Oklahoma Water Resources Research Institute
Annual Technical Report
FY 2011

Introduction

2011 brought significant changes to the Oklahoma Water Resources Research Institute (OWRRI). OWRRI moved from the Division of the Vice President for Research at Oklahoma State University (OSU) to join the Water Research and Extension Center (WREC) in the Division of Agricultural Sciences and Natural Resources. Together these units form the Oklahoma Water Resources Center. This move brought new opportunities and a greater emphasis on information transfer activities to the OWRRI.

This report summarizes some of our accomplishments in 2011. Highlights are presented below.

1. We awarded three research grants of $50,000 each to researchers at both OSU and the University of Oklahoma to conduct studies of the utility of freshwater mussel populations for developing environmental flow recommendations for Oklahoma streams, on the possible bioaccumulation of organic compounds in lawns and gardens that are irrigated with rooftop runoff, and the development of a novel approach to predicting drought severity by measuring plant available moisture in the soil via the Oklahoma Mesonet. Funding for these projects was provided by the USGS WRI Program and the Oklahoma Water Resources Board.

2. Research activities continued on our two 104G projects. In 2010 an OSU and University of Arkansas research team won a $200,000, two-year grant to investigate the subsurface flow of phosphorus through preferential flow channels in the alluvium of streams in eastern Oklahoma and western Arkansas. In 2009, a team based at OSU and OU, received a $225,000, three-year grant to investigate the impact of eastern red cedar encroachment on groundwater.

3. We co-sponsored and co-hosted the 9th annual Water Research Symposium and 32th annual Governor's Water Conference in Norman, which was attended by more than 450. The keynote address was delivered by Charles Fishman, the author of *The Big Thirst*.

4. We concluded our 4.5-year project to update the Oklahoma Comprehensive Water Plan by working closely with the OWRB to develop a list of water policy recommendations for the 2012 legislative session.

5. We addressed the Joint Legislative Committee for Water Planning to explain the public participation process of the Water Plan update. The OWRRI also hosted a Website to accept public comments for this Committee.

6. We electronically published three issues of our newsletter the Aquahoman, conducted seminars for Extension staff on the Water.

7. The Water Resources Center began production of a series of videos intended to assist landowners and agriculture producers in coping with drought. A total of fourteen videos are planned.

Research Program Introduction

In 2011, proposals were solicited from all comprehensive universities in Oklahoma. Proposals were received from Oklahoma State University and the University of Oklahoma. Eight proposals were submitted, and from these, three projects were selected for funding for one year each.

- Incorporating Ecological Costs and Benefits into Environmental Flow Recommendations for Oklahoma Rivers: Phase 1, Southeastern Oklahoma (Dr. Caryn Vaughn, OU) investigated the environmental needs of freshwater mussels to understand their responses to various flow rates.

- Drought monitoring: a system for tracking plant available soil moisture based on the Oklahoma Mesonet (Dr. Tyson Ochsner, OSU) completed the second phase of this effort to develop a near-real-time online map of plant available moisture using the Oklahoma Mesonet's soil moisture measurements.

- Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff. (Dr. Jason Vogel, OSU) assessed whether the contaminants from the roofing materials have the potential for long-term accumulation in soils from harvested rainfall used as urban irrigation.

Eastern redcedar encroachment and water cycle in tallgrass prairie

Basic Information

Title:	Eastern redcedar encroachment and water cycle in tallgrass prairie
Project Number:	2009OK141G
Start Date:	9/1/2009
End Date:	9/30/2012
Funding Source:	104G
Congressional District:	3
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Hydrology, Ecology
Descriptors:	baseflow, evapotranspiration, grassland, precipitation interception, sapflow, soil water dynamic, streamflow, water budget and water cycle
Principal Investigators:	Chris Zou, Dave Engle, Sam Fuhlendorf, Don Turton, Rodney Will, Kim Winton

Publications

1. Zou Chris, Peter Folliott, Michael Wine. 2010. Streamflow responses to vegetation manipulations along a gradient of precipitation in the Colorado River Basin. Forest Ecology and Management 259:1268-1276.
2. Zou Chris, Shujun Chen. 2009. Eastern redcedar encroachment and alternations of ecohydrological properties in tallgrass prairie. IUFRO Forest and Water. Raleigh, NC, USA.
3. Zou Chris, Don Turton, Rod Will, Sam Fuhlendorf, David Engle,Kim Winton. 2009. Eastern Redcedar Encroachment and the Water Cycle in Mesic Great Plains Grasslands.The Oklahoma Water Research Symposium. Oklahoma City.
4. Zou Chris, Don Turton, Rod Will, Sam Fuhlendorf, David Engle, Jenny Hung. 2010. Estimating watershed level evapotranspiration using water budget method. ESA 95th Annual Meeting.
5. Zou Chris, Peter Folliott, Michael Wine. 2010. Streamflow responses to vegetation manipulations along a gradient of precipitation in the Colorado River Basin. Forest Ecology and Management 259:1268-1276.
6. Zou Chris, Shujun Chen. 2009. Eastern redcedar encroachment and alternations of ecohydrological properties in tallgrass prairie. IUFRO Forest and Water. Raleigh, NC, USA.
7. Zou Chris, Don Turton, Rod Will, Sam Fuhlendorf, David Engle,Kim Winton. 2009. Eastern Redcedar Encroachment and the Water Cycle in Mesic Great Plains Grasslands.The Oklahoma Water Research Symposium. Oklahoma City.
8. Zou Chris, Don Turton, Rod Will, Sam Fuhlendorf, David Engle, Jenny Hung. 2010. Estimating watershed level evapotranspiration using water budget method. ESA 95th Annual Meeting.
9. Zou, CB, Turton D, Engle D. 2010. How eastern redcedar encroachment affects the water cycle of Oklahoma rangelands. NREM-2888. Oklahoma Coop. Ext. Serv. Oklahoma State University, Stillwater.
10. Stebler E, Turton D, Zou C. 2011. Impact of eastern redcedar (Juniperus virginiana) encroachment on streamflow in Oklahoma grassland watersheds. Poster presentation at Oklahoma Clean Lakes and Watershed Association Conference, Edmond OK, April 7 8, 2011. (Poster, Abstract)

11. Stebler E, Turton D, Zou C. 2010. Rainfall interception by eastern redcedar (Juniperus virginiana) and its implications for water balance in Oklahoma grassland watersheds. Governor's Water Conference and OWRRI Water Research Symposium. 2010. Norman, Oklahoma. (Poster, Abstract)
12. Hung J, Zou CB, Engle D, Turton, Will R, Fuhlendorf S, Winton K. 2010. Temporal dynamics of soil-water content and soil-water depth in mesic tallgrass prairie and eastern redcedar woodland. Governor's Water Conference and OWRRI Water Research Symposium. 2010. Norman, Oklahoma (Poster, Abstract)
13. Zou CB. Climatic change and ecohydrology. Special session. 2010. The 95th ESA Annual Meeting, Pittsburgh, PA. (Oral presentation, Abstract)
14. Zou CB, Turton D, Will R, Fuhlendorf S, Engle D, Hung J. 2010. Estimating watershed level evapotranspiration using water budget method. The 95th ESA Annual Meeting, Pittsburgh, PA (Poster, Abstract).
15. Wine ML, Zou CB. 2012. Long-term streamflow relations with riparian gallery forest expansion into tallgrass prairie in the Southern Great Plains, USA. Forest Ecology and Management 266: 170 179.
16. Zou CB, Turton D, Engle D, Will R, Fuhlendorf S, Winton K. 2011. Eastern Redcedar Encroachment and Water: Update of 2010 Research. Water Research and Extension Center. WREC-101. Oklahoma Coop. Ext. Serv. Oklahoma State University, Stillwater
17. Zou C, Will R, Turton D, Acharya B, West A. Encroachment of redcedar into grassland - change in soil water and carbon. AAAS SWARM April 7, 2012, Tulsa, OK
18. Hung J, Zou CB, Will RE, Engle DM, Fuhlendorf SD. 2011. Interactive effects of vegetation and soil types on soil water dynamics in woody-encroached grasslands. The 94th Ecological Society of America Annual Meeting, August 7 -12, 2011, Austin, TX.
19. Turton D, Zou C, Will R, Stebler E. 2012. Watershed research on the effects of redcedar encroachment on water quantity: Initial results. AAAS SWARM April 7, 2012, Tulsa, OK
20. Caternia G, Will R, Turton D, Zou C, 2012. Water use of individual redcedar trees; How much, how variable, and what factors affect it. AAAS SWARM April 7, 2012, Tulsa, OK

Interim Report 2012

Title: Eastern redcedar encroachment and water cycle in tallgrass prairie

Start Date: 09/01/09

End Date: 12/31/13

Congressional District: Oklahoma Congressional District 3

Focus Category: ECL, FL, GW, HYDROL, INV, SW, WS, WU

Descriptors: baseflow, evapotranspiration, grassland, precipitation interception, sapflow, soil water dynamic, streamflow, water budget and water cycle

Principal Investigators:

Chris Zou, Don Turton, Rod Will, Samuel Fuhlendorf, David Engle at Oklahoma State University and Kim Winton at Oklahoma Water Science Center

Supported Students:

Student Status	Number	Disciplines
Undergraduate	1	Engineering
M.S.	1	Natural Resource Ecology and Management
Ph.D.	1	Natural Resource Ecology and Management
Post Doc	0	
Total	3	

Problem and Research Objectives:

The overall objectives are to develop an improved understanding of the effects of eastern redcedar encroachment in tallgrass prairie on ecohydrological processes and potential effect on water supplies.

The specific objectives for this reporting period include:

- Data collection and analysis of streamflows of grassland watersheds and grassland heavily encroached by redcedar;
- Data collection of redcedar transpiration using sapflow systems and onsite calibration;
- Monthly measurement of grassland evapotranspiration using ET chamber;

- Data collection and analysis of canopy interception.

Summary of research program progress and research findings

- We have obtained a complete and sophisticated interception dataset from over 70 rainfall events with a diverse distribution of rainfall size and intensity. We are in the process to conclude the canopy interception from both grassland and redcedar woodland. We have completed a full-year measurement of redcedar transpiration using sapflow measurement, grassland evapotranspiration using the ET chamber. At the end of May 2012, we will have a three-year data set of soil moisture for grassland and redcedar woodland.

- 2011 was an extreme drought year at our research site and for the Southern Great Plains in general. This unique condition helped us to capture the streamflow response under below average precipitation condition, and we have requested a no-cost extension to extend the experiment to capture streamflow response under mean precipitation condition.

- During this report period, we have proactively participated in professional meetings and initiated outreach activities. We have done extension and service training for county extension educators and we have also organized multiple tours for research scientists, land management professionals and a regional conference. Our research project has started to show broad impact. For example, some of our results from this project were quoted in the most recent issue of Science magazine (Science Vol 336). Our researches appeared in the SUNUP program broadcast on Oklahoma's public television (OETA).

- For the next reporting period, we will focus on data analysis, manuscript writing, and producing extension materials.

Publications

For this reporting period (June 2011 – May 2012), we published one peer-reviewed paper, one current report, four presentation/abstracts in regional and national meetings.

Peer-reviewed –

1. Wine ML, Zou CB. 2012. Long-term streamflow relations with riparian gallery forest expansion into tallgrass prairie in the Southern Great Plains, USA. Forest Ecology and Management 266: 170 – 179.

Extension and current report -

1. Zou CB, Turton D, Engle D, Will R, Fuhlendorf S, Winton K. 2011. Eastern Redcedar Encroachment and Water: Update of 2010 Research. Water Research

and Extension Center. WREC-101. Oklahoma Coop. Ext. Serv. Oklahoma State University, Stillwater

Abstract in conference proceedings-

1. Zou C, Will R, Turton D, Acharya B, West A. Encroachment of redcedar into grassland - change in soil water and carbon. AAAS – SWARM April 7, 2012, Tulsa, OK
2. Hung J, Zou CB, Will RE, Engle DM, Fuhlendorf SD. 2011. Interactive effects of vegetation and soil types on soil water dynamics in woody-encroached grasslands. The 94th Ecological Society of America Annual Meeting, August 7 - 12, 2011, Austin, TX.
3. Turton D, Zou C, Will R, Stebler E. 2012. Watershed research on the effects of redcedar encroachment on water quantity: Initial results. AAAS – SWARM April 7, 2012, Tulsa, OK
4. Caternia G, Will R, Turton D, Zou C, 2012. Water use of individual redcedar trees; How much, how variable, and what factors affect it. AAAS – SWARM April 7, 2012, Tulsa, OK

Drought monitoring: a system for tracking plant available soil moisture based on the Oklahoma Mesonet

Basic Information

Title:	Drought monitoring: a system for tracking plant available soil moisture based on the Oklahoma Mesonet
Project Number:	2010OK184B
Start Date:	3/1/2010
End Date:	6/30/2012
Funding Source:	104B
Congressional District:	3
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Agriculture, Water Quantity
Descriptors:	
Principal Investigators:	Tyson Ochsner, Jeffrey Basara, Chris Fiebrich, Bradley Illston, Albert Sutherland

Publications

1. Ochsner, T.E., B.L. Scott, J. Basara, B. Illston, A. Sutherland, and C. Fiebrich. 2010. Drought monitoring: A system for tracking plant available water based on the Oklahoma Mesonet. Oklahoma Water Resources Research Symposium. Norman, OK. Oct. 26, 2010.
2. Scott, B.L., T.E. Ochsner, J.B. Basara, and B.G. Illston. 2011. Developing a soil physical property database for the Oklahoma mesonet. ASA-CSSA-SSSA International Annual Meetings. San Antonio, TX. Oct. 16-19, 2011.

Interim Technical Report 2012

Project Title:
Drought monitoring: a system for tracking plant available soil moisture based on the Oklahoma Mesonet

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Start Date: March 1, 2011
End Date: February 28, 2012 (extension granted until 30 June, 2012)

Congressional District: Oklahoma's 3rd Congressional District

Focus Category: AG, CP, DROU, ECL, HYDROL, M&P, WQN

Descriptors: drought, soil moisture, Oklahoma Mesonet

Principal Investigators:
same as authors

Publications:

Scott, B.L., T.E. Ochsner, J.B. Basara, and B.G. Illston. 2011. Developing a soil physical property database for the Oklahoma mesonet. ASA-CSSA-SSSA International Annual Meetings. San Antonio, TX. Oct. 16-19, 2011.

Problem and Research Objectives:

Real-time drought monitoring is essential for early detection and adaptive management to mitigate the negative impacts of drought on the people, economy, and ecosystems of Oklahoma, and improved drought monitoring is a key need identified in the 1995 Update of the Oklahoma Comprehensive Water Plan. Drought impacts can be severe in Oklahoma. For example, the 2006 drought cost the state's economy over $500 million from lost crop production alone. While drought monitoring is critical to Oklahoma's resource managers, it is hampered by a lack of data on a crucial drought indicator: plant available water. Crop yield losses and, by extension, the economic impacts of drought, are strongly linked to plant available water. Plant available water (PAW) is the amount of soil moisture currently in the profile which is available for plant uptake. Some water is held so strongly by the soil that it is not available to plants.

The *long term goal* of the team of collaborators representing Oklahoma State University, the Oklahoma Mesonet, the Oklahoma Climatological Survey, and the University of Oklahoma is to develop the Mesonet as an innovative tool for understanding and managing the water resources of Oklahoma. The *objective of this proposal* is to bring to completion a first-generation drought monitoring system for Oklahoma based on PAW. The rationale for the proposed research is that providing resource managers with daily data on PAW will enable them to adopt management strategies to mitigate drought impacts. The proposal team is well prepared to succeed with this project due to the extensive expertise and strong achievement records in soil moisture related research, leadership in managing the Oklahoma Mesonet, and experience in the development of online products through the popular websites www.mesonet.org and www.agweather.mesonet.org. The following specific aims are proposed as part of the project:

Specific aim #1: Develop a scientifically-sound procedure for interpolating plant available water between Mesonet sites. Existing meteorological and geostatistical interpolation schemes will be tested for PAW and optimized to create a first-generation method suitable for mapping large-scale patterns in PAW.

Specific aim #2: Create and release a new daily plant available water map for drought monitoring in Oklahoma. The measured soil properties, the real-time Mesonet sensor data, and the chosen interpolation scheme will be combined to create operational PAW maps on the Mesonet and Agweather websites.

Specific aim #3: Discover the similarities and differences between plant available water and other significant drought indicators (preliminary work only). A statewide PAW database will be created using archived Mesonet data from 1997-2010. Spatial and temporal patterns of PAW will be compared to those of other drought indicators. The goal is to generate preliminary data to leverage future funding opportunities.

Methodology:

Specific aim #1: Develop a scientifically-sound procedure for interpolating plant available water between Mesonet sites. We will develop a scientifically-sound procedure for interpolating PAW between Mesonet sites and for estimating the uncertainty of the interpolation. We will test two candidate methods: the meteorologically-derived Barnes objective analysis and a geostatistical approach called ordinary kriging.

The Barnes objective analysis was selected as a candidate method because it is widely accepted in meteorology and is currently used for interpolating many of the above- and below-ground variables measured by the Mesonet. The Barnes scheme was originally developed for interpolating sea-level pressure across the US. It is an inverse distance weighting approach in which the influence of a given observation drops off exponentially as the distance from the observation increases. Multiple "passes" or iterations of the interpolation are performed and compared to the observation set with the accuracy of the interpolation improving upon each pass. Three or four passes are recommended for optimal performance (Barnes, 1994). Barnes objective analysis requires only about 10% as much computing time as ordinary kriging (Su and Stensland, 1988), and in some cases the Barnes scheme can be as accurate as ordinary kriging (Dirks et al., 1998). We will evaluate the effectiveness of a four pass Barnes scheme for interpolating PAW. In the testing phase, the scheme will be implemented using the "barnes.m" function (Pierce, 2010) in Matlab (Mathworks, Inc. Natick, MA).

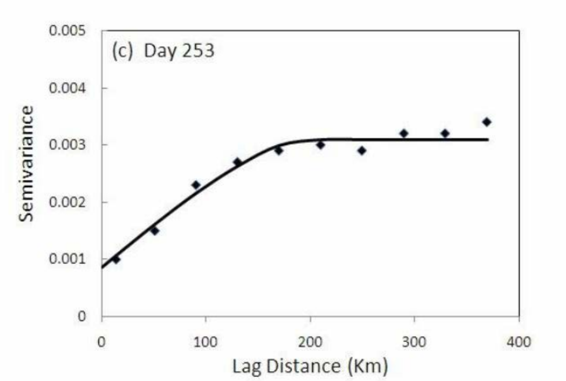


Fig. 1. Empirical (symbols) and theoretical (line) semivariograms for Mesonet soil moisture, 9/10/03.

The second method evaluated will be ordinary kriging (Matheron, 1971). This method is built on the semivariogram, which shows how the spatial variance increases with the separation distance (lag) between the points. Ordinary kriging was selected as a candidate method in part because it has been successfully applied in a recent study of the Mesonet soil moisture data (Lakhankar et al., 2010). Figure 1 is reproduced from that study and shows an empirical and a fitted theoretical semivariogram of soil moisture in Oklahoma. The lag distance at which the semivariogram approaches the maximum value (or "sill") is called the "range", and that value defines how far spatial dependence extends. In this example, the range is ~175 km. The positive y-intercept in Fig. 1 is called the "nugget" and arises from small-scale spatial variability primarily due to variability in processes and properties at the land surface scale. Based on Fig. 1, these scales and processes accounted for about 33% of the total spatial variance in soil moisture (ratio of nugget to sill).

Ordinary kriging offers some distinct advantages. In some cases it significantly outperforms inverse distance weighted methods like the Barnes objective analysis (Engel, 1999; Zimmerman et al., 1999). It will also result in semivariogram parameters for PAW which will be of tremendous scientific value for tasks like distributed hydrologic modeling, remote sensing validation, or designing future PAW monitoring networks. And, significantly, ordinary kriging can produce uncertainty maps for the interpolated PAW. Thus, it provides a built in indicator of the interpolation quality. But, as we have mentioned, the ordinary kriging is more complex than the Barnes objective analysis. For our application it is possible that the semivariogram parameters will have to be recalculated for each day of data. And, ordinary kriging assumes that the variable of interest is stationary, i.e. has the same mean value everywhere in the domain. Fortunately, it has been demonstrated that using localized search neighborhoods makes ordinary kriging fairly robust to nonstationary data (Journel and Rossi, 1989; Yost et al., 1982). We will evaluate the effectiveness of ordinary kriging for interpolating PAW. We will use the Geostatistical Analyst extension in ArcGIS (ESRI, Redlands, CA) to accomplish the ordinary kriging during the testing phase.

To evaluate the performance of the two interpolation methods, a set of 15 Mesonet stations will be left out and not used when optimizing the parameters of the interpolation schemes. The 15 omitted stations then provide independent validation data. The value of PAW on selected days as predicted by interpolation at those 15 locations will be compared to the measured values from the Mesonet sensors. Standard statistics such as bias, RMSE, and coefficients of determination will be calculated to determine the accuracy of the interpolation. These validation statistics will be key in quantifying the uncertainty associated with the interpolated PAW values. A similar validation procedure has already been successfully applied for evaluating the interpolation of Mesonet soil moisture data (Lakhankar et al., 2010). We hypothesize that ordinary kriging will lead to greater interpolation accuracy but at the cost of higher computational requirements. We will consider both of these factors in selecting the interpolation method for creating the operational PAW maps.

Specific aim #2: Create and release a new daily plant available water map for drought monitoring in Oklahoma. The measured soil properties, the real-time Mesonet sensor data, and the selected interpolation scheme will be combined to create these first-generation maps. Operational PAW maps will be added to the Mesonet and Agweather websites and disseminated to a broad range of end users.

Software developers from the Oklahoma Climatological Survey will integrate the formulas for plant available water calculation and interpolation into the C++ based, derived-variable calculation engine for the Mesonet's WeatherScope visualization software. The plant available water formulas will be made available to customers in version 1.9 of WeatherScope. This code will also be incorporated into the WeatherMapper software for server-side generation of map images, and WeatherWriter software for text product generation. Finally, the formulas will be incorporated into PHP-based software that produces vector graphs in HTML for display in web browsers.

We will incorporate new versions of these software packages into the Mesonet's operational data processing system, and configure that system to produce map and graph products for plant available water. The new products will be incorporated into the Mesonet and Agweather web sites and made available to the public. The maps will include an indication of the uncertainty of the interpolation. If the Barnes method is chosen, then we will provide a single uncertainty value applicable to the entire PAW map, e.g. reported values are accurate to within +/- XX mm. If the kriging method is chosen, we will be able to provide uncertainty values for any point in the State.

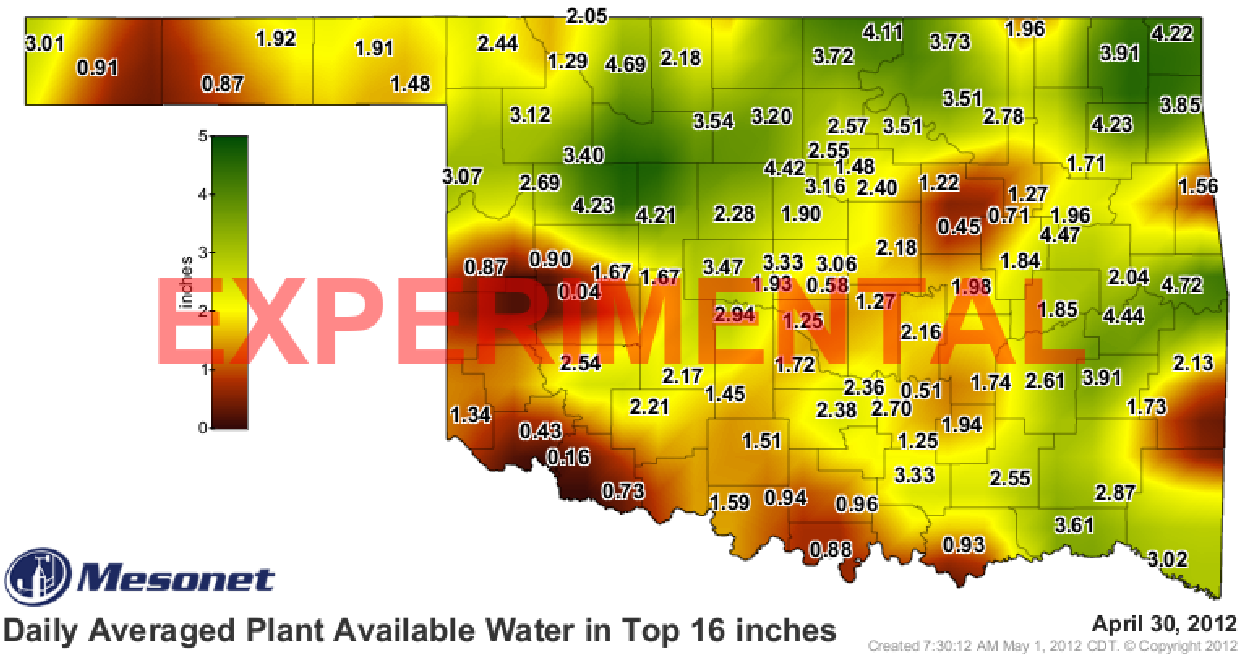
Specific aim #3: Discover the similarities and differences between plant available water and other significant drought indicators (preliminary work only). Multiple techniques have been developed to provide qualitative and quantitative assessments of the magnitude and spatial extent of drought conditions. Quiring (2009) provides a thorough overview of drought monitoring analyses and notes that each methodology has relative strengths and weaknesses. In particular, the use of real-time soil moisture conditions is drastically limited in operational drought monitoring. As noted previously, Illston and Basara (2003) discovered that soil moisture anomalies in Oklahoma were often displaced from regions identified as experiencing drought conditions via the PSDI and the SPI.

Preliminary analysis of PAW estimates utilizing Oklahoma Mesonet data demonstrate that the values provide enhanced insight regarding the spatial and temporal variability of water within the near-surface soil column. In regards to drought monitoring, a great challenge is identifying when meteorological drought conditions impact agricultural and hydrological drought conditions both during the onset and at the conclusion of drought. Because PAW provides an integrated value of soil moisture in the soil column, it captures longer-term trends associated with wetting and drying of the soil useful for monitoring drought. Further, PAW can be monitored in near real-time using Oklahoma Mesonet data.

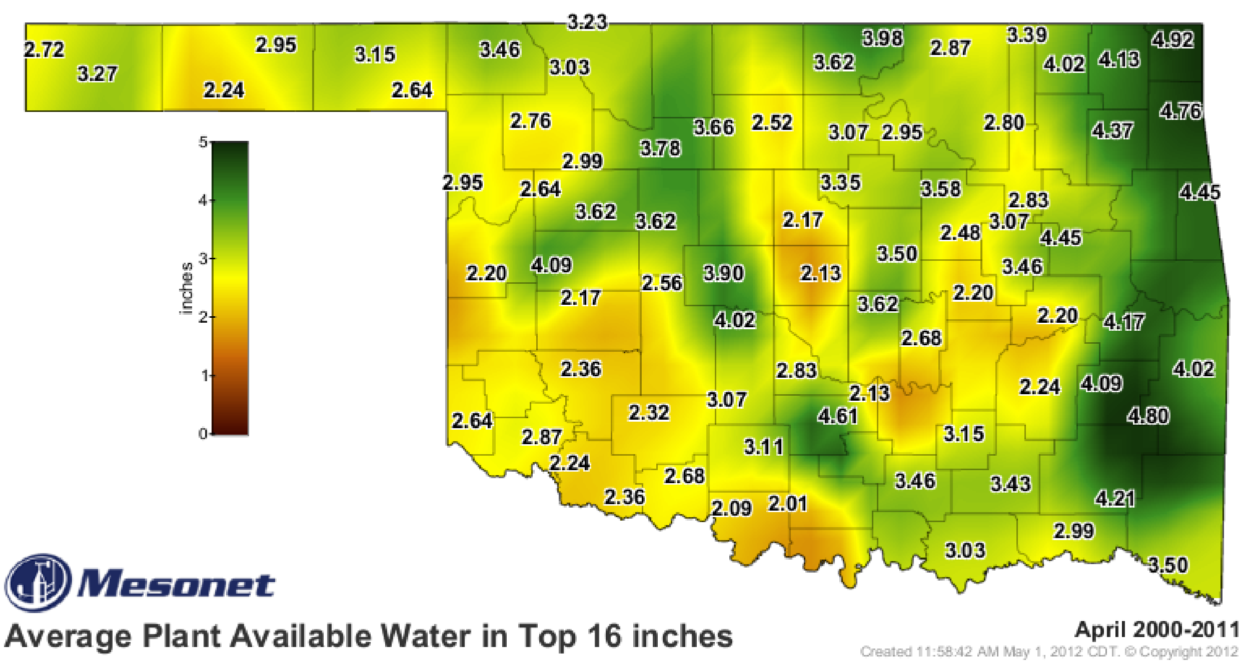
To quantify the utility of PAW as a drought monitoring tool, a 14-year, statewide, PAW database will be created using archived Mesonet data from 1997-2010. Spatial and temporal analyses of PAW will be compared to other drought indicators including PSDI, SPI, the effective drought index (Byun and Wilhite, 1999), percent normal values, and deciles/percentiles (Gibbs and Maher, 1967). In addition, analyses from the U. S. Drought Monitor (http://drought.unl.edu/dm/monitor.html), available beginning in 2000, will also be compared with PAW. This work will enable us to begin to discover and document the connections between PAW and other accepted indicators of drought. The goal is to generate quantifiable results demonstrating the utility of real-time drought monitoring in Oklahoma using PAW that can be used to leverage future funding opportunities.

Principal Findings and Significance:

We have made great progress toward the development of a system for tracking PAW based on mesoscale observations from the Oklahoma Mesonet. We have developed and are currently testing an experimental version of the statewide daily PAW map as described in specific aims #1 and #2 (Fig. 2).



We have also created and released publicly via www.mesonet.org user-selectable, historical maps of statewide PAW as described in specific aim #3 (Fig. 3).



Student Status	Number	Disciplines
Undergraduate	2	Environmental Sci.
M.S.	1	Plant and Soil Sciences
Total	3	

Scale Dependent Phosphorus Leaching in Alluvial Floodplains

Basic Information

Title:	Scale Dependent Phosphorus Leaching in Alluvial Floodplains
Project Number:	2010OK192G
Start Date:	9/1/2010
End Date:	8/30/2012
Funding Source:	104G
Congressional District:	3
Research Category:	Water Quality
Focus Category:	Nutrients, Groundwater, Water Quality
Descriptors:	None
Principal Investigators:	Garey Fox, Brian E. Haggard, Todd Halihan, Phil D Hays, Chad Penn, Andrew Sharpley, Daniel E. Storm

Publications

There are no publications.

Second Annual Progress Report

SCALE-DEPENDENT PHOSPHORUS LEACHING IN ALLUVIAL FLOODPLAINS

USGS Award No. G10AP00137

Garey Fox, Todd Halihan, Chad Penn, and Daniel Storm
Oklahoma State University

Brian Haggard, Andrew Sharpley, and Phil Hayes
University of Arkansas and USGS

This report is the second of two annual progress reports for this two-year project.

Because it is concise, no executive summary is provided.

SCALE-DEPENDENT PHOSPHORUS LEACHING IN ALLUVIAL FLOODPLAINS
USGS AWARD NO. G10AP00137

Principal Investigators:
Garey Fox, Todd Halihan, Chad Penn, and Daniel Storm
Oklahoma State University

Brian Haggard and Andrew Sharpley
University of Arkansas

Phil Hayes
University of Arkansas and Arkansas USGS

Start Date: 9/1/2010

End Date: 8/31/2012

Congressional District: 2nd and 3rd in Oklahoma; 3rd in Arkansas

Focus Category: AG, GEOMOR, GW, HYDROL, NPP, NU, ST, SW, WQL

(1) Problem and Research Objectives

This research hypothesizes that macropores and gravel outcrops in alluvial floodplains have a significant, scale-dependent impact on contaminant leaching through soils; therefore, both soil matrix and macropore infiltration must be accounted for in an analysis of nutrient transport. However, quantifying the impact and spatial variability of macropores and gravel outcrops in the subsurface is difficult, if not impossible, without innovative field studies. This research proposes an innovative plot design that combines these and other methods in order to characterize water and phosphorus movement through alluvial soils.

The specific objectives of this research are twofold. The first objective is to quantify the phosphorus (P) transport capacity of heterogeneous, gravel soils common in the Ozark ecoregion. Two characteristics of the soil are expected to promote greater infiltration and contaminant transport than initially expected: (1) macropores or large openings (greater than 1-mm) in the soil (Thomas and Phillips, 1979; Akay et al., 2008; Najm et al., 2010) and (2) gravel outcrops at the soil surface (Heeren et al., 2010). This research will estimate P concentration and P load of water entering the gravelly subsoil from the soil surface for various topsoil depths, storm sizes, and initial P concentrations. Second, the impact of experimental scale on results from P leaching studies will be evaluated. If a material property is measured for identical samples except at various sample sizes, a representative element volume (REV) curve can be generated showing large variability below the REV. This provides a helpful framework for evaluating scales in P leaching. What minimum land area is necessary to adequately measure P leaching? It is hypothesized that measured P leaching (kg m^{-2} s^{-1}) will generally increase as the scale increases from point (10^{-3} m^2) to plot (10^2 m^2) scales. This will be evaluated by measuring P leaching at the point scale in the laboratory and at plot scales with bermed infiltration experiments for three plot sizes (approximately 10^0, 10^1, and 10^2 m^2).

If subsurface transport of P to alluvial groundwater is significant, these data will be critical for identifying appropriate conservation practices based on topsoil thickness. Riparian buffers are primarily aimed at reducing surface runoff contributions of P; however, their effectiveness within floodplains may be significantly reduced when considering heterogeneous subsurface pathways.

Methodology and Principal Findings/Significance

The three selected riparian floodplain sites are located in the Ozark region of northeastern Oklahoma and western Arkansas. The Ozark ecoregion of Missouri, Arkansas, and Oklahoma is characterized by karst topography, including caves, springs, sink holes, and losing streams. The erosion of carbonate bedrock (primarily limestone) by slightly acidic water has left a large residuum of chert gravel in Ozark soils, with floodplains generally consisting of coarse chert gravel overlain by a mantle of gravelly loam or silt loam (Figure 1). The three floodplain sites are located adjacent to the Barren Fork Creek, Pumpkin Hollow and Clear Creek (Figure 2).

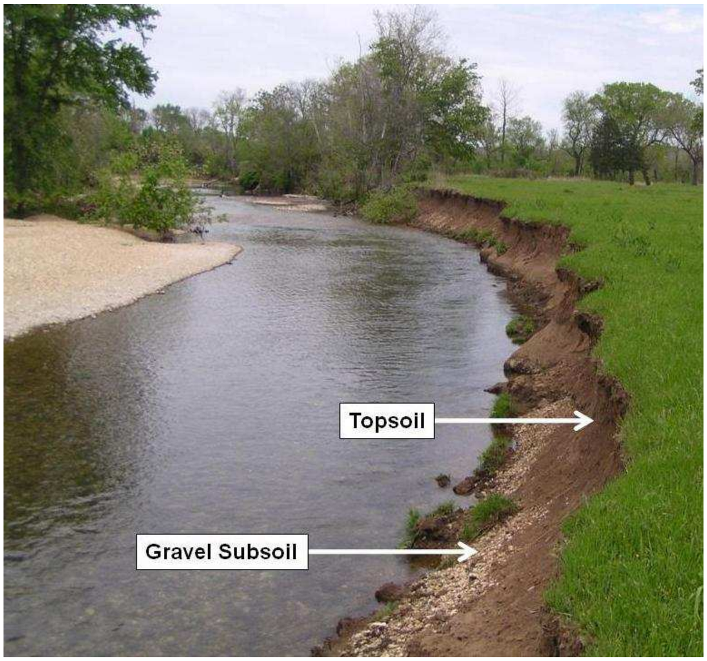


Figure 1. Floodplains in the Ozark ecoregion generally consist of coarse chert gravel overlain by a mantle (1-300 cm) of topsoil.

Figure 2. Location of riparian floodplain sites in the Ozark ecoregion of Oklahoma and Arkansas.

Barren Fork Creek Site (Oklahoma)

The Barren Fork Creek site, five miles east of Tahlequah, Oklahoma, in Cherokee county (latitude: 35.90°, longitude: -94.85°), is located just downstream of the Eldon U.S. Geological Survey (USGS) gage station (07197000). A tributary of the Illinois River, the Barren Fork Creek has a median daily flow of 3.6 $m^3 s^{-1}$ and an estimated watershed size of 845 km^2 at the study site. Historical aerial photographs of the site demonstrate the recent geomorphic activity including an abandoned stream channel that historically flowed in a more westerly direction than its current southwestern flow path (Figure 3).

Fuchs et al. (2009) described some of the soil and hydraulic characteristics of the Barren Fork Creek floodplain site. The floodplain consists of alluvial gravel deposits underlying 0.5 to 1.0 m of topsoil (Razort gravelly loam). Topsoil infiltration rates are reported to range between 1 and 4 m/d based on USDA soil surveys. The gravel subsoil, classified as coarse gravel, consists of approximately 80% (by mass) of particle diameters greater than 2.0 mm, with an average particle size (d_{50}) of 13 mm. Estimates of hydraulic conductivity for the gravel subsoil range between 140 and 230 m d^{-1} based on falling-head trench tests (Fuchs et al., 2009). Soil particles less than 2.0 mm in the gravelly subsoil consist of secondary minerals, such as kaolinte and noncrystalline Al and Fe oxyhydroxides. Ammonium oxalate extractions on this finer material estimated initial phosphorus saturation levels of 4.2% to 8.4% (Fuchs et al., 2009).

Figure 3. Aerial photos for 2003 (left) and 2008 (right) show the southward migration of the stream toward the bluff and the large deposits of gravel in the current and abandoned stream channels. The study site is the hay field in the south-central portion of each photo (red arrow).

The floodplain site is a hay field with occasional trees (Figure 4). The field has a Soil Test Phosphorus (STP) of 33 mg/kg (59 lb/ac) and has not received fertilizer for several years. The southern border of the floodplain is a bedrock bluff that rises approximately 5 to 10 m above the floodplain elevation and limits channel migration to the south. The floodplain width at the study site is 20 to 100 m from the streambank (based on the 100 year floodplain); however, water was observed 200 m from the streambank (to the bluff) during a 6 year recurrence interval flow event (Figure 4).

Figure 4. The Barren Fork site is a hay field (left). The site becomes completely inundated during large flow events (right).

Pumpkin Hollow Site (Oklahoma)

The Pumpkin Hollow site, 12 miles northeast of Tahlequah, Oklahoma, in Cherokee County (Figure 5, latitude: 36.02°, longitude: -94.81°) has an estimated watershed area of 15 km^2. A small tributary of the Illinois River, Pumpkin Hollow is an ephemeral stream in its upper reaches. The Pumpkin Hollow site is pasture for cattle (Figure 6). The entire floodplain is 120 to 130 m across. Soils in the study area include Razort gravelly loam and Elsah very gravelly loam.

Figure 5. Pumpkin Hollow is a narrow valley ascending from the Illinois River to the plateau.

Figure 6. The Pumpkin Hollow site in spring (left) and winter (right). The site includes soils with shallow layers of topsoil and gravel.

Clear Creek Site (Arkansas)

The Clear Creek site is 5 miles northwest of Fayetteville, Arkansas, in Washington County (Figure 7, latitude: 36.125°, longitude: -94.235°). Clear Creek is a fourth order stream, and is a tributary to the Illinois River. Streamflow during baseflow conditions is estimated to be around 0.5 cms. The Clear Creek site is also pasture for cattle (Figure 8). The floodplain is approximately 300 to 400 m across. The soils included intermixed layers of gravel and silt loam (Figure 8).

Figure 7. Clear Creek and an overflow channel at the Clear Creek floodplain site.

Figure 8. The Clear Creek site is pasture (left). Soils are composed of gravel and silt loam alluvial deposits (right).

Electrical Resistivity Imaging

Electrical Resistivity Imaging (ERI) is a geophysical method commonly used for near-surface investigations which measures the resistance of earth materials to the flow of DC current between two source electrodes. The method is popular because it is efficient and relatively unaffected by many environmental factors that confound other geophysical methods. According to Archie's Law (Archie, 1942), earth materials offer differing resistance to current depending on grain size, surface electrical properties, pore saturation, and the ionic content of pore fluids.

Normalizing the measured resistance by the area of the subsurface through which the current passes and the distance between the source electrodes produces resistivity, reported in ohmmeters (Ω-m), a property of the subsurface material (McNeill, 1980). Mathematical inversion of the measured voltages produces a two-dimensional profile of the subsurface showing areas of differing resistivity (Loke and Dahlin, 2002, Halihan et al., 2005).

ERI data were collected using a SuperSting R8/IP Earth Resistivity Meter (Advanced GeoSciences Inc., Austin, TX) with a 56-electrode array. Fourteen lines were collected at the Barren Fork Creek site, three at the Pumpkin Hollow site, and eight lines at the Clear Creek site. One line at the Barren Fork Creek site and all of the lines at Pumpkin Hollow were “roll-along” lines that consisted of sequential ERI images with one-quarter overlap of electrodes. The profiles at the Barren Fork Creek site employed electrode spacing of 0.5, 1.0, 1.5, 2.0 and 2.5 m with associated depths of investigation of approximately 7.5, 15.0, 17.0, 22.5 and 25.0 m, respectively. All other sites utilized a 1.0-m spacing. The area of interest in each study site was less than 3 m below the ground surface and thus well within the ERI window. The resistivity sampling and subsequent inversion utilized a proprietary routine devised by Halihan et al. (2005), which produced higher resolution images than conventional techniques.

The OhmMapper (Geometrics, San Jose, CA), a capacitively-coupled dipole-dipole array, was effectively deployed at the relatively open Barren Fork Creek site for large scale mapping. The system used a 40 m array (five 5 m transmitter dipoles and one 5 m receiver dipole with a 10 m separation) that was pulled behind an ATV. Two data readings per second were collected to create long and data-dense vertical profiles. The depth of investigation was limited to 3 to 5 m. Positioning data for the ERI and OhmMapper were collected with a TopCon HyperLite Plus GPS with base station. Points were accurate to within 1 cm.

Barren Fork Creek

Resistivity at the Barren Fork Creek site appeared to conform generally to surface topography with higher elevations having higher resistivity, although the net relief was minor (~1 m). This was most evident in the OhmMapper resistivity profiles which covered most of the floodplain and which revealed a pattern of high and low resistivity that trended SW to NE (Figure 9). More precise imaging with reduced spatial coverage was obtained with the ERI. A composite ERI line collected from the site is shown in Figure 10. The line, which is approximately parallel to the stream, begins only 5 m from the stream. Gravel outcrops are indicated by gray colors reaching closer to the surface and will be the location for induced leaching experiments at different spatial scales at this site.

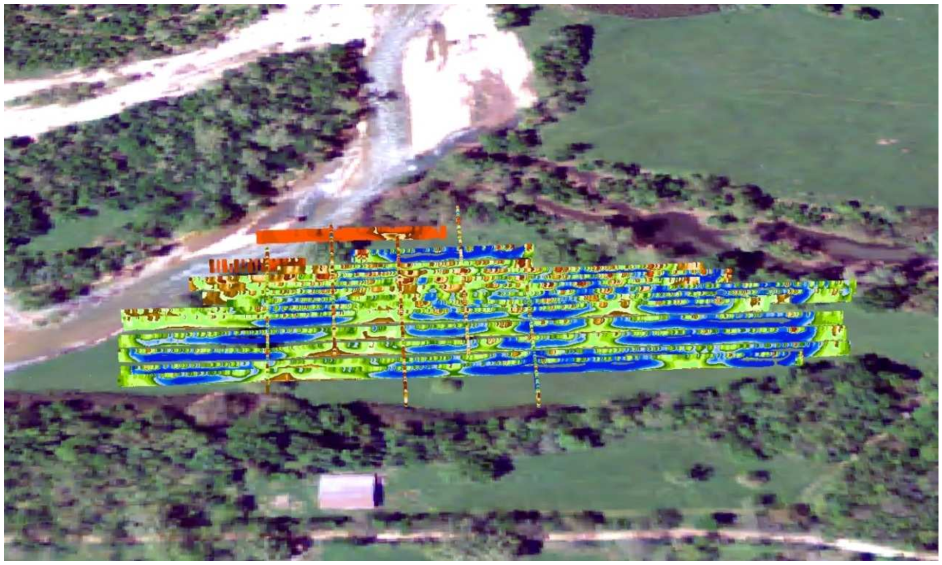


Figure 9. OhmMapper coverage of the Barren Fork Creek alluvial floodplain showing SW to NE trends of low (blue) and high (orange) resistivity. View is to the North and subsurface resistivity profiles are displayed above the aerial image for visualization purposes. Modified from Heeren et al. (2010).

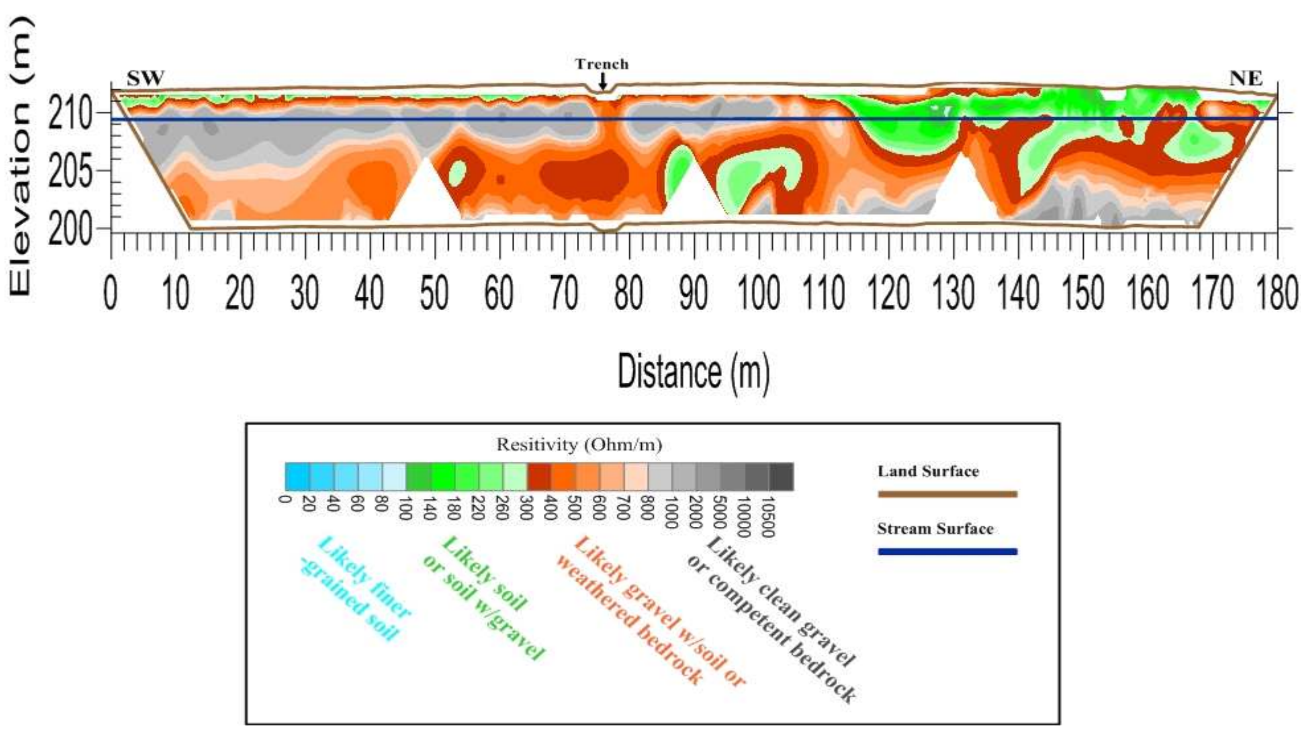


Figure 10. Composite SuperSting image, showing mapped electrical resistance (Ω-m), running southwest to northeast along a trench installed for studying subsurface phosphorus transport in the gravel subsoils by Fuchs et al. (2009). The *x*-axis represents the horizontal distance along the ground; the *y*-axis is elevation above mean sea level. Source: Heeren et al. (2010).

Pumpkin Hollow

Pumpkin Hollow differed from the other streams because it was a headwater stream with a smaller watershed area. The valley at the study site was approximately 200 m wide and the roll-along lines spanned nearly the entire valley width, crossing Pumpkin Hollow Creek at about the midpoint of the line. The ERI survey at Pumpkin Hollow consisted of three lines oriented W-E with 1 m electrode spacing, 12.5 m depth, and 97 m (lines 1-2 and 3-4) or 139 m (line 5-6-7) length (Figure 11).

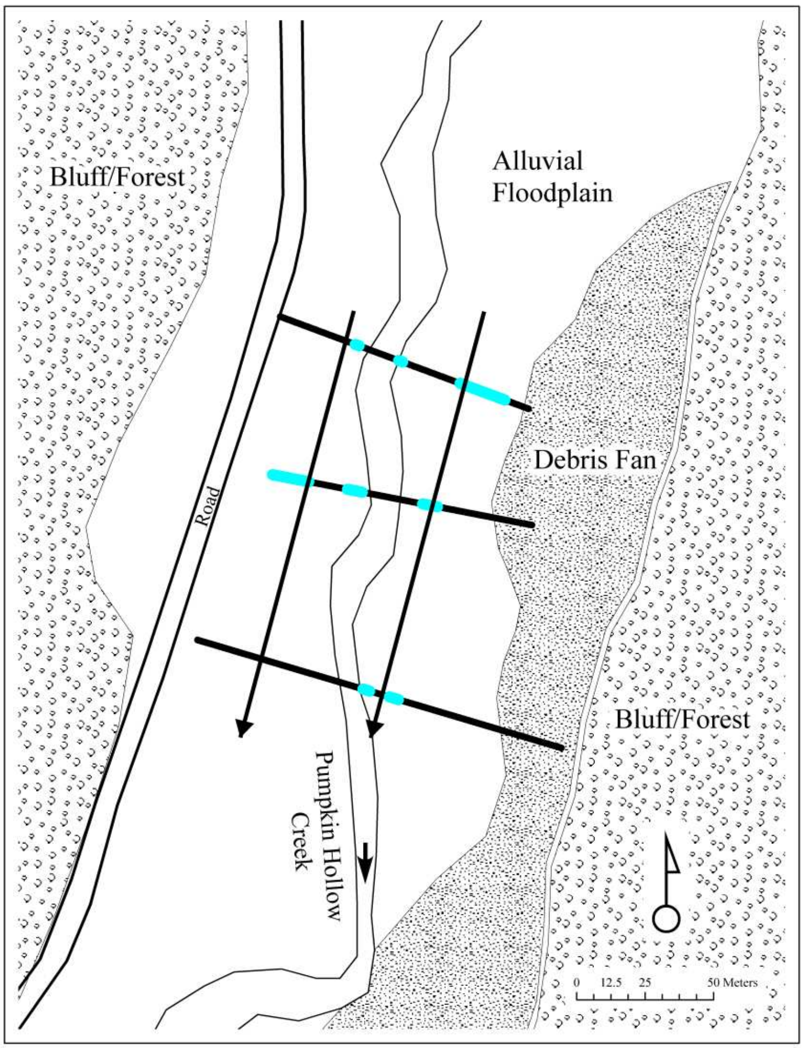


Figure 11. High resistivity feature locations on ERI lines at the Pumpkin Hollow site are shown in blue. Arrows represent potential connections between them and the direction of flow.

The Pumpkin Hollow ERI profiles also had a unique configuration consisting of a low resistivity layer between a high resistivity surface layer and high resistivity at depth (Figure 12). Observations at the site included the close proximity of large gravel debris fans originating from nearby upland areas. Jacobson and Gran (1999) noted similar pulses of gravel in Ozark streams in Missouri and Arkansas originating from 19th and early 20th century deforestation of plateau surfaces, implying that a possible interpretation of the low resistivity layer in the ERI profiles was a soil layer buried by gravel from the nearby plateau surfaces. The streambed elevation was approximately 262 m with the general floodplain surface being about 1 m above that elevation. The area of interest included the elevations above 262 m (note that the mean elevation was 262.9 m and that the maximum elevation 265 m occurred at the valley edge) and was therefore thin compared to the other study sites. The resistivity at Pumpkin Hollow ranged from 58 to 3110 Ω-m with a mean of 387 Ω-m. Like the other sites, the Pumpkin Hollow resistivity suggested a pattern of discrete areas of high resistance that indicated gravel outcrops (Figure 12). These were generally associated with topographic high areas and appeared to have the potential to direct flow down-valley parallel to the stream.

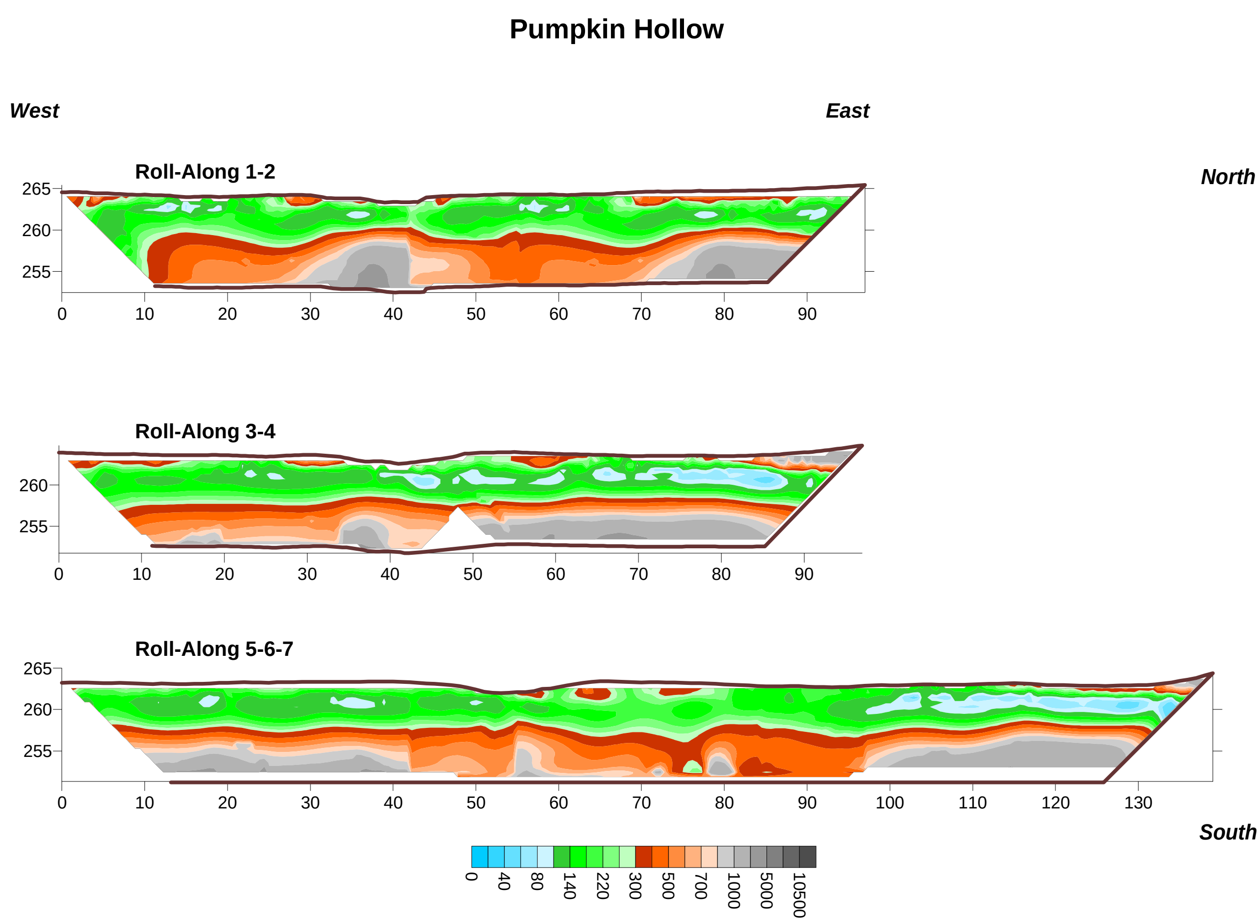
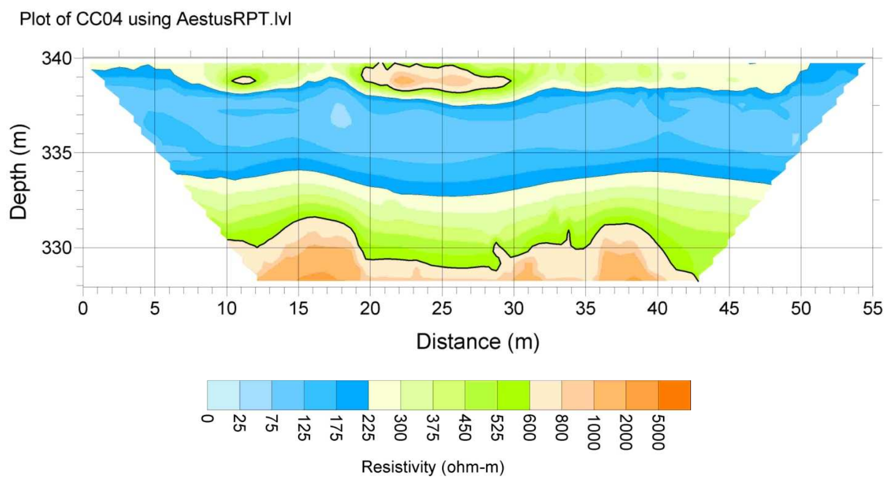


Figure 12. ERI images of three “roll-along” lines for the Pumpkin Hollow site. The *x*-axis represents the horizontal distance along the ground; the *y*-axis is elevation above mean sea level. The color bar is the electrical resistivity in Ohm-meters.

Clear Creek

Geophysical mapping was first performed between the overflow channel and Clear Creek shown in Figure 7; however, limited gravel outcrops were observed in this area and therefore the control (non-gravel outcrop) leaching experiments will be performed at this location (Figure 13a). Most of the shallow profile possessed electrical resistivities less than 450 Ω-m. On the east side of Clear Creek, layered profiles demonstrated the potential for lateral flow and transport to the stream, and this feature was clearly visible based on exposed streambanks and supported by the ERI data. Electrical resistivities at the surface were on the order of 600 to 1000 Ω-m with lower resistivity soils below this surface feature (Figure 13b).

(a)



(b)

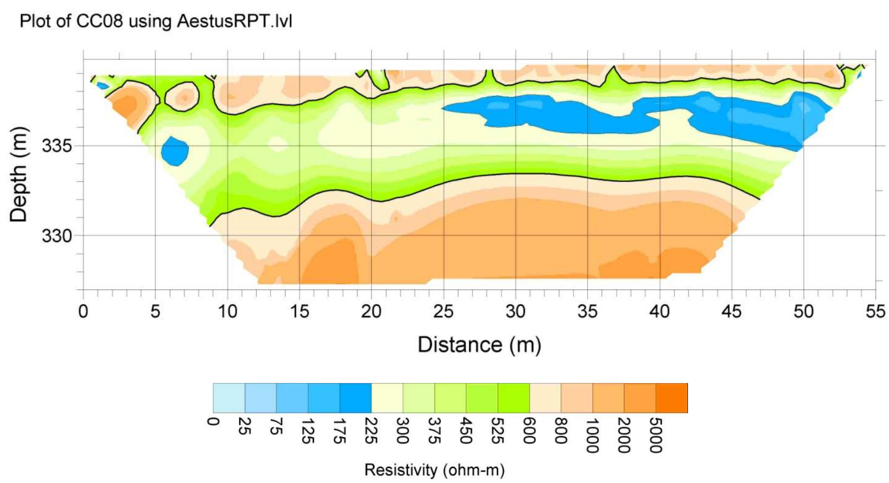


Figure 13. ERI images of two lines at the Clear Creek site where (a) is a line between the overflow channel and the creek with limited gravel outcrop area and (b) is a line on the east side of Clear Creek with gravel outcrops at the surface. The *x*-axis represents the horizontal distance along the ground; the *y*-axis is elevation above mean sea level.

Point Scale Laboratory Testing: Flow-Cell Experiments

Fine material (diameter less than 2.0 mm) from the Clear Creek site in Arkansas was used in laboratory flow-through experiments to investigate the P sorption characteristics with respect to the flow velocity (DeSutter et. al., 2006). Approximately 5.0 g of the fine materials was placed in each flow-through cell. A Whatman 42 filter was placed at the bottom of each cell to prevent the fine material from passing through the bottom. Each cell had a nozzle at the bottom with a hose running from the nozzle to a peristaltic pump (Figure 14). The pump pulled water with predetermined P and potassium chloride (KCl) concentrations through the cells and fine material at a known flow rate (mL/min).

Two different flow rates were used on the peristaltic pumps to evaluate the effect of velocity on P sorption. The flow rates were 0.20 mL/min for the low flow experiments and 0.75 mL/min for the high flow experiments. These flow rates corresponded to average flow velocities of 0.42 and 1.59 m/d, respectively. First, a 0.01M KCl solution was pulled through the soil to determine the background P that was removed from the soil. Then, a KH_2PO_4 and 0.01M KCl solution was injected into each cell at different concentrations (1.0 to 10.0 mg/L of P) and kept at a constant head using a Mariott bottle system (Figure 14). The experiments were run for approximately 8 hours. Samples were taken periodically throughout each experiment. The samples were analyzed in the laboratory for P using the Murphy-Riley (1962) method.

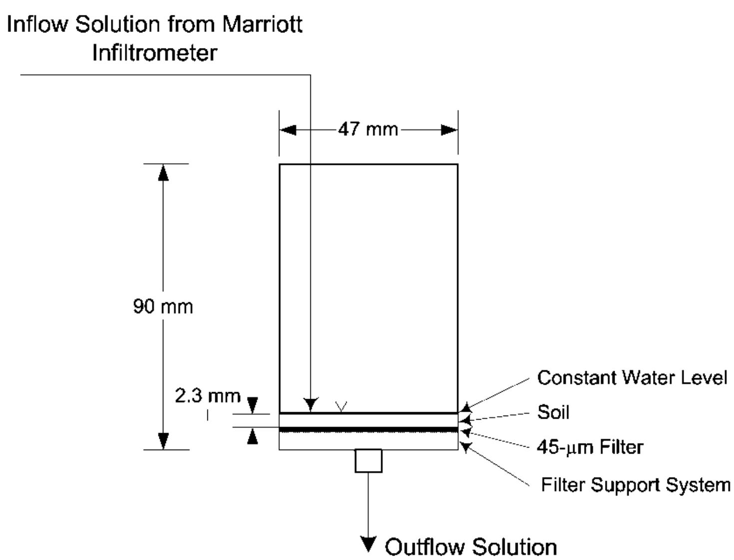


Figure 14. Laboratory flow-through experimental setup. The experimental setup follows that of DeSutter et al. (2006) and Fuchs et al. (2009).

Data were analyzed based on concentrations of P in the outflow compared to the total amount of P added to the system for both low flow and high flow scenarios. The principle of this method was that the measured P concentrations in the outflow should be approximately equal if flow velocity does not have an effect on P sorption. The mass of P added per kilogram of soil (mg P/kg soil) was found by multiplying Q (mL/min) by the inflow P concentration (mg/L) and by the elapsed time of the experiment (min). These data were plotted against the P concentrations (mg/L) detected in the outflow solutions for both flow velocities. If equivalent sorption was occurring, the curves associated with each data set would be approximately equal. Data were also analyzed using contaminant transport theory relative to the dimensionless concentration and number of pore volumes passed through the soil.

Both the contaminant transport and load perspectives suggested that the flow velocities in the experimental range had no effect on the sorption capabilities of the system, but instead illustrated that the initial P concentrations were important (Figure 15).

(a)

(b)

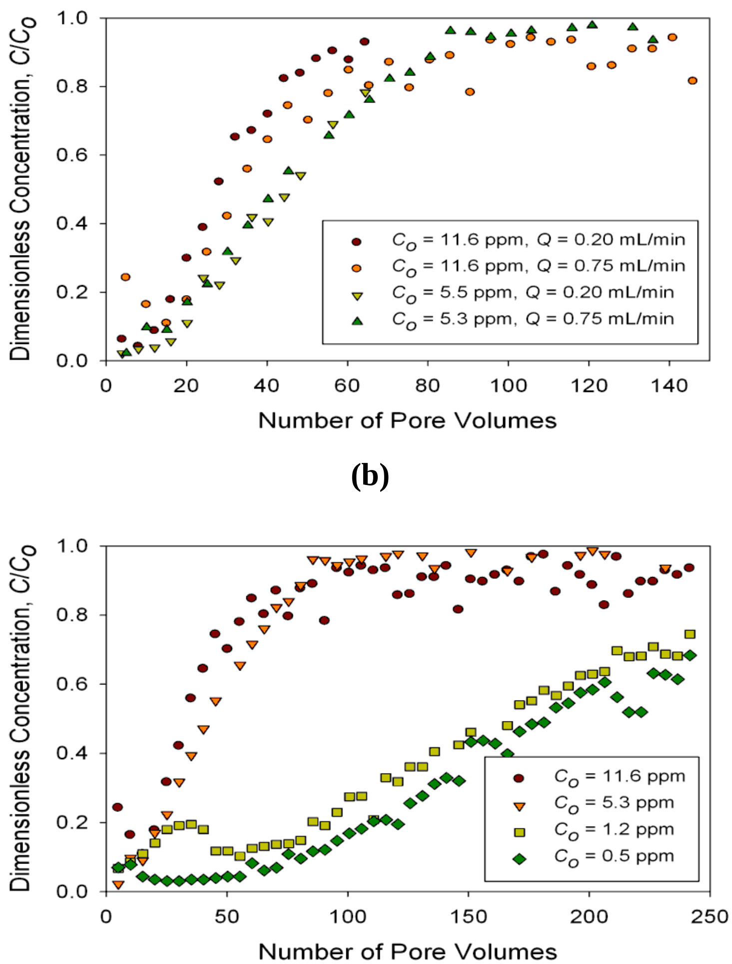


Figure 15. Phosphorus (P) breakthrough curves demonstrating (a) no influence of flow velocity on transport at the range of conditions studied and (b) influence of initial P concentration on transport.

Plot Scale Testing: Tracer/Rhodamine WT/P Infiltration Tests

As of May 2012, all the 1 m by 1 m and 3 m by 3 m plot scale infiltration and leaching tests have been performed. Remaining field experiments include the 10 m by 10 m plots at the three field sites. Data analysis has been completed at the Barren Fork Creek site at this time, and analyses are continuing at the remaining sites.

Description of the Berm Infiltration/Leaching Technique – 1 m by 1 m and 3 m by 3 m Plots

The berm was constructed of four sections of 15 cm vinyl hose attached to four 90^{o} elbows constructed from 15 cm steel pipe (Figure 16). Each elbow had an air vent and one elbow had a gate valve with a garden hose fitting for water. The vinyl hoses were secured to the elbows with stainless steel hose clamps and sealed with silicone sealant. The berms were then partially filled with water to add weight, but excess pressure was avoided to ensure the vinyl did not separate from the elbows.

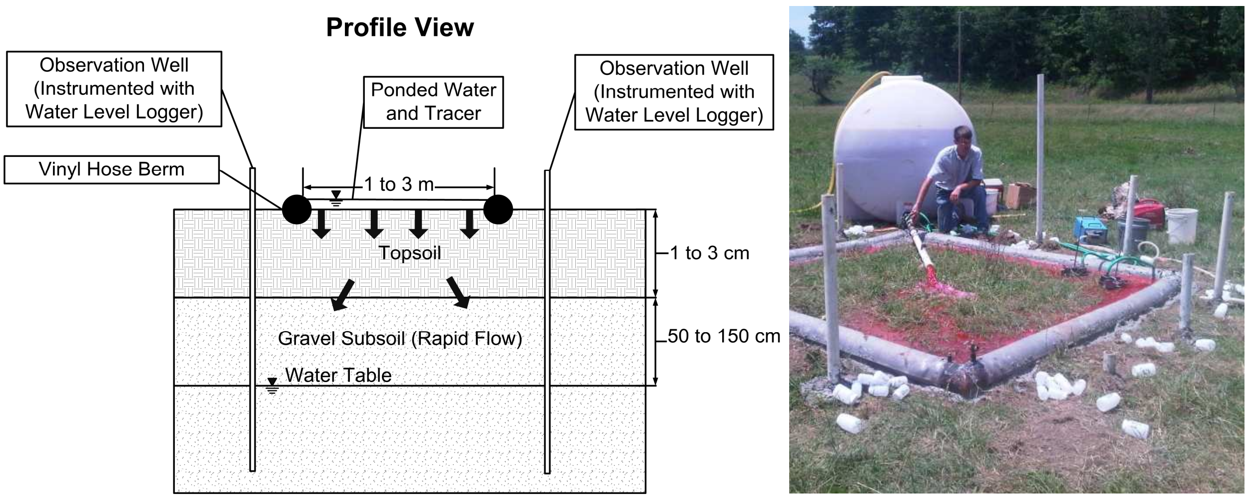


Figure 16. Berm infiltration method, including vinyl berms to contain water-tracer solution and observation wells for collecting groundwater samples: design (left) and implementation at the Pumpkin Hollow floodplain site in eastern Oklahoma (right).

Plots were located on relatively level areas in an attempt to maintain uniform water depths. Larger plots required shallower slopes to ensure that the entire plot could be inundated without overflowing the berm. The vinyl hose was placed in a shallow trench (3 to 5 cm) cut through the surface thatch layer to minimize lateral flow at the surface. A thick bead of liquid bentonite was also placed on the inside and outside of the berm to create a seal between the berm and the soil. High-density polyethylene tanks, 4.9 and 0.76 m^3, were used for the 3 m by 3 m and the 1 m by 1 m plots, respectively, to mix water and a potassium chloride tracer, Rhodamine WT, and a phosphorus solution. Tanks were instrumented with automated water level data loggers with an accuracy of 0.5 cm (HoboWare U20, Onset Computer Corp., Cape Cod, MA) to monitor water depth (pressure) and temperature at one minute intervals. An additional water level data logger was used to monitor atmospheric pressure. Logger data were processed with HoboWare Pro software, which adjusted for changes in atmospheric pressure and water density. Tank water depth over time was used to calculate flow rate with a volumetric rating curve.

A combination of 5.1 cm diameter Polyvinyl chloride (PVC) pipe with a manual gate valve and vinyl garden hoses with float valves were used to deliver gravity fed water from the tanks to the plots. For low flow rates, one to two garden hoses with float valves were sufficient. When higher flow rates were required to achieve the desired constant head, flow was dominated by the larger PVC pipe and the garden hoses with float valves were relatively ineffective. For these cases a fine-adjustment gate valve was required to manually control the flow rate to achieve a relatively constant head in the plots. When a tank was nearly empty, flow was temporarily stopped while water and tracer was added to the tank. Chloride was used as a conservative tracer and Rhodamine WT as a visual tracer with injection concentrations 20 to 30 times background levels. Phosphorus was also injected into the plot. Depth in each plot area was monitored with a water level data logger. Heads were maintained between 3 and 10 cm across the plots.

A Geoprobe Systems drilling machine (6200 TMP, Kejr, Inc., Salina, KS), which has been found to be effective in coarse gravel soils (Heeren et al., 2011; Miller et al., 2011), was used to install four to twelve observation wells around each plot. Boreholes were sealed with liquid bentonite to avoid water leaking down the hole. Observation wells were instrumented with water level data loggers. Reference water table elevations, obtained with a water level indicator and laser level data for each well, were then calculated. Water table elevation data had an accuracy of 1 cm. Low flow sampling with a peristaltic pump was used to collect water samples from the top of the water table, which ranged from 50 to 150 cm below ground surface.

Finite Element Modeling

Porous media flow from hypothetical 1 m by 1 m infiltration plots were simulated using HYDRUS-3D (Šimůnek et al., 2006) for three different soil types: sand, loam, and silt. This method was not expected to be used on soils finer than silt. HYDRUS is a finite element model for simulating two- and three-dimensional movement of water, heat, and multiple solutes in variably saturated media (Šimůnek et al., 2006; Akay et al., 2008). The HYDRUS code numerically solves the Richards equation for saturated-unsaturated water flow (Šimůnek et al., 2006).

The finite element grid consisted of triangular prism elements spaced equally every 25 cm in the horizontal, lateral, and vertical directions. The simulation domain consisted of a 1 m by 1 m constant head infiltration plot centered within a 10 m by 10 m area with a 3-m deep soil profile (Figure 17). All cells on the surface of the simulation domain outside the infiltration plot were no-flux boundaries. A constant head boundary condition was used to simulate the infiltration plot with constant heads ranging from 2.54 to 15.24 cm. The initial water table depth was varied between simulations, which included depths of 1.0, 2.0, and 2.5 m below ground surface. Below the water table, a no flux boundary condition was specified for the shell and bottom of the simulation domain to simulate the presence of a regional groundwater system. Above the water table, the shell boundary condition was a possible seepage face (Figure 17). At the water table depth, observation nodes were added to the simulation domain located at various distances (0 to 450 cm) away from the edge of the infiltration plot.

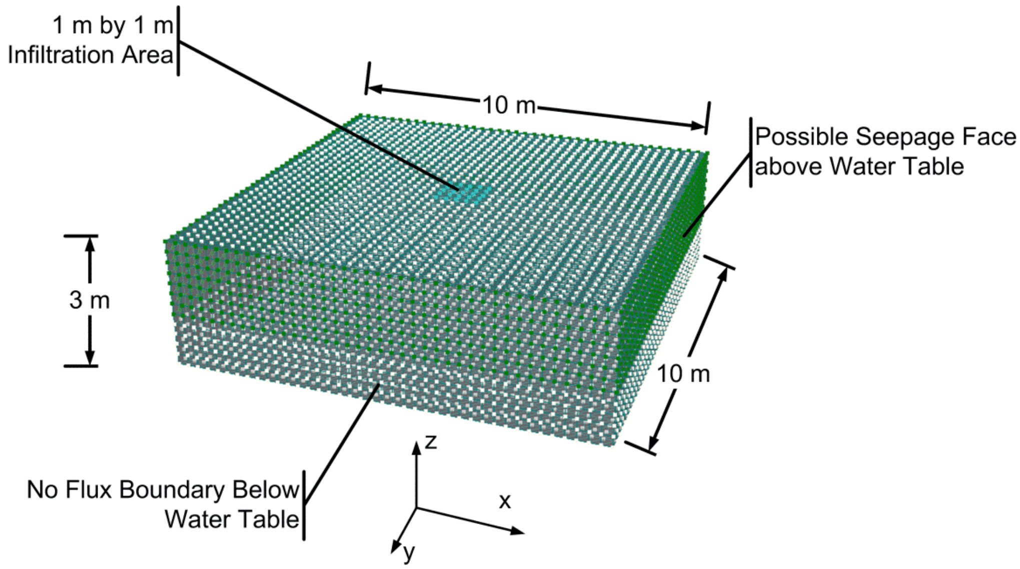


Figure 17. Simulation domain for HYDRUS-3D modeling of hypothetical infiltration experiments with a 1 m by 1 m infiltration plot.

The van Genuchten-Mualem model (van Genuchten, 1980) was used to describe the water retention, $\theta(h)$, and conductivity, $K(h)$, functions for the assumed homogeneous soil matrix:

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{\left[1 + |\alpha h|^n\right]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \quad (1)$$

$$K(h) = K_s S_e^l \left[1 - (1 - S_e^{1/m})^m\right]^2 \qquad m = 1 - 1/n, \quad n > 1 \quad (2)$$

where $S_e = (\theta - \theta_r)/(\theta_s - \theta_r)$ is the effective saturation; α (L^{-1}), n, and l are empirical parameters; θ_s is the saturated water content (L^3L^{-3}); θ_r is the residual water content (L^3L^{-3}); and K_s (LT^{-1}) is the saturated hydraulic conductivity. Hydraulic parameters for the sand, loam, and silt soils were acquired from the soil catalog in HYDRUS, derived from Carsel and Parrish (1988), in order to represent average values for these different textural classes (Table 1).

HYDRUS simulations were conducted to determine the time at which a detectable water table rise, defined as 1 cm, was observed in the observation nodes. This information was used to correlate the response time in observation wells installed next to the infiltration plot relative to the soil type, head in the infiltration plot, distance the observation well was installed from the infiltration plot edge, and the water table depth.

Table 1. Soil properties for the sand, loam, and silt soils simulated by HYDRUS-3D for the hypothetical 1 m by 1 m infiltration experiments. Soil properties were from the soil catalog for the textural classes in HYDRUS.

Soil Type	Residual Water Content, θ_r ($cm^3\ cm^{-3}$)	Saturated Water Content, θ_s ($cm^3\ cm^{-3}$)	α* (cm^{-1})	*n**	Saturated Hydraulic Conductivity, K_s ($cm\ min^{-1}$)	Pore-Connectivity Parameter, *l*
Sand	0.045	0.430	0.145	2.68	0.495	0.5
Loam	0.078	0.430	0.036	1.56	0.017	0.5
Silt	0.034	0.460	0.016	1.37	0.004	0.5

*Empirical constants.

As an example, infiltration rates measured at Pumpkin Hollow ranged from 5 to 70 cm/hr, indicating considerable heterogeneity in the infiltration rates of the floodplains due to the occurrence of gravel outcrops. These data were higher than the U.S. Natural Resources Conservation Service (NRCS) Adair County, Oklahoma Soil Survey (NRCS, 2012), indicating the need for larger scale field measurements of infiltration rate. The NRCS Soil Survey (NRCS, 2012) estimated permeability of the limiting layer to be in the range of 1.5 to 5 cm/hr for the Razort gravelly loam. This method was successful in quantifying high infiltration rate soils (i.e., gravels) even for large 3 m by 3 m plots, and lower infiltration rates could be easily measured. Larger plot sizes may require excessively large tanks, and thus continuous pumping and dosing to inject tracers directly into the pump hose may provide a better alternative for adequate mixing.

Figure 18 shows the relationship between flow rate and the time to empty the tank, which can be used to aid the design of infiltration experiments. For example, one of the 3 m by 3 m plots had a quasi-steady state infiltration rate of 6.3 cm/hr, which required an average flow rate of 9.5 L/min. According to Figure 18, the tank will need to be refilled every 8 hr for a 4.9 m^3 tank. Actual times to empty the tank after quasi-steady state was reached were 6.5, 6.0, and 8.0 hr at Pumpkin Hollow for example, which is consistent with the fact that refills were performed before the tank was completely empty.

A constant head assumption was considered valid if the water depth in the infiltration plot was within 1.5 cm of the mean depth at least 85% of the time. All experiments met this requirement (Figure 19). Float valves were reliable and effective, allowing the system to run automatically for several hours at a time. Manual gate valves required attentive monitoring in order to be effective. Observed response times based on chloride detection in groundwater wells (located 0.5 m from the edge of the berm) ranged from 18 minutes (coarse gravel outcrop) to more than 32 hours. All plots had at least some wells where chloride was never detected above background levels (duration of experiments ranged from 3 to 32 hours), again indicating significant heterogeneity within the floodplain soils.

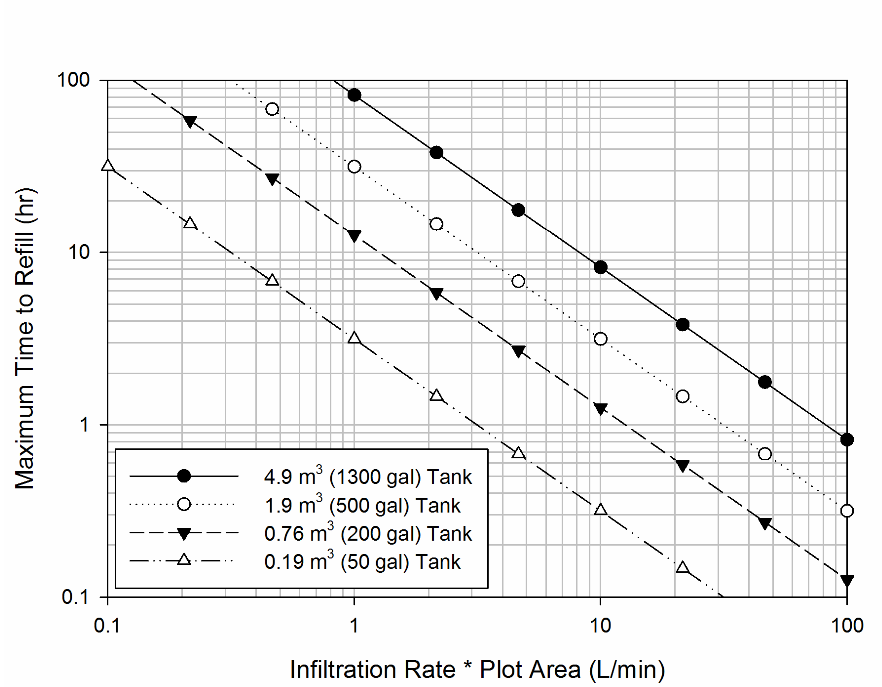


Figure 18. Relationship between expected infiltration flow rate and time to empty water tank for different size water tanks.

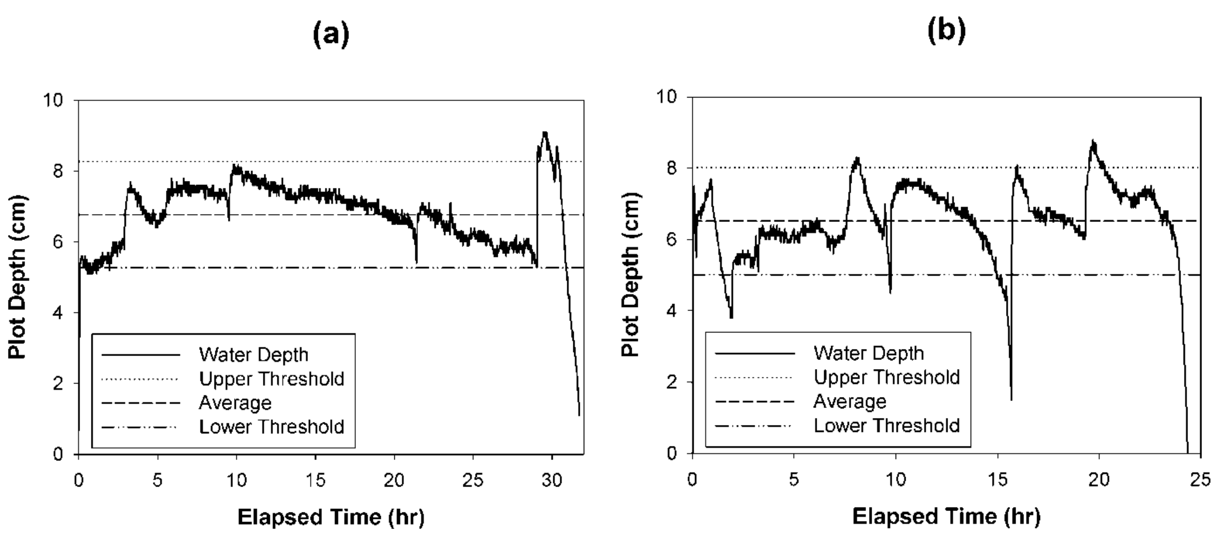


Figure 19. Measured plot water depth over time for a 1 m by 1 m plot with flow controlled primarily by an automatic float valve (a) and for a 3 m by 3 m plot with flow controlled primarily by a manual gate valve (b). Water depths were within 1.5 cm of the mean depth 92% (left) and 89% (right) of the time, meeting the prescribed requirements for constant head infiltration.

Modeled response times using HYDRUS-3D were more dependent on water table depth than distance from the plot edge. In sand and coarser soils (Figure 20), response times were predicted to be less than 200 minutes (approximately 3 hrs), even with a deep water table (250 cm) and observation wells installed as much as 4 m from the edge of the infiltration plot. For silt and finer soils, experiments would need to be conducted for multiple days when sampling from a groundwater table 200 cm below ground surface (Figure 20).

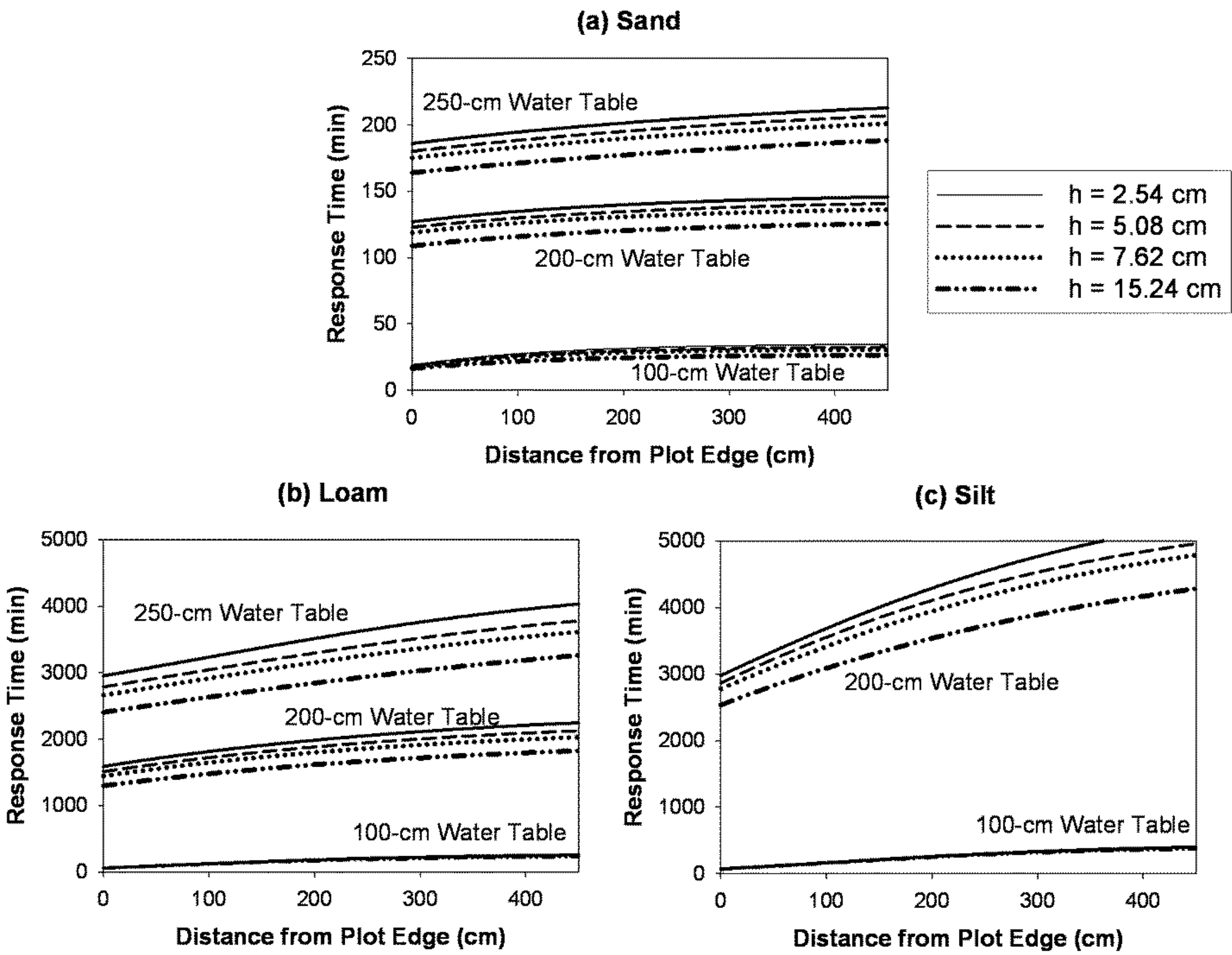


Figure 20. HYDRUS-3D predicted response times in observation wells installed next to infiltration plots as a function of soil type, head in the infiltration plot (h), distance the observation well was installed from the infiltration plot edge, and the depth to water table.

This research successfully demonstrated an innovative method for quantifying infiltration rates and leaching in highly conductive gravelly soils at the plot scale, maintaining a constant head at least 85% of the time during experiments. Guidelines have been provided for future infiltration experiments. The berm infiltration method allows investigations of various plot sizes and was demonstrated to be capable of measuring infiltration rates ranging from 5 to 70 cm/hr. Larger plot sizes may require continuous pumping and tracer injection directly into the pump hose instead of using tanks. Numerical modeling indicated that experimental times in homogeneous soils were more dependent on water table depth than distance from the plot edge, especially for coarser soils. Experimental durations may be less than 200 minutes in sand and coarser soils to multiple days for silt and finer soils.

Data Analysis from 1 m by 1 m and 3 m by 3 m Plot Experiments at Barren Fork Creek

Locations for the 1 m by 1 m and 3 m by 3 m plots were selected based upon a relatively flat surface in order to ensure an even distribution of water within the plots. Locations were also determined from previous surveys conducted with electrical resistivity imaging that determined where gravel outcrops below the surface of the soil were located. The given sites were located approximately 10 m to 20 m from the streambank for the 1 m by 1 m and 3 m by 3 m plots, respectively.

Observation wells were installed with a Geoprobe Direct Push Drill (TMP) to a depth just below the water table to monitor the groundwater surrounding the plots, which was located approximately 3.0 to 3.5 m below the surface of the soil. Five wells (A through E) were installed around the 1 m by 1 m plot and 12 wells (I through T) were installed surrounding the 3 m by 3 m plot. The wells were located 0.5 m outside the berm (Figure 16). The wells were 5.1-cm diameter PVC pipe with approximately 3 m of screened section. Sand was packed around the screen, and bentonite was then poured and packed around the rest of well to ensure surface and lateral flow containing the injected solutes did not enter the wells before the depth of the screen. Water level loggers were installed in the wells to measure changes in the water table.

For the study, conservative and non-conservative tracers were injected into the area inside the berm (inflow water) and water samples were collected from the wells surrounding the plot. The tracers were premixed with water located in tanks (Figure 16) before distribution to the plots, with target concentrations of 100 mg/L Cl^-, 20 mg/L Rhodamine WT (RhWT, where WT means water tracing), and 10 mg/L P (in the form of PO_4^{-3}). Water added to the tanks to mix the solutions was pumped directly from the Barren Fork Creek using water pumps. The water pumped from the stream was drawn from the edge of the current, ensuring it was not drawn from stagnant pools. Water level loggers were used in both tanks to measure the head of the water in the tank, and another logger was put on the ground outside of the tanks to record the atmospheric pressure.

Both the 1 m by 1 m and 3 m by 3 m plots were started at 5:30 P.M. on June 30, 2011. An attempt was made to keep the water level in both plots at approximately 0.05 to 0.10 m to ensure a constant head on the soil. Water level loggers were placed at the lowest point in each plot to record any variability in the depth of water present in the plots.

When determining whether to collect water samples from a given well, an electrical conductivity (EC) meter, calibrated against background EC levels, was used to determine whether the Cl^- tracer had reached the well. Wells were checked approximately every 30 minutes for the first two hours of the experiment, then on the hour for the next two hours, then every four hours for the remainder of the experiment. If the EC of the water in a given well increased, a sample would be taken at that time. Another indicator used to determine whether the tracers had reached a well was to examine the water being drawn from the well to visually determine whether it had any RhWT, a pink dye. Generally, Cl^- would increase before RhWT, which in turn would appear before the P, due to the increasing magnitude of sorption, with Cl^- being conservative or non-reactive. Samples were collected to measure RhWT, Cl^-, and P concentrations. The P samples were filtered within 24 hours using 0.45 µm filters to remove any possible particulate P. The samples were then sent to the University of Arkansas to measure the Cl^- and P concentrations. To measure the concentrations of RhWT, a Trilogy laboratory fluorometer was used with the fluorescence module to measure the relative fluorescence units (RFU). Then, the RFU was used to calculate the RhWT concentration in ppb.

Using rating curves for the tanks, the change in the volume of water in the tank was calculated for the duration of the test, with the change in volume over time being equivalent to the rate of water being distributed to the plot. Then, using the plot area and the rate of distribution, the infiltration rate of the water was calculated for the two scales (1 m^2 and 9 m^2). These infiltration rates were compared to infiltration rates from small-scale infiltration tests conducted using double ring infiltrometers.

The infiltration throughout the experiments for both plots was relatively consistent. The average infiltration rate for the 1 m by 1 m and 3 m by 3 m plots was 10.7 (Figure 21) and 12.6 cm/hr, respectively. For a two to four hour period, the 3 m by 3 m plot was not covered with water due to equipment malfunction. This may have led to variations in the concentrations for wells I through T.

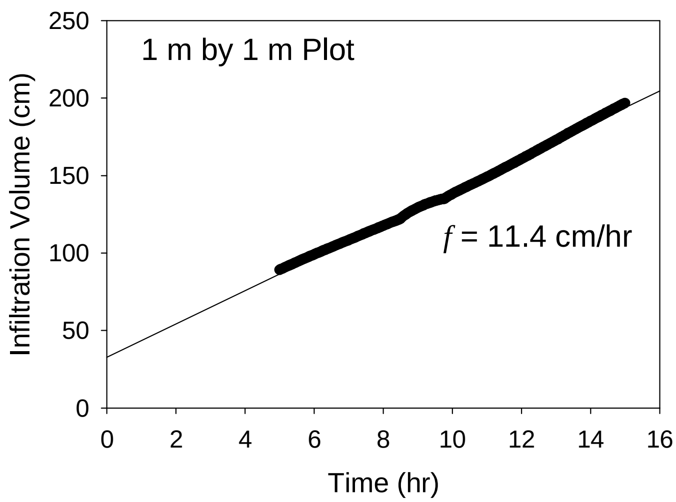


Figure 21. Infiltration of water on the 1 m by 1 m plot for a specific period in which the infiltration rate was constant. The slope of the line indicates the average infiltration rate.

Nonetheless, the average infiltration for the 3 m by 3 m was greater than the 1 m by 1 m plot, which in turn was greater than the infiltration of the soil conducted with a double ring infiltrometer at the same site the previous year (Figure 22). This in turn is leading to future research to determine whether the size of a given plot will affect the rate of P absorption due to the velocity off water moving through the soil. The difference in the rates of infiltration appear to follow a logarithmic relationship (Figure 22); additional 10 m by 10 m plots are going to be tested in the same manner, and the infiltration rates will be compared in the future to confirm whether there is indeed a scaling factor when conducting experiments dealing with water infiltration.

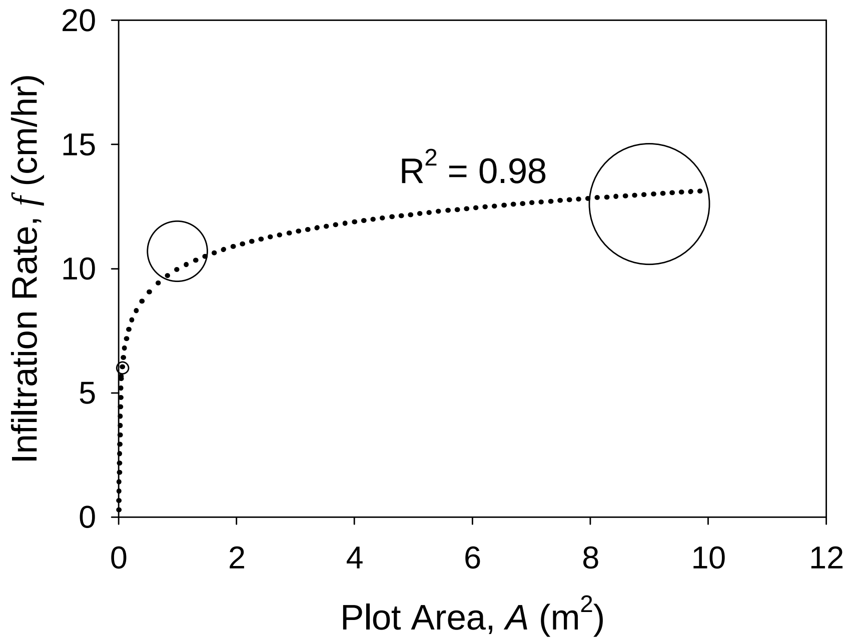


Figure 22. Infiltration rate versus the size of the plot at the Barren Fork Creek floodplain site. The smallest plot size was a 30-cm diameter double-ring infiltrometer.

For all wells, the RhWT and Cl^- concentrations increased by the second sample after the start of the experiment, which was approximately two hours after the start of the experiment. In fact, slight increases in concentrations of both RhWT and Cl^- were observed after the first sample in some wells, which was taken approximately thirty minutes to one hour after the start of the experiment. The concentration of the wells reached approximately 50% of the applied chloride within two hours of the initial introduction of the tracers. The water collected from the wells was approximately 3 m below the surface, meaning the tracers could have had an average transport rate of up to 10 cm/min. The NRCS Soil Survey (NRCS) estimated permeability of the limiting layer to be in the range of 1.5 to 5.0 cm/hr for Razort gravelly loam, the soil found at the Barren Fork Creek field site. This suggests the possibility of preferential pathways being present on the plots, meaning that water could be moving through macropores at a rate much faster than the average soil infiltration. Also, another possibility is that the soil is not homogeneous, and there is a thinner layer of soil on top of the gravel in smaller areas that allowed for an introduction of tracers to the groundwater at a faster rate than the average of the entire plot.

The concentration ratio between the concentration in the well and the concentration injected into the plot for RhWT, Cl^-, and P (i.e. dissolved P) were used to examine changes in the wells (Figure 23). The timing of when the tracers reach the well should be in the following order: Cl^-, RhWT, and P. The Cl^- should reach the wells first due to the fact that it does not bind with soil particles. RhWT only binds to organic materials, but does not bind to any other particles to a large extent. P, on the other hand, binds to both organic matter and mineral surfaces.

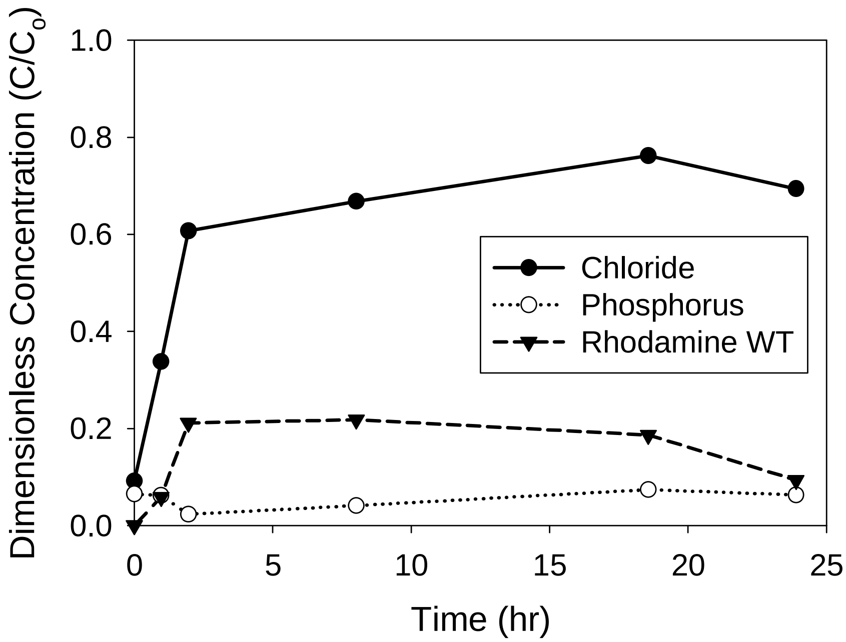


Figure 23. Dimensionless concentration calculated as the ratio of the concentration in the well (*C*) to the injected concentration (C_o) into the berm versus time for well B in the 1 m by 1 m plot.

Consider the example shown in Figure 23, RhWT and Cl^- concentration ratios were directly proportional for all measurements taken until the last measurement, where the concentration of the RhWT decreased while the Cl^- concentration increased. The P concentration appeared to be high at the beginning, and then after the first two readings, a low concentration of P was observed, and then the P concentration increased for the rest of the experiment.

The soils in the alluvial floodplain were extremely heterogeneous, as shown by previous studies conducted by Oklahoma State University (Heeren et al., 2011). Further, when testing on a larger scale plot (3 m by 3 m), the flow containing tracers did not follow the expected flow for soils of homogeneous composition; the wells surrounding the 3 m by 3 m plot did not show equal maximum concentrations of RhWT, Cl^-, nor P. The wells that showed a significant difference in RhWT, Cl^-, and P concentrations were all adjacent on the southern corner of the plot (wells O, P, W, R, and S, Figure 24) with some variability in the P concentrations.

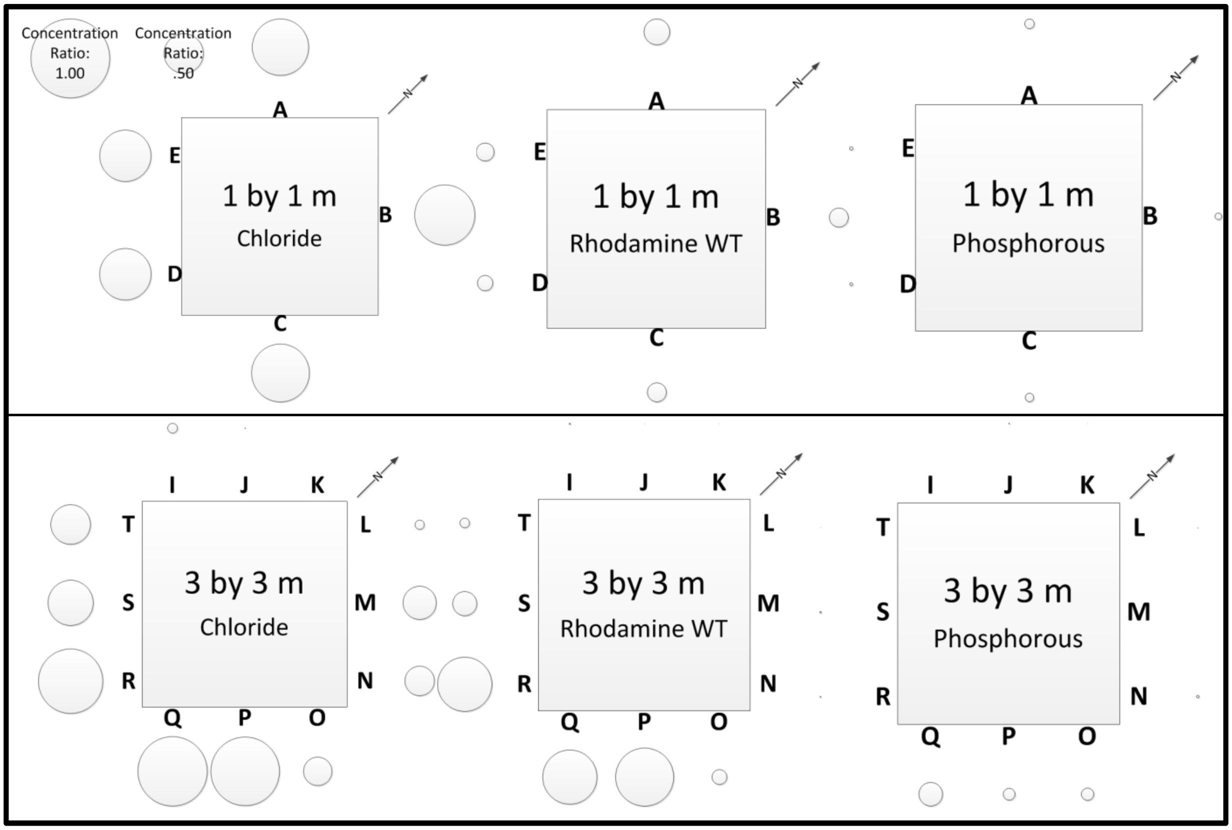


Figure 24. Maximum concentration ratios (C/C_o, where C_o is the inflow concentration) of samples from each well. Note that the plots are not drawn to scale. Size of the circle around each given well represents the concentration ratio.

These results show that infiltrated water may not be necessarily flowing vertically to the groundwater, but can flow laterally, potentially following preferential pathways. Conversely, the tracers may have reached the groundwater, and then moved laterally prior to reaching the wells surrounding the plot. When comparing the 3 m by 3 m to the 1 m by 1 m plot (Figure 24), it must be noted that the wells surrounding their given plots are located the same distance. For the 1 m by 1 m plot, RhWT was present in all wells at approximately the same concentration magnitude, unlike the 3 m by 3 m plot. This points to a lack of homogeneous composition of soils in this given floodplain because the tracers did not move the same distance to the wells on the 3 m by 3 m plot than they did on the 1 m by 1 m plot. The results of these experiments demonstrated a significant amount of infiltration by the Cl^- levels within this time period. While Cl^- was the only tracer to reach over 50% of the initial tracer concentration within the 26 hr timeframe of the experiment, it is possible that the RhWT and the P levels would become elevated past 50% of the initial tracer concentration given enough time. Future research should include modeling of the soil profile to predict how P leaching increases over longer time scales.

When considering the effectiveness of the plot size to realistic conditions, two factors come into play: how realistically does water move into the soil compared to natural conditions, and how can measurements and samples be taken from directly underneath the plume, where lateral flow of tracers is not a dependent factor for accurately sampling the concentration of the tracers in the groundwater? While there are not currently any effective techniques for taking measurements from underneath a given plot in these gravelly soils, plot scale experiments realistically simulate field conditions compared to smaller infiltrometers and laboratory testing. It was shown that infiltration rate is correlated to plot size, with the data suggesting a logarithmic relationship between infiltration rate and the area of the plot. Further investigations into this relationship should be, and are being investigated; there will be a 10 m by 10 m plot experiment conducted at the Barren Fork Creek site as well as two other field sites both in Oklahoma and Arkansas.

These experiments showed a relationship between plot size and infiltration rate of water. The injected Cl^-, RhWT, and P were observed in groundwater samples, but due to the movement patterns seen in the wells, it can be deduced that the soils in these alluvial floodplains are complex and not homogeneous.

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(2) PUBLICATIONS

Storm, P.Q. and G.A. Fox. Plot-scale leaching of phosphorus in an alluvial floodplain in the Ozark ecoregion. *Oklahoma State University Undergraduate Journal of Research* (provisionally accepted).

Heeren, D.M., D.E. Storm, and G.A. Fox. A berm infiltration method for conducting leaching tests at various spatial scales. *Journal of Hydrologic Engineering* (In review).

Heeren, D.M., G.A. Fox, D.E. Storm, T. Halihan, C. Penn. Influence of heterogeneity in gravel riparian floodplains on infiltration and contaminant transport rates. (In Preparation, To be Submitted August 2012).

(3) INFORMATION TRANSFER PROGRAM

A project website on subsurface P transport has been created with links to relevant publications and data from the project (http://biosystems.okstate.edu/Home/gareyf/ AlluvialPTransport.htm). Two presentations were given during the annual report period with two additional presentations and conference proceedings paper to be submitted in June 2012 for the American Society of Agricultural and Biological Engineers Annual International Meeting (AIM):

Heeren, D.M., G.A. Fox, R.B. Miller, D.E. Storm, and A.R. Mittelstet. 2011. Groundwater phosphorus preferential transport in alluvial floodplains. ASABE Annual International Meeting, Louisville, KY, 10 August 2011.

Heeren, D.M., G.A. Fox, D.E. Storm, B. Haggard. 2011. Influence of Scale on Quantifying Phosphorus Leaching in Ozark Floodplains. Arkansas Water Resources Center, Annual Watershed and Research Conference, July 6-7, 2011, Fayetteville, Arkansas.

The PI, co-PIs, and students will appear on an informative segment on the Oklahoma State University SUNUP TV program for the Oklahoma agricultural community this summer. Research results and field methods have been incorporated into an environmental contaminant transport class for graduate students during the summer of 2011 and spring 2012 semesters.

(4) STUDENT SUPPORT

Support has been provided for two graduate students (Ph.D. student in Biosystems and Agricultural Engineering at Oklahoma State and a Master of Science student in Environmental Sciences at Oklahoma State University) and four undergraduate students. Also, the research supported a 2010-2011 Oklahoma State University Wentz Research Scholars project for an additional undergraduate student.

Student Status	Number	Disciplines
Undergraduate	5	Biosystems Engineering
M.S.	1	Environmental Sciences (Geology)
Ph.D.	1	Biosystems Engineering
Post Doc		
Total	7	

(5) STUDENT INTERSHIP PROGRAM

No students completed an internship during the reporting period.

(6) NOTABLE ACHIEVEMENTS AND AWARDS

None to report at this time.

Incorporating Ecological Costs and Benefits into Environmental Flow Recommendations for Oklahoma Rivers: Phase 1, Southeastern Oklahoma

Basic Information

Title:	Incorporating Ecological Costs and Benefits into Environmental Flow Recommendations for Oklahoma Rivers: Phase 1, Southeastern Oklahoma
Project Number:	2011OK207B
Start Date:	3/1/2011
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	4
Research Category:	Not Applicable
Focus Category:	Ecology, Hydrology, Models
Descriptors:	
Principal Investigators:	Caryn Vaughn, Jason P. Julian

Publications

There are no publications.

Interim Report

Title: Incorporating Ecological Costs and Benefits into Environmental Flow Recommendations For Oklahoma Rivers: Phase 1, Southeastern Oklahoma.

Start Date: 8/1/11

End Date: 2/29/12

Congressional District: 2 and 4

Focus Category: COV, DROU, ECL, HYDROL, MOD, SW, WQN

Descriptors: stream, environmental flows, flow-ecology, hydrology, temperature, solar radiation, freshwater mussel, Unionidae

Principal Investigators: Caryn C. Vaughn and Jason P. Julian, University of Oklahoma

Publications: none to date

Problem and Research Objectives:

Providing a safe and sustainable water supply to the growing Oklahoma population while also providing for economic growth and maintaining natural ecosystems is the most serious challenge facing Oklahoma policy makers in the coming decades. Accomplishing this will require consideration of both the economic and ecological costs and benefits of different water allocation and management strategies (Arthington et al. 2006, Richter 2010).

Multiple approaches have been used to attempt to quantify the amount of water needed by natural water bodies in Oklahoma. In-stream flows (ISFs) quantify the amount of water that needs to be left in a stream to maintain non-consumptive uses such as fisheries or riparian areas (OWRB 2009). Currently, there are over 200 methods for determining ISFs, ranging from designation of minimum flows to those that mimic natural flow regimes (Turton et al. 2009). A group of researchers at Oklahoma State University are using the USGS Hydroecological Integrity Assessment Process (HIP) to characterize environmental flows in 88 streams through out Oklahoma. This process uses the historical hydrologic record to characterize the magnitude, timing, frequency, duration, and rate of change and predictability of flow events. Using the HIP process, Turton et al. (2009) found flow regimes of OK streams generally follow ecoregional boundaries. They also stated that HIP classification is a first step in determining environmental flows, and should be followed by development of specific environmental flow recommendations for rivers in each ecoregion that protect natural ecological function (Poff et al. 2010).

Rivers in the Ouachita and Gulf Coastal Plains ecoregions of southeastern Oklahoma provide an excellent test system for examining the ecological costs and benefits of in-stream flow recommendations. These rivers are known for their relatively abundant and pristine water and harbor the highest aquatic biological diversity in the state (Matthews et al. 2005). However, the water in these rivers also is in high demand to meet regional, human water needs (http://www.owrb.ok.gov/supply/ocwp/ocwp.php). We need to determine the appropriate volume and timing of water diversions from these rivers to meet human needs while maintaining natural ecological function.

Freshwater mussels are large, long-lived bivalve mollusks that perform important ecosystem services in streams including water filtration and nutrient recycling (Vaughn and Hakenkamp 2001, Vaughn 2010). Mussels are very sensitive to changes in flow regimes and temperature (Strayer et al. 2004), making them an early-warning test system for determining the ecological costs and benefits of environmental flow recommendations. Adult mussels are highly sedentary; they move very slowly and only short distances if they move at all (Allen and Vaughn 2009). Thus, unlike fish, mussels cannot move to new habitat, such as the bottom of a pool, when flows are inappropriate, and in-stream flow models developed for fish and other mobile organisms typically do not work well for mussel populations (Layzer and Madison 1995, Gore et al. 2001).

North America contains the highest global diversity of freshwater mussels with over 300 species, 55 of these occur in Oklahoma, and over 35 (or 64% of the state's mussel fauna) occur in the Kiamichi and Little Rivers, including three federally listed species (Ouachita Rock Pocketbook, *Arkansia wheeleri*; Scaleshell, *Leptodea leptodon*; Winged Mapleleaf, *Quadrula fragosa*) (Vaughn and Taylor 1999, Galbraith et al. 2008). Establishing environmental flows that safeguard mussel populations will protect these endangered species and hopefully prevent future litigation related to these species. In addition, because mussels provided important habitat and other services for other river organisms such as insects and fish, protecting mussels also protects these other groups (Vaughn and Spooner 2006, Aldridge et al. 2007).

Freshwater mussels are filter feeders that move large amounts of water over their gills. Vaughn et al. (2004) found that mussels in the Kiamichi River could turn over or filter the total volume of water in a river reach up to ten times as it passed over them, depending on the biomass of the mussels and the volume and flow rate of the water. This "pre-filtration" or biofiltration by mussels means that water extracted for human uses from rivers with healthy mussel populations should require less treatment than water from rivers without mussels, saving money (Kreeger and Bushek 2008).

Like most invertebrates, mussels are ectotherms whose physiological processes are governed by external, environmental temperatures. Vaughn's laboratory has discovered that different mussel species prefer different environmental temperatures and perform ecosystem services differently at these different temperatures (Spooner and Vaughn 2008). Because of these differences in thermal preferences and performance, the amount of water filtered by mussels and nutrient cycling rates differ with the species makeup of mussel communities, water volume, and water temperature

(Vaughn et al. 2008, Vaughn 2010). For example, Vaughn (2010) used laboratory-derived mussel biofiltration and ammonia excretion rates, and actual discharge and temperature data from the Kiamichi River, to model the ecosystem services provided by mussel communities composed of different proportions of two species under real flow regimes. In this model, under typical summer conditions of high water temperature and low flow, *Amblema* dominated communities had higher filtration rates, whereas *Actinonaias* dominated communities contributed more ammonia. Under milder conditions of lower water temperature and higher flow, *Actinonaias* dominated communities had higher filtration rates, and *Amblema* dominated communities contributed more ammonia. Thus, freshwater mussels are an excellent test system for determining ecological costs and benefits of environmental flow recommendations because we can actually quantify the ecosystem services they provide under different flow regimes.

Vaughn and her students monitored mussel communities in the Kiamichi River over a 15-year period that included the severe drought of the early 2000's (Galbraith et al. 2005). They found that mussel communities changed over this time period with species that could tolerate high water temperatures becoming relatively more common in comparison with thermally sensitive species. They demonstrated that these changes were caused by mortality of thermally sensitive species during periods of low flow when water temperatures in isolated pools sometimes exceeded 40°C, and they found that low water conditions were exacerbated by management of an upstream reservoir (Sardis Reservoir) (Galbraith et al. 2010), because progressively less water was released relative to inflow as the drought progressed.

Water temperatures in rivers are influenced by numerous factors (including quantity of groundwater inputs, watershed snow coverage, air temperature, and wind speed), but the dominant control is solar radiation (Allan and Castillo 2007). The direct absorption of solar radiation is the main heat input into river waters; convective warming by the air plays only a minor role. The reason that many studies have found strong linear relationships between air and water temperature (Wetzel 2001) is because air temperature is also strongly correlated to incoming solar radiation. Anthropogenic inputs/outputs can also affect water temperatures in rivers. Man-made reservoirs, in particular, have the potential to warm downstream waters (via greater absorption of solar radiation from increased water surface area, and longer water residence times) or cool downstream waters (via cool-water releases from the bottom of the reservoir) (Stanford et al. 1996, Allan and Castillo 2007). Because of the various unobservable pathways and interactions of water throughout a watershed, it is practically impossible to derive a numerical model that accounts for all water-heat fluxes. A much more practical strategy of predicting river water temperatures is by using a physically-based empirical model, one that takes into account solar radiation fluxes across the watershed and hydrologic budgets. This type of empirical model is effective at quantifying how much solar radiation is actually absorbed by rivers (along with its spatio-temporal variability) at both the reach scale (Julian et al. 2008a) and watershed scale (Julian et al. 2008b).

In this project we are combining information on (1) discharge and water temperature under various in-stream flows in different seasons with (2) information on how mussel communities perform the ecosystem services of water filtration and nutrient cycling under those conditions to (3) produce an empirical, predictive model of the ecosystem services provided by mussel communities under various flow and atmospheric conditions in the Kiamichi River watershed. We are modeling the Kiamichi River because we already have rigorous data on mussel communities (Galbraith et al. 2005) and the physical characteristics of river reaches where these communities occur (Jones and Fisher 2005), and because this river is under the most pressure for regional water diversions. Our multi-component model will be used to evaluate various in-stream flow models, such as HIP, to make specific environmental flow recommendations.

There is a great need to incorporate ecological costs and benefits into regional, environmental flow standards. An important step in accomplishing this is “defining the relationships between altered flow and ecological characteristics that can be tested with existing and newly collected field data” (Poff et al. 2010). Our proposed study will quantify the relationship between various environmental flow scenarios and the measured, mechanistic response (in terms of temperature-driven biofiltration and nutrient cycling) of an important, sensitive faunal group, freshwater mussels. Once we have derived an empirical model for the Kiamichi River, we will be able to use this approach to produce models for other important rivers in the region (i.e. Little, Mountain Fork, Glover) because these rivers have similar flow regimes, geomorphic features and mussel faunas (Matthews et al. 2005). Thus, our end result should be a model that can be used to recommend regional flow standards for southeastern Oklahoma that maintain ecological integrity. This same approach could be used for other ecoregions in the state, but would be based on the flow regime-ecological response of aquatic organisms that are important in those rivers such as the endangered/threatened Arkansas River Shiner and Arkansas Darter in Central and Western Oklahoma, both of which have been considerably impacted by flow alterations (Labbe and Fausch 2000, Durham and Wilde 2006, Kehmeier et al. 2007).

To produce our model we are obtaining additional thermal preference/performance data on a wider variety of mussel species, obtaining additional information on how water temperature in the Kiamichi River is dictated by atmospheric (with emphasis on seasonal changes) and flow (regulated vs. unregulated) conditions, and then using these data to produce the empirical model.

<u>Objectives:</u>

1. Conduct laboratory experiments to obtain thermal preference and performance (body condition and respiration rates, filtration rate, and nitrogen and phosphorus recycling rates) for 11 species of freshwater mussels from southeastern Oklahoma.
2. Place automatic recording level loggers in ten river reaches/mussel beds in the Kiamichi River to obtain daily information on flow discharge and water temperature across seasons.

3. Create a GIS-based model that quantifies (i) incoming solar radiation to the Kiamichi watershed (using Oklahoma Mesonet data); (ii) water-surface reflection and topographic and riparian shading (using methods from Julian et al. 2008b); and (iii) water budgets (using flow and hydrographic data). This GIS-based model will be combined with empirical data from Objective 2 to develop predictive relationships of water temperature based on variable flow and atmospheric conditions.
4. Compare model results with various in-stream flow scenarios to make environmental flow recommendations that protect mussel populations and system-wide ecological function.

Methodology:

Temperature and ecosystem services provided by mussels: Vaughn and her students performed laboratory experiments examining the effects of temperature (5, 15, 25, 35^{o}C) on resource acquisition (filtration rate), resource assimilation (metabolism and condition) and the subsequent ecosystem services (nutrient excretion rates and organic matter deposition) provided by eight mussel species that are common in eastern Oklahoma. They found that these species could be placed in two general guilds based on their performance at warm temperatures (35^{o}C): *thermally tolerant* species with increased resource assimilation and higher rates of ecosystem services and *thermally sensitive* species which displayed a range of functional responses including both increased/decreased filtration and nutrient excretion (Spooner and Vaughn 2008). However, to accurately predict ecosystem function from mussel species composition in the Kiamichi River and across the region, we need to collect data on a broader range of species. In particular, we would like to be able to predict how species will behave based on easily measured traits such as phylogeny and/or size. Our measurements to date indicate a relationship between phylogeny and thermal tolerance. For example, we examined four species in the tribe Lampsilini; three of these can be classified as sensitive. The 4th species, *Obliquaria reflexa*, is tolerant and is also the least derived of the lampsilines we tested. For the other mussels we tested, we don't have a large enough sample size from each tribe to make conclusions about the relationship between tolerance and phylogeny. In addition, we only examined species within the largest mussel subfamily, Ambleminae, and we need to also test the more primitive Unioninae. In this project we are determining the thermal characteristics of additional mussel species across two subfamilies, four tribes, and a range of adult sizes (small, < 50mm; medium, 50 – 100 mm; large, > 100 mm adult shell length). We have chosen species based on their placement in recent phylogenetic analyses (Graf and Cummings 2007, Bogan and Roe 2008), range of adult size, and our ability to collect sufficient individuals for analysis. All species occur within the Kiamichi River, other rivers of the Ouachita Highlands/Gulf Coastal Plain, and many occur in rivers across eastern North America.

We are measuring the performance and condition of mussels for six temperatures (5,15, 20, 25, 30, 35 ^{o}C) that represent the natural range and extremes of temperatures experienced by mussels in the Kiamichi River and the Ouachita/Gulf Coastal Plain ecoregions. Because our previous studies indicate that differences between species are more prevalent at warmer temperatures, we have chosen to examine a narrower range of warm temperatures. Mussels are acclimated to experimental temperatures for two weeks in 500-L Frigid Unit Living Streams®. Mussels are fed cultured algae while acclimating, and then starved for 24 hr before conducting the experiments (Vaughn et al. 2004). Measurements on individual mussels are conducted in continuously stirred, covered glass beakers (500 ml or 1500 ml, depending on mussel size) housed in 1.8 m^3 temperature-controlled chambers. Following Spooner and Vaughn (2008) we add an aliquot of cultured algae to each beaker, allow mussels to filter for 1.5 hrs, and measure filtration rate as the mass-specific change in chlorophyll concentration. Feces and pseudofeces (rejected particles) are filtered. Each mussel is then placed in a second beaker with pre-filtered water for an additional 1.5 hrs where we measure respiration rate as the change in oxygen concentration and collect water samples to determine excretion (NH_3, PO_4, N: P) rates. At the end of the experiment, mussels are measured for shell dimensions, weighed, and a tissue sample (Berg et al. 1995) taken for tissue glycogen content as a measure of mussel condition. Glycogen will be quantified with the phenol-sulfate method (Naimo et al. 1998). Feces and psuedofeces are dried, weighed, and ashed to determine organic matter biodeposition rates. We will use changes in Q_{10} rates in anabolism (oxygen consumption) and catabolism (ammonia excretion) to assign mussels to thermal categories (guilds) (Spooner and Vaughn 2008).

Collection of discharge, temperature and solar radiation data: In 2003 and 2004, Dr. William Fisher and his students at Oklahoma State University measured hydraulic characteristics of ten mussel beds in the Kiamichi River (Jones and Fisher 2005). These beds were established by the P.I. (Vaughn) as mussel monitoring sites in the 1990s (Vaughn and Pyron 1995) and resurveyed concurrently with Dr. Fisher's study in 2003-04 (Galbraith et al. 2005). Jones and Fisher (2005) determined discharge at each of these sites following standard stream gaging procedures (Bovee 1994) at multiple flow rates and determined the water surface elevation associated with each flow rate. They used automatic data loggers to record water level on a daily basis, and then used these water level data to predict discharge. Thus, for each of these sites we already have good information on the relationship between discharge and water level; however, we need to know how discharge and water temperature are related throughout the stream network and particulary downstream of reservoirs.

We have installed submerged data loggers (HOBO model U20 water level data loggers) at nine sites throughout the Kiamichi River network that automatically record water level (via air and water pressure) and water temperature at preset intervals. These sites were strategically selected to capture influences from reservoirs and tributaries. We installed an additional three non-submerged (atmospheric) HOBOs within the study area to calibrate the nine submerged HOBOs with atmospheric pressure. The non-submerged HOBOs also record air temperature at the same preset intervals. Daily solar radiation data is collected from OK Mesonet stations distributed across the Kiamichi watershed. The Mesonet is a network of 120 environmental monitoring stations distributed across Oklahoma (http://www.mesonet.org/index.php/site/about). All of these stations collect air temperature (°C) and solar radiation (400-1100 nm; W/m^2) in 5-minute intervals.

Model production:
We will use the framework of the benthic light availability model (BLAM; Julian et al. 2008a) and a GIS model (incorporating hydrography) of the Kiamichi watershed to quantify the amount of incoming solar radiation (insolation) entering the stream throughout the watershed. Insolation will be calculated using Mesonet stations distributed across the watershed. By using a digital elevation model (DEM) in combination with the *Solar Analyst* extension in ArcGIS, we will quantify the percentage of this insolation that is topographically shaded (i.e. does not reach the stream). We will then use hemispherical canopy photographs and *Gap Light Analyzer* software (Frazer et al. 1999) to calculate the percentage of remaining insolation that is shaded by riparian vegetation. Insolation reflected off the water surface will also be quantified and subtracted from available insolation. After these three light attenuation mechanisms are accounted for, we will be left with the amount of solar radiation that enters the stream network. In order to reduce uncertainty associated with water travel times and thus increase our predictive power, we will use daily values of solar radiation (megajoules/m^2/d). These daily solar radiation values will then be compared to daily flow volumes and average water temperatures at monitored sites (via HOBOs) to develop rating curves that predict water temperature for variable flow and atmospheric conditions. In particular, we will compare sites upstream and downstream of reservoirs in order to assess the effects that reservoirs and dam releases have on downstream water temperatures.

Comparison of model results with mussel ecosystem services data to make environmental flow recommendations: The water temperature rating curves will be compared to the ecosystem services performance data from our laboratory experiments to develop environmental flow recommendations for various mussel groups. In future work, these environmental flow recommendations can be used in cost-benefit analyses related to reservoir releases and water diversions to metropolitan areas. Our rating curves could also be used in computional hydraulic models such as the USGS Surface-Water Modeling System (SWMS) to develop reach-scale characterizations of water temperature, further aiding environmental flow recommendations.

Principal Findings and Significance:

We installed nine submerged HOHO loggers in the Kiamichi watershed in summer 2011 (Figure 1). We installed three atmospheric loggers: at most the upstream site, the most downstream site, and one in the middle of the study area at Clayton. Data from the loggers are downloaded at periodic intervals. We have also taken and analyzed 21 canopy photographs throughout the watershed. From these photos, we have calculated how much solar radiation enters the stream, which we are in the process of relating to stream temperature. We have also downloaded and processed all flow discharge for the Kiamichi, including discharge releases from Sardis Dam. We have also downloaded all Mesonet data (air temp & solar radiation) for the watershed. We are currently using these data to develop empirical rating curves that will be used to model stream temperature in the Kiamichi and how it is affected by Sardis' release schedule.

This spring we measured thermal characteristics of two native mussel species, *Quadrula verrucosa* and *Plectomerus dombeyanus*, and an invasive bivalve, *Corbicula fluminea*. We are collecting additional mussel species this summer and will hold them in ponds until we can perform the rest of the experiments with them in fall 2012.

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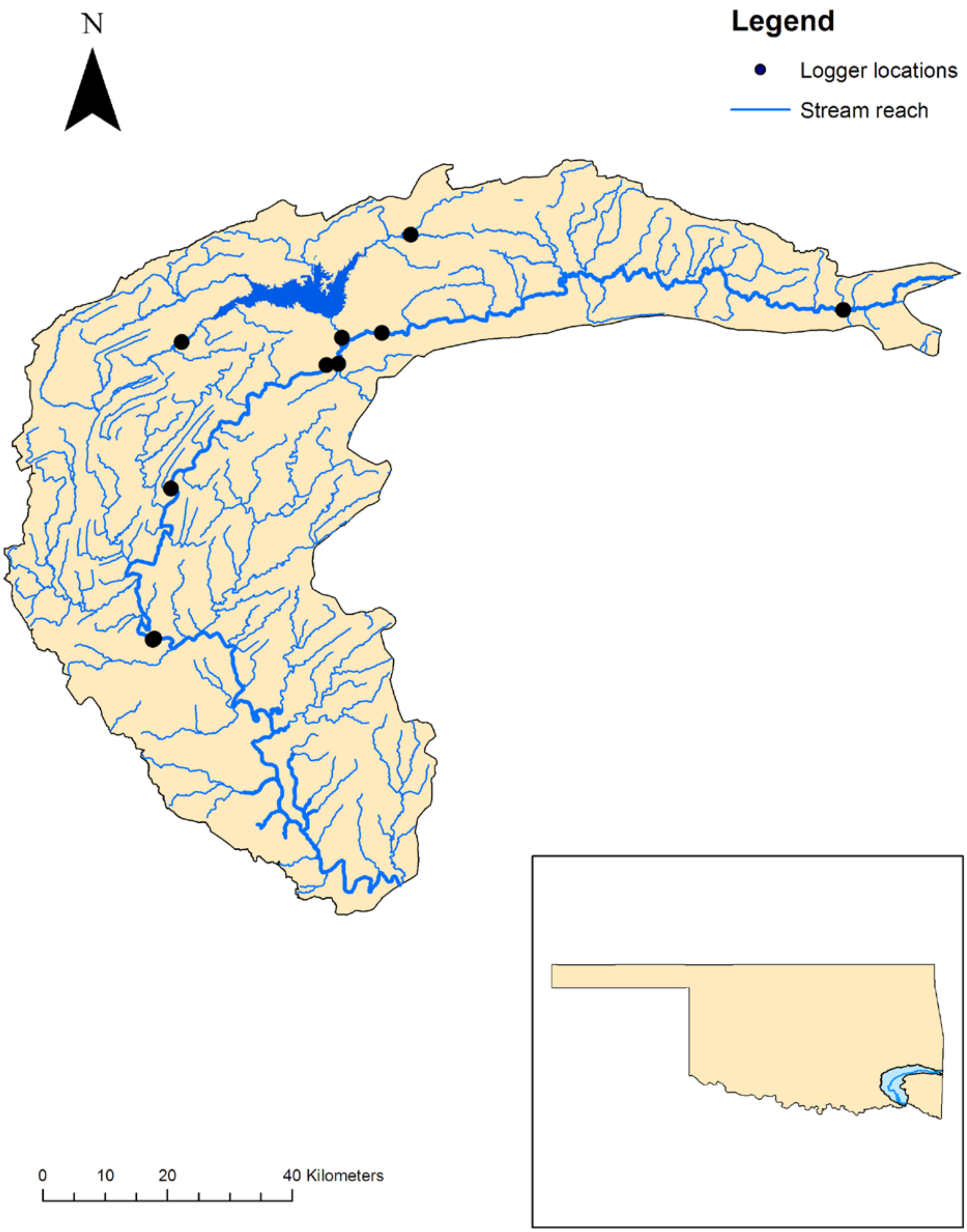
Figure 1. Location of data loggers in the Kiamichi River Watershed.



Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff

Basic Information

Title:	Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff
Project Number:	2011OK213B
Start Date:	3/1/2011
End Date:	6/30/2012
Funding Source:	104B
Congressional District:	3
Research Category:	Engineering
Focus Category:	Water Use, Non Point Pollution, Conservation
Descriptors:	
Principal Investigators:	Jason Vogel, Jason B Belden, Glenn Brown

Publications

1. Vogel, J.R., J.J. Lay, J.B. Belden, and G.O. Brown, 2012 Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff. 2012 ASCE EWRI World Environmental and Water Resources Congress. Albuquerque, NM, May 21-24, 2012.
2. Lay, J.J., J.R. Vogel, J.B. Belden, and G.O. Brown, 2011. Quantifying the First Flush in Rooftop Rainwater Harvesting through Continuous Monitoring and Analysis of Stormwater Runoff, National Low Impact Development Symposium. Philadelphia, PA, Sep. 25-28, 2011.
3. Lay, J.J., J.R. Vogel, J.B. Belden, and G.O. Brown, 2011. Quantifying the First Flush in Rooftop Rainwater Harvesting through Continuous Monitoring and Analysis of Stormwater Runoff. 2011 International Conference of the ASABE. Louisville, KY, Aug. 7-10, 2011.

Interim Report

Title: Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff

Start Date: 03/01/11

End Date: 12/31/12

Congressional District: OK03

Focus Category: COV, HYDROL, NPP, WQN

Descriptors: rainwater harvesting, first flush, polycyclic aromatic hydrocarbons, flame retardant

Principal Investigators: Jason Vogel, Biosystems and Agricultural Engineering, Oklahoma State University; Jason Belden, Zoology, Oklahoma State University; Glenn Brown, Biosystems and Agricultural Engineering, Oklahoma State University

Publications:

Vogel, J.R., J.J. Lay, J.B. Belden, and G.O. Brown, 2012 Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff. 2012 ASCE EWRI World Environmental and Water Resources Congress. Albuquerque, NM, May 21-24, 2012.

Lay, J.J., **J.R. Vogel**, J.B. Belden, and G.O. Brown, 2011. Quantifying the First Flush in Rooftop Rainwater Harvesting through Continuous Monitoring and Analysis of Stormwater Runoff, National Low Impact Development Symposium. Philadelphia, PA, Sep. 25-28, 2011.

Lay, J.J., **J.R. Vogel,** J.B. Belden, and G.O. Brown, 2011. Quantifying the First Flush in Rooftop Rainwater Harvesting through Continuous Monitoring and Analysis of Stormwater Runoff. 2011 International Conference of the ASABE. Louisville, KY, Aug. 7-10, 2011.

Problem and Research Objectives:

This research will develop and evaluate strategies for implementing the recommendation from the Marginal Quality Workgroup report for determining the potential for use and storage of stormwater runoff for non-potable demands. This research will be used to partially support the Master's work of National Science Foundation Fellow Jessica Lay in the Biosystems and Agricultural Engineering department as Oklahoma State University, and will also provide a 4-month half-time assistantship for a zoology master's student. The objective of this research will be to investigate two questions that remain regarding the implementation of rainwater harvesting as a solution for decreasing demand on water systems from water used for urban irrigation. This objective will be investigated by testing two hypotheses: (1) a more site specific, first flush can be quantified based on the roofing material, roof orientation, and geographical location by continuous monitoring and analysis of contaminants found in the rooftop runoff throughout a storm event, and (2) PAHs and flame retardants have the potential for long-term accumulation in soils from harvested rainfall used as urban irrigation.

Methodology:

The hypotheses to be tested is being investigated by a combination of continuous and discrete monitoring of harvested rainfall from three buildings with different roof types in central Oklahoma; continuous and discrete monitoring of harvested and simulated rainfall from 18 smaller structures to be constructed near Stillwater, Oklahoma; a field survey of accumulation concentrations of PAHs, PBDEs, and selected pyrethroid insecticides in soils below downspouts from 18 buildings (representing 3 roof types) in central Oklahoma; and, a leaching test on the parent roofing material to determine leaching potential. Replicate and field blank samples are being collected at a rate of 10 percent of the environmental sample count for quality assurance/quality control of the results. All water samples are being collecting under the direction of Dr. Jason Vogel and Dr. Glenn Brown of the Biosystems and Agricultural Engineering Department using approved sampling protocols.

Three locations with different roof types--built up (flat with tar and gravel), asphalt shingles, and metal--will be evaluated using continuous and discrete monitoring of three buildings with different roof types in central Oklahoma. In order to help quantify the first flush occurrence, these locations have continuous monitoring of specific conductance and turbidity, as well as collection of discrete samples with an autosampler at six times during ten storms to characterize the samples for total suspended solids (TSS), PAHs, flame retardants, bacteria, and nitrate (NO_3^-) throughout the duration of the storm event. Composite rainfall samples based on rainfall intensity are also being analyzed at each field site during these storms to estimate the mass loading in rooftop runoff. These three sites will be on the campus of OSU-OKC, which is located next to Interstate 44. Appropriate safety precautions related to working on rooftops when installing, maintaining, and operating the rainfall simulator.

Variables that may influence the concentrations of contaminants in rooftop runoff include roof type, roof orientation, and rainfall intensity. To investigate the impact of these variables on rooftop-runoff quantity and quality, 18 structures were built and sampled using rainfall simulations. The structures include two sets of nine roofs, comprised of roofs with asphalt shingles, corrugated metal, and clay-tile roofing materials constructed in triplicate. One set of these constructed roofs was oriented north-south and one east-west to determine if roof orientation towards the sun and prevailing winds plays a significant role. Rainfall simulations tests were run at each constructed roof using deionized water at three different intensities. Rainfall simulation procedures adopted by the National Phosphorus Research Project will be employed in this study, using a modified rainfall simulator mounted on a trailer.

For the field and rainfall simulation studies, replicate and field blank samples were collected at a rate of 10 percent of the environmental sample count for quality assurance/quality control of the results.

If PAHs, PBDEs, or pyrethroid insecticides accumulate in soils, the most likely location for this to occur is directly below downspouts. A total of 36 soil samples are being analyzed from the receiving soils of downspouts in buildings with roofs similar to the rainwater sample collection—6 paired samples from tar and gravel roofs, six paired samples from asphalt shingles, and 6 paired samples from metal roofs. These samples are being analyzed for PAHs, flame retardants, and selected pyrethroid insecticides in the laboratory of Dr. Jason Belden in the department of Zoology.

In addition to water samples, parent roofing material from each of the roofs at the field sites and rainfall simulation sites will be tested for the leaching potential of contaminants by rotating the material at a 1:20 ratio with buffered rain water solution for 24 hours. The leachate will be analyzed to determine the total amount of material available for potential leaching at each site. After all sample collection and analysis is complete, the leaching capacity of the roofing materials at these two commercial sites will be determined using sorption isotherms and other approaches as appropriate for each of the analytes detected during the rainfall simulations. Using detected concentrations and chemical properties from the literature and recommended irrigation rates for the area, the potential accumulation of emerging contaminants in the soil will be estimated.

Samples collected from the three field sites were analyzed for specific conductance, TSS, bacteria, and NO_3^- using standard methods. Samples from all tasks in this project are being analyzed in the laboratory of Dr. Jason Belden in the Zoology Department at Oklahoma State University for select PAHs (18 compounds listed in EPA 8270), flame retardants, and pyrethroid insecticides (bifenthrin, lambda cyhalothrin, cypermethrin) using solid phase extraction of whole water samples and soxhlet extraction of soil samples. Analysis of extracts will be conducted using gas chromatography with mass spectrometry detection. Electron ionization was used for detection of PAHs and negative chemical ionization will be used for flame retardants and pyrethroids. Detection will be performed using select ion-monitoring using 3-ions per analyte. Prior to analyzing samples, accuracy and precision studies as well as method detection limit studies have been performed. Laboratory blanks and spikes are run at a frequency of 10% of samples.

Principal Findings and Significance Thus Far:

All rainfall simulations have been run in the field. The data for the third test is still being compiled. However, the major findings thus far from the rainfall simulations include:

- Turbidity and specific conductance decreased with decreasing rainfall intensity
- Atmospheric deposition appears to be a major contributor of most PAHs

- For fluoranthene and TDCPP, roofing material appears to also be contributing to the overall loading
- Intensity appears to play a major factor in how much of the PAH's come off in the first flush and later in the storm.
- For PAH's, asphalt shingle roofs have a higher retention time than the metal and clay tile roofs and appear to contribute PAH's from parent material as well as the dust.
- For PAH's, asphalt shingle roofs have a higher retention time than the metal and clay tile roofs and appear to contribute PAH's from parent material as well as the dust.

For the field sample collection and continuous monitoring from actual storms at facilities in Oklahoma City, 7 of 10 storms have been sampled as of May 25, 2012. The other three storms are expected to be collected by the end of June 2012. Data for these storms has not been organized and analyzed at the time of this report.

The sample collection for soil samples below downspouts began in May 2012. Analysis and interpretation of this data is expected to be completed by the end of July 2012.

The leaching test of parent materials is expected to begin in June 2012 and be completed by October 2012.

Overall, based on these results, there does appear to be an increased potential for soil accumulation of PAHs when watering lawns and gardens with harvested rainwater that has no first-flush diversion. The magnitude of this issue, however, has yet to be determined. Additional research questions arising from this research that may be explored in further research include:

- Are common water-quality constituents correlated to PAH concentrations?
- What is the PAH concentration in the dust at our sites?
- What is the effect of non-uniform intensity storms on the first flush in rooftop runoff?
- Is there a correlation between antecedent rain period and the magnitude of the first flush?
- Is there a seasonal effect on the magnitude and length of the first flush?

Information Transfer Program Introduction

Activities for the efficient transfer and retrieval of information are an important part of the OWRRI program mandate. The Institute maintains a website that provides information on the OWRRI and supported research, grant opportunities, and upcoming events. Abstracts of technical reports and other publications generated by OWRRI projects are updated regularly and are accessible on the website. With the conjoining of the OWRRI and the WREC, the website has been completely revised and now has a new and more memorable address (water.okstate.edu).

2011 Information Transfer

Basic Information

Title:	2011 Information Transfer
Project Number:	2011OK225B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	3
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Will J Focht

Publications

There are no publications.

An essential part of the mission of the OWRRI is the transfer of knowledge gathered through university research to appropriate research consumers for application to real world problems in a manner that is readily understood. To do this in 2011, OWRRI undertook five efforts: (1) publication of a newsletter, (2) meetings with agency personnel, (3) maintenance of an up-to-date website, (4) assisting with water law and policy training seminars, and (5) holding a Water Research Symposium.

Newsletter: The OWRRI's quarterly newsletter is the *Aquahoman*. With a distribution list of 860, the *Aquahoman* not only provides a means of getting information to the general public, but also informs researchers throughout the state about water research activities. In 2011, *The Aquahoman* was produced three times: March, June, and August. The *Aquahoman* is distributed to state and federal legislators; to water managers throughout Oklahoma; to state, federal, and tribal agency personnel; to water researchers at every university in the State, to members of our Water Research Advisory Board, and to anyone who requests one. It is also available through the OWRRI website.

Meetings with Agency Personnel:

Water Research Advisory Board - The WRAB consists of 22 water professionals representing state agencies, federal agencies, tribes, and non-governmental organizations. This advisory board was formed in 2006 to assist the OWRRI by setting funding priorities, recommending proposals for funding, and providing general advice on the direction of the Institute. The Board members have found that they also benefit from their involvement in at least two ways. First, they profit from the opportunity to discuss water issues with other professionals. Second, the semiannual meetings afford them the opportunity to stay informed about water research and water resource planning in Oklahoma. This is accomplished, in part, by having the investigators of the previous year's projects return and present their findings to the Board.

Thus, the WRAB is an important part of the OWRRI's efforts to disseminate research findings to state agencies for use in problem solving. In 2011, the WRAB met twice. The January meeting included presentations by the five finalists in our research grant competition, selection of three of these finalists for funding, and an update on the State's water plan. The July meeting included presentations on the results of the 2010 OWRRI-funded projects, and selection of the funding priorities for 2012. The funding priorities are distributed as part of the RFP for the annual competition.

Instream Flows Discussion Group – The Water Center hosted a series of meetings to discuss the needs of the state regarding instream flows. The meetings included OSU, state agency, and federal agency personnel.

Website: The OWRRI continues to maintain an up-to-date website to convey news and research findings to anyone interested. Site visitors can obtain interim and final reports from any research project sponsored by the OWRRI (reports from 1965-1999 are available via email; reports from 2000-present are available for immediate download). All OWRRI project reports (1965 to present) are available through a website maintained by the OSU Edmon Low Library. This makes them more readily available to the public and more easily located using web search engines. Also available are newsletters beginning in 2005, information about the annual grants competition including the RFP and guidelines for applying, and details about the OWRRI's effort to gather public input for the state's revision of the State's comprehensive water plan. The website is also a major source of information about our annual Research Symposium.

In 2011, the Water Resources Center began production of a series of videos intended to assist landowners and agriculture producers in coping with drought. A total of fourteen videos are planned. We established a You Tube Channel that allows all of these videos to be viewed from any media platform with internet access.

Training: As part of the statewide water planning effort, OWRRI had an attorney on staff who provided training regarding water issues in Oklahoma to various community groups, such as Rotary Clubs. In addition, she was the featured speaker at an event that offered CLE credit for those in the legal profession.

OWRRI also provided updates on the State's Water Planning effort to staff of the Oklahoma Cooperative Extension Service. Extension staff are located in county offices throughout the State and regularly answer questions from the public about water related issues.

Research Symposium: The OWRRI has held an annual Water Research Symposium since 2002. The purpose of this event is to bring together water researchers and water professionals from across the state to discuss their projects and network with others. Again this year, the Symposium was combined with the Oklahoma Water Resources Board's annual Governor's Water Conference. The keynote address was delivered by Charles Fishman, author of *The Big Thirst*. The two-day event drew over 450 water professionals, agency staff, politicians, members of the press, researchers, participants in the water planning effort, and interested citizens. This combination of events provided a unique opportunity for interchange between those interested in water policy (who traditionally attend the Governor's Water Conference) and those interested in water research (who traditionally attend the Research Symposium).

The Symposium includes a student poster contest which involves not only staff time, resources, and supplies, but also $1500 used as prize money (provided by gifts from the Sac and Fox, Cherokee, and Choctaw Nations). At the 2011 Symposium, nine students from three universities presented posters. Each student received feedback on improving the quality of his/her poster from a panel of three judges.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	6	0	0	8
Masters	2	2	0	0	4
Ph.D.	2	2	0	0	4
Post-Doc.	0	0	0	0	0
Total	6	10	0	0	16

Notable Awards and Achievements

Publications from Prior Years

1. 2003OK16B ("Algal-nutrient dynamics in fresh waters: direct and indirect effects of zooplankton grazing and nutrient remineralization") - Articles in Refereed Scientific Journals - Hargrave, Chad W., K. David Hambright, and Lawrence J. Weider, 2011, Variation in resource consumption across a gradient of increasing intra- and interspecific richness, Ecology,92(6), 1226-1235.