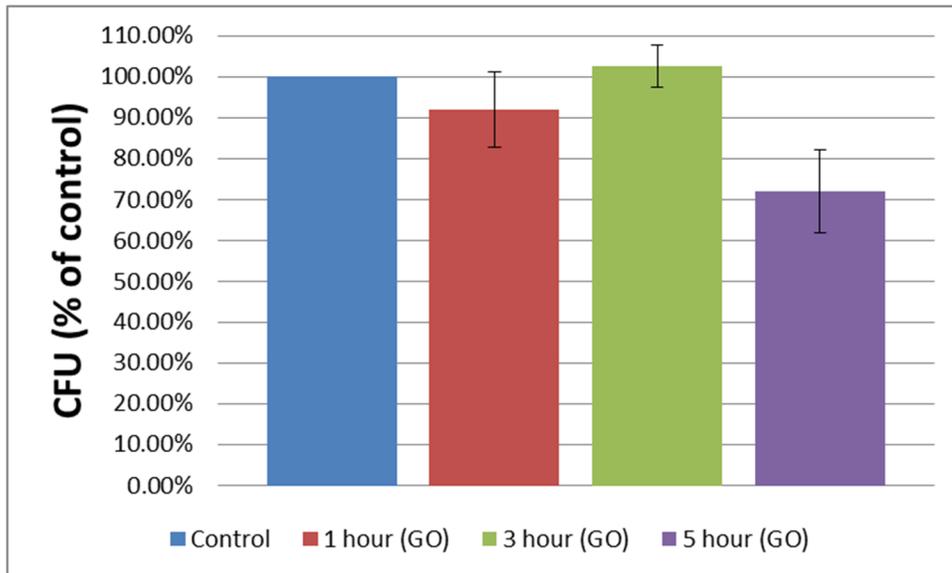


Figure 1: Bacterial inactivation results

Results from the bacterial inactivation experiment are shown in Figure 8. There were 92% of cells remaining after the 1 hour contact time and 72% remaining after the 5 hour period. The percentage of cells that remained alive after 3 hour of contact time was similar to that after 1 hour of contact time. The GO coated membranes showed increased inactivation properties when compared with the polyethersulfone membranes besides for a few exceptions. Increase of contact time with the GO membrane increased contact time improves bacterial inactivation for GO membranes. Bacterial inactivation tests were conducted for membranes created using layer by layer

deposition method, but no inactivation was measured. A study conducted using similar GO coated membranes reported 41% of *E. coli* cells remaining after a 1 hour contact time (Perreault et al., 2013). They also stated that increased contact time increased the inactivation of cells.

6. Summary of the findings

The focus of the study was to develop a graphene oxide (GO) coated membrane, and test its applicability for water filtration. Two methods were used to produce the GO coated membranes. Method 1 was based on direct deposition via vacuum filtration of GO, and Method 2 was based on a chemical layer-by-layer deposition. Following is a summary of the findings:

- Pure water flux measurements revealed that increasing the loading rate of the GO coating on the polyethersulfone following Method 1 decreased the pure water flux. Pure water flux measurements ranged from 16 to 133 L m⁻² h⁻¹ bar⁻¹. Pure water flux values in this range suggest that GO coated membranes can efficiently pass water.
- The SEM images and FTIR measurements revealed complete coverage of GO on the polyethersulfone membrane following Method 1 and a lack of coverage when using Method 2.
- Water contact angles for unmodified GO surfaces had a contact angle of 28° while the modified GO surface following Method 1 had a contact angle of 59°. The increased contact angle suggests that the GO membranes modified with NaOH can more quickly pass water than an unmodified GO membrane. The membranes from Method 2 were not able to support a water droplet which supports the SEM images and FTIR measurements that reveal a limited coverage of GO on the polyethersulfone membrane support.
- Method 1 is a practical method for creating GO coated membranes because it allows the ability to easily create multiple membranes following the creation of the batch GO suspension. The difficulties of suspending GO and 1,3,5-benzenetricarbonyl trichloride (TMC) in Isopar as well as the inability to easily create various GO coated membranes at once make Method 2 a less practical method.
- Limited salt and organic dye rejection was measured for GO membranes created using Method 1 and Method 2. The limited rejection in Method 1 membranes is likely due to swelling between individual GO flakes that occurred when submerged in water. The Method 2 membrane's lack of rejection values is due to the limited GO coverage on the base membrane. The results suggest that the two methods created as reported are not effective for water purification purposes.

- Bacterial inactivation tests revealed that GO coated membranes using Method 1 had some bactericidal properties. Increased trials are likely to reveal higher inactivation rates for longer contact times. Coating membranes with GO is likely to reduce the formation of biofilms and decrease fouling. By decreasing fouling, GO coatings have the potential to increase the life of a membrane.
- Purchased GO may contain slightly different properties that effect the contaminant removal and inactivation properties of the GO coated membranes. By creating GO as opposed to purchasing it, the methods used to coat the polyethersulfone membrane with GO may provide improved contaminant rejection and bactericidal properties.

References:

Dreyer, Daniel R., Sungjin Park, Christopher W. Bielawski, and Rodney S. Ruoff. "The Chemistry of Graphene Oxide." *Chemical Society Reviews* 39 (2010): 228-40. RSC. The Royal Society of Chemistry, 3 Nov. 2009. Web. 13 Nov. 2013.

Yi Han, Zhen Xu, and Chao Gao. "Ultrathin Graphene Nanofiltration Membrane for Water Purification." *Advanced Functional Materials* (2012): 1-8. *Wiley Online Library*. 13 Dec. 2012. Web. 13 Nov. 2013.

Hu, Meng, and Baoxia Mi. "Enabling Graphene Oxide Nanosheets as Water Separation Membranes." *Environmental Science & Technology* 47 (2013): 3715-723. Print.

Perreault, F., Tousley, M., & Elimelech, M. (2013). Thin-Film Composite Polyamide Membranes Functionalized with Biocidal Graphene Oxide Nanosheets. *Environmental Science & Technology Letters*, 1, 71-76.

Rourke, Jonathan P., Priyanka A. Pandey, Joseph J. Moore, Matthew Bates, Ian A. Kinloch, Robert J. Young, and Neil R. Wilson. "The Real Graphene Oxide Revealed: Stripping the Oxidative Debris from the Graphene-like Sheets." *Angewandte Chemie* 50 (2011): 3173-177. *Wiley Online Library*. 25 Feb. 2011. Web. 20 Nov. 2013.

Sun, Pengzhan, Miao Zhu, Kunlin Wang, Minlin Zhong, Jinquan Wei, Dehai Wu, Zhiping Xu, and Hongwei Zhu. "Selective Ion Penetration of Graphene Oxide Membranes." *ACS Nano* 7 (2012): 428-37. *ACS Nano*. American Chemical Society, 7 Dec. 2012. Web. 20 Nov. 2013.

Development of a National Database of Depreciated Structure Replacement Values for Inclusion with SimSuite/HAZUS and Flood Mitigation Reconnaissance Studies

Basic Information

Title:	Development of a National Database of Depreciated Structure Replacement Values for Inclusion with SimSuite/HAZUS and Flood Mitigation Reconnaissance Studies
Project Number:	2013NE257S
USGS Grant Number:	G13AP00006
Sponsoring Agency:	COE/IWR
Start Date:	1/1/2013
End Date:	7/31/2014
Funding Source:	Supplemental
Congressional District:	
Research Category:	Social Sciences
Focus Category:	Floods, Economics, Management and Planning
Descriptors:	
Principal Investigators:	Suat Irmak, Steven Shultz

Publications

1. None
2. None

Shultz NIWR-IWR Project Report

'Development of a National Database of Depreciated Structure Replacement Values for Inclusion with SimSuite/HAZUS and Flood Mitigation Reconnaissance Studies'

Progress Report

GIS coverages of census geography (block groups and tracts) for were obtained for three study site locations Fargo/Moorhead (ND/MN), Minot, ND, and Sarpy County, NE.

Then both residential and non-residential DSRVs (from existing USACE feasibility studies) for these same three study areas were aggregated and summarized within both census block group and tract levels of geography This required GIS database development, quality control, and the merging of various database files from the USACE and sub-contractors who collected the original DSRV values.

HAZUS data points collected and modified by the USACE-IWR (HEC) staff were also obtained and integrated within the GIS database and assigned to specific floodplain and DSRV inventory areas.

New for this year is that updated HAZUS data (based on 2012 census data was used.

Also The LEHD Origin-Destination Employment Statistics (LODES) were obtained for the above census geographies in order to model the relationships between HAZUS non-residential inventory values, tax assessor valuations, and commercial business data within LODES. This is seen as the best alternative for predicting non-residential structural values nationally

Fate of steroid hormone conjugates and E. coli from manure in soil: Potential sources of free hormones and pathogens in forages and the environment?

Basic Information

Title:	Fate of steroid hormone conjugates and E. coli from manure in soil: Potential sources of free hormones and pathogens in forages and the environment?
Project Number:	2014NE260B
Start Date:	3/1/2014
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Agriculture, Non Point Pollution, Solute Transport
Descriptors:	None
Principal Investigators:	Amy Millmier Schmidt, Shannon Bartelt-Hunt, Xu Li, Daniel Davidson Snow

Publications

There are no publications.

Fate of steroid hormone conjugates and *E. coli* from manure in soil: Potential sources of free hormones and pathogens in forages and the environment?

Amy Millmier Schmidt, Dan Snow, Xu Li and Shannon Bartelt-Hunt

Publications

None

Progress Report

Introduction

The continued use of livestock manure for fertilization of agricultural land and the implications of manure-borne contaminants in the environment are important regionally and nationally. The nearly 5 million head of cattle finished and marketed in Nebraska annually provide a basis for the state's ranking among the top beef-producing states in the country. But given that cattle from a single 1,000-head beef feedlot could potentially produce over 20 billion pounds of manure annually, the volume of beef manure produced in Nebraska and the potential environmental contaminants contained in that material are significant. Among the compounds found in manure are pathogenic organisms, steroids, hormones, and other endocrine disrupting compounds (EDCs) (USEPA, 2004). Metabolites of steroid compounds administered to livestock are among the growing list of EDCs that are suspected as harmful to humans and animals for their ability to disrupt their natural hormone system. The fate of pathogens and EDCs in the environment has received increased scrutiny in recent years for their potential detrimental effects on water quality, aquatic life, and human health.

Steroid Hormones. Research has revealed that endogenous (naturally occurring) steroidal hormones are commonly found in the manure and urine of livestock (Hoffmann *et al.*, 1997; Bartelt-Hunt *et al.*, 2012) and in runoff from feedlots housing beef cattle (Bartelt-Hunt *et al.*, 2012). Likewise, synthetic steroidal hormones are widely used in the United States for beef cattle growth promotion (Preston, 1999) and can be found in the manure produced by beef cattle (Schiffer *et al.*, 2001).

Although "free" steroid hormones have been detected in surface waters at concentrations that are of concern (Kolpin *et al.*, 2002), there is question about what influences the deconjugation of steroids that are excreted in conjugated forms (glucuronides and sulfates) and are biologically less active than free steroids. Deconjugation, or hydrolysis, of steroid conjugates to their free form can be carried out by biological (enzymatic) or chemical (non-enzymatic) means (Gomes *et al.*, 2009). *Escherichia coli* (*E. coli*) has been suggested as a potential microorganism responsible for this process (D'Ascenzo *et al.*, 2003).

Pathogens. Livestock fecal wastes can contain pathogenic microorganisms such as *E. coli*, *Listeria*, *Campylobacter*, and *Salmonella* (Hinton and Bale, 1991; Mawdsley *et al.*, 1995; Pell, 1997; Nicholson *et al.*, 2005). Research has shown that *E. coli* O157:H7 and *Salmonella* can persist for up to two weeks in soil fertilized with inoculated manure (Looper *et al.*, 2009) and that *E. coli* O157:H7 can be transported by runoff water (Chapman *et al.*, 2000).

While *E. coli* O157:H7 is a very prevalent enterohemorrhagic *E. coli* (EHEC) associated with disease in humans, Shiga toxin-producing *E. coli* (STEC) O26 bacteria is recognized as an emerging pathogen of concern to both human and ruminant health. The World Health

Organization has identified O26 STEC as the second most important serogroup of *E. coli* (WHO, 1998). Though researchers have identified persistence of *E. coli* O157:H7 in soil (Looper et al., 2009), water (Chapman et al., 2000), and vegetable plant tissue (Solomon et al., 2002), the potential for internalization of this and other strains of *E. coli* in forage crops has been studied very little by comparison. Looper et al. (2009) reported that *E. coli* O157:H7 may become internalized in tall fescue plant tissue. As researchers investigate methods by which pathogenic *E. coli* are transmitted from an infected animal to a non-infected animal, the potential for the presence of these bacteria in the tissue of grazed forages cannot be overlooked.

A limiting factor to the analysis of pathogen migration and transport from land-applied manure has been the inability to physically track pathogens in real-time. Transforming bacteria with bioluminescent plasmids has been suggested to be a successful means of tracking bacteria in real-time (Moulton *et al.*, 2009a) and would provide a valuable model for identifying the migration and vector of transportation of pathogens in the environment. Detection of bioluminescent cells is extremely sensitive when using an intensified charge-coupled device camera, with as few as 50 colony forming units being distinguishable (Siragusa *et al.*, 1999).

Summary. Runoff from feedlots is a human health and environmental concern regardless of whether growth-promoting hormones are used or not. Management practices that may reduce the losses of these compounds during runoff from feedlots or following manure application to cropland need to be explored. Determining the role of manure-borne pathogens as drivers of steroid deconjugation may provide insight into how these EDCs persist in the environment following excretion by livestock. Furthermore, the potential for forages to serve as both a means of bioremediation of hormones and pathogens and as a vector for the spread of pathogens among cattle warrants exploration.

This research project is designed to quantify the effect of *E. coli* O26:H11 on deconjugation of steroids excreted by beef cattle and examine the ability of a common Nebraska forage to internalize steroid hormones and pathogenic *E. coli* present in soil. Specific objectives, in pursuit of the *long-term objective* of identifying methods for controlling losses to the environment of pathogens and EDCs from livestock production areas and land receiving application of livestock manure, are:

1. Identify and quantify steroid conjugates in fresh beef cattle urine.
2. Assess the effect of *E. coli* O26:H11 on deconjugation of steroids contained in soil.
3. Quantify the internal accumulation of steroid hormones and bioluminescent *E. coli* O26:H11 in plant tissue of tall fescue receiving contaminated wastewater.

We anticipate that the presence of *E. coli* in soils receiving applications of steroid hormones in cattle urine will increase the transformation of conjugated steroids to free steroids and facilitate the uptake of these compounds by growing forage crops. Furthermore, we anticipate internalization of *E. coli* in the plant tissue of tall fescue grown on soil receiving applications of the pathogen.

Proposed Plan

The project will be conducted in a biosecurity level-2 (BSL-2) room in the Insectary Greenhouse on UNL East Campus starting in Summer 2015. The Institutional Biosafety Committee protocol for the project has been approved and the necessary BSL-2 laboratory space and equipment for the project have been secured in Chase Hall. Fescue seeding in plant trays will begin in June 2015 with application of treatments to growing fescue planned for August 2015.

Soil and Plant Preparation. Tall fescue will be seeded into plastic trays (4 trays per treatment, 18 cells per tray, n=72 plants per treatment) containing a commercial potting soil. Plants will be allowed to grow to a height of six inches before treatments are applied. Prior to application of treatments, plants will be manually trimmed to a uniform height of four inches.

Luminescent Bacteria Preparation. *E. coli* O26:H11 strain EH1534 (ATCC BAA-1653) will be acquired and transformed with light producing plasmid (pAK1-*lux*) following the methods described by Moulton *et al.* (2009b).

Urine Preparation. Fresh urine will be collected from beef cattle at the Animal Science Research Center and undergo an enzymatic deconjugation treatment to quantify steroid conjugate concentrations in the urine using the methods described by Gomes *et al.* (2009).

Experimental Design. Each treatment (ECU, U, EC and CTRL) will be applied to three trays as illustrated in Figure 1. All trays will receive 1 L of liquid applied to the tray beneath the plants for uptake by roots (rather than surface applied to soil). Liquid will be comprised of dechlorinated water spiked with urine and/or transformed *E. coli*. Additional liquid will be added to plants daily to facilitate plant growth and simulate the regular excretion of urine from cattle while grazing.

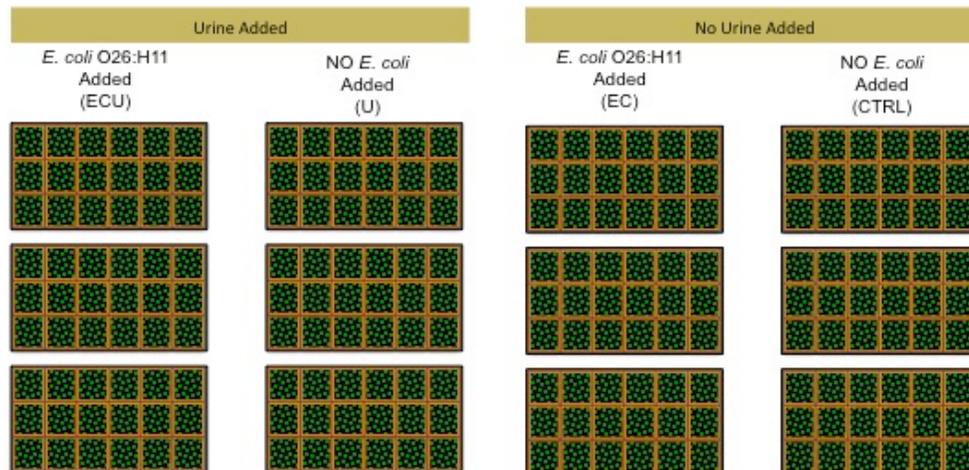


Figure 1. Experimental design

Plant Tissue Analysis. Three plants will be randomly selected from each tray at 1, 4, 7, 14, 21 and 28 d following application of treatments and the top 10 to 13 cm of plant tissue growth removed using sterile methods. Plants will be surface sterilized by rinsing with distilled water to remove all organic matter, individually immersing in 100% ethanol for 20 s, and allowing to air dry for 15 min. Plant tissue samples will be minced into 2- to 3-mm pieces using sterile scissors or scalpels and a sub-sample of each tissue sample will be homogenized in sterile distilled water. One milliliter samples of homogenate will be serially diluted in 10-fold increments in phosphate buffered saline, plated on LB agar, and incubated for 24 h at 37°C. Dilution plates will be counted for total colony-forming units (CFU) and photonic images of plates will be taken. *E. coli* O26:H11 \log_{10} values will be determined based upon total CFU counted from LB agar minus non-emitting colonies ($\log_{10} = \text{Total CFU} - \text{non-emitting CFU}$). Remaining plant tissue samples will be sub-sampled and analyzed via microwave assisted solvent extraction followed by LC-MS/MS (Snow *et al.*, 2013) to quantify concentrations of free steroid hormones present in the tissue.

Soil Analysis. Soil samples will be collected from the area around the roots of each plant and sub-sampled for bacterial culture and steroid hormone analysis using the same procedure as described for plant tissue analysis.

Statistical Analysis. Percentage of soil and plant tissue samples positive for *E. coli* O26:H7 will be calculated for each collection period and used to determine the effect of length of time on percentage of soil and plant tissue samples positive for this strain of *E. coli*. Concentrations of steroid hormones in soil and plant tissue components will be analyzed to determine the effects of time, *E. coli* treatment, and *E. coli* treatment x time.

References Cited

- Bartelt-Hunt, S., D.D. Snow, W.L. Kranz, T.L. Mader, C.A. Shapiro, S.J. vanDonk, D.P. Shelton, D.D. Tarkalson, and T.C. Zhang. 2012. Effect of growth promotants on the occurrence of endogenous and synthetic steroid hormones on feedlot soils and in runoff from beef cattle feeding operations. *Environ. Sci. Technol.* 46(3):1352-1360.
- Chapman, P.A., J. Cornell and C. Green. Infection with verocytotoxin-producing *Escherichia coli* O157 during a visit to an inner city open farm. *Epidemiol. Infect.* 2000; 125:531-6.
- D'Ascenzo, G., A. DiCorcia, A. Gentili, R. Mancini, R. Mastropasqua, M. Nazzari, and R. Samperi. 2002. Fate of natural estrogen conjugates in municipal sewage transport and treatment facilities. *Sci. of the Total Environ.* 302: 199-209.
- Gomes, R.L., W. Meredith, C.E. Snape, and M.A. Sephton. 2009. Analysis of conjugated steroid androgens: Deconjugation, derivatisation and associated issues. *J. of Pharm. Biomed. Anal.* 49:1133-1140.
- Hinton, M. and M.J. Bale. 1991. Bacterial pathogens in domesticated animals and their environment. *J. Appl. Bacteriol.* 70:81S-91S.
- Hoffman, B., T.G. dePinho, and G. Schuler. 1997. Determination of free and conjugated oestrogens in peripheral blood plasma, feces and urine of cattle throughout pregnancy. *Exp. Clin. Endoc. Diab.*(105):296-303.
- Khan, S.J., D.J. Roser, C.M. Davies, G.M. Peters, R.M. Stuetz, R. Tucker, and N.J. Ashbolt. 2008. *Environ. International.* 34:839-859.
- Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: A national reconnaissance. *Environ. Sci. Technol.* 36(6):1201-1211.
- Looper, M.L., T.S. Edrington, T.R. Callaway, and C.F. Rosenkrans, Jr. 2009. Fate of *Escherichia coli* O157:H7 and *Salmonella* from contaminated manure slurry applied to soil surrounding tall fescue. *Letters in Microbiol.* 513-516.
- Mawdsley, J.L., R.D. Bardgett, R.J. Merry, B.F. Pain, and M.K. Theodorou. 1995. Pathogen in livestock waste, their potential for movement through soil and environmental pollution. *App. Soil Ecol.* 2(1):1-15.
- Moulton, K., P. Ryan, D. Christiansen, R. Hopper, C. Klauser, W. Bennett, S. Rodts-Palenik, and S. Willard. 2009a. Ex vivo bioluminescence imaging of late gestation ewes following intrauterine inoculation with *lux*-modified *Escherichia coli*. *Comp. Immun. Microbiol. Infect. Dis.*; 429-438.
- Moulton, K., P. Ryan, D. Lay and S. Willard. 2009b. Postmortem photonic imaging of *lux*-modified *Salmonella Typhimurium* within the gastrointestinal tract of swine after oral inoculation in vivo. *J Anim Sci* 87:2239-44.
- Nicholson, F.A., S.J. Groves, and B.J. Chambers. 2005. Pathogen survival during livestock manure storage and following land application. *Bioresource Tech.* 96(2):135-143.
- Pell, A.N. 1997. Manure and microbes: Public and animal health problem? *J. Dairy Sci.*

80(10):2673-2681.

- Schiffer, B., A. Daxenberger, K. Meyer, and H.H. Meyer. 2001. The fate of trenbolone acetate and melengestrol acetate after application as growth promoters in cattle: environmental studies. *Environ. Health Perspect.* 109(11):1145-1151.
- Siragusa, G.R., K. Nawotka, S.D. Spilman, P.R. Contag and C.H. Contag. Real-time monitoring of *Escherichia coli* O157:H7 adherence to beef carcass surface tissues with a bioluminescent reporter. *Appl. Envir. Microbio.* 1999; 65:1738-45.
- Snow, D.D., T. Damon-Powell, S. Onanong, and D.A. Cassada. 2013. Sensitive and simplified analysis of natural and synthetic steroids in water and solids using on-line solid-phase extraction and microwave-assisted solvent extraction couple to liquid chromatography tandem mass spectrometry atmospheric pressure photoionization. *Anal. Bioanal. Chem.* 405(5):1759-1771.
- USEPA. 2004. Risk management evaluation for concentrated animal feeding operations. EPA-600-R-04-042. USEPA, Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, OH.
- World Health Organization. 1998. Zoonotic non-O157 Shiga toxin-producing *Escherichia coli* (STEC). Report of a WHO scientific working group meeting. WHO/CSR/APH/98.8. World Health Organization, Geneva, Switzerland.

Documenting Stream/Groundwater Interaction in the South Platte River

Basic Information

Title:	Documenting Stream/Groundwater Interaction in the South Platte River
Project Number:	2014NE261B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	NE - 3rd District
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Surface Water, Hydrology
Descriptors:	None
Principal Investigators:	Douglas R Hallum, Les Howard, Steve Sibray

Publications

There are no publications.

BACKGROUND

The project area includes the South Platte River valley between Julesburg, CO and North Platte, NE (Figure 1). Important locations include stream gages at Julesburg, CO, and the diversion and spill records from North Platte River canals that provide the water budget framework relating to surface water inflow for the reach, the DNR stream gage at North Platte and the NPPD spill at North Platte that together provide the total stream discharge for the project area, the Roscoe, NE stream gage that bisects the reach to refine the overall water budget, the Western Irrigation District (WID) and Koryt diversions that divert and retime water within the reach, and monitoring locations at Big Springs, the WID spill area, east of Ogallala, east of Paxton, east of Hershey and in North Platte.

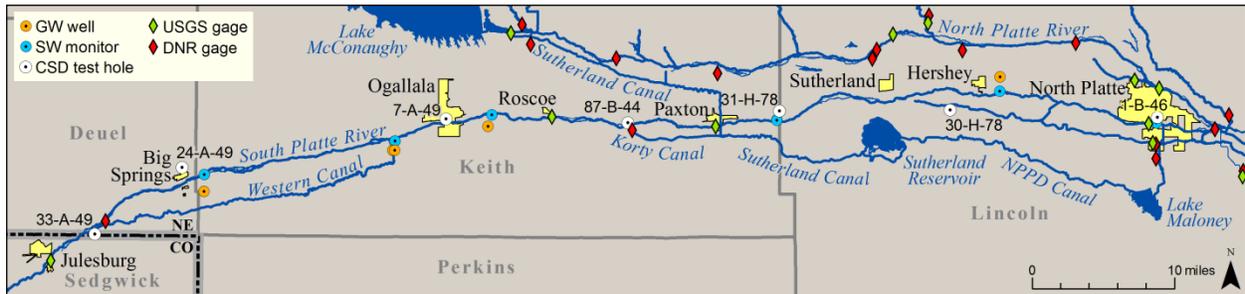


Figure 1: Project overview showing the South Platte River, canals, USGS and DNR stream gages, and monitoring locations of groundwater (GW well) and surface water (SW monitor) installed for this project.

Streamflow

Historically, the South Platte River is known to lose flow between the Julesburg, CO and Roscoe, NE gages. This means that the downstream gage (Roscoe) has routinely measured lower stream flow than the upstream (Julesburg) gage (Figure 2). Between Roscoe and North Platte, the river is generally known to gain up to 200 cubic feet per second (cfs) of streamflow, which represents much of the typical flow in the South Platte River at North Platte. This knowledge is only partly reflected in the data compiled for this study. When accounting for water diverted from and returned to the reach, data collected for this project indicate a 213 cfs reach gain on average between Julesburg and Roscoe, different from the expected loss, while the average gain between Roscoe and North Platte is 146 cfs, which is fairly consistent with the historic concept (Figure 3). While losses are generally expected between Julesburg and Roscoe, it is apparent that in a particular year this may not be the case.

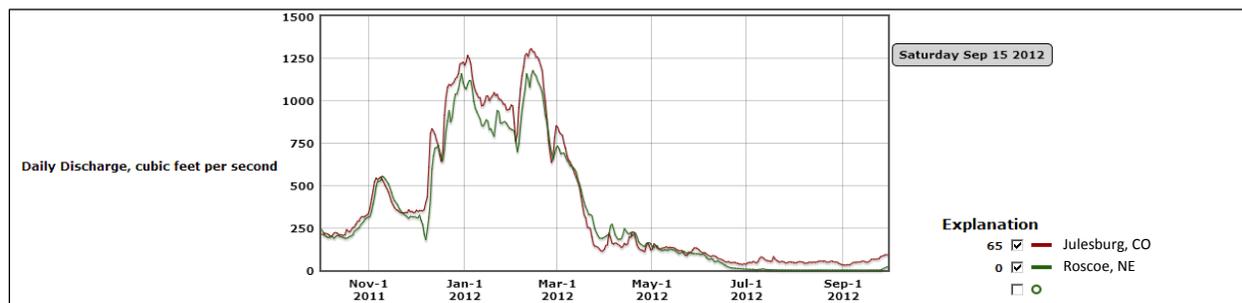


Figure 2: Chart showing 2011-2012 stream flow between Julesburg, CO and Roscoe, NE. Times when the Julesburg flow (red) is higher than the Roscoe flow (green) illustrate when the reach is losing water to the aquifer and adjacent lands.

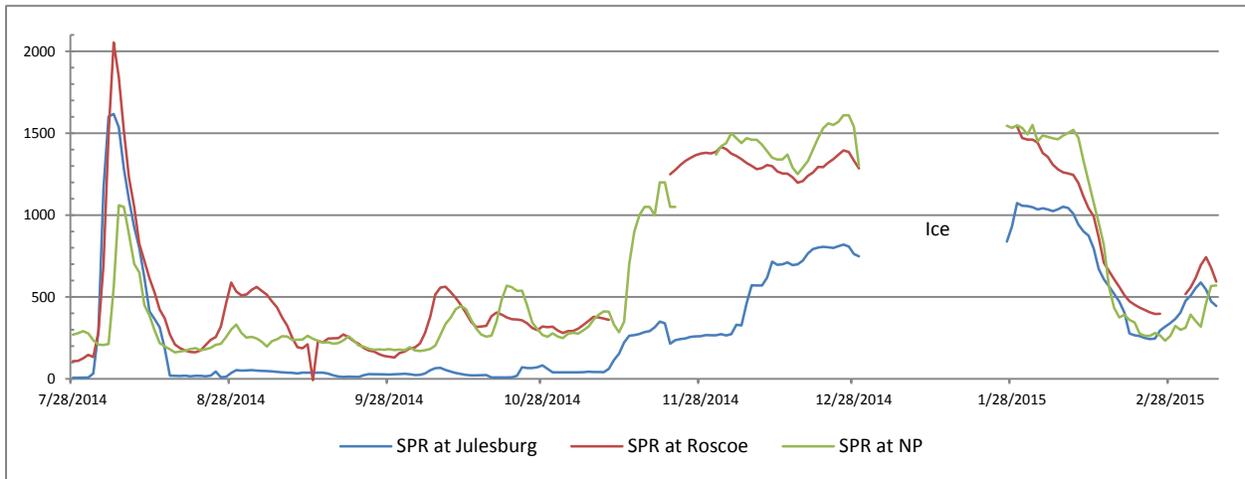


Figure 3: Chart showing daily streamflow (cfs) of the South Platte River at Julesburg, Co, Roscoe, NE, and North Platte, NE during the period of this study, demonstrating dominantly increasing streamflow downstream.

Geology

Geologically, there is distinctly different bedrock along the upper and lower portions of this reach, consisting of the Eocene to Oligocene White River Group, a regional aquiclude and base of the High Plains aquifer locally, and the Miocene Ogallala Formation, our principle aquifer unit, respectively (Figure 4). The White River Group is formed of fine-grained, dominantly wind-blown silty sediments. The river deposited Ogallala formation is formed of mixed alluvial sediments from gravels, to sands, to silts, and occasionally clay. Along the stream, the South Platte River and its associated Quarternary alluvial sediments, rests directly on the White River Group in Deuel County and in western Keith County, and on the Ogallala Formation in the remainder of our study area. The Ogallala Formation thickens to the east, such that it is up to five hundred feet thick at the downstream end of the study area in North Platte. The White River Group thins or terminates to the south, being absent in parts of southern Keith and Lincoln Counties. In areas where the White River Group is absent, the Cretaceous Pierre shale represents the base of aquifer. Within the upper Ogallala Formation, there is a zone of fine grained material (an aquitard) that partly separates upper and lower water producing zones, as shown in Figure 5.

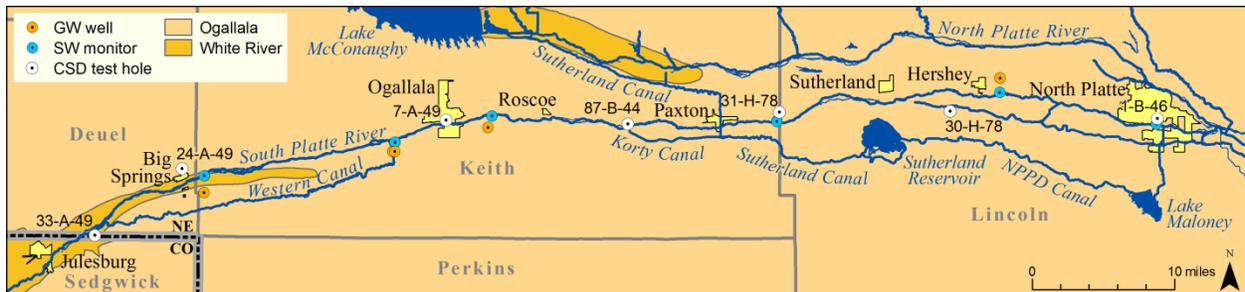


Figure 4: Bedrock Geology showing the relatively impervious White River Group (silty sediments) in the river valley in Sedgwick County, Colorado, as well as Deuel and western Keith County in Nebraska and the Ogallala Formation underlying the remainder of the reach. Regionally, the extent of the Ogallala Formation is considered to be equivalent to the extent of the High Plains aquifer, even though an alluvial aquifer exists along the stream margin upstream into Colorado.

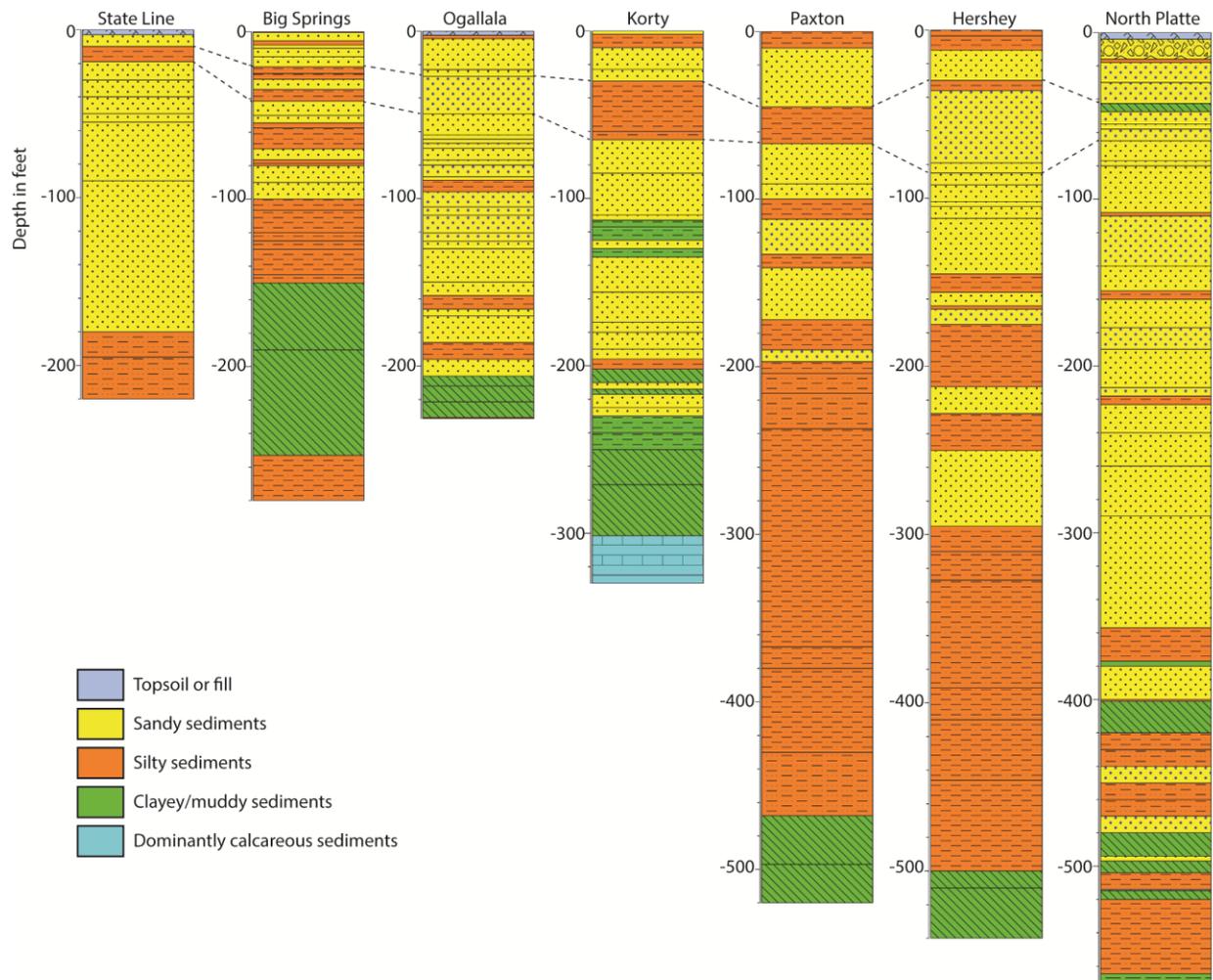


Figure 5: Lithologic logs from the CSD test hole database ordered from upstream to downstream, left to right. Lines between the logs connect zones of relatively low hydraulic conductivity, which may mitigate the effects of aquifer or surface water stresses (head changes) across the boundary locally. Lithological differences between locations may indicate lateral discontinuity of the low hydraulic conductivity zone.

Land Use

Land management practices have changed through time within the reach. Early producers used available natural flow from the reach to irrigated crops, either by direct diversion of water, or through the development of irrigation districts, like the Western Irrigation District. The Western Irrigation District diverts water just downstream of Julesburg, CO, and serves acreage on the south side of the valley in Deuel and Keith Counties. Historical information was examined and it was discovered that aerial imagery from 1938 and 1954 was available for portions of Deuel and Keith Counties, respectively as shown in Figure 6.

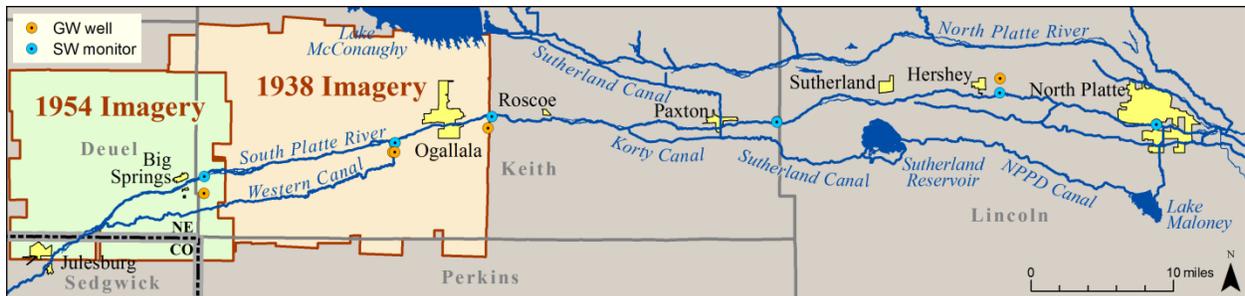


Figure 6: Project area map showing locations where historical aerial photography was scanned and geo-referenced for geographic analysis.

Figure 7 illustrates land use changes recognizable from the aerial imagery collected from the region between the Big Springs and the WID spill monitoring locations in 1938 and 2012, respectively. In addition to the stark change relating to center pivot irrigation, both sets of images show relatively abundant riparian vegetation. The imagery collected in 2012 shows a much better developed active channel that is clearly distinguishable from the surrounding riparian woodland, while the imagery collected in 1938 apparently shows woody vegetation distributed much more regularly across the riparian zone with a less obvious channeling.



Figure 7: Sampling of historical aerial imagery processed for the study from 1938 (above) compared to modern aerial imagery collected in 2014 (below) for the reach from Big Springs to the WID spill groundwater (orange) and surface water (blue) monitoring locations.

OBJECTIVES

The overall objective of the project was to gain better understanding of the South Platte River and the relative effects that gaining and losing reaches of the river play with respect to translating stresses through the hydrogeological system, particularly relating to the western margin of the High Plains aquifer, and to relate water measurements collected to water and land use management practices in the region such that local water managers and producers can identify and employ best management

practices locally while understanding regional implications. The study was successful in identifying that the streamflow data collected at the gages can indicate a dominantly gaining condition, while the automated measurements collected for this study are indicative of a generally losing condition. The relationship between this apparent disconnect is not yet well understood.

Specific accomplishments of this study included summarizing stream flow and canal diversion data, scanning and geo-referencing historical aerial photographs to provide land use information, installing stream stage recording devices in proximity to existing groundwater monitoring wells, collecting hourly stream stage and groundwater levels for 7 months, and building a generalized water budget of the reach relating to streamflow. Synthesizing hydrologic and hydrogeological conceptual models of the reach is an objective that remains, which is largely a result of inconsistent data necessitating further investigation. Measurements summarized and conducted for this study are consistent with the water budgets produced by management models to the extent current flow measurements are consistent with historical ranges. Comparing newly hypothesized conceptual models and measured water budget components to regional modeling tools is not possible at this time, since the data collected do not coincide temporally with the water budgets simulated in the models.

METHODS

Seven stream stage measurement stations within 1.2 miles of seven groundwater monitoring well nests (shallow and deep) were installed. Stream stage measurement stations consisted of a two inch by three foot stainless steel screen and a five foot stainless steel riser that were driven into the stream bed. The South Platte River stream stage was measured hourly at seven locations corresponding with each of the groundwater well nests. Groundwater was measured hourly at seven locations by pressure transducers in previously existing monitoring well nests maintained by the Twin Platte Natural Resources District near Big Springs, the WID spill area (2 locations), Ogallala, Paxton, Hershey, and North Platte. Two transducers were deployed at each location, one each under water table (shallow) and semi-confined (deep) conditions. Shallow groundwater conditions were measured between 14' and 40' below ground surface, while deep conditions were measured between 67' and 150' below land surface.

Landowners reported that the winter flow in the river was much higher than normal, and that ice buildup was more severe than they had witnessed to date. Historical flow data for the decade of 1994 to 2004 indicate average flow during winter months around 300 cubic feet per second, demonstrating that the flows gaged during the study were abnormally high. Correspondingly, several surface water monitoring sites were damaged by ice and/or debris during times when river stage was high and ice flow was large. The shallow screens installed at Hershey, Ogallala, upstream and downstream of the Western Irrigation District, and at Big Springs were damaged or moved enough that they were replaced, or re-installed.

Surveys were conducted and markers installed by the Nebraska Department of Natural Resources at each location to establish survey-grade vertical control, and the monitoring point on each well and surface water monitoring point was surveyed by optical level from the survey markers.

Twenty-one transducers were programmed to collect hourly synchronized data and were installed, programmed and deployed between July 1 and July 28, 2014. All data reported herein are from the 111,405 measurements collected between July 28, 2014 and March 9, 2015, a time period when all sensors were operating. Data from the pressure transducers was uploaded during periodic (approximately bi-monthly) site visits. Figure 8 shows the temporal variability of surface water and groundwater elevations at North Platte.

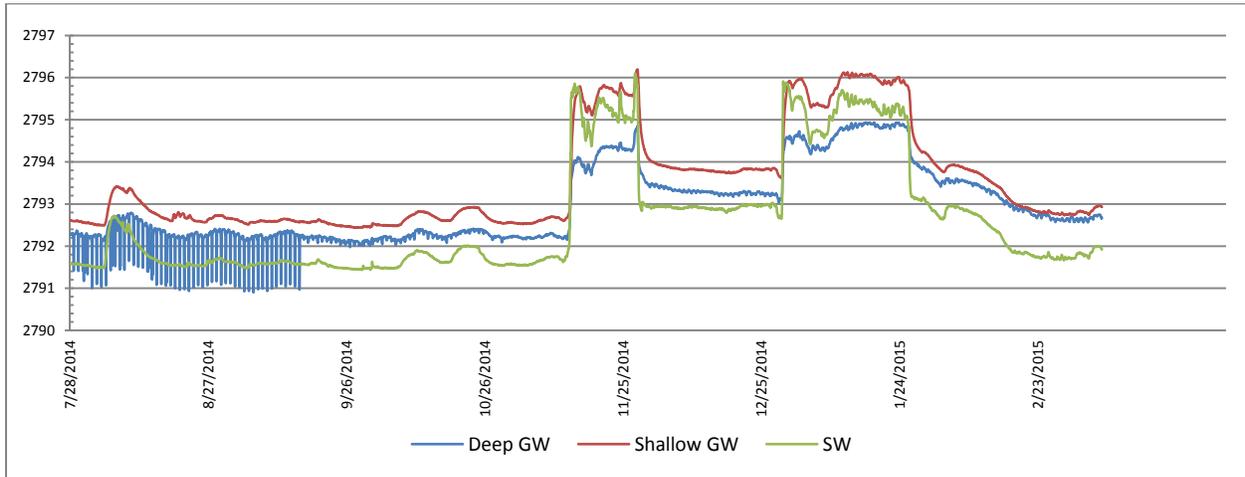


Figure 8: Chart illustrating temporal relationship between stream stage (SW), and shallow and deep groundwater elevation (ft) at North Platte. The chart illustrates that the relative elevations of the stream and shallow groundwater, as well as between shallow and deep groundwater, vary, and even reverse themselves in response to changes in the groundwater system (e.g. 7/28/2014-9/15/2014) and the surface water system (e.g. 11/13/2014-11/29/2014, and 12/29/2014-1/24/2015).

Transducer data were converted to elevation and stream/groundwater gradients were calculated by dividing the difference in shallow groundwater elevation and stream stage by the horizontal distance between the monitoring points, quantifying the relative slope of the water table between the points. Negative slope indicates that water in the stream is higher than in the ground, and should therefore induce losses from the stream to the ground, while positive slope indicates the opposite, that water table elevation in the ground is higher than the stream, so should discharge groundwater into the stream.

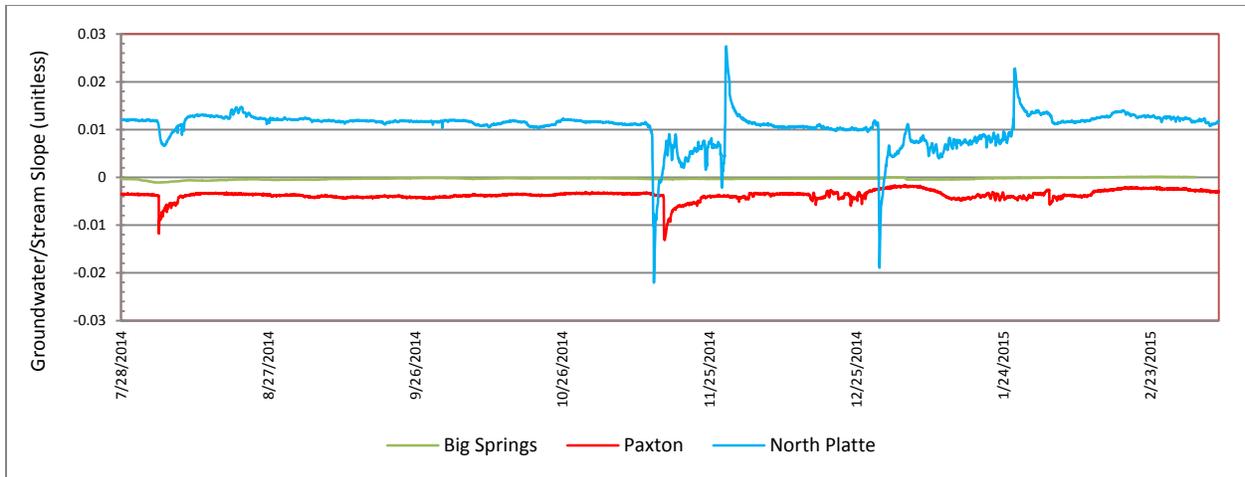


Figure 9: Chart illustrating the spatial and temporal variability of water table slope near the stream. The upstream locations (Big Springs and Paxton) have negative slopes most of the time, while the downstream location (North Platte) has a positive slope most of the time, except when the surface water has extremely high stage (from Figure 7). The magnitude of the slope (either positive or negative) is inversely related to the distance between the surface water and groundwater measurements, as demonstrated by the Big Springs slope is much less negative than that at Paxton, because the distance between measuring points is much greater at Big Springs (6245') than Paxton (110').

Canal diversion data is recorded continuously and aggregated to daily values reported by the Nebraska Department of Natural Resources (DNR). Water spilled from the WID was also measured by the DNR. Stream flow measurements are recorded and reported by the DNR and the US Geological Survey (USGS). The measurements serve as the water budget framework for the study (Figure 10).

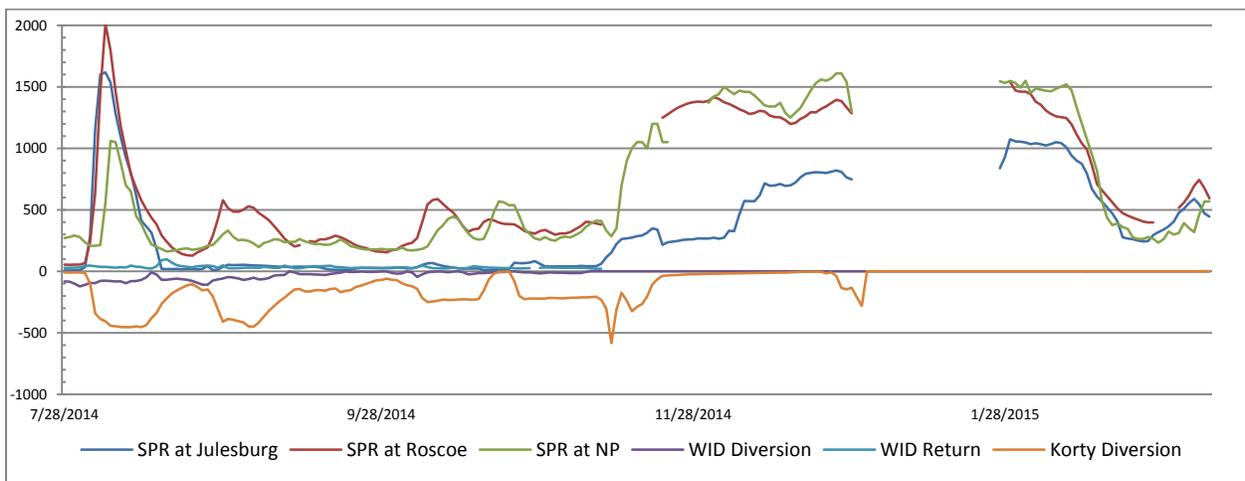


Figure 10: Chart illustrating temporal variability of reach water budget. System discharge (stream flow and canal spills) is shown as positive values, while canal diversions for consumptive use and incidental/intentional recharge to groundwater are shown as negative values. Times when downstream flow is less than upstream flow, such as during the August high flow event near the left of the chart, essentially represent diversions distributed through the reach between the respective gages that will augment groundwater storage and consumptive use of phreatophyte vegetation.

RESULTS

The primary results of this project include the collection of nearly 300,000 new measurements of water level, temperature, barometric pressure, and conductivity. Water levels, when converted to a common datum via surveying, provide a means to quantify water table slope relative to the South Platte River, and to determine if water should move into or out of the stream. Barometric pressure measurements are necessary to process the water level data. Temperature and conductivity data can be used as local tracers over short timeframes. The data are being used to begin answering a number of questions at a variety of temporal and spatial scales along the reach. A summary of representative site specific elevation data is provided to illustrate the different stream/groundwater relationships that were observed.

Big Springs

Big Springs is the west most monitoring location on the right bank of the active channel at the upstream extent of the High Plains aquifer. It is underlain by about 20' of Quarternary alluvium at the surface water and groundwater monitoring sites and about 80' of Ogallala Formation at the groundwater monitoring site. There are several layers of silt shown in the test hole logs that can function as aquicludes between the shallow and deep aquifer. The sites are both about one mile east of the town of Big Springs; the surface water monitor directly east, and groundwater to the southeast (Figure 11). It is approximately midway between the WID diversion at Julesburg, and the WID spill west of Ogallala. The groundwater wells are screened at depths of 20-30' and 67-70' below ground surface, and the surface water monitor screen is approximately 2-5' below the riverbank surface.



Figure 11: Map showing the Big Springs site configuration.

Data collected at Big Springs show that for much of the monitoring period, the surface water elevation was significantly higher than the groundwater elevation, and that the shallow and deep groundwater levels were virtually indistinguishable, possibly indicating a direct connection between shallow and deep groundwater, or lack of an aquitard. When the levels were below 3,344.5' (8/15/2014), the deep groundwater measurement is lower than the shallow groundwater measurement, possibly the result of the shallow well going dry (Figure 12). In the latter part of February and March, groundwater levels increased enough to reverse the water table slope, indicating a gaining condition at this location. The mean elevation of surface water was 3,349.64', and the mean elevation of shallow groundwater was 3,347.89', resulting in a mean water table slope of - 0.00028, or one foot of vertical fall in about 3,600 feet horizontal, meaning the water table over the measurement timeframe sloped to the south on average, away from the South Platte River.

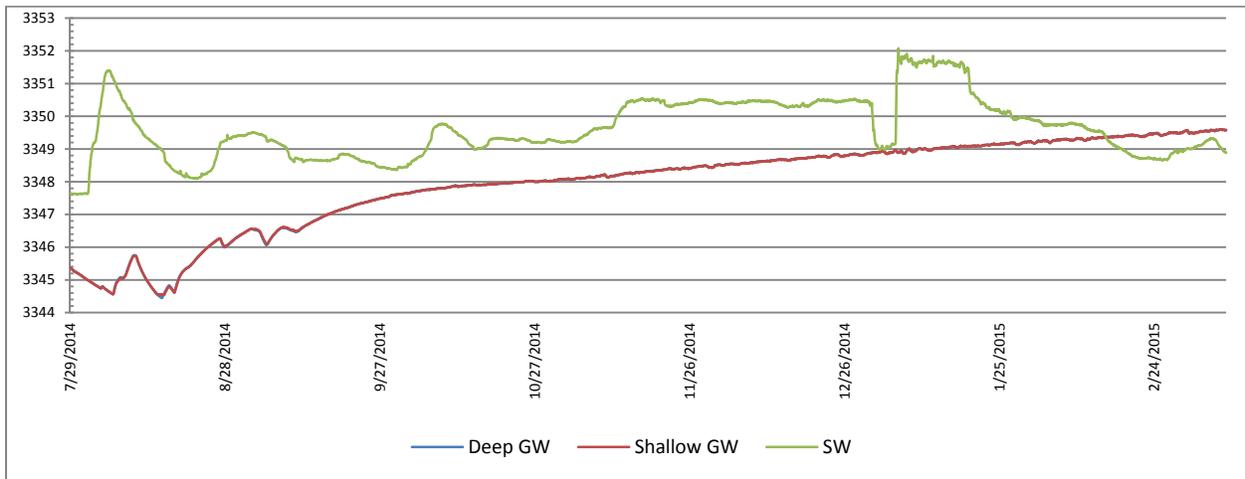


Figure 12: Time series showing groundwater and surface water elevations (ft) at the Big Springs site.

Ogallala

The Ogallala site is about 2.5 miles east of the city of Ogallala, on the right bank of the active channel (Figure 13). It is underlain by about 30' of Quarternary alluvium and about 35' of sandy silt which comprises the top portion of the Ogallala Formation. This could serve as a local aquitard between the shallow and deep portions of the aquifer, which extends to a depth of about 230'. The groundwater wells are screened at depths of 20-30' and 110.5-113.5' below ground surface, and the surface water monitor screen is approximately 1-4' below the riverbank surface.



Figure 13: Map showing the Ogallala site configuration.

Data collected at Ogallala show that for much of the monitoring period, the surface water elevation was significantly higher than the shallow groundwater elevation, and that the shallow groundwater levels were lower than both the surface water and deep groundwater, indicating the presence of a local aquitard between the shallow and deep monitoring well screens and that water should move from the stream and deep portion of the aquifer into the shallow portion of the aquifer, driven by the differences in head (water elevation) (Figure 14). The mean elevation of surface water was 3,180.40', and the mean elevation of shallow groundwater was 3,173.25', resulting in a mean water table slope of -0.00162, or one foot of vertical fall in about 620 feet horizontal distance, meaning the water table over the measurement timeframe sloped to the south on average, away from the South Platte River.

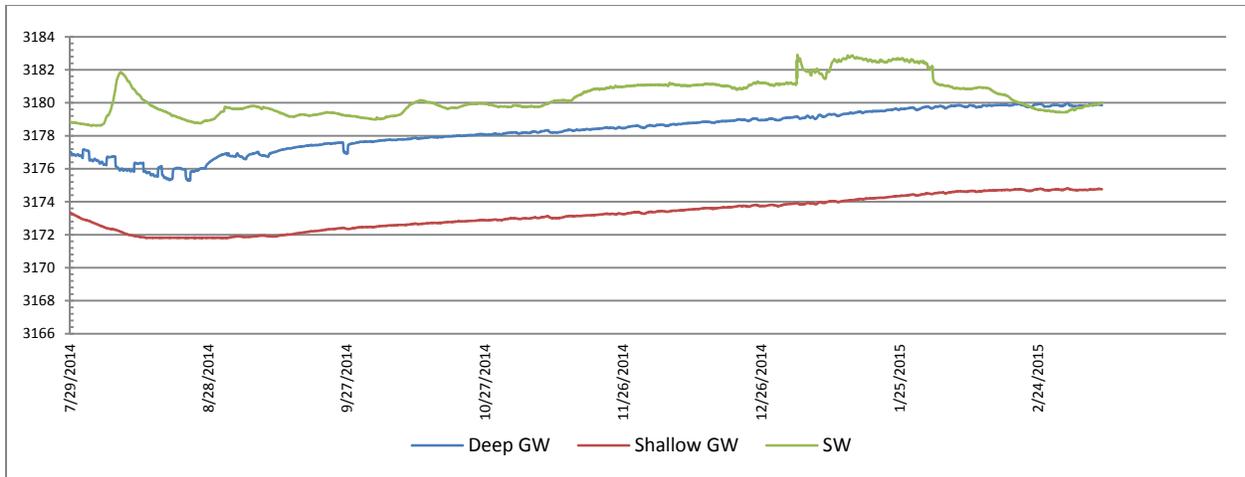


Figure 14: Time series showing groundwater and surface water elevations (ft) at the Ogallala site.

Paxton

The Paxton location is approximately the middle of the reach, on left bank of a flood channel about three miles east of Paxton (Figure 15). The area is underlain by about 40' of Quaternary alluvium and about 160' of Ogallala Formation, with about 20' of silt functioning as an aquitard. The groundwater wells are screened at depths of 20-30' and 91-94' below ground surface, and the surface water monitor screen is approximately 0.5-3.5' below the riverbank surface. Since this monitoring site is situated on a flood channel that is peripheral to the main stream flow, the channel containing the surface water monitor does not always contain water.



Figure 15: Map showing the Paxton site configuration.

Data collected at Paxton show that for the entire monitoring period, the surface water elevation was mimicked by the shallow groundwater elevation, with the surface water being about a foot higher in elevation. Both the shallow groundwater and surface water are higher than the deep groundwater elevation, indicating that the Paxton site is part of the recharge area for the deeper portions of the aquifer. For most of September into October, the shallow groundwater levels and those in the surface water monitor were uncharacteristically stable, possibly the result of the stream monitor screen going dry (Figure 16). Under this condition, the effective distance to surface water in the active channel changes from 114' to 724', a greater than six-fold increase which should mute the timing effects of stream stage changes. The mean elevation of surface water was 3,017.12', while the mean elevation of shallow groundwater was 3,016.31', resulting in a mean water table slope of -0.0071, or one foot of

vertical fall in about 140 feet horizontal distance, meaning the water table over the measurement timeframe sloped to the north, away from the South Platte River. Deep groundwater experienced significant and abrupt water level changes during the irrigation season when irrigation wells were operating, and more subtle changes during significant stream stage and shallow groundwater increases during the fall and winter months.

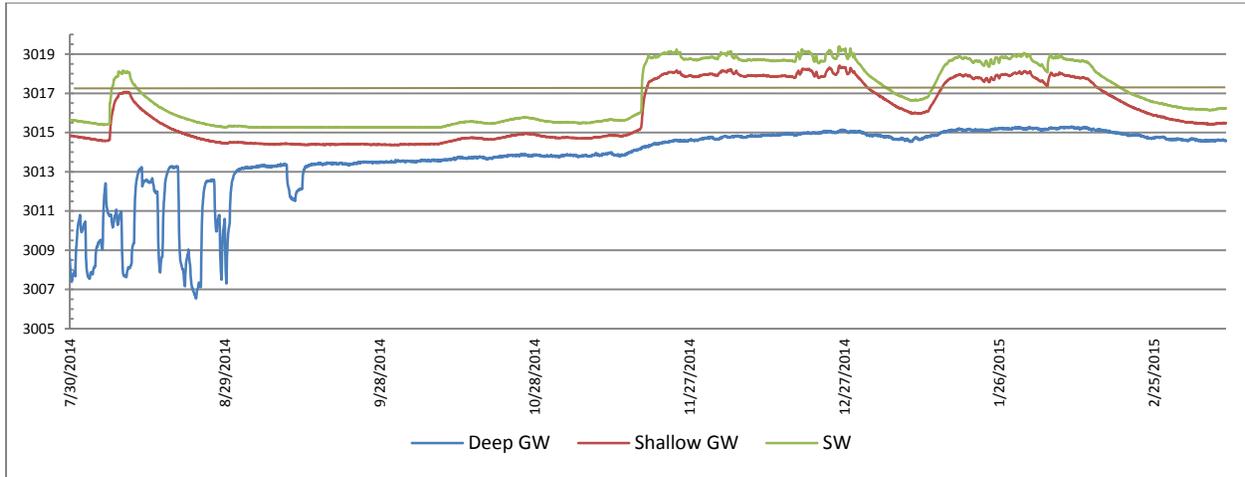


Figure 16: Time series showing groundwater and surface water elevations (ft) at the Paxton site. The tan line at 3017.2' illustrates the flood channel elevation, when the SW elevation is lower, the channel would be expected to be dry.

North Platte

North Platte is the east most monitoring location on left bank of the active channel immediately downstream of the US Highway 83 Bridge in the city of North Platte (Figure 17). It is also near the downstream extent of the South Platte River, which joins with the North Platte River just a few miles east of the monitoring site to form the Platte River. It is underlain by about 40' of Quarternary alluvium and more than 400' of Ogallala Formation. Thin layers of fine-grained muddy sediments and cemented sandy sediments comprise a possible aquitard at the top of the Ogallala Formation. The groundwater wells are screened at depths of 14-19' and 145-150' below ground surface, and the surface water monitor screen is approximately 0.5-3.5' below the riverbank surface.

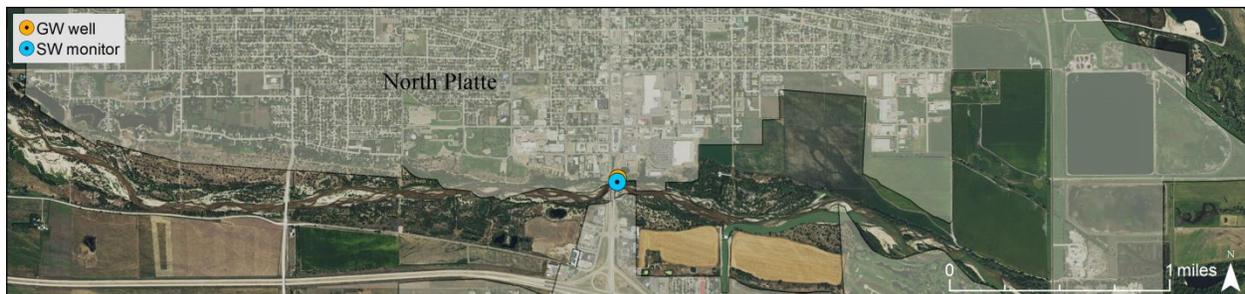


Figure 17: Map showing the North Platte site configuration.

Data collected at North Platte show that for much of the monitoring period, the surface water elevation was lower than the groundwater elevation, and the shallow groundwater was higher than the deep

groundwater (Figure 18). The mean elevation of surface water was 2,791.67', while the mean elevation of shallow groundwater was 2,792.69', resulting in a mean water table slope at the site of 0.0119, or one foot of vertical fall in about 84 feet horizontal distance, meaning the water table over the measurement timeframe sloped to the south, toward the South Platte River. Similar to the Paxton location, deep groundwater elevation was lower than the shallow elevation, and shallow groundwater at the North Platte site is also part of the recharge area for the deeper portions of the aquifer. Unique to the North Platte location is that shallow groundwater supplies both deep groundwater recharge and stream discharge.

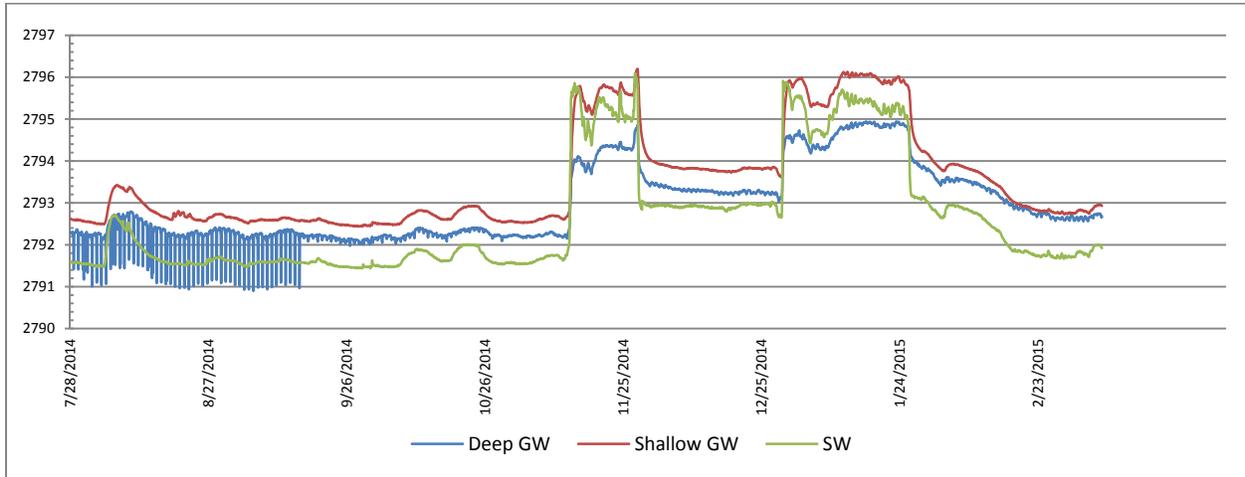


Figure 18: Time series showing groundwater and surface water elevations (ft) at the North Platte site.

CONCLUSIONS

It is possible to measure water levels and produce temporally refined water table slopes (gradients) which can be used to help estimate fluxes along the reach. Water table slopes tend to be negative (away from the stream) at, and upstream of Paxton, and positive at North Platte, supporting the conventional understanding that the South Platte River in this region tends to be a losing stream to the west, and gaining stream to the east. What was not well understood previously because of the wide spacing of stream gages was the extent of negative slope as far downstream as Paxton. Refining stream stage measurement spatially and groundwater level measurement temporally enabled us to build temporally and spatially correlated information pairs which can be used to illustrate the stream-groundwater interaction by measuring the respective head (elevation) and computing the hydraulic gradient hourly.

Based on the relative elevations of the observations, the shallow and deep groundwater systems are not discernable at the western end of the reach; at Big Springs, Ogallala and Paxton, streamflow appears to be a source of recharge for shallow groundwater, while at North Platte, shallow groundwater is a source of discharge to the stream; and at Ogallala, deep groundwater also seems to be a source of recharge to shallow groundwater, while at Paxton and North Platte, shallow groundwater appears to be a source of deep groundwater.

Data from the Paxton and North Platte monitoring sites demonstrates that short-term groundwater/surface water relationships can be observed and relationships observed across the groundwater/surface water interface, and between the shallow and deep portions of the High Plains aquifer, at least when observations are in close proximity and stage changes are significant. Future measurements will serve to refine these conclusions. Additional observations over several years may be needed to better understand the head relationships (if any) between surface water and shallow and deep groundwater between monitoring points that are more than a mile apart.

Aggregating temporally refined gradients into meaningful metrics for development of accounting tools (including detailed water budgets) requires system and modeling knowledge. Regional models like those currently in use by Nebraska managers are built on much coarser time units and streams are simulated on much finer spatial units, requiring a method of temporal aggregation and spatial distribution of the observations collected for this study. Further, current regional accounting models are not yet operated on a current water year basis, confounding a meaningful water budget, or stream/groundwater gradient comparison with the observations collected during this study.

Observations of deep groundwater at each location show drawdown effects of pumping groundwater during the growing season of crops and grasses at all locations. In some instances, it may be possible to combine observations of drawdown and/or recovery of the semi-confined parts of the aquifer with measured or estimated operational information relating to pumping wells in the vicinity of the monitoring sites and physical aquifer characteristics to generate new estimates of aquifer properties.

Local lithology along the reach relating to an aquitard between the shallow and deep parts of the High Plains aquifer is variable, possibly indicating a laterally discontinuous low hydraulic conductivity zone.

The winter of 2014 -2015 was cold and the stream wet, so ice posed a significant logistical challenge for maintaining the surface water monitors through the winter months. Locating surface water monitors near existing stream gages and in sheltered locations, or building more robust monitors may improve the winter reliability of stage measurements.

ACKNOWLEDGMENTS

In addition to the project funding provided by the USGS through the Water Resources Institutes Program and the Nebraska Water Center, the authors wish to acknowledge significant contributions of time and in-kind service from the Twin Platte Natural Resources District and the Nebraska Department of Natural Resources surveying crew and the Nebraska Department of Natural Resources Bridgeport field office; this project would not have been possible without their valuable assistance. Additionally, the project was improved by consultations with local experts from The Nature Conservancy, the Department of Natural Resources Bridgeport field office, and the West Central Research and Extension Center.

Hydroclimatic controls on the conjunctive use of surface and ground water in the Platte River Basin

Basic Information

Title:	Hydroclimatic controls on the conjunctive use of surface and ground water in the Platte River Basin
Project Number:	2014NE262B
Start Date:	3/1/2014
End Date:	10/31/2015
Funding Source:	104B
Congressional District:	1st
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Climatological Processes, Groundwater
Descriptors:	None
Principal Investigators:	Francisco MunozArriola

Publications

1. Livneh B., T.J. Bohn, D.S. Pierce, F. Munoz-Arriola, B. Nijssen, R. Vose, D. Cayan, and L.D. Brekke, 2015: A spatially comprehensive, hydrometeorological data set for Mexico, the U.S., and southern Canada 1950-2013, Nature Scientific Data (submitted).
2. Smith, K. B. Kimbal, M. Morton, and F. Munoz-Arriola. Soil Moisture and Evapotranspiration Responses to Extreme Hydrometeorological Events in the Platte River Basins (in progress).

2015 Annual Report

Project # 2014NE262B:

Hydroclimatic Controls on the Conjunctive use of Surface and Ground Water in the Platte River Basin

May 5, 2015

Principal Investigator: Francisco Munoz-Arriola, Assistant Professor
Department of Biological System Engineering and School of Natural Resources,
University of Nebraska-Lincoln

Reporting Period: March 1, 2014 through February 28, 2015

Financial support: USGS

Participants:

Undergraduate students: Mallory Morton and Daniel Rico

Graduate students: Katherine Smith*

Postdocs: Carlos Carrillo-Cruz*

*Directly funded by this funding

I. INTRODUCTION

1. Project Summary: Problem and research objectives

A major challenge for global to local sustainable development of human activities and ecosystems is present and future availability of water. Water availability (by quantity and quality) is component of an environmental state in a particular time, forced by climate variability and change and regulated by human activities such as land-use changes and population growth. Water quantity and quality (components of a water state) are regulated by the interplay between water and agricultural management practices, which alter the transfer of water across the continuum from the atmosphere to the aquifer and the biogeochemical cycles of elements such as Nitrogen and Phosphorous, both modifying the natural availability of water. Also, resource management practices play a key role shaping the water, energy, and food security under a changing climate through (un)sustainable management practices of water and agricultural resources. Funding of the present project allow the Hydroinformatics and Integrated Hydrology research group to launch a number of activities aiming to improve our ability to predict future water states. Our broad hypothesis states that improved initial conditions and modeling capabilities will be reflected in better representations of future availability of water. Thus, we developed new datasets to force our land surface hydrology models, implement dynamical changes in land use (using remote sensing), and develop the foundation for model integration. Undergraduate, graduate, postdocs have been involved in this project, contributing and lead technologic developments as well as communicating or scientific progresses. We expect to complete this project by October of 2015, in the mean time we present the present (first) report.

2. Objective

To identify the most suitable integration mechanisms to integrate a land-surface hydrologic model and a conjunctive use of surface water-groundwater model through the use of hydroclimatic controls`.

2.1. Particular objectives

- a. Simulate the land surface hydrology of the Platte River Basin using Variable Infiltration Capacities model (VIC).
- b. Develop disaggregation techniques to increase the resolution of VIC forcings and parameters.
- c. Evaluate the sensitivity of land surface hydrology variables and state variables to gradual increments in spatial resolution.
- d. Identify the pertinence of daily to monthly time-steps in vadose zone hydrology simulations using HYDRUS2D (coupled off-line with VIC).

II. RESEARCH PROGRAM

1. The assessment of the hydroclimatology of the Platte River Basin

a. Land Surface Hydrology Model Implementation

At the first stage of the project we characterized the climatology of the Platte River Basin with focus on six sub-basins: Elkhorn, Loup, Lower Platte, Middle Platte, North Plate, and South Platte (Fig. 1). The Platte River Basin encompasses an approximate area of 220,000 km², and ranges from the eastern Rocky Mountains in Colorado and Wyoming to its outlet at the Missouri River in eastern Nebraska. The hydroclimatology across the basin varies, with the western basins receiving much less precipitation than the eastern basins (Fig. 2).

Nebraska relies heavily on the conjunctive use of groundwater and surface water to irrigate agricultural land. The state ranks first nationally in terms of irrigated acres, with about 8.5 million (Census of Agriculture, 2007). Over 565,000 of those acres are irrigated with surface water that has been diverted from streams or rivers. A major contributor to these streams is precipitation in the form of rainfall or snowmelt.

Using the Variable Infiltration Capacity (VIC) model, evapotranspiration (ET) and soil moisture (SM) were simulated. The forcings of the VIC model include precipitation, minimum and maximum temperature, and wind speed. Figure 3 shows the influence precipitation has on ET and SM in the Platte River Basin. These are monthly climatologies for the 2000-2013 period.

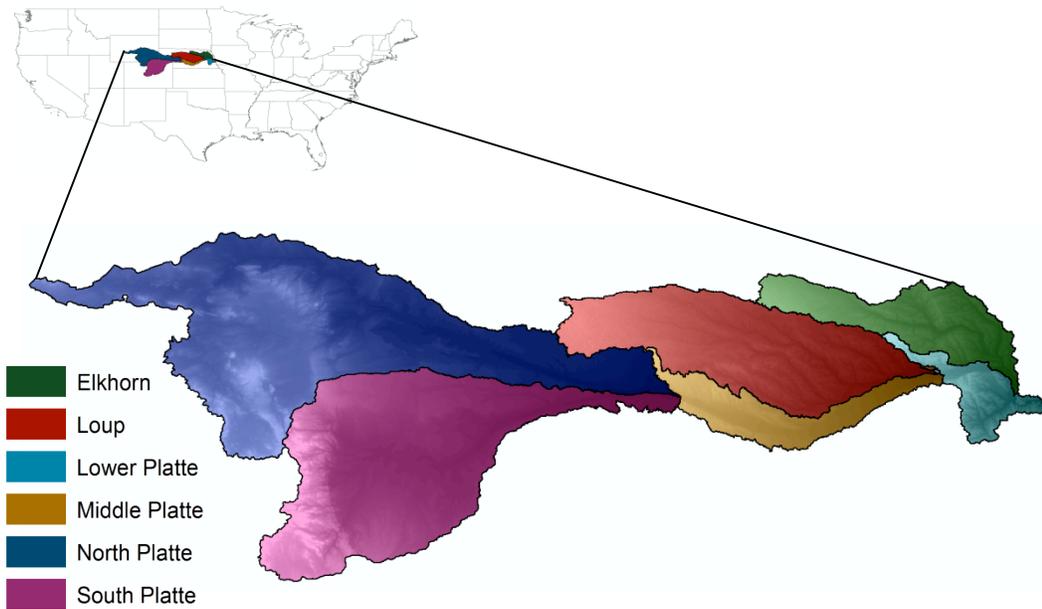


Figure 1: Location of the Platte River Basin with the sub-basins: Elkhorn, Loup, Lower Platte, Middle Platte, North Platte, and South Platte.

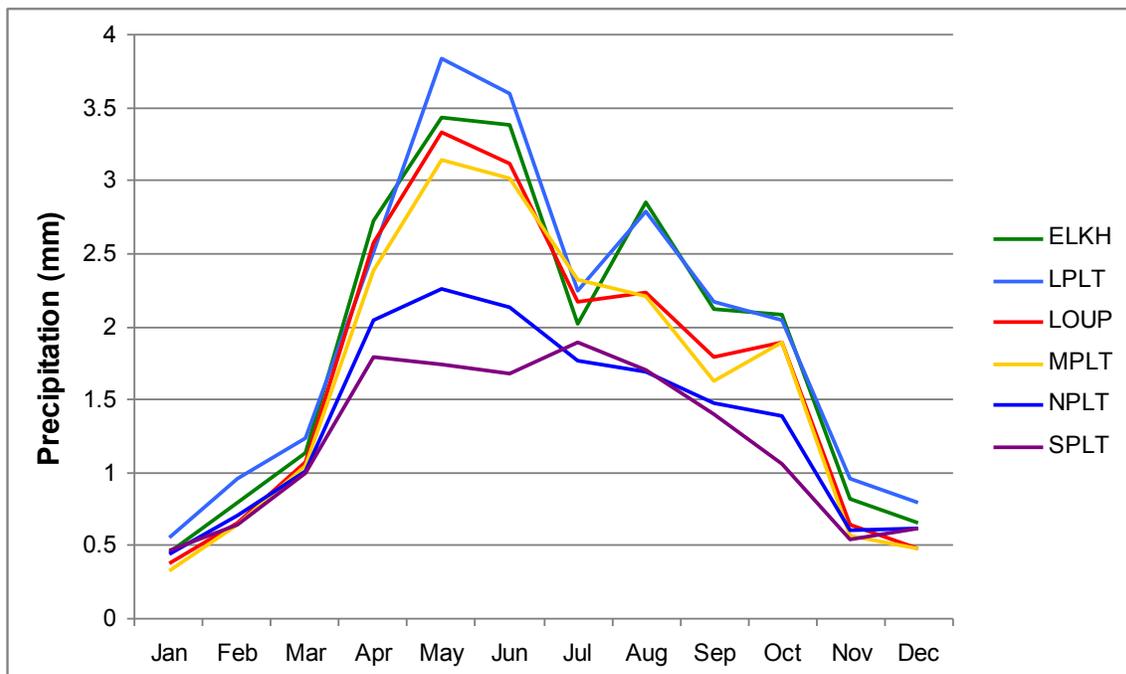


Figure 2: Annual cycle of average precipitation over the sub-basin indicated in Fig. 1.

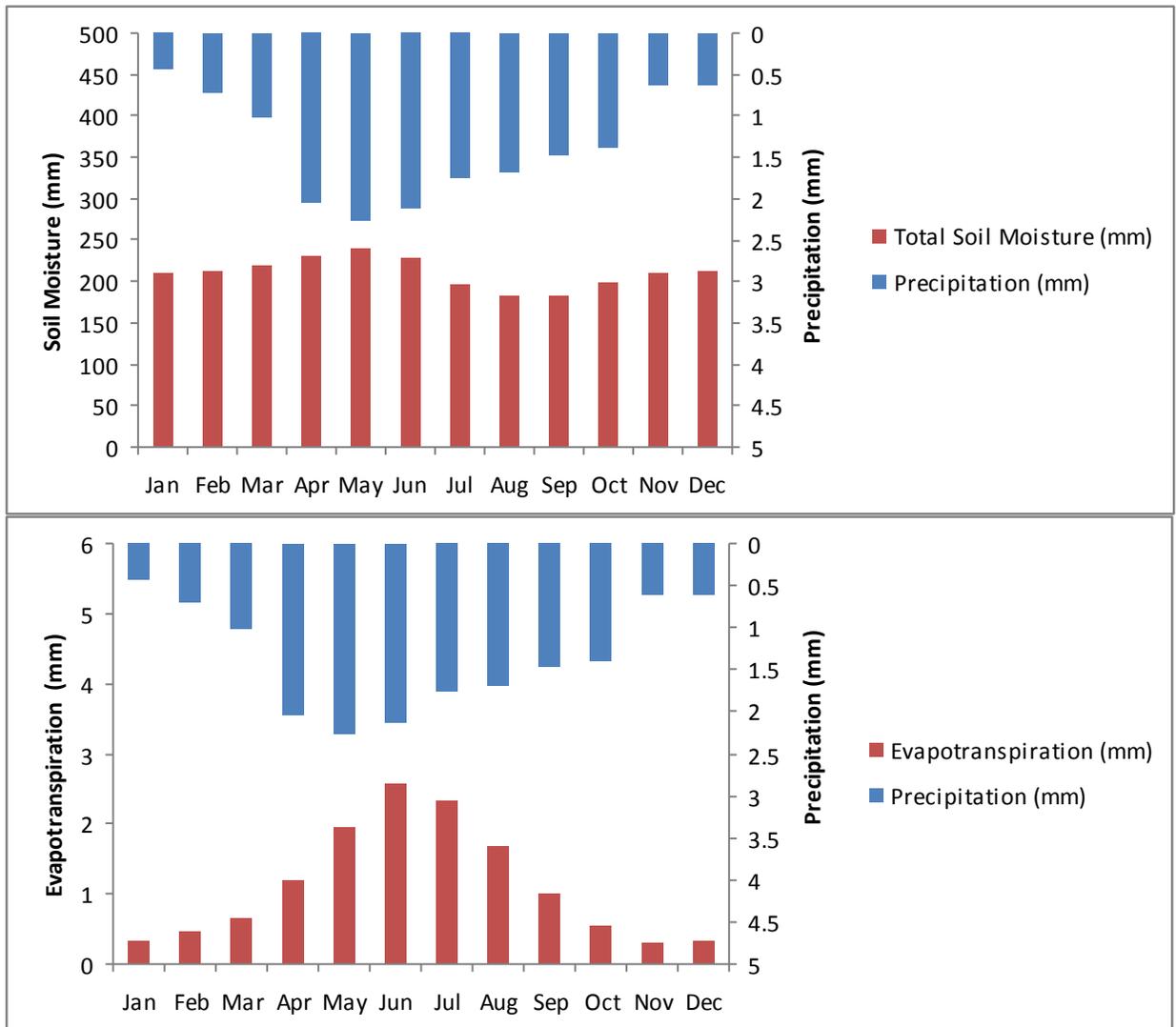


Figure 3: Annual cycle of simulated total soil moisture (top) and evapotranspiration (bottom) as simulated with VIC model over the Platte River Basin.

b. Hydroclimatic Controls

We implemented an experiment using the Land Surface Hydrology (LSH) Variable Infiltration Capacity (VIC) model, which was coupled with a routing model on the PRB to simulate streamflow. A streamflow sensitivity experiment with respect to precipitation and temperature was conducted over the Platte River Basin (PRB) during the years 1925-2005, to investigate if rising temperature or increase in changes in precipitation will be the main drivers of crop irrigation requirements in Nebraska. Our modeling simulation suggests that the PRB is sensitive to changes in precipitation and

temperature, with more conspicuous results for precipitation than temperature. For example, the north region of the PRB experienced a 0.02% (0.09%) change in streamflow value for every 1% change in temperature (precipitation) (Fig. 5). Similarly, the South PRB equaled a 0.02% (0.05%) change in streamflow for every 1% change in temperature (precipitation). The other two selected basins (Loup, and Elkhorn; Fig. 4) show a similar tendency. This work was presented in the 2015 American Meteorological Society annual meeting.

We also developed some tools to pre-process and post-process hydrologic and atmospheric data. In order to manipulate massive input and output files for VIC model, Python (a general purpose high level programming language) scripts were developed. Python codes were used to post process data as well as develop graphs from data in several formats such as ASCII and NetCDF. The advantage of converting VIC flux files into NetCDF format is compact and requiring very little overhead to store the ancillary data that makes the datasets self-describing. We expect to make these codes available to the public for our final report.

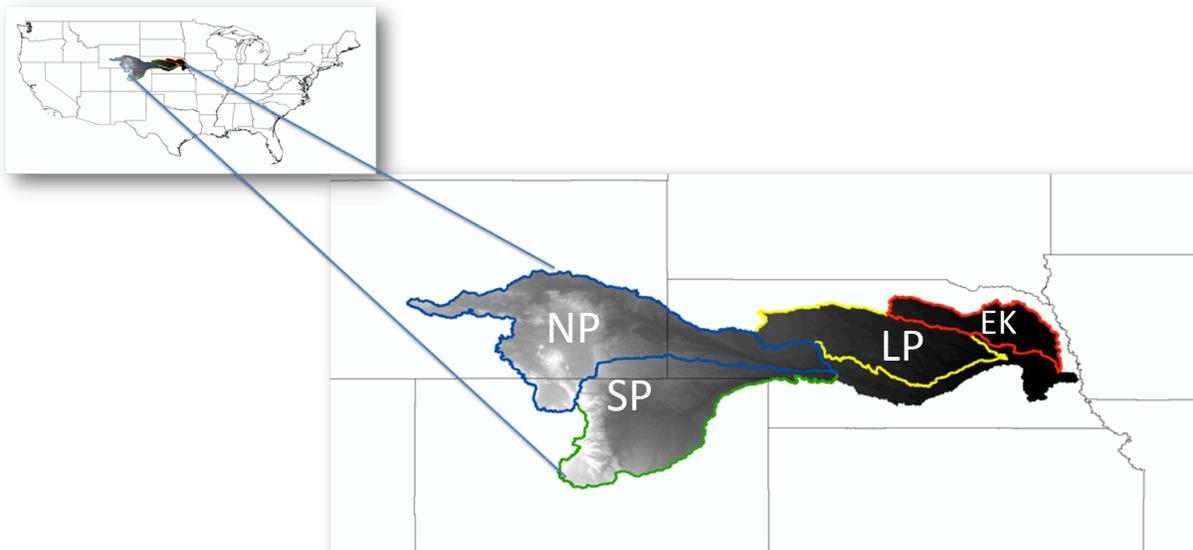


Figure 4: The PRB composed in ArcGIS delineating the four sub basins (North Platte, South Platte, Loup, and Elkhorn).

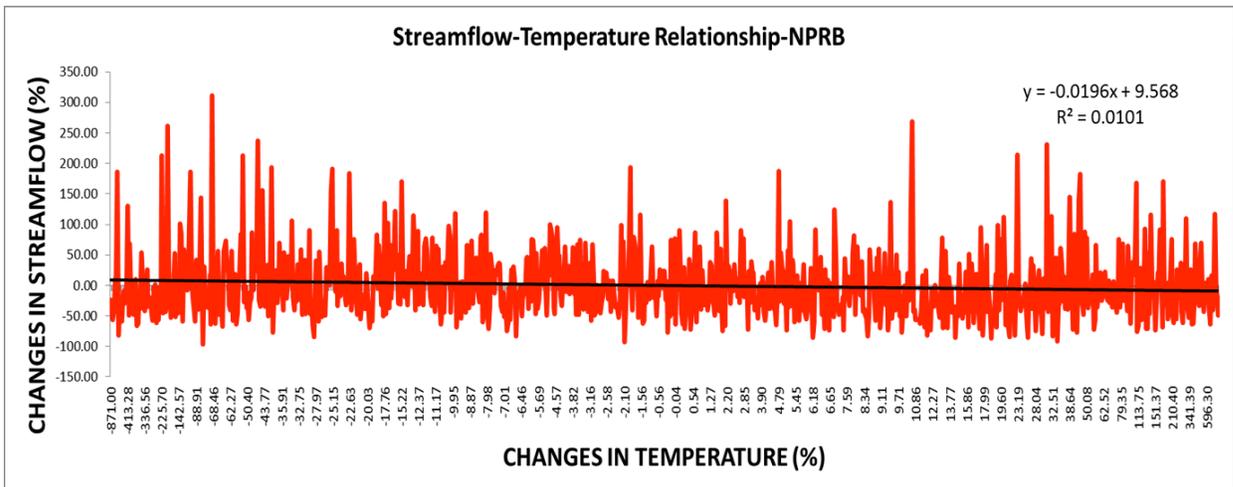
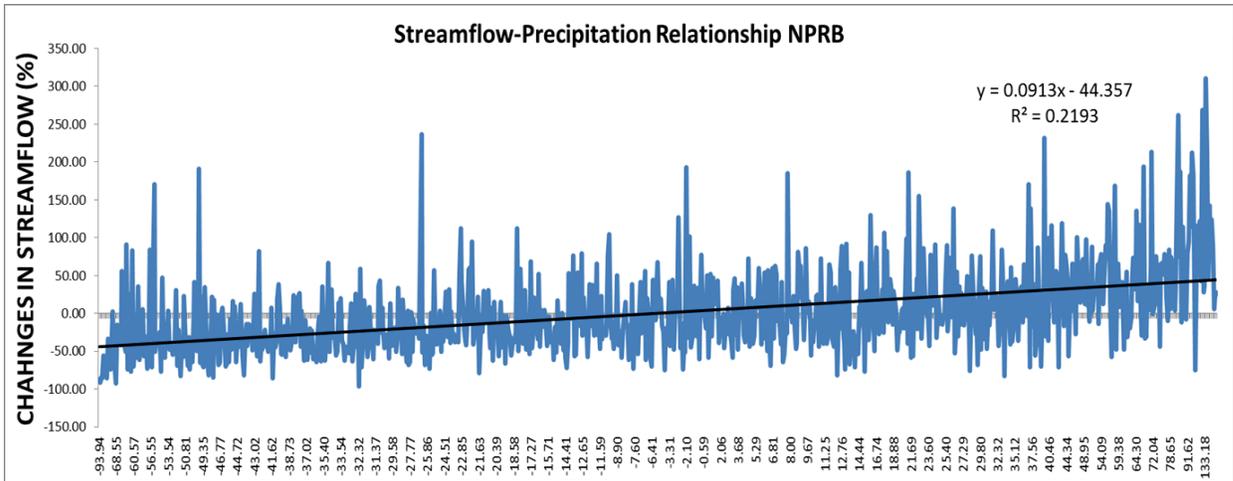


Figure 5: Sensitivity Analysis for the NPRB (additional representations of such analysis are just described) from 1925-2005

c. Crop Irrigation Requirements' responses to Climate Variability

A data set of leaf area index (LAI), evapotranspiration, soil moisture, and other hydroclimatic variables at one sixteenth degree resolution were produced from MODIS data and variable infiltration capacity model (VIC) simulations. LAI is used to characterize plant canopies. It is a vegetation parameter in VIC used to calculate water intercepted by the canopy, canopy resistance, root uptake rate, and evapotranspiration rate. In Figure 6 we evidence the role of dynamical changes in vegetation, through the use of MODIS's LAI. Some of those changes are more conspicuous during the summer, which is a critical season for plant growth and crop productivity. Changes in land use as a product of the influence of extreme Hydrometeorologic and climate events are part of our main interest. We have found that this dynamic LAI variability has an important impact

in extreme years (Fig. 8), which show the soil moisture variability for both a wet (2011) and a dry (2012) event. Thus, Soil moisture (SM) with dynamic LAI provides a comprehensive estimate of water availability for agricultural and ecosystem services' sustainability. Therefore, April-to-July SM and SM percentiles, representing the agricultural growing season, illustrate the effect of floods (i.e. 2011) and droughts (i.e. 2012). Two posters were presented at the American Geophysical Union 2014 Fall meeting and 2015 AMS conference, showing the hydrologic and crop irrigation responses to floods and droughts in the PRB, respectively. The latter was awarded as the best student poster in the Hydrology section.

Although is out of the scope of the present project, we are also exploring the suitability of LANDSAT-LAI to estimate crop evapotranspirative needs in regional hydrologic modeling (Fig. 7). LANDSAT- and MODIS-LAI are aimed to identify how dynamical changes in land-use influence the ET and its relationship with soil moisture. This is of the interest of our colleagues of the Nebraska and California Water Science Centers (Steve Peterson and Randall Hanson, respectively) whom we have started to identify areas of mutual interest and collaboration.

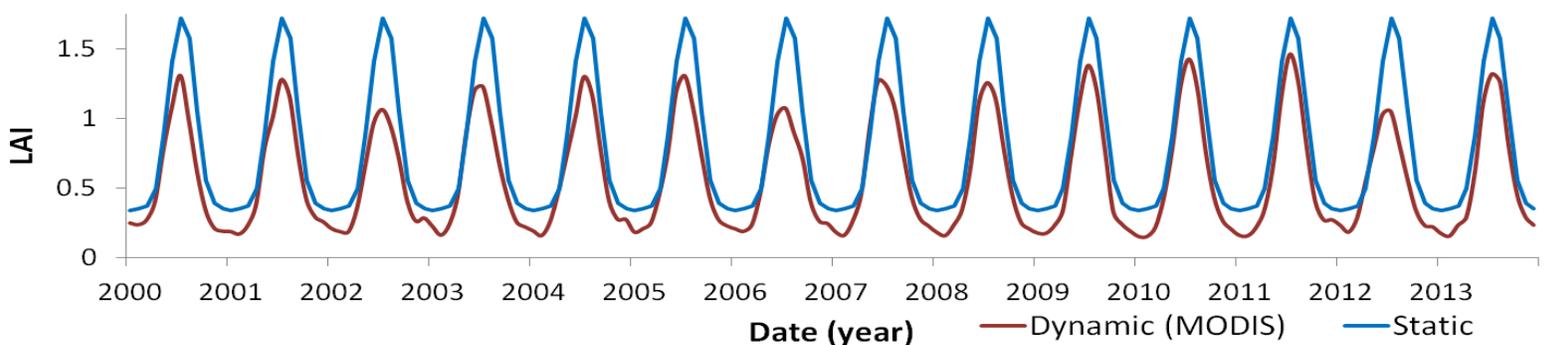


Figure 6: Static Leaf Area Index (LAI; in blue) as is described by default in the VIC model, and the obtained with MODIS dataset (in red) to incorporate interannual variation of greenness in the VIC simulation.

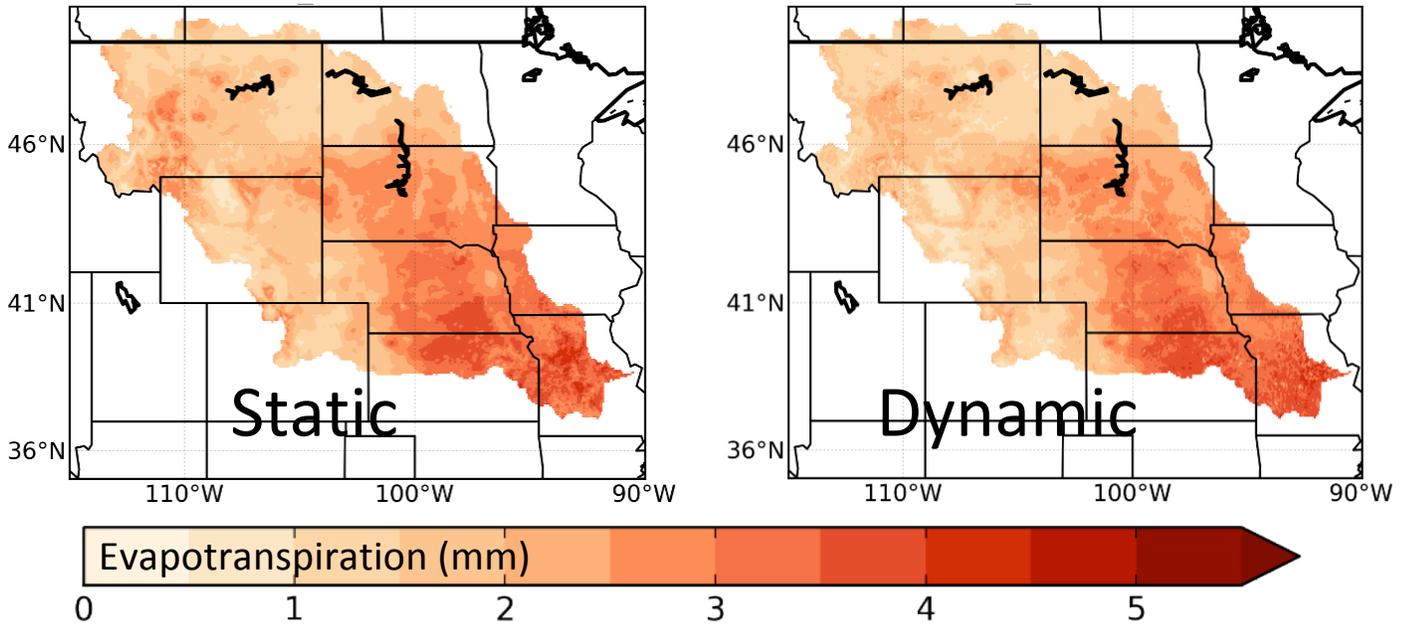


Figure 7: Evaporation simulated by VIC model under two scenarios: with static LAI (left) and dynamic LAI (right) as obtained by LANSDAT imagery.

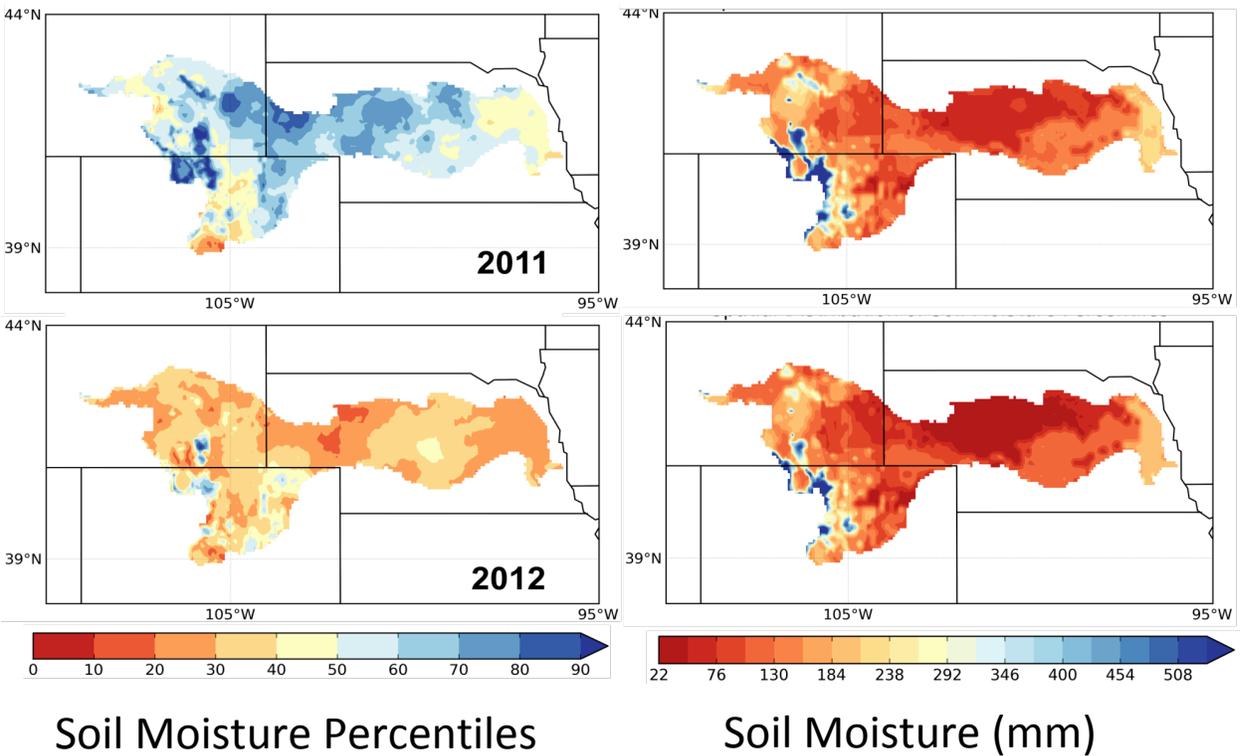


Figure 8: Response of the dynamic LAI variability on soil moisture described with percentiles (left panel) and absolute values (right) for two extreme years 2011 (wet) and 2012 (dry).

2. Resolution

With colleagues of the University of Colorado-Boulder, Arizona State University, NASA, and the US Army Corp of Engineers we developed and implemented a new precipitation, minimum and maximum temperatures, and wind speed daily dataset at 1/16th degree resolution for Southern Canada, the US, and Mexico (1950-2013). This dataset is unique because of the spatiotemporal resolution and the accountancy of topography along the subcontinent (Figure 8). Simulations in section 1 used this dataset and the previous version at 1/8th degree resolution. A paper submitted to Nature databases (Livneh et al., submitted) will describe the process, challenges, and opportunities. Currently we are automatizing the procedure in order to develop a test-bed for resolution-driven experiments but also to test uncertainties in estimations and interpolation techniques.

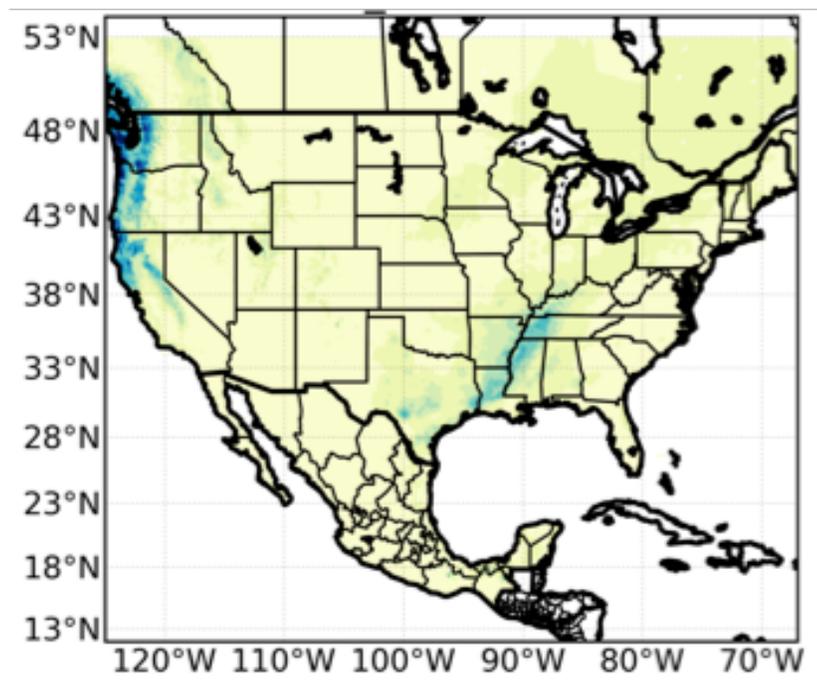


Figure 8. Sub continental precipitation historical average (mm/day) at 1/8th degree resolution from 1950-2013.

3. Pending work

Below is listed the pending work we are implementing in the following stage of the project:

- a. Our contribution to address the suitability of time-step and grid-size as a key step toward the improvement of Surface Water-Groundwater connections across spatiotemporal scales.
- b. Explore the integration of the Land Surface Hydrology (LSH) scheme to' MODFLOW-FMP (or the development of WATCOM).

Also, Dr. Carlos Carrillo was hired as Water Cycle modeler. His expertise in data analyses and model implementation will allow us to implement the pending tasks. Also, we have started our collaborations with USGS's Nebraska Water Science Center, which we expect will expedite our MODFLOW-FMP implementation.

III. INFORMATION TRANSFER PROGRAM

The present project provided training to undergraduate and graduate students as well as postdoctoral professionals. Two undergraduate students have contributed in the analyses of the hydroclimatology of the Platte River Basin. They focused on two aspects, soil moisture and snow water equivalent responses to large-scale phenomena and the streamflow and evapotranspiration sensitivity to changes in temperature. These two undergraduates, were awarded by the UCARE-program fellowship and have presented at International conferences such as the 2015 American Meteorological Society annual meeting. On the other hand, Katherine Smith, MSc student, funded by the present project contributed to (1) assess the hydroclimatology of extreme hydrometeorologic and climate events in the Platte River Basin; (2) document and run the first steps to implement MODFLOW in two locations in the state of Nebraska. Katherine Smith and Mallory Morton, also received the NASA received the "Recruitment Fellowship" award and has presented a preliminary report at the NASA Nebraska Space Grant, which also contributed to this project.

The information produced by the undergraduate and graduate students will contribute to elucidate the proper mechanisms to a fully integrated modeling system. The extreme-event assessment represents the diagnostic component of a predictability framework complemented by an assessment of VIC's integration into the Farming Process package. Future work will explore the integration of VIC and FMP from physical and computational perspectives.

Other information transfers include the possible transfer of Livneh et al. (submitted) dataset to NASA's Land Data Assimilation System, which is currently available upon request to the public. Also, codes for pre-processing and post-processing hydrologic data in multiple formats (ASCII, netCDF, HDF, among others) will be available for online access in our web page before the submission of our final report.

1. Participation in workshops and conferences:

Morton, F., K. Smith, A. Mohammad Abadi, I. Luna, and F. Munoz-Arriola. Assessing Land Surface Hydrologic Resilience to Extreme Hydrometeorological Events in Natural and Water-controlled Ecosystems. *American Meteorological Society*, Phoenix, AZ. January 9th 2015.

Smith, K., M. Morton, D. Rico, A. Mohamad Abadi, I. Luna, B. Livneh, and Francisco Munoz-Arriola. Hydroclimatology of Flood and Drought Events in the Northern High Plains, U.S. *American Geophysical Union, Fall Conference*, San Francisco, CA. December 16th 2014.

Munoz-Arriola, F. R. Walko, A. Mohamad Abadi, L. Castro-Garcia. Toward Improving Predictability of Extreme Hydrometeorological Events in the Northern High Plains. *American Geophysical Union, Fall Conference*, San Francisco, CA. December 18th 2014.

Morton, M., D. Rico, J. Abraham Torres, A. Mohammad Abadi, I. Luna, and F. Munoz-Arriola. Assessing Soil Moisture Response to Extreme Hydrometeorological Events in the Platte River Basin. *University of Nebraska-Lincoln Summer Research Symposium*, Lincoln, NE. August 6th 2014.

Rico, D.A., Abraham, J.T., Azar, M., Mallory, M., Francisco, M. (2014). *Determining Streamflow Sensitivity to Changes in Temperature on the Platte River Basin*. Poster presented at the *University of Nebraska-Lincoln Summer Research Symposium*, Lincoln, NE. August 6th 2014.

Information Transfer Program Introduction

The Nebraska Water Center has a long and proud tradition of actively pursuing a widely diverse information transfer program. USGS funding underwrites a range of public and professional information and educational efforts, including: (1) four quarterly issues of the Water Current newsletter, which are mailed to more than 2,800 subscribers and appears as an online pdf; (2) updating and reprinting Water Center fact sheets and informational brochures; (3) more than 20 press releases reporting on water-related research, education, event and outreach programming from across the University of Nebraska or promoting the Nebraska Water Center and its affiliated NU Water Sciences Laboratory; (4) direct support for two internet web sites and several Facebook, Twitter and YouTube accounts; (5) publicity and supporting materials for an annual water law conference, public lecture series, water symposium, and water and natural resources tour; (6) coordinating UNL Extension's largest public program and student recruitment event of the year at Farm Progress Co.'s Husker Harvest Days farm show; (7) other publications and events; and (8) publication and distribution of a full-color, public 2013-14 annual report.

The Nebraska Water Center is part of the Robert B. Daugherty Water for Food Institute, a global initiative involving all University of Nebraska water faculty and staff with a mission of greater global agricultural water management efficiency. NWC and DWFI co-located to offices at the University of Nebraska's new "Nebraska Innovation Campus" in September 2014. The two units continue serving unique clientele and missions, as well as cooperating closely in a number of areas. We are also coordinating more closely on mutual communications needs and sharing of staff and resources.

Information Transfer Plan/Water Education

Basic Information

Title:	Information Transfer Plan/Water Education
Project Number:	2008NE173B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	None
Principal Investigators:	Chittaranjan Ray, Steven W. Ress

Publications

1. Newsletter: The Water Current newsletter has a free, subscriber-based distribution of approximately 3,100 copies per issue, more than 95% of which are requested subscriptions. It is published quarterly in a full-color magazine format, and is available online. Water-related research, engagement, education and outreach faculty and water-related professional staff are featured in each issue. Guest columns and articles are encouraged. A director’s column is published in each issue. News Releases: The Water Center produces about 30 press releases annually focused on research results or progress, extension programming, educational opportunities, public tours, seminars, lectures, symposiums and conferences, awarding of major research grants and other matters of public impact involving the Water Center and other natural resource-focused UNL entities. These releases support a wide variety of UNL water-related research and outreach that cross departmental and academic disciplines. They focus on public impacts of UNL-sponsored research and programming. The UNL Water Center writes these for many UNL environmental science-related departments and faculty members who do not have a staff communicator available to them. The Water Center coordinates public media requests for information and interviews with sources on any water-related topic of interest to them and devotes significant attention to cultivating long-term relationships with members of the working media. The Water Center has a long reputation as a willing and reliable “source” among local, state and regional media for water and natural resources news. Media calls are frequent and water-related faculty and staff are accustomed to fielding questions from the media, doing radio and television interviews, etc. The Water Center makes wide use of electronic and broadcast journalism sources, as well as more traditional print (newspaper) sources.
2. Brochures and pamphlets: All full color. Produced as needed. These include, but are not limited to, mission and programming of the UNL Water Center, UNL Water Sciences Laboratory, Tern and Plover Conservation Partnership, annual Water and Natural Resources Tour and for other units or programs affiliated with or sponsored by the Water Center. All have online versions, as well.
3. Water Center fact sheets: All full-color, generally one sheet. Used to inform and promote both general themes, such as the Water Center itself, or to announce specific programs, seminars, courses, etc. There are various editions, designed for specific internal and external audiences.
4. Nebraska Water Map: A 24 x 36” full-color map of Nebraska surface and groundwater resources. Includes inset maps, diagrams and photos that describe the basics of water quantity, quality and use in Nebraska. The map is used for educational purposes across the state, and is available online. More than 65,000 have been distributed statewide. A range of publications produced outside the UNL

Information Transfer Plan/Water Education

Water Center, particularly fact sheets, research project results and other print materials from USGS, Nebraska Department of Environmental Quality, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, local Natural Resources Districts and University of Nebraska-Lincoln Extension, are available through Water Center and School of Natural Resources web sites or in print form. UNL Water Center assists with content, design, editing and production for many of these publications.

5. Electronic Resources: Print materials produced by the UNL Water Center, and other information, are available online. The Water Center co-sponsors, designs and maintains the following related Internet web sites: UNL Water: <http://water.unl.edu> UNL Water Center: <http://watercenter.unl.edu/> Water Sciences Laboratory: <http://waterscience.unl.edu> UNL School of Natural Resources: <http://snr.unl.edu/water/index.asp>
6. Full color, 2013-2014 annual report. 35 pages. Mailed to “Water Current” newsletter subscribers and distributed at NWC-sponsored events.
7. NWC also frequently responds to media requests for information and interviews and devotes significant attention to cultivating long-term relationships with members of the working press. NWC has a well-earned reputation for being a reliable “source” for water and natural resources news. Media calls are frequent and water-related faculty and staff are accustomed to fielding media questions.

Publications:

1. Newsletter: The *Water Current* newsletter, now in its 46th consecutive year of publication, has a free, subscriber-based distribution of more than 2,800 copies per issue. Subscriptions are by request. The newsletter publishes quarterly in full-color and is available online as a pdf. One or two water-related faculty and/or professional staff are featured in each issue. Guest columns and articles are encouraged. Research, outreach and extension programming involving the NWC and DWFI are featured. A director's column/report is included in each issue.
2. News Releases: NWC publishes more than 20 press releases annually focused on water-related research, outreach, extension programming, educational opportunities, public tours, seminars, lectures, symposiums and conferences, major research grants and other matters of public interest. They support the activities of many water faculty and staff and cross many academic disciplines. NWC frequently writes and distributes these for many water-related programs and faculty members who do not have their own communications staff.
3. NWC also frequently responds to media requests for information and interviews and devotes significant attention to cultivating long-term relationships with members of the working press. NWC has a well-earned reputation for being a reliable "source" for water and natural resources news. Media calls are frequent and water-related faculty and staff are accustomed to fielding media questions.
4. Full color, 2013-2014 annual report. 35 pages. Mailed to "Water Current" newsletter subscribers and distributed at NWC-sponsored events.

Other Print Resources (distributed free to clientele and public):

Brochures and pamphlets:

Produced as needed to support Water Center programming and activities. These include, but are not limited to, mission and programming of the Nebraska Water Center, NU Water Sciences Laboratory, annual Water and Natural Resources Tour and for other units or programs affiliated with or sponsored by the Nebraska Water Center. All have electronic versions posted online, as well.

Water Center fact sheets:

Generally one sheet, front-to-back, full color and illustrations and produced as needed. Used to inform and promote general themes, such as the Nebraska Water Center and NU Water Sciences Laboratory, or to announce specific programs, seminars, conferences, tour, courses, etc. Used for both specific internal and external audiences.

A range of publications produced outside the Nebraska Water Center, particularly fact sheets, research project results and other print materials from U.S. Geological Survey, Nebraska Department of Environmental Quality, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, local Natural Resources Districts and University of Nebraska-Lincoln Extension, are available via the Nebraska Water Center web site or in print form. Nebraska Water Center assists with content, design, editing and production for many of these publications.

Electronic Resources:

The Nebraska Water Center co-sponsors, designs and helps maintain the following Internet resources:

Nebraska Water Center:

<http://watercenter.unl.edu/>

NU Water Sciences Laboratory:

<http://waterscience.unl.edu>

Robert B. Daugherty Water for Food Institute:

<http://waterforfood.nebraska.edu/>

Facebook:

<facebook.com/NebraskaWaterCenter>

Twitter:

<twitter.com/NebrWaterCenter>

Conferences, Seminars, Tours, Workshops, Other Outreach:

Water and Natural Resources Seminars:

An annual series of eight free weekly lectures conducted roughly every other week from January to April. The series dates to the early 1970's. It covers a broad range of water and natural resource-related topics. Individual lectures attract a broad public audience of 60 to 100. Normally 20-25 students enroll in the seminar as a one credit hour course. Lecture attendees include faculty, government and organizational employees and policy makers. News releases, Internet and social media postings and posters advertise and support the lectures. Most lectures are taped and posted online for viewing. The series used to number 12 to 14 lectures, but was changed to eight lectures in 2014 to leave room in the schedule for student classroom discussions and for additional lectures as visiting speakers are available. The new schedule has increased both student enrollment and public attendance.

Water and Natural Resources Tour:

The tour is in its 43rd year, dating to UNL Extension "Irrigation tours" first conducted in the 1970's. The 2014 tour examined surface water and irrigation issues in northern Colorado, eastern Wyoming and western Nebraska, centering on the U.S. Bureau of Reclamation's North Platte Project near Caspar, Wyo. Attendees include state legislators, congressional staff, faculty, students, agricultural producers and water-related professionals from a wide variety of public and private concerns. For the first time, the tour hosted young water professionals in the Nebraska State Irrigation Association's "Water Leaders Academy." The event is co-sponsored with the Kearney Area Chamber of Commerce, Central Nebraska Public Power and Irrigation District, USGS Nebraska Water Science Center and Robert B. Daugherty Water for Food Institute.

Water Law Conference:

A one-day event focused on Nebraska water law issues such as water rights transfers, drainage issues, Clean Water Act enforcement, etc. It is targeted to practicing attorneys but open to all. The event is co-sponsored by the University of Nebraska College of Law. Continuing Legal Education (CLEs) credits are made available in Nebraska, Iowa and Colorado. The event was not held in 2014 due to scheduling conflicts. It will next be held in March 2015.

Climate, Water and Ecosystems Symposium:

A one-day event preceding the water law conference focusing on Great Plains climate, water and ecosystems issues and showcasing impacts at the intersection of climate change or variability, water and related disciplines. Topics include infrastructure, design, hydropower, agriculture, ecosystem services, drinking water and many others. Focus is on the Great Plains, including research or programming transferrable to the Great Plains. This event was not held in 2014 due to scheduling conflicts. It will next be held in March 2015.

Mentoring:

The Nebraska Water Center helps mentor new water faculty, as well as graduate students and post-doctoral researchers to help them establish successful careers. Newer faculty from the many academic units associated with the Nebraska Water Center attend brown bag sessions during the year where they can get acquainted and get advice from senior faculty and external partners on topics such as working with stakeholders, multidisciplinary research, and managing large data sets over their careers. In addition to helping link individual faculty members to groups, Nebraska Water Center faculty and staff meet with faculty individually as needed on an ongoing basis. Bi-Weekly news and funding opportunity emails are sent to all water-related faculty and staff.

Other Outreach:

Nebraska Water Center staff routinely provides talks for groups and respond to requests for information. These include requests for water-related presentations from the public schools.

The Nebraska Water Sciences Laboratory, established in 1990, is part of the Nebraska Water Center. It is a unique, state of the art analytical laboratory focused on teaching student researchers and developing new methodologies for the detection of trace contaminants such as explosives; pesticides and their metabolites; pharmaceuticals; steroid hormones in water, tissues, sediments and wastewater; cyanotoxins in lake environments; and new tools for isotope fingerprinting and geochemical tracers. Publicity, media relations, Internet visibility, marketing and other communications requirements of the laboratory are handled by the Nebraska Water Center.

The University of Nebraska-Lincoln's Pesticide Education Office, a unit tasked with educating licensed pesticide applicators on proper use of restricted and non-restricted use pesticides of all types, also relies on the Nebraska Water Center for much of its media needs, as well as helping publicize a statewide series of educational seminars for applicators preparing to take state license examinations. The unit has no communications staff of its own and due to its essential water quality-related mission, depends on the Nebraska Water Center to help fulfill those needs.

Educational Displays:

The Nebraska Water Center makes frequent public displays in association with conferences, symposiums, trade shows, educational open houses and water and environmental education festivals. Nebraska Water Center staff make presentations and sit on steering committees for such annual educational and informational festivals as “Earth Wellness Festival” and others. Water Center staff superintends UNL research and extension exhibits at “Husker Harvest Days,” one of the largest commercial agricultural expos in the country. More than 25,000 tour NU exhibits during this three-day event in mid-September.

Primary Information Dissemination Clientele:

U.S. Department of Agriculture
U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
U.S. Bureau of Land Management
Nebraska Department of Natural Resources
Nebraska Department of Agriculture
Nebraska Health and Human Services System
Nebraska Department of Environmental Quality
Nebraska Environmental Trust Fund
Nebraska Association of Resources Districts (and 23 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 Resources Research Institutes
University and college researchers and educators
NU students Public and parochial science teachers
Farmers
Irrigators
Irrigation districts and ditch companies
Private citizens

Cooperating Entities:

In addition to primary support from the USGS, the following agencies and entities have helped fund communications 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
Nebraska Environmental Trust
Nebraska Department of Environmental Quality
National Water Research Institute
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
University of Nebraska Robert B. Daugherty Water for Food Institute
NU College of Law
USGS Nebraska Water Science Center
Nebraska Center for Energy Sciences Research
Nebraska Water Balance Alliance

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	4	0	0	0	4
Masters	2	0	0	0	2
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	8	0	0	0	8

Notable Awards and Achievements

1) Elli Kaufmann (an undergraduate student) received a UNL UCARE research award to carry out research on this project during the summer, fall and spring of 2014-2015.

2) Research carried out under this project resulted in the three following poster awards at local and regional conferences:

a) 2nd Place Undergraduate Poster Award, UNL Chemistry Department Research Symposium, Lincoln, NE, August 2014 b) Special Recognition Poster Award, 2015 Molecular Mechanisms of Disease Symposium, Lincoln, NE, April 2015 c) 1st Place Undergraduate Poster Award, 2015 UNL Research Fair, Lincoln, NE, 2015