

Arkansas Water Resources Center Annual Technical Report FY2017

2018 June



ARKANSAS WATER RESOURCES CENTER | UNIVERSITY OF ARKANSAS
FUNDED BY THE US GEOLOGICAL SURVEY 104B PROGRAM

Arkansas Water Resources Center Annual Technical Report FY2017

Erin E. Scott¹ and Brian E. Haggard²

¹Arkansas Water Resources Center

²Director and Professor, Arkansas Water Resources Center, 203 Engineering Hall, Fayetteville, Arkansas, 72701

Corresponding author: awrc@uark.edu

Abstract

This publication serves as the annual report to the U.S. Geological Survey regarding the 104B program projects and activities of the Arkansas Water Resources Center (AWRC) for FY2017. This document provides summary information for each of the projects funded through the 104B base grant. This year, the AWRC funded 3 faculty research proposals and 2 student centered proposals with faculty advisors. Faculty projects include: 1)“Regionalizing Agricultural Field Evapotranspiration Observations”, Benjamin Runkle, University of Arkansas, Department of Biological and Agricultural Engineering; 2)“Herbicide Mitigation Potential of Tailwater Recovery Systems in the Cache River Critical Groundwater Area”, Cammy D. Willett, University of Arkansas, Department of Crop, Soil, and Environmental Sciences; 3)“Combined Application of Nutrient Manipulation and Hydrogen Peroxide Exposure To Selectively Control Cyanobacteria Growth and Promote Eukaryote Phytoplankton Production in Aquaculture Ponds”, Amit Kumar Sinha, University of Arkansas at Pine Bluff, Department of Aquaculture and Fisheries. Student projects with a faculty advisor that were funded include: 1) “Investigating Impact of Lead Service Lines in Drinking Water Distribution Systems at the City of Tulsa”, Kaleb Belcher and Wen Zhang, University of Arkansas, Department of Civil Engineering; 2) “Assessment of Strategies To Address Future Irrigation Water Shortage in the Arkansas Delta”, Tyler Knapp and Qiuqiong Huang, University of Arkansas, Department of Agricultural Economics and Agribusiness.

Keywords: Arkansas Water Resources Center, 104B Program Funding, Information Transfer, Water Quality

Report Introduction

The Arkansas Water Resources Center (AWRC or Center) is part of the network of 54 water institutes established by the Water Resources Research Act of 1964 and is located at the University of Arkansas in Fayetteville. Since its formation, the AWRC in cooperation with the US Geological Survey and the National Institutes for Water Resources has focused on helping local, state and federal agencies understand, manage, and protect water resources within Arkansas.

The Center has contributed substantially to the State's understanding of its water resources through scientific research and volunteer monitoring efforts, student training, and information transfer. The AWRC directs its research funding priorities toward providing local, state, and federal agencies the scientific data necessary to make informed decisions that enhance their ability to protect and manage water resources throughout the State and region. In addition to, funding faculty researchers at colleges and universities in Arkansas, the Center helps other organizations implement volunteer science programs to add to the water quality data in Arkansas. AWRC helps to fund and coordinate research to ensure good water quality and adequate quantity to meet the needs of Arkansas today and into the future.

Another priority of the Center is the transfer of water resources information to stakeholders within Arkansas and around the country. The AWRC holds an annual water conference to address current water issues and solutions. The Center also publishes numerous types of publications including technical reports, peer-reviewed journal articles, and monthly electronic water newsletters. The use of social media has allowed the Center to reach more people, with a growing number of interested individuals from state agencies, water organizations, and the greater public.

The AWRC continues to enhance its activities to successfully implement its core mission – to provide scientific information that improves the understanding and management of water resources. Also, AWRC continues to uphold its core goals – to improve or maintain resilient water supplies for communities, promote healthy riparian areas, wetlands, streams, rivers, and lakes, advance sustainable water use and food production, support future scientists through training and education, and transfer information to decision-makers, environmental professionals, and the public.

This report details the activities of the Center during the past project year (March 1, 2017-February 29, 2018).

Research Management Introduction

Since its formation, the Arkansas Water Resources Center (AWRC or Center) has focused on helping local, state, and federal agencies manage and protect Arkansas' water resources. The Center has contributed substantially to the State's understanding of its water resources through scientific research volunteer monitoring efforts, and the training students – the future generations of scientists and engineers. These Center-related activities help to ensure that Arkansas can be able to meet its water needs now and into the future.

Scientific Research

Each year, several researchers across the state submit proposals for research grants from the AWRC through the USGS 104B program. The AWRC directs its research funding priorities toward providing local, state, and federal agencies with scientific data necessary to make informed decisions that enhance their ability to protect and manage water resources throughout the State. Center projects generally focus on topics concerned with the quality and quantity of surface water and ground water, especially regarding non-point source pollution, land use and climate change, agricultural water use, and sensitive ecosystems.

When soliciting research proposals for funding through the USGS 104B program, the Center emphasized the following objectives:

- Arrange for applied research that addresses water supply and water quality problems
- Train the next generation of water scientists and engineers
- Support early career faculty in water research and preliminary data
- Support faculty changing focus or addressing emerging water issues
- Transfer research results to stakeholders and the public
- Publish 104B funded research in peer-reviewed scientific literature
- Cooperate with other colleges, universities, and organizations in Arkansas to create a coordinated statewide effort to address state and regional water problems.

Each of the proposals selected for funding this past year addressed the priority research topics and the objectives of the Center. The Center also funded research proposals that support the USGS national water mission in one of its broad areas, including:

- Increase knowledge of water quality and quantity
- Improve understanding of water availability
- Evaluate how climate, hydrology and landscape changes influence water resources
- Create and deliver decision-making tools that support water management
- Improve the country's response to water-related emergencies

To formulate a research program relevant to current water issues in Arkansas, the Center worked closely with its technical advisory committee (TAC). The TAC is composed of representatives from state and federal water resources agencies, academia, industry and private groups. Members of the advisory committee reviewed and ranked proposals submitted to the AWRC, which helped ensure that funds addressed a variety of current and regional water resource issues.

In FY2017, the AWRC, with the guidance of the TAC, funded 3 faculty research proposals totaling \$67,476 and 2 student research proposals with a faculty advisor totaling \$10,067.

Faculty projects that were funded include:

- 1) “Regionalizing Agricultural Field Evapotranspiration Observations”, Benjamin Runkle, University of Arkansas, Department of Biological and Agricultural Engineering;
- 2) “Herbicide Mitigation Potential of Tailwater Recovery Systems in the Cache River Critical Groundwater Area”, Cammy D. Willett, University of Arkansas, Department of Crop, Soil, and Environmental Sciences;
- 3) “Combined Application of Nutrient Manipulation and Hydrogen Peroxide Exposure To Selectively Control Cyanobacteria Growth and Promote Eukaryote Phytoplankton Production in Aquaculture Ponds”, Amit Kumar Sinha, University of Arkansas at Pine Bluff, Department of Aquaculture and Fisheries.

Student projects with a faculty advisor that were funded include:

- 1)“Investigating Impact of Lead Service Lines in Drinking Water Distribution Systems at the City of Tulsa”, Kaleb Belcher and Wen Zhang, University of Arkansas, Department of Civil Engineering;
- 2)“Assessment of Strategies To Address Future Irrigation Water Shortage in the Arkansas Delta”, Tyler Knapp and Qiuqiong Huang, University of Arkansas, Department of Agricultural Economics and Agribusiness.

The research program emphasized the training of future scientists and engineers who are focused on water resources and watershed management, and supported undergraduate, Masters, and Ph.D. level students. The “seed” grants provided to research faculty through this program have led to the development of larger research proposals submitted to other funding agencies and also have provided research opportunities to new faculty and more senior faculty investigating new areas in water resources. In fact, Dr. Benjamin Runkle was funded through 104B for three years and received the National Science Foundation’s CAREER grant in March of this year.

Once these researchers were funded, the Center coordinated and administered the grants, allowing the researchers to concentrate on providing a quality project. Support was provided to researchers in the form of accounting, reporting and water sample analysis (through the AWRC Water Quality Laboratory).

Volunteer Water Quality Monitoring

The Center continued supporting and working closely with Ozarks Water Watch (OWW), a non-profit watershed organization in northwest Arkansas. There are two volunteer programs of OWW that AWRC is involved with: AWRC personnel provided guidance to the Beaver LakeSmart program by serving on the advisory board and supported the StreamSmart program by helping train volunteers and analyzing water samples.

For the StreamSmart program, AWRC personnel conducted a formal training workshop related to sample collection and site assessment to volunteers. The Center and 104B program funding also supported this

program by analyzing water samples collected by volunteer citizen scientists. During this project year, the AWRC Water Quality Lab analyzed 65 water samples and over 450 analytes for the StreamSmart program. OWW uses these data to develop their annual “Status of the Watershed” report that characterizes water quality in the White River Watershed using their volunteer data along with water data from other agencies.

Volunteer monitoring programs can be valuable in many ways. For example, these programs may supplement data collected by professionals in academic or government agencies, provide volunteers with an enhanced understanding and sense of stewardship, and provide public education and outreach. Without support from the Water Center and 104B program funds, these volunteer programs might not be possible.

Student Training

Student training is key to the mission of the AWRC and the Center accomplishes this in many ways. For example, funding priorities are given to research proposals that emphasize student support and training. The Center also provides several training opportunities directly. This direct student support included:

- The AWRC participated in the Ecosystems Services Research Experience for Undergraduates (EcoREU) program, funded by the National Science Foundation, by mentoring students in their research labs on the scientific method.
- The AWRC helped train undergraduate students by mentoring them through their freshman engineering research projects or honors projects at the University of Arkansas.
- The Center supported paid student work where the student gained experience in the water quality laboratory and in data organization and analysis.
- The AWRC continued with its fourth-annual paid internship during this last summer. The student intern was trained in website development and coding languages and successfully completed several projects that enhanced the aesthetic quality, content, and usability of our website.

During this past year, 27 students and postdoctoral researchers were trained through participation in research projects and through the AWRC directly.

Project Title: Comparative Microbial Community Dynamics in a Karst Aquifer System and Proximal Surface Stream in Northwest Arkansas
Project Number: 2016AR384B
Start Date: 3/1/2017
End Date: 2/28/2018
Funding Source: 104B
Congressional District: 3rd
Research Category: Water Quality
Focus Category: Groundwater, Non Point Pollution, Ecology
Descriptors: None
Principal Investigator: Matthew D Covington, Kristen Elizabeth Gibson

Publications:

Rodriguez, J., Covington, M.D., Gibson, K.E., Almeida, G., and J.M. Jackson, Comparative microbial community dynamics in a karst aquifer system and proximal surface stream in Northwest Arkansas, South-Central Geological Society of America Meeting, 13-15 March 2017, San Antonio, TX.

Rodriguez, J.; advisors: M. Covington and K. Gibson, 2017 (expected), Comparative microbial community dynamics in a karst aquifer system and proximal surface stream in Northwest Arkansas, MS Thesis, Geosciences Department, Fulbright College, University of Arkansas, Fayetteville, AR.

Rodriguez, J., Covington, M.D., Gibson, K.E., Almeida, G., and J.M. Jackson, Comparative microbial community dynamics in a karst aquifer system and proximal surface stream in Northwest Arkansas, South-Central Geological Society of America Meeting, 13-15 March 2017, San Antonio, TX.

Rodriguez, J.; advisors: M. Covington and K. Gibson, 2017 (expected), Comparative microbial community dynamics in a karst aquifer system and proximal surface stream in Northwest Arkansas, MS Thesis, Geosciences Department, Fulbright College, University of Arkansas, Fayetteville, AR.

Comparative Microbial Community Dynamics in a Karst Aquifer System and Proximal Surface Stream in Northwest Arkansas

Matthew D. Covington¹, Kristen E. Gibson², Josue Rodriguez¹

¹Department of Geosciences, University of Arkansas, Fayetteville, AR

²Department of Food Sciences, University of Arkansas, Fayetteville, AR

Core ideas:

- *Escherichia coli* concentrations were significantly higher in Little Sugar Creek (median=120 MPN/100 mL) than in Blowing Spring Cave (median=56 MPN/100 mL).
- *E. coli* concentrations at Blowing Spring Cave were strongly correlated with discharge (Spearman's $R=0.79$, $p<<0.05$), whereas concentrations at Little Sugar Creek showed no statistically significant correlation with discharge.
- There was significant dissimilarity in microbial composition among water and sediment samples regardless of location or event type.

Executive Summary:

Northern Arkansas is underlain largely by carbonate bedrock, with relatively well-developed karst flow systems. Much of this region is rapidly urbanizing, leading to a variety of potential threats to groundwater, including increased, and redirected, runoff and the potential introduction of contaminants into the subsurface via septic systems, effluent wastewater discharge, and agricultural runoff. Because of the karst system, threats to groundwater quality are also threats to surface water quality, which is used widely in the region for both drinking water and recreation. Here, Blowing Springs Cave (BSC) and Little Sugar Creek (LSC) were selected to serve as a model for how non-point source pollution may move through the subsurface and subsequently impact springs as well as receiving streams via contaminated water and resuspension of contaminated sediments. The objectives of the study were to: 1) explore structure, diversity, and temporal variability of microbial communities in BSC and LSC; 2) differentiate allochthonous bacteria from land surface runoff with bacteria in the sediments and water of the karst aquifer; 3) determine impact of sediment movement from karst springs to LSC through comparison of microbial communities; and 4) delineate the recharge area of BSC and constrain potential sources of *E. coli*. Water and sediment samples were collected routinely once per month for 9 months and during 2 rain events in a 3-day time series (1, 2, 4 d). The following methods were applied: *E. coli* analysis of water samples by Colilert + Quantitray 2000 system; dye tracing tests to constrain recharge area of BSC; and 16s rRNA metagenomic analysis. During the study period, 92 water samples and 89 sediment samples were collected. Analysis of water samples for *E. coli* showed significantly higher median levels in LSC (120 MPN/100mL) when compared to BSC (56 MPN/100mL). Moreover, there was a strong correlation between discharge and levels of *E. coli* at BSC (Spearman's $R=0.79$, $p<<0.05$); however, this same relationship was not observed in LSC. It is evident that there are significant differences in the microorganisms present in water and sediment samples regardless of event type and sampling location. Last, dye tracing indicated a connection between Blowing Spring and a sinkhole located ~1 km to the NE. The average flow velocity of the tracer between the injection point and spring was approximately 40 m/day. The results of the study suggest that sources of *E. coli*, and microbial diversity in general, are different between the karst system and surface stream, even though LSC is under the influence of BSC.

Introduction:

Northern Arkansas is underlain largely by carbonate bedrock, with relatively well-developed karst flow systems. Much of this region is rapidly urbanizing, leading to a variety of potential threats to

groundwater including increased and redirected runoff and the potential introduction of contaminants into the subsurface via septic systems, effluent wastewater discharge, and agricultural runoff (Heinz et al. 2009; Katz et al. 2010). Impacts to groundwater can harm fragile karst ecosystems, but also pose direct threats to the public utilizing groundwater (Johnson et al. 2011). The karst systems within the Ozark Plateaus contain numerous linkages to surface water, with water often repeatedly entering and leaving the subsurface through karst sinking streams and springs. A large percentage of the population of Northern Arkansas utilizes decentralized wastewater treatment systems located within karst terrain. Consequently, threats to groundwater quality are also threats to surface water quality, which is used widely in the region for both drinking water and recreation.

The sites selected for the present study—Blowing Springs Cave (BSC) and downstream receiving surface water, Little Sugar Creek (LSC)—do not currently reside in an ANRC 319 Nonpoint Source Pollution Program priority watershed nor is the LSC or its tributaries listed on the ADEQ 303(d) list; however, there are several reasons for selecting these study sites. The Elk River Watershed (ERW) in which LSC resides, was identified in 1998 as impaired by the Missouri Department of Natural Resources due to excess nutrients primarily related to livestock and population growth. The ERW is bound in the east and west by the White River and Illinois River basins, respectively. Finally, Sugar Creek in MO has been listed on the 303(d) list for impairment related to low dissolved oxygen levels since 2006 though the source has yet to be identified.

Meanwhile, BSC is the site of several past and ongoing scientific studies. Specifically, Knierim et al. (2015) provided over six years of data on the presence of the *Escherichia coli* at the BSC discharge point as well as nitrate and chloride levels from 1992 to 2013. From 2007 to 2013, *E. coli* concentrations at BSC ranged from <1 to 2,420 most probable number (MPN) or colony forming units (CFU) per 100 mL. Median *E. coli* concentrations at base flow periods and during storm events were reported at 41 and 649 MPN or CFU per 100 mL, respectively, and storm event *E. coli* was significantly greater than base-flow concentrations. Based on the data, Knierim et al. (2015) hypothesized that septic tank effluents were a major contributor to chloride, nitrate, and *E. coli* levels in BSC. This hypothesis was largely based on the estimated recharge area for the spring, which was within a residential area that was known to have septic tanks present. Therefore, we selected the sites in the present study to serve as a possible model for how septic tank effluents may move through the subsurface and subsequently impact springs as well as receiving streams via contaminated water as well as resuspension of contaminated sediments.

The objectives of this study were to: 1) explore structure, diversity, and temporal variability of microbial communities in BSC and LSC; 2) differentiate allochthonous bacteria from land surface runoff with bacteria in the sediments and water of the karst aquifer; 3) determine impact of sediment movement from karst springs to LSC through comparison of microbial communities; and 4) delineate the recharge area of BS and constrain potential sources of *E. coli*.

Methods:

Sample Collection.

Routine sampling was conducted in BSC and LSC once per month from March to November of 2016. Samples were collected from three sites along the main stream of BSC and from LSC at four sites, one rural and three within the town of Bella Vista (Figure 1). Water samples consisted of 500 mL grab samples. Sediment samples (10cm depth) were collected using a core sampler or scoop and placed in sterile Whirl-Pak® bags. Two storm events were also sampled at higher temporal resolution, with a threshold precipitation of 0.5 inch in a 24 hour period to trigger a storm sampling series. Storm sampling was conducted during the receding limb with samples taken approximately 1, 2, and 4 days following peak flow.

Dye tracing.

A dye tracing test was conducted to better constrain the recharge area of BSC. The hypothesized recharge area for BSC (Knierim et al. 2015) was searched for potential injection sites, and a single

Dye Trace

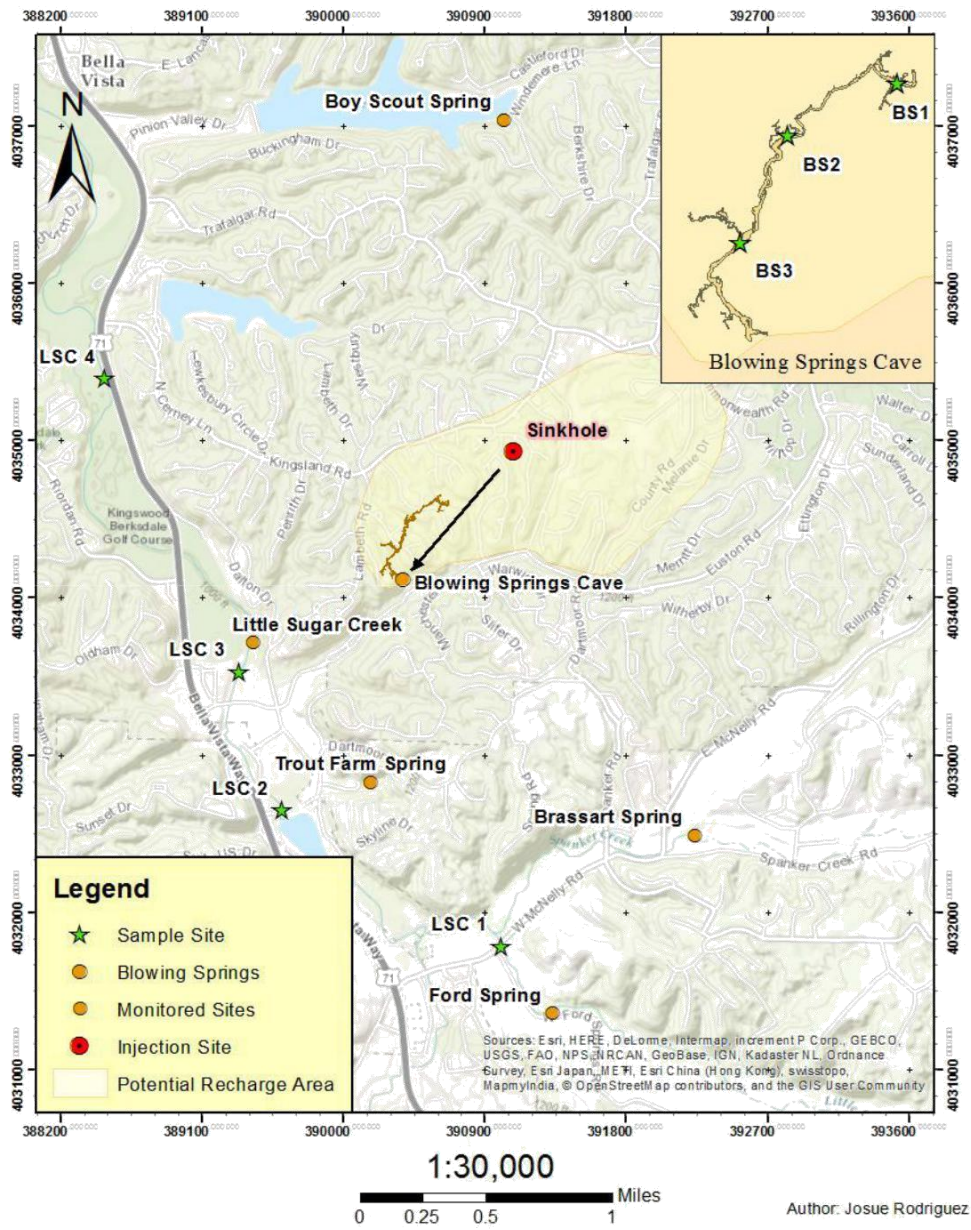


Figure 1. Locations of the sampling points, dye injection, and charcoal packet deployment. A positive trace was detected from the sinkhole site to Blowing Spring Cave (indicated by arrow), but not at the other monitored sites.

prominent sinkhole was identified within the basin. Fluorescein dye was chosen for the tracing experiment to minimize adsorption onto sediment within the sinkhole. Before introduction of dye into the sinkhole approximately 50 gallons of BSC water were dumped into the sinkhole. This was followed by 55 grams of fluorescein dye dissolved in 500 mL of water, and then an additional 450 gallons of spring water. Dye was detected using activated charcoal packets, which were deployed in the field to cumulatively absorb dye. Dye was extracted from the charcoal packets in the lab using an alcohol-potassium hydroxide eluent. Elutant was analyzed on a Shimadzu RF-5301 Spectrofluorophotometer. Before injection of dye, charcoal packets were placed in the field to determine any background fluorescence. Charcoal packets were placed in BSC, LSC, and all other nearby springs that were identified. To better determine the timing of the dye pulse, a GGUN-FL24 field fluorometer was deployed in the cave stream.

***E. coli* Analysis.**

For detection and enumeration of *E. coli* in water samples, Standard Method 9223B IDEXX Quanti-tray® 2000 system with Colilert™ reagent was used to determine the Most Probable Number (MPN) in each sample. A negative control containing 100 ml of 0.1% peptone was analyzed by Colilert™ for each batch of samples.

DNA Extraction – Water and Sediments.

For each sampling event, 200 ml of water from BSC and LSC was filtered through a 0.2-µm, 47mm Supor-200 filter membrane to capture total bacterial cells. Filter membranes were placed at –80°C in 500 µl of guanidine isothiocyanate buffer. The total genomic DNA (gDNA) was extracted from prepared filters using the Fast DNA Spin Kit for Soil (MP Biomedicals). Genomic DNA was extracted from sediment samples as described by Gomes et al. (2007). Total gDNA was quantified using a NanoDrop UV spectrophotometer.

16S rRNA Metagenomic Analysis.

Extracted gDNA from water and sediment samples was used as template DNA for amplification of 16S ribosomal RNA (rRNA) gene by polymerase chain reaction (PCR) as described by Kozich (2013). The PCR analysis was completed through the service center at the University of Arkansas under the direction of Program Associate Dr. Si Hong Park. Briefly, forward and reverse primers targeting the 16s rRNA gene including the partial adapter overhang sequence, PCR master mix, and templated DNA were combined in a single PCR reaction well for each sample. The resulting PCR amplicons were verified by gel electrophoresis. 16S rRNA metagenomics for determination of bacterial community structures in water and sediment samples collected from the karst aquifer system (BSC) and receiving surface stream (LSC) over a 9-month period was completed at the University of Arkansas . The high quality sequence reads have been assembled. For data analysis, bioinformatics procedures using QIIME for operational taxonomic unit (OTU) assignment was applied as described by Kozich et al. (2013). Data are currently being analyzed to answer research questions.

Results:

Both monthly and rain event water samples were collected at BSC (n=42) and LSC (n=56) (Tables 1 and 2). *E. coli* MPN/100mL ranged from 0.9 to 921 at BSC and 4 to >2419.6 at LSC. *E. coli* concentrations were compared against discharge at both sites (Figure 2). Similar to Knierim et al. (2015), the highest *E. coli* concentrations at BSC in the present study were seen during and following high flow events. The correlation between discharge and *E. coli* was strong at BSC as quantified using Spearman’s rank correlation coefficient ($R_s=0.79$, $p<<0.05$). In contrast, LSC showed no statistically significant correlation between discharge and *E. coli* concentrations ($R_s=-0.1$, $p=0.33$). Though *E. coli* concentrations generally increase at BSC during high discharge events, the relationship between discharge and *E. coli* displays some hysteresis, with peak concentrations occurring after peak

Table 1. *E. coli* concentrations (MPN/100 mL) and stream discharge at the Blowing Spring Cave sites.

Date	<i>E. coli</i> _{BSC1}	<i>E. coli</i> _{BSC2}	<i>E. coli</i> _{BSC3}	Q _{bs} (cms)
3/7/2016	1.0	0.9	0.9	0.038
4/4/2016	10.9	12.2	23.3	0.04
5/2/2016	435.2	285.1	290.9	0.097
5/25/2016	63.7	63.7	63.7	0.055
5/26/2016	165.0	165.0	165.0	0.093
5/27/2016	866.4	920.8	648.8	0.062
6/6/2016	143.0	165.8	117.8	0.041
7/11/2016	224.7	209.8	325.5	0.052
8/8/2016	161.6	88.2	88.0	0.052
9/8/2016	4.1	4.1	4.1	0.032
10/5/2016	48.7	48.7	48.7	0.015
10/6/2016	34.1	44.8	35.5	-----
10/7/2016	18.3	18.9	24.3	-----
11/10/2016	2.0	9.7	4.1	0.029

discharge and during the time of flow recession (Figure 3). *E. coli* concentrations were statistically higher in LSC than in BSC as indicated by a nonparametric Mann-Whitney U test ($p=0.0013$). The median *E. coli* concentration at BSC was 56 MPN/100 mL, whereas the median at LSC was 120 MPN/100 mL. While *E. coli* concentrations were typically similar at all of the cave sites (Figure 4a), the LSC site located just downstream from Bella Vista Lake (LSC2) frequently had higher concentrations (Figure 4b), with a median value of 380 MPN/100 mL.

Figures 5a and 5b show the genus level metagenomic results for water and sediment samples from the different sampling sites in BSC and LSC during a routine sampling event on 5/2/2016. The most abundant bacterial genus in water samples was *Acinetobacter*--a Gram negative bacteria commonly found in soil and water--followed by *Pseudomonas* and *Flavobacterium*, again both common to the soil and freshwater environments (Figure 5a). The family *Enterobacteriaceae* which includes *E. coli* is also represented at most water sampling locations though at lower percentages. With respect to sediment collected during the same routine sampling event, the microbial make up is quite different than paired water samples across all sampling sites (Figure 5b). The major bacterial families identified in sediment were *Bacillaceae* and *Enterobacteriaceae*, and one of the primary genera detected was *Clostridium*. The family *Bacillaceae* includes *Bacillus*, a microbe ubiquitous in nature. Meanwhile, *Clostridium* is also a soil microbe as well as an inhabitant of the intestinal tract of animals, including humans.

Samples were also analyzed by sample type for beta diversity which is the diversity of microbes between samples within a specific group. The weighted principal coordinate analysis (PCoA) UniFrac plot shown in Figure 6 illustrates the level of abundance of operational taxonomic units (OTUs) among sample types and their respective phylogenetic distances. In Figure 6, each data point representing an individual sample was aligned in

Table 2. *E. coli* concentrations (MPN/100 mL) and stream discharge at the Little Sugar Creek sites.

Date	<i>E. coli</i> _{LSC1}	<i>E. coli</i> _{LSC2}	<i>E. coli</i> _{LSC3}	<i>E. coli</i> _{BSC3}	Q _{LSC} (cms)
3/7/2016	22.7	45.3	15.4	22.7	2.41
4/4/2016	22.8	116.2	4.1	12.2	4.08
5/2/2016	137.6	86.0	100.8	93.2	7.40
5/25/2016	920.8	2419.6	2419.6	2419.6	3.73
5/26/2016	78.9	2419.6	816.4	770.1	7.00
5/27/2016	275.5	1413.6	344.8	365.4	5.34
6/6/2016	61.3	23.5	73.8	124.6	4.79
7/11/2016	36.4	461.1	113.7	41.4	7.84
8/8/2016	30.5	58.3	75.4	13.0	4.34
9/8/2016	1413.6	106.1	125.9	31.5	1.06
10/5/2016	160.7	2419.6	816.4	488.4	1.74
10/6/2016	95.9	980.4	410.6	248.1	1.94
10/7/2016	114.5	920.8	579.4	547.5	2.07
11/10/2016	52.8	298.7	218.7	83.9	1.54

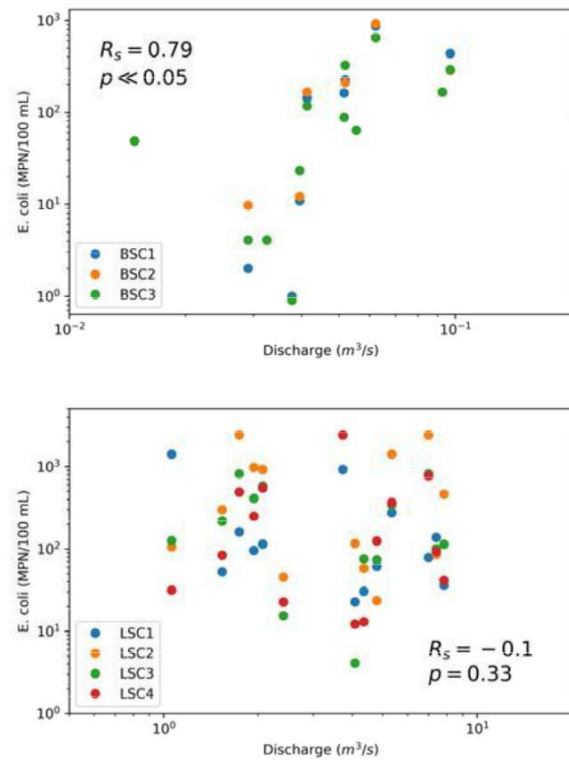


Figure 2. Discharge versus *E. coli* concentrations in Blowing Spring Cave (a) and Little Sugar Creek (b) during the study period. BSC1 is the site that is furthest downstream within the cave, and BSC3 is furthest upstream. LSC1 is the site that is furthest upstream, and LSC4 is furthest downstream. Spearman rank correlation coefficients (R_s) indicate that there is a strong positive correlation between *E. coli* and discharge at BSC, but there is no statistically significant correlation at LSC.

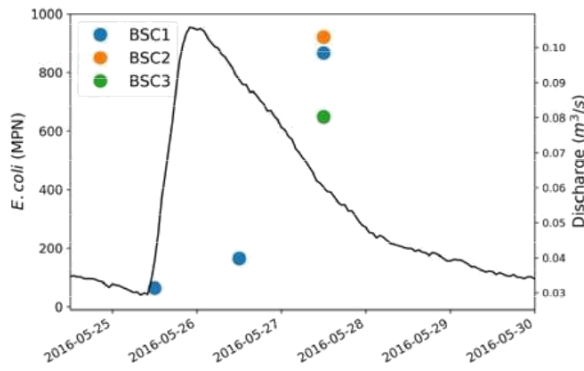


Figure 3. Hydrograph and *E. coli* concentrations at Blowing Spring Cave during a storm event. Peak *E. coli* concentrations occur after the time of peak discharge, during recession flow.

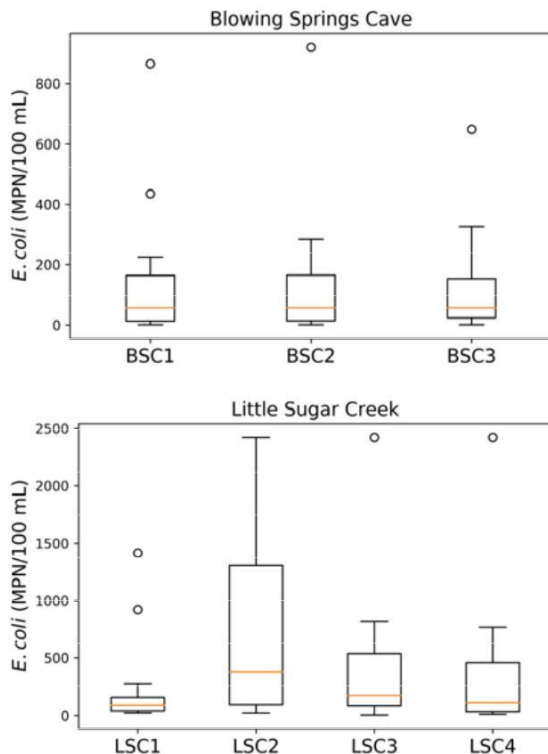


Figure 4. Boxplots of *E. coli* concentrations at: a) the three sites within Blowing Spring Cave from downstream (BSC1) to upstream (BSC3), and b) the four sites within Little Sugar Creek. Boxes indicate the median and quartile values and whiskers represent the range. Circles depict outliers, which are data points that lie outside of the box by more than 1.5 times the interquartile range. Note that the y-axis range on the Little Sugar Creek plot is much larger than on the Blowing Spring plot.

parallel on the PC1 axis with 38.68%. A R value close to 1 was used to indicate that there was dissimilarity among sample type while an R value near 0 meant no separation. An R value from the weighted PCoA plot was 0.71 which implied a significant dissimilarity among water and sediment samples regardless of location or event type.

Fluorescein dye (55 grams) was injected into the sinkhole site on February 27, 2017 during a relatively dry period. Following heavy rains, dye was detected at Blowing Spring within a charcoal packet that was deployed from March 13-27, 2017. Additionally, a fluorescein pulse was detected on the field fluorometer on March 25, 2017. This suggests a travel time of approximately 26 days over a straight-line distance of 1100 m, giving an average velocity of roughly 40 m/day. There were no positive detections at the other monitored sites. This trace confirms a positive connection between BSC and a portion of the recharge area hypothesized by Knierim et al. (2015) that lies within a residential area that contains some remaining septic tanks.

Conclusions, Recommendations and Benefits:

Even though Little Sugar Creek (LSC) receives contributions from numerous karst springs, such as Blowing Spring, the *E. coli* dynamics at the two sites are quite different, with concentrations at BSC displaying a strong positive correlation with discharge, and LSC showing no statistically significant correlation. *E. coli* concentrations at BSC peak during the recession period of storm events rather than during peak discharge. This could indicate that the contaminants are not mobilized from storage within the system but rather are delivered after recharging storm water has reached the spring. LSC frequently shows *E. coli* concentrations above the primary contact limit (410 CFU/100 mL) and sometimes above the secondary contact limit (2050 CFU/100 mL), indicating potential concerns for recreational users of the stream. The lack of correlation with discharge suggests that introduction of *E. coli* into the stream is not

strongly linked with runoff, and that the sources are different than in BSC, where the contamination is hypothesized to result from septic tanks in the recharge area (Knierim et al. 2015). Concentrations just downstream of Bella Vista Lake (at LSC2) are particularly high, suggesting a source near that reach of the

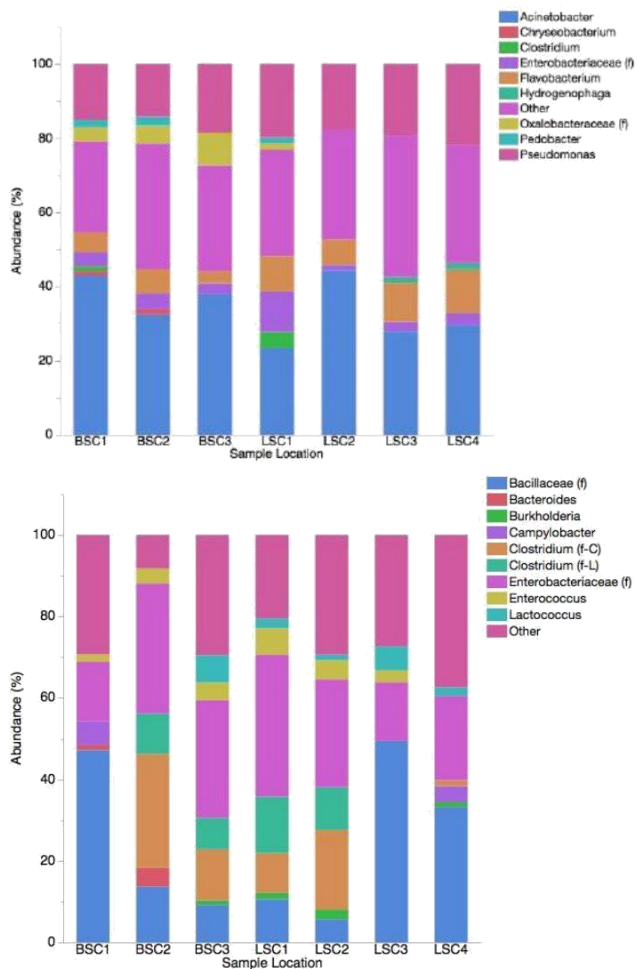


Figure 5. Relative abundance of major bacteria across the various sampling locations at the genus level in water (a) and sediment (b) collected on 5/2/2016. f in parenthesis indicates family, while f-C indicates family *Clostridiaceae* and f-L indicates family *Lachnospiraceae*—two families containing the genus *Clostridium*.

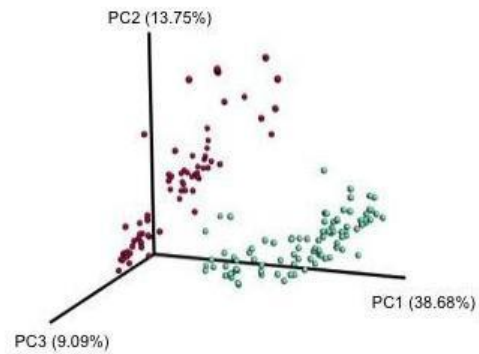


Figure 6. Beta diversity analysis among sample type, water (green) and sediment (red). Weighted principal coordinate analysis (PCoA) Unifrac plot of individual samples for each sample type.

stream. Metagenomic analysis indicates that the microbial communities within the water and sediment are significantly different, and the cave and surface stream communities also display some differences. This study provides insight into the microbial communities of karst spring and surface waters within a mixed urban and agricultural setting, where much of the population relies on decentralized wastewater treatment. This combination of geology and land use is common throughout the Ozark Plateaus and more widely throughout the southern and eastern United States. Therefore, insight gained here is likely to apply widely across the region.

References:

- Gomes, N.C.M., L.R. Borges, R. Paranhos, F.M. Pinto, E. Krögerrecklenfort, L.C.S. Mendonça-Hagler, and K. Smalla. 2015. Diversity of *ndo* genes in mangrove sediments exposed to different sources of polycyclic aromatic hydrocarbon pollution. *Applied and Environmental Microbiology*. 73(22):7392-7399.
- Heinz, B., S. Birk, R. Liedl, T. Geyer, K.L. Straub, J. Andresen, K. Bester, and A. Kappler. 2009. Water quality deterioration at a karst spring (Gallusquelle, Germany) due to combined sewer overflow: evidence of bacterial and micro-pollutant contamination. *Environmental Geology*. 57:797-808.
- Johnson, T.B., L.D. McKay, A.C. Layton, S.W. Jones, G.C. Johnson, J.L. Cashdollar, D.R. Dahling, et al. 2011. Viruses and bacteria in karst and fractured rock aquifers in East Tennessee, USA. *Ground Water*. 49(1):98-110.
- Katz, B.G., D.W. Griffin, P.B. McMahon, H.S. Harden, E. Wade, R.W. Hicks, and J.P. Chanton. 2010. Fate of effluent-borne contaminants beneath septic tank drainfields overlying a karst aquifer. *Journal of Environmental Quality*. 39:1181-1195.

- Kozich, J.J., Westcott, S.L., Baxter, N.T., Highlander, S.K., & Schloss, P.D. 2013. Development of a dual-index sequencing strategy and curation pipeline for analyzing amplicon sequence data on the MiSeq Illumina sequencing platform. *Applied and Environmental Microbiology*. 79:5112–5120.
- Knierim, K.J., P.D. Hays, and D. Bowman. 2015. Quantifying the variability in *Escherichia coli* (*E. coli*) throughout storm events at a karst spring in northwestern Arkansas, United States. *Environmental EarthSciences*.74:4607-4623.

Project Title: Tracking the Growth of On-site Irrigation Infrastructure in the Arkansas Delta with Remote Sensing Analysis
Project Number: 2016AR386B
Start Date: 3/1/2017
End Date: 2/28/2018
Funding Source: 104B
Congressional District:
Research Category: Social Sciences
Focus Category: Water Quantity, Irrigation, Economic
Descriptors: None
Principal Investigator: Kent Kovacs Kovacs

Publications:

West, Grant H., Rachael M. Moyer. 2016. "The Impact of Agency Actors' Value Predispositions on the Perceived Effectiveness of Water Conservation Policies in Arkansas." In 2016 Annual Meeting, Nov. 3-5, 2016, Washington D.C. Association of Public Policy Analysis and Management.

West, Grant H., Rachael M. Moyer. 2016. "The Impact of Agency Actors' Value Predispositions on the Perceived Effectiveness of Water Conservation Policies." In 2017 Annual Meeting, April 6-9, 2017, Chicago, IL, Midwest Political Science Association.

West, Grant H., and Kent Kovacs. 2018 (anticipated). Spatio-temporal Adoption of Long-term Water Management Strategies in Arkansas Agriculture. PhD. Public Policy Program, University of Arkansas, Fayetteville, AR.

West, Grant H., Rachael M. Moyer. 2016. "The Impact of Agency Actors' Value Predispositions on the Perceived Effectiveness of Water Conservation Policies in Arkansas." In 2016 Annual Meeting, Nov. 3-5, 2016, Washington D.C. Association of Public Policy Analysis and Management.

West, Grant H., Rachael M. Moyer. 2016. "The Impact of Agency Actors' Value Predispositions on the Perceived Effectiveness of Water Conservation Policies." In 2017 Annual Meeting, April 6-9, 2017, Chicago, IL, Midwest Political Science Association.

West, Grant H., and Kent Kovacs. 2018 (anticipated). Spatio-temporal Adoption of Long-term Water Management Strategies in Arkansas Agriculture. PhD. Public Policy Program, University of Arkansas, Fayetteville, AR.

West, Grant H. and Kent Kovacs, 2017, Evaluating the Dynamic Surface Water Extent (DSWE) Landsat Product for Use in Tracking Adoption of Irrigation Infrastructure, in Watersmart Innovations Conference, Las Vegas, NV.

Tracking the Growth of On-site Irrigation Infrastructure in the Arkansas Delta with Remote Sensing Analysis

Grant H. West, Department of Agricultural Economics and Agribusiness, University of Arkansas - Fayetteville

Kent Kovacs, Department of Agricultural Economics and Agribusiness, University of Arkansas - Fayetteville

Core Ideas:

Publicly available imagery can identify on-farm surface water storage built in Eastern Arkansas. The algorithm developed to identify the facilities for surface water storage identifies more than 98% of verified reservoirs.

Executive Summary:

Surface water impoundments built on farms to store water in the wet season for irrigation later in the year are one approach to reduce groundwater pumping and to sustain aquifers. However, there is limited information on where and how many of these reservoirs are present in Eastern Arkansas. This information would be useful to formulate effective policies to encourage the construction of more surface water systems. Analysis of Landsat imagery from 1995 to 2015 provides evidence for where and when reservoirs and tail-water recovery systems are present, doing so with annual resolution. Comparing our analysis – which extends the Dynamic Surface Water Extent (DSWE) algorithm for Landsat to identify irrigation storage reservoirs in Arkansas County – to the verified locations of these surface water impoundments, the analysis identifies 98% of all reservoirs in the verified study area.

Introduction:

The sustainability of the Mississippi River Valley Alluvial Aquifer (MRVA) is vital to maintaining long-term agricultural profitability in Arkansas (Maupin and Barber, 2005; Konikow, 2013). The extent of the aquifer includes seven states, and Arkansas is the largest consumer of water from the aquifer (Maupin and Barber, 2005). Although Arkansas has often been considered an area rich in water resources with annual precipitation amounts ranging from approximately 50 to 57 inches (NOAA, 2014), there are several key constraints to maintaining agricultural profitability in the region. The first is lack of timely rainfall, and the second is the increasing need for irrigation. The number of irrigated acres continues to increase in Arkansas in order to maintain and increase yields and mitigate risk as a result of recurring drought conditions (Vories and Evett, 2010). Moreover, most irrigated acres result from producers privately funding the installation of irrigation wells that draw groundwater from the MRVA. It is known that the current rate of withdrawals from the aquifer is not sustainable, especially as the number of irrigated acres continues to increase each year (Barlow and Clark, 2011; ANRC, 2012; Evett et al., 2003).

The Agricultural Act of 2014 (or 2014 U.S. Farm Bill) introduced the Regional Conservation Partnership Program (RCPP) which consolidated several programs including the Mississippi River Basin Healthy Watersheds Initiative, Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP), in order to promote coordination between Natural Resources Conservation Service (NRCS) and its partners and provide technical and financial assistance to producers and landowners. These federal and state programs encourage more efficient and effective irrigation and have contributed to the voluntary implementation of water conservation practices such as tail-water recovery ditches, on-farm storage reservoirs, and use of sensor technologies, to name a few. Despite the

prevalence of programs that are targeted to help farmers sustainably manage agro-ecosystems in Arkansas, the level of information about the use of these management practices and technologies is less than ideal and can be improved significantly. We do not yet know how much adoption of water conservation measures has already occurred and to what extent these various water conservation measures reduce pumping pressure on the MRVA. This lack of knowledge is a pressing problem, especially as federal incentive programs face increased public scrutiny. We need to determine if conservation practices are effective at reducing groundwater declines in the MRVA and also which practices are most frequently adopted and retained by farmers.

While the National Agricultural Statistic Service (NASS) does collect some data on water conservation practices, they depend on problematic sampling techniques when only a small proportion of producers use a practice, which is the case for on-site water storage and tail-water recovery. Further, NASS data do not disclose the location of the producer adopting a practice, and this prevents a full assessment of available surface water and what spatial features of the landscape might have caused the producer to adopt the practice.

The objective of this research is to understand the construction of on-site water storage and tail-water recovery systems over time in the critical groundwater area of Arkansas County. Using various sources of multispectral imagery and aerial photography, we aim to identify and map the spatial extents of on-site water storage in the area and to attribute construction dates in a GIS database layer.

Methods:

Data

Because of its continuous operation over the last several decades and its frequent return times, Landsat satellite imagery was used to track the construction of on-site irrigation storage reservoirs. Using the United States Geological Survey (USGS) EarthExplorer tool, we acquired all Landsat scenes overlying a study area of Arkansas County, Arkansas between January 1995 and December 2015. Landsat data are multispectral images with a spatial resolution of 30 meters and a return time of 16 days. Landsat-based methods for identifying on-site water storage are cost-effective, time-efficient, reliable, and easily repeatable.

Water Identification

In order to make the initial classification of all surface water we use the Provisional Dynamic Surface Water Extent (DSWE) algorithm developed by USGS (Jones and Starbuck, 2015; Jones, 2015). The identified scenes were pre-processed using the provisional DSWE algorithm which classifies water and non-water pixels in the Landsat imagery according to their surface reflectance and slope characteristics. Primary inputs to the algorithm are a Digital Elevation Model (DEM) and the Landsat reflectance bands for Blue, Green, Red, NIR, SWIR1, and SWIR2, along with the CFMASK band used to filter cloud and cloud shadow (Jones and Starbuck, 2015).

Extending the Algorithm for Reservoir Identification

Using Python and the *arcpy* library, all non-water pixels, including cloud and shadow, were reclassified to a value of "0" while all pixels identified as water were assigned a value of "1". This was done for each scene between 1995 and 2015. With only surface water pixels containing values, we use *TerrSet* Geospatial Monitoring and Modeling software in combination with Python to apply filters based upon size and shape characteristics. Using *TerrSet's Group* function, clusters of water pixels were identified as bodies of water and all pixels in a water body were assigned an ID value for that body of water. The *Area* and *Perim* functions calculated the area and perimeter of each grouped and identified

water body, assigning these values to each pixel in a group. We characterize shape using a measure for compactness ratio and TerrSet's *cratio* function. Using the area and perimeter layers as inputs, the *cratio* function calculates the square root of the ratio of the area of the polygon to the area of a circle having the same perimeter as that of the polygon. This value is assigned to each pixel in a group.

We use Python and the *arcpy* library to filter out bodies of water with size and shape traits that are uncharacteristic of on-site irrigation storage reservoirs. Data on the characteristic size of reservoirs were obtained from both a 2016 survey (Edwards, 2016) and communication with Charolette Bowie of the USDA Natural Resources Conservation Service (NRCS) in Lonoke, Arkansas. The USDA-NRCS administers the EQIP program and maintains records on the construction of irrigation reservoirs under the cost-share program. Based on the information obtained from these sources, bodies of water smaller than 2.5 acres and larger than 600 acres were removed from all scenes.

Features with a high compactness ratio have a high likelihood of being man-made (McKeown and Denlinger, 1984). Because some of the constructed reservoirs do have organic, natural, shape qualities, we apply a minimal level of filtering based upon compactness. We do this primarily to eliminate streams and rivers with the lowest compactness ratios. Bodies of water with a compactness ratio less than .005 were removed from all scenes. For each scene, we executed a *BooleanAnd* operation, keeping surface-water pixels that satisfied both the area and compactness criteria. The results of this operation represent potential reservoirs in each individual scene.

The three-month period of March, April, and May is the wettest period of the year, and being prior to the growing season, irrigation storage reservoirs are likely to be most full. Interpreting Landsat scenes in these months is complicated by the presence of cloud cover (Kaufman, 1987; Ju and Roy, 2008). Due to this, we created a composite of probable reservoirs for the period (March – May) by taking the *union* of all algorithm-processed scenes within the calendar period, doing this for each year (1995 – 2015). Compositing of Landsat images provides a method for addressing data gaps resulting from cloud cover (Roy et al., 2010; Wulder et al., 2011). Probable reservoirs missing in one scene due to cloud cover are likely to be captured in the composite by another scene. Figure 1 summarizes the extended algorithm, while supplemental material reports the Landsat scenes used in constructing each of the annual composites.

Verification and Construction of Annualized Reservoir Data Layer

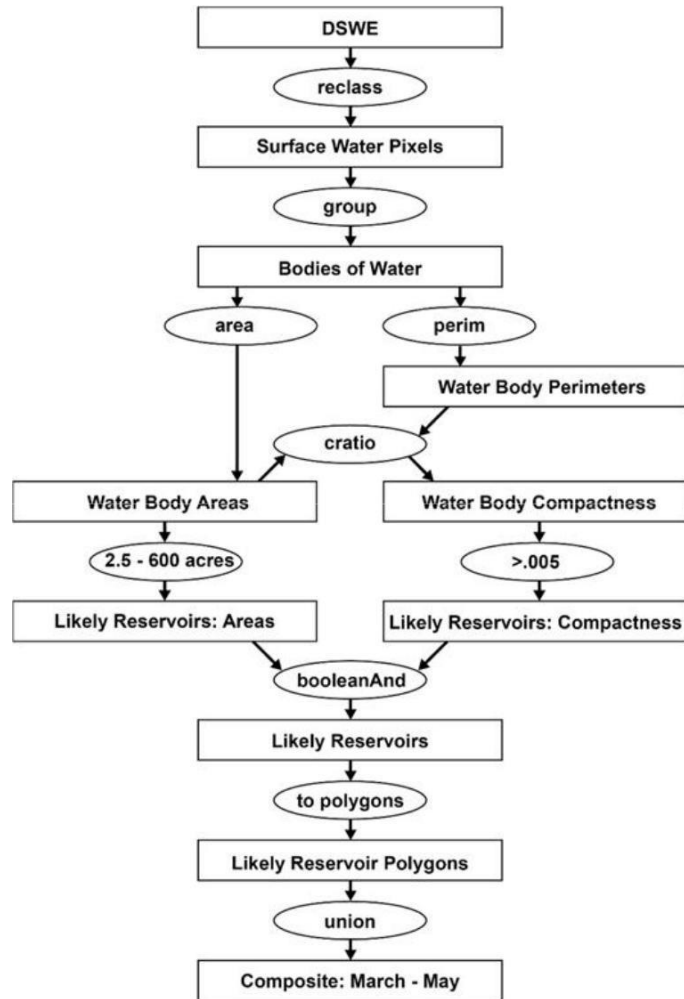
High-resolution imagery from the National Agriculture Imagery Program (NAIP) and Google Earth were necessary to identify tail-water recovery ditches and verify the presence of irrigation storage reservoirs. Mary Yeager and Michele Reba with USDA Agricultural Research Service (USDA-ARS) recently used these imagery sources and manual methods to identify and map irrigation storage reservoirs with tail-water recovery ditches for 2015 in the Cache and Grand Prairie areas, including Arkansas County. Though Yeager and Reba were not able to produce an annualized data layer, they do use NAIP imagery and historical imagery from Google Earth to verify reservoirs for each of the years 1996, 2000, 2006, 2009, 2010, and 2013, in addition to 2015.

We use this layer to assess the accuracy of reservoir identification for our extension of the DSWE algorithm and to aid in verifying annual reservoir locations. For each year verified manually, reservoir extents were compared to annual composites from the matching year. We also construct an annualized reservoir data layer using the annual composites, verified years, and some cases of deductive reasoning. We create Boolean identifiers in a GIS data layer to indicate the presence of a reservoir in a given year from 1995 to 2015.

Results:

We compare probable reservoirs from the conceptual model (annual composites) to available years of verified reservoir locations. Table 1 reports the results of the algorithm accuracy assessment using manually verified years. The percentage of the manually verified reservoirs that were identified by matching annual composites ranged from 95.7% to 99.1% for the seven years included in the assessment. The most accurate composite was 2013 where 221 of 223 reservoirs were identified by the algorithm. The composite for 1996 failed to identify the largest number of reservoirs, missing seven, and was the least accurate by percentage identified. Between 2000 and 2006, the number of reservoirs increased by 30 which is the largest increase between verified years. It is also the longest period without available high-resolution imagery.

Table 2 reports the percentage of water bodies from the outputs of the conceptual model that positively identify verified reservoirs. On average, approximately 10% of probable reservoirs detected by the model proved to be actual reservoirs in the verified layer. The least accurate model year was 2006 (5.1% positive identification), while 2015 was more than twice as accurate as the



This summarizes the algorithm used to process Landsat scenes for identifying irrigation storage reservoirs. It takes scenes processed using the U.S. Geological Survey’s Provisional Dynamic Surface Water Extent (DSWE) algorithm and extends that using spatial and temporal constraints (Jones and Starbuck, 2015; Jones, 2015). Rectangles in the figure represent data layers used or created in the algorithm, while ovals represent operations applied using Python and GIS.

Table 1. Accuracy Assessment, Percentage of Verified Reservoirs Identified.

NAIP-verified years	Number of verified reservoirs	Number identified by matching composite	Percentage Identified by composite
1996	164	157	95.7%
2000	176	171	97.2%
2006	206	204	99.0%
2009	215	212	98.6%
2010	219	215	98.2%
2013	223	221	99.1%
2015	229	225	98.3%

This summarizes the results of the accuracy assessment comparing annual composites to years with verified reservoir layers (Type II error).

Table 2. Accuracy Assessment, Percentage of Model Water Bodies Identifying Verified Reservoirs

NAIP-verified years	Total water bodies identified by model	Number positively identifying verified reservoirs	Percentage identifying verified reservoirs
1996	2476	150	6.1%
2000	1862	152	8.2%
2006	3763	193	5.1%
2009	2031	207	10.2%
2010	2597	201	7.7%
2013	2358	208	8.8%
2015	1115	226	20.3%

This summarizes the results of the accuracy assessment comparing annual composites to years with verified reservoir layers (Type I error).

average (20.3% positive identification). We construct an annualized GIS reservoir data layer for Arkansas County (Figure 2) using annual composites and verified years. Between 2000 and 2001 and between 2002 and 2003 there were 10 new reservoirs constructed, making these the most significant single years for growth in on-site irrigation storage infrastructure. In total, 69 storage reservoirs were constructed in Arkansas County from 1995 to 2015, with a majority built during the first 10 years of that period.

Conclusions, Recommendations and Benefits:

We develop an algorithm using Landsat imagery that is more than 98% accurate at identifying verified surface water reservoirs. This algorithm is useful for application to future imagery without undertaking expensive travel to verify the presence of the reservoirs or to identify the presence of a reservoir not readily visible from public roadways. The ability to employ an accurate algorithm with Landsat imagery enables manual verification using high-resolution imagery to be much more feasible. In addition, the algorithm works with public Landsat imagery that is available at high frequencies. This could allow a temporally more granular investigation of the water levels at these storage systems to help irrigation specialists understand how these systems are in use throughout the year. The information gathered about the storage systems is useful for tailoring programs and policies to encourage more surface water use for irrigation and to help stabilize the aquifer levels in Eastern Arkansas.

We note that feedback obtained about the characteristic size of reservoirs indicated substantial variability in the depth and constructed dimensions of reservoirs. This fact, along with the prevalence of organically shaped reservoirs, meant that Landsat-based methods were inadequate for estimating reservoir storage volumes. Furthermore, the algorithm is only roughly accurate at the reservoir scale for identifying the presence of reservoirs. This fact decreases confidence that estimated reservoir areas are accurate enough to report.

Future research to complement the imagery information is to collect data on the groundwater levels, weather patterns, and producer characteristics near the farms where the storage systems are present. This should help us to identify which of the factors that potentially drives the adoption of these systems plays the greatest role. A pilot survey or a series of focus groups might provide this information for the areas where clusters of the storage systems are present and built with greater frequency over the past few years.

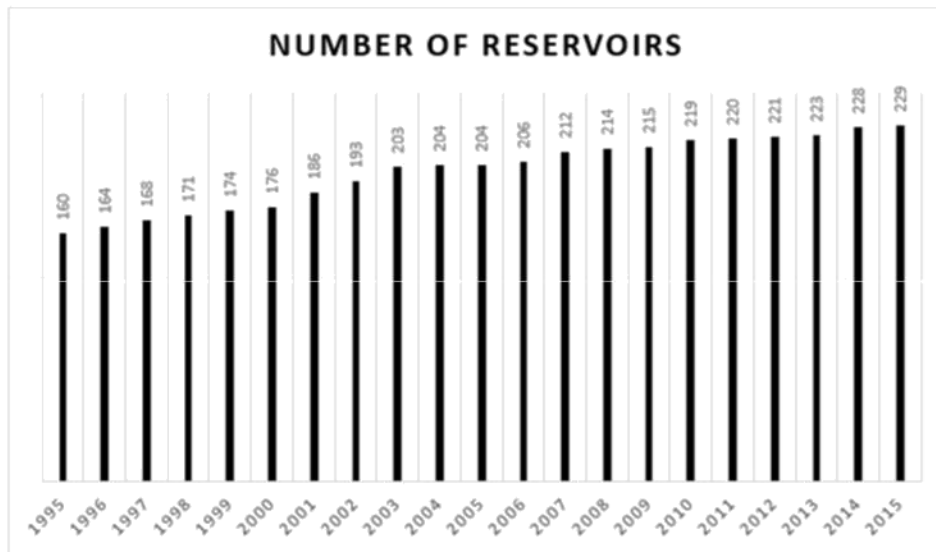


Figure 2. Reservoirs in Annualized GIS Data Layer.

References:

- Arkansas Natural Resources Commission (ANRC). 2012. Arkansas Groundwater Protection and Management Report for 2011. Little Rock, AR.
- Barlow, J.R.B. and B.R. Clark. 2011. Simulation of water-use conservation scenarios for the Mississippi Delta using an existing regional groundwater flow model. U.S. Geological Survey Scientific Investigations Report 2011-5019. p. 14.
- Edwards, J. F., (2016). *Crop Irrigation Survey: Arkansas*. Technical Report: Mississippi State University, Social Science Research Center.
- Evelt, S., D. Carman and D. Bucks. 2003. Expansion of Irrigation in the Mid-South United States: Water Allocation and Research Issues. In: Proceedings, 2nd International Conference on Irrigation and Drainage, Water for a Sustainable World – Limited Supplies and Expanding Demand. U.S. Committee on Irrigation and Drainage. pp. 247-260.
- Jones, J.W. 2015. Efficient wetland surface water detection and monitoring via Landsat: Comparison with in situ data from the Everglades Depth Estimation Network. *Remote Sensing*. 7(9): 12503 – 12538.
- Jones, J.W., & Starbuck, M.J. 2015. USGS.gov. Retrieved from Dynamic Surface Water Extent (DSWE): http://remotesensing.usgs.gov/ecv/document/dswe_algorithm_description.pdf
- Ju, J., D.P. Roy. 2008. The availability of cloud-free Landsat ETM+ data over the coterminous United States and globally. *Remote Sensing of Environment*. 112: 1196 – 1211.
- Kaufman, Y.J. 1987. The effect of subpixel clouds on remote sensing. *International Journal of Remote Sensing*. 83: 3 – 15.
- Konikow, L.F. 2013. Groundwater depletion in the United States (1900–2008): U.S. Geological Survey Scientific Investigations Report 2013–5079. p. 63. Available online at <http://pubs.usgs.gov/sir/2013/5079>.

Maupin, M.A. and N.L. Barber. 2005. Estimated Withdrawals from Principal Aquifers in the United States, 2000. U.S. Geological Survey Circular 1279. pp.46.

McKeown, D.M, J.L. Denlinger. 1984. Map-guided feature extraction from aerial imagery. Presented at the IEEE Workshop on Computer Vision, April 30-May 2, 1984 in Annapolis, Maryland.

NOAA. 2014. National Climatic Data Center, Climate at a Glance, Time Series: 1895-2013. Available online at <http://www.ncdc.noaa.gov/cag/>.

Roy, D.P., J. Ju, K. Kline, P.L. Scaramuzza, V. Kovalsky, M. Hansen, T.R. Loveland, E. Vermote, C. Zhang. 2010. Web-enabled Landsat Data (WELD): Landsat ETM+ composited mosaics of the coterminous United States. *Remote Sensing of Environment*. 114: 35 – 49.

Vories, E.D. and S.R. Evett. 2010. Irrigation Research Needs in the USDA Mid-South and Southeast, Humid and Sub-Humid Regions. Proceedings for the 5th National Decennial Irrigation Conference, ASABE #IRR10-8679, American Society of Agricultural and Biological Engineers (ASABE) and the Irrigation Association. pp. 1-12.

Wulder, M.A., J.C. White, J.G. Masek, J. Dwyer, and D.P. Roy. 2011. Continuity of Landsat observations: Short term considerations. *Remote Sensing of Environment*. 115: 747 – 751.

Supplement: Annual Composite Scene Lists

1995	LT50230361996137XXX01_b1	LT50230361998126XXX02_b1
LT50240361995141aaa01_b1	LT50230371996073AAA01_b1	LT50230361998142AAA02_b1
LT50240361995125xxx01_b1	LT50230371996105XXX01_b1	LT50230371998062AAA03_b1
LT50230361995070aaa02_b1	LT50230371996121XXX02_b1	LT50230371998110XXX02_b1
LT50230361995086xxx02_b1	LT50230371996137XXX01_b1	LT50240361998069AAA02_b1
LT50230361995102xxx02_b1	LT50240361996064XXX01_b1	LT50240361998085AAA02_b1
LT50230361995118aaa03_b1	LT50240361996080XXX01_b1	LT50240361998101XXX01_b1
LT50230361995134xxx01_b1	LT50240361996112XXX01_b1	LT50240361998133XXX01_b1
LT50230361995150xxx02_b1	LT50240361996128XXX01_b1	LT50240361998149XXX01_b1
LT50230371995070aaa02_b1	LT50240361996144XXX01_b1	
LT50230371995086xxx02_b1	1997	1999
LT50230371995102xxx02_b1	LT50230371997075XXX01_b1	LT50230361999081XXX01_b1
LT50230371995118aaa03_b1	LT50230371997107XXX02_b1	LT50230361999097XXX02_b1
LT50230371995134xxx01_b1	LT50230371997123XXX03_b1	LT50230361999113AAA01_b1
LT50230371995150xxx02_b1	LT50230371997139XXX01_b1	LT50230361999129XXX02_b1
LT50240361995077xxx02_b1	LT50240361997066AAA02_b1	LT50230361999145XXX01_b1
LT50240361995093xxx01_b1	LT50240361997082AAA02_b1	LT50230371999081XXX01_b1
LT50240361995109xxx01_b1	LT50240361997114XXX01_b1	LT50230371999097XXX02_b1
	LT50240361997130XXX02_b1	LT50230371999113AAA01_b1
1996		LT50230371999129XXX02_b1
LT50230361996073AAA01_b1	1998	LT50230371999145XXX01_b1
LT50230361996105XXX01_b1	LT50230361998062AAA03_b1	LT50240361999120XXX02_b1
LT50230361996121XXX02_b1	LT50230361998110XXX02_b1	LT50240361999136XXX01_b1

2000

LE70230362000060EDC01_b1
LE70230362000108EDC00_b1
LE70230372000060EDC01_b1
LE70230372000108EDC00_b1
LE70240362000099EDC00_b1
LE70240362000131EDC00_b1
LT50230362000084XXX01_b1
LT50230362000116XXX02_b1
LT50230362000132XXX02_b1
LT50230362000148XXX02_b1
LT50230372000068XXX02_b1
LT50230372000116XXX02_b1
LT50230372000132XXX02_b1
LT50230372000148XXX02_b1
LT50240362000107XXX02_b1
LT50240362000139XXX00_b1

2001

LE70230362001142EDC00_b1
LE70230372001142EDC00_b1
LE70240362001069EDC00_b1
LE70240362001085EDC00_b1
LE70240362001117EDC00_b1
LE70240362001133EDC00_b1
LT50230362001086XXX02_b1
LT50230362001102XXX02_b1
LT50230362001118XXX02_b1
LT50230362001134XXX02_b1
LT50230372001086XXX02_b1
LT50230372001118XXX02_b1
LT50230372001134XXX02_b1
LT50240362001077AAA02_b1

2002

LE70230362002081EDC00_b1
LE70230372002081EDC00_b1
LE70240362002072EDC00_b1
LT50230362002121LGS03_b1
LT50230372002121LGS03_b1
LT50240362002128LGS01_b1

LT50240362002144LGS01_b1

2003

LE70230362003100EDC00_b1
LE70230362003132EDC00_b1
LE70230362003148EDC00_b1
LE70240362003091EDC00_b1
LE70240362003107EDC00_b1
LT50230362003092LGS01_b1
LT50230362003108LGS01_b1
LT50230362003124LGS01_b1
LT50230362003140LGS01_b1
LT50230372003092LGS01_b1
LT50230372003108LGS01_b1
LT50230372003124LGS01_b1
LT50240362003083LGS01_b1
LT50240362003115LGS01_b1
LT50240362003131LGS01_b1
LT50240362003147LGS01_b1

2004

LE70230362004071EDC02_b1
LE70230362004087EDC02_b1
LE70230362004119EDC02_b1
LE70230372004071EDC02_b1
LE70230372004087EDC02_b1
LE70230372004119EDC02_b1
LE70240362004094EDC01_b1
LE70240362004126EDC03_b1
LE70240362004142EDC02_b1
LT50230362004079PAC02_b1
LT50230362004095PAC02_b1
LT50230362004111PAC02_b1
LT50230362004127PAC02_b1
LT50230362004143PAC02_b1
LT50230372004079PAC02_b1
LT50230372004111PAC02_b1
LT50230372004127PAC02_b1
LT50230372004143PAC02_b1
LT50240362004070PAC03_b1
LT50240362004086PAC02_b1
LT50240362004118PAC05_b1

LT50240362004134PAC02_b1

LT50240362004150PAC02_b1

2005

LE70230362005073EDC00_b1
LE70230362005105EDC00_b1
LE70230362005121EDC00_b1
LE70230362005137EDC00_b1
LE70230372005073EDC00_b1
LE70230372005105EDC00_b1
LE70230372005121EDC00_b1
LE70230372005137EDC00_b1
LE70240362005112EDC00_b1
LT50230362005065PAC01_b1
LT50230362005081PAC01_b1
LT50230362005113PAC01_b1
LT50230362005129PAC01_b1
LT50230362005145PAC01_b1
LT50230372005065PAC01_b1
LT50230372005081PAC01_b1
LT50230372005113PAC01_b1
LT50230372005129PAC01_b1
LT50230372005145PAC01_b1
LT50240362005072PAC01_b1
LT50240362005088PAC01_b1
LT50240362005104PAC01_b1
LT50240362005136PAC01_b1

2006

LE70230362006060EDC00_b1
LE70230362006076EDC00_b1
LE70230362006108EDC00_b1
LE70230362006140EDC00_b1
LE70230372006060EDC00_b1
LE70230372006076EDC00_b1
LE70230372006108EDC00_b1
LE70230372006140EDC00_b1
LE70240362006083EDC00_b1
LE70240362006099EDC00_b1
LE70240362006131EDC00_b1
LE70240362006147EDC00_b1
LT50230362006100PAC01_b1

LT50230362006132PAC01_b1
LT50230362006148PAC01_b1
LT50230372006100PAC01_b1
LT50230372006132PAC01_b1
LT50230372006148PAC01_b1
LT50240362006091PAC01_b1
LT50240362006107PAC01_b1
LT50240362006123PAC01_b1
LT50240362006139PAC01_b1

2007

LE70230362007063EDC00_b1
LE70230362007079EDC00_b1
LE70230362007095EDC00_b1
LE70230362007111EDC00_b1
LE70230362007143EDC00_b1
LE70230372007063EDC00_b1
LE70230372007079EDC00_b1
LE70230372007095EDC00_b1
LE70230372007111EDC00_b1
LE70230372007143EDC00_b1
LE70240362007102EDC00_b1
LE70240362007118EDC00_b1
LE70240362007134EDC00_b1
LT50230362007071PAC01_b1
LT50230362007087PAC01_b1
LT50230362007119PAC01_b1
LT50230372007071PAC01_b1
LT50230372007087PAC01_b1
LT50230372007119PAC01_b1
LT50230372007135EDC00_b1
LT50230372007151EDC00_b1
LT50240362007062PAC01_b1
LT50240362007078PAC01_b1
LT50240362007094PAC01_b1
LT50240362007110PAC01_b1
LT50240362007126PAC01_b1
LT50240362007142PAC01_b1

2008

LE70230362008082EDC00
LE70230362008098EDC00

LE70230362008114EDC00
LE70230362008130EDC00
LE70230362008146EDC00
LE70230372008082EDC00
LE70230372008098EDC00
LE70230372008114EDC00
LE70230372008130EDC00
LE70230372008146EDC00
LE70240362008105EDC00
LE70240362008121EDC00
LT50230362008074PAC01
LT50230362008106PAC01
LT50230362008138PAC01
LT50230372008074EDC00
LT50230372008106EDC00
LT50230372008138EDC00
LT50240362008065PAC01
LT50240362008081PAC01
LT50240362008097PAC01
LT50240362008113PAC01
LT50240362008129PAC01
LT50240362008145PAC02

2009

LE70230362009068EDC00_b1
LE70230362009116EDC00_b1
LE70230372009116EDC00_b1
LE70240362009091EDC00_b1
LE70240362009139EDC00_b1
LT50230362009060PAC01_b1
LT50230362009076PAC01_b1
LT50230362009140PAC01_b1
LT50230372009060EDC00_b1
LT50230372009076EDC00_b1
LT50230372009140EDC00_b1
LT50240362009067PAC01_b1
LT50240362009115PAC01_b1
LT50240362009147PAC01_b1

2010

LE70230362010103EDC00_b1
LE70230362010119EDC00_b1

LE70230372010071EDC00_b1
LE70230372010103EDC00_b1
LE70230372010119EDC00_b1
LE70230372010151EDC00_b1
LE70240362010062EDC00_b1
LE70240362010078EDC00_b1
LE70240362010110EDC00_b1
LE70240362010126EDC00_b1
LE70240362010142EDC00_b1
LT50230362010063PAC02_b1
LT50230362010079PAC01_b1
LT50230362010095PAC01_b1
LT50230362010111PAC01_b1
LT50230362010127EDC00_b1
LT50230362010143EDC00_b1
LT50230372010063CHM01_b1
LT50230372010079EDC00_b1
LT50230372010095EDC00_b1
LT50230372010111EDC00_b1
LT50230372010127EDC00_b1
LT50230372010143EDC00_b1
LT50240362010070PAC01_b1
LT50240362010086PAC01_b1
LT50240362010102PAC01_b1
LT50240362010118PAC01_b1
LT50240362010134PAC01_b1
LT50240362010150PAC02_b1

2011

LT50240362011137PAC01_b1
LT50240362011105PAC01_b1
LT50240362011089PAC01_b1
LT50230372011130EDC00_b1
LT50230372011114EDC00_b1
LT50230362011130PAC01_b1

2012

LE70230362012061EDC00_b1
LE70230362012093EDC00_b1
LE70230362012109EDC00_b1
LE70230362012125EDC00_b1
LE70230362012141EDC00_b1

LE70230372012109EDC00_b1
LE70230372012125EDC00_b1
LE70230372012141EDC00_b1
LE70240362012084EDC00_b1
LE70240362012100EDC00_b1
LE70240362012148EDC00_b1

2013

LC80230362013103LGN01_b1
LC80230362013135LGN01_b1
LC80230362013151LGN00_b1
LC80230372013103LGN01_b1
LC80230372013119LGN01_b1
LC80230372013135LGN01_b1
LC80230372013151LGN00_b1
LC80240362013110LGN01_b1
LC80240362013142LGN01_b1
LE70230362013095EDC00_b1
LE70230362013111EDC00_b1
LE70230372013095EDC00_b1
LE70230372013111EDC00_b1
LE70240362013086EDC00_b1
LE70240362013102EDC01_b1
LE70240362013134EDC00_b1

2014

LC80230362014090LGN00_b1
LC80230362014106LGN00_b1
LC80230362014122LGN00_b1
LC80230372014090LGN00_b1
LC80230372014106LGN00_b1
LC80230372014122LGN00_b1
LC80240362014081LGN00_b1
LC80240362014097LGN00_b1
LC80240362014113LGN00_b1
LC80240362014145LGN00_b1
LE70230362014082EDC00_b1
LE70230372014130EDC00_b1
LE70240362014105EDC00_b1
LE70240362014121EDC00_b1

2015

LC80230362105093LGN00_b1
LC80230362105125LGN00_b1
LC80230372105109LGN00_b1
LC80230372105125LGN00_b1
LC80240362015084LGN00_b1
LC80240362015100LGN00_b1
LC80240362015116LGN00_b1
LC80240362015132LGN00_b1
LC80240362015148LGN00_b1
LC70230372015101EDC00_b1
LC70240362015124EDC00_b1

Project Title: Assessment of Strategies to Address Future Irrigation Water Shortage in the Arkansas Delta
Project Number: 2017AR396B
Start Date: 3/1/2017
End Date: 2/28/2018
Funding Source: 104B
Congressional District: AR-003
Research Category: Social Sciences
Focus Category: Water Use, Economics, Conservation
Descriptors: None
Principal Investigator: Qiuqiong Huang

Publications:

Knapp, T., K. Kovacs, Q. Huang, C. Henry, R.M. Nayga, Jr., J. Popp and B. Dixon. 2018. Willingness to pay for irrigation water when groundwater is scarce. *Agricultural Water Management* 195(1): 133-141.

Knapp, T., K. Kovacs, Q. Huang, C. Henry, R.M. Nayga, Jr., J. Popp, B. Dixon. 2017. Willingness to pay for irrigation water when groundwater is scarce. Selected Presentation, the 2017 Western Agricultural Economics Association (WAEA) Annual Meeting, Lake Tahoe, NV.

Knapp, Tyler, 2017, Willingness to Pay for Irrigation Water under Scarcity Conditions, MS Thesis, Department of Agricultural Economics and Agribusiness, University of Arkansas, Fayetteville, AR, 66.

Assessment of strategies to address future irrigation water shortage in the Arkansas Delta

Tyler Knapp¹ and Qiuqiong Huang²

¹Program Associate, Community and Economic Development, University of Arkansas
Cooperative Extension Service, Little Rock, AR

²Associate Professor, Department of Agricultural Economics and Agribusiness, The University
of Arkansas, Fayetteville, AR

Core Ideas

More than 70% of sample producers in Arkansas are likely to be willing to pay more than the average pumping cost of groundwater to purchase surface water from an irrigation district. The level of willingness to pay for surface water is positively correlated with the extent of groundwater shortage as perceived by producers. The existence of other conservation programs may lower the level of willingness to pay for surface water.

Executive Summary

Conversion to surface water irrigation has been identified as one of the critical initiatives to address the decline in groundwater supply in Arkansas. Using the Arkansas Irrigation Use Survey conducted by the PIs with collaborators, this study uses statistical analysis to estimate Arkansas agricultural producers' willingness to pay (WTP) for off-farm surface water and examine which factors have predictive powers of producers' WTP for irrigation water. The estimated mean WTP for irrigation water is \$33.21/acre-foot. Comparison indicates a significant share of producers are likely to have higher WTPs for surface water than the average pumping cost in the study area. Producers located in areas with less groundwater resources have higher WTPs. Producers that are more concerned with a water shortage occurring in the state in the next 10 years have higher WTPs. A somewhat unexpected result is that participation in the Conservation Reserve Program predicts lower WTPs. One possible explanation is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases.

Introduction

Irrigation is the most important input in Arkansas's crop production. Nearly 86% of irrigation water in Arkansas in 2013 was sourced from groundwater in the Mississippi River Valley alluvial aquifer (MRVAA, NASS, 2014; Schrader 2008). However, the continuous and unsustainable pumping has put the MRVAA in danger by withdrawing at rates greater than the natural rate of recharge. In the 2014 Arkansas Water Plan by the Arkansas Natural Resources Commission (ANRC), an annual gap in groundwater as large as 8.6 billion cubic meters (7 million acre-feet) is projected for 2050 and most of the expected shortfall is attributed to agriculture (ANRC, 2015). To combat growing projected scarcity, two critical initiatives have been identified: conservation measures to improve on-farm irrigation efficiency and infrastructure-based solutions to convert to surface water (ANRC, 2015). Surface water in Arkansas is relatively abundant and is allocated to farmers based on riparian water rights. The ANRC (2015) estimates that average annual excess surface water available for interbasin transfer and non-riparian use is about 7.6 million acre-feet.

Currently, the purchase of off-farm surface water is relatively rare in Arkansas. In the Farm and Ranch Irrigation survey conducted by the National Agricultural Statistics Service (NASS) of the USDA, only 4.82% of all farms reported utilization of off-farm surface water in Arkansas in 2012 (NASS, 2014).

In total, ANRC (2015) estimates that the construction of needed infrastructure to shift groundwater irrigation to surface water irrigation in the nine major river basins of eastern Arkansas will cost between \$3.4 and \$7.7 billion. Financing these projects has grown increasingly difficult because of decreases in the availability of federal grants, cost-share and loans (ANRC, 2015). As such, understanding the nature of water use and quantifying the full value of irrigation water to agricultural producers in the Delta will be critical for continued funding and long-run success of irrigation district projects, as well as the long-run viability of agricultural production in Arkansas.

This study has two objectives: 1). to estimate Arkansas agricultural producers' willingness to pay (WTP) for off-farm surface water; 2). to examine which factors have predictive powers of producers' WTP for irrigation water. This study is the first to provide estimates of Arkansas producers' WTP for irrigation water. In areas where infrastructure needs to be constructed to deliver surface water, estimates of the economic value of irrigation water to producers would be needed to conduct cost-benefit analysis of such projects as well as assess the financial viability of surface water irrigation systems. Our research findings also help water policy makers design policies to facility infrastructure projects that bring surface water to farming communities in Arkansas.

Methods

The data set comes from the Arkansas Irrigation Use Survey conducted by the PIs with collaborators from Mississippi State University. The survey was completed in October 2016 via telephone interviews. Potential survey respondents come from the water user database managed by the ANRC and all commercial crop growers identified by Dun & Bradstreet records for the state of Arkansas. The final sample size is 199 producers that completed the survey in its entirety.

The key information used in this study comes from the WTP section. Each producer first answered an initial question "Would you be willing to pay \$___ per acre-foot of water to purchase water from an irrigation district?" When a respondent answered "yes" ("no"), the question was repeated at a higher (lower) bid value with a 50% increment; by increasing the interval between the first and second bid as the initial bid level increase we control for acquiescence bias (Alhassan et al., 2013; Lee et al. 2015). For respondents who answered "no" to the initial bid and "no" to the following lower bid, a third WTP question with a nominal bid amount of 50¢/acre-foot was used to determine whether true WTP was zero or if the respondent was offering a protest bid. To reduce starting point bias, when a respondent was interviewed, one out of the six values in the unit of \$/acre-foot (10, 20, 30, 40, 50, 60) was randomly selected to ask the producer (Aprahamian, Chanel and Luchini 2007; Flachaire and Hollard 2006). This range of values was tested in a pilot survey and confirmed as appropriate. The responses to the questions are summarized in Table 1.

The mean WTP, $E(WTP)$, is related to the cumulative density function, $F(\cdot)$ as

$$E(WTP) = \int [1-F(b)]db \quad (1)$$

where b is any positive amount of money and $F(b)$ is $Prob(WTP \leq b)$. With the assumption of a logistic distribution,

$$Prob(WTP \leq b) = 1/[1+\exp(-\alpha-\beta b-z'\delta)] \quad (2)$$

Table 1. Number of Yes and No Responses at Each Bid Level

	Bid	Yes (%)	No (%)	Total Responses
Bid Set 1	Lower bid: 0.4¢/m ³ (\$5/aft)	2 (0.33)	4 (0.67)	20
	Initial bid: 0.8¢/m ³ (\$10/aft)	14 (0.70)	6 (0.30)	
	Upper bid: 1.2¢/m ³ (\$15/aft)	10 (0.71)	4 (0.29)	
Bid Set 2	Lower bid: 0.8¢/m ³ (\$10/aft)	5 (0.63)	3 (0.38)	13
	Initial bid: 1.6¢/m ³ (\$20/aft)	5 (0.38)	8 (0.62)	
	Upper bid: 2.4¢/m ³ (\$30/aft)	4 (0.80)	1 (0.20)	
Bid Set 3	Lower bid: 1.2¢/m ³ (\$15/aft)	5 (0.56)	4 (0.44)	18
	Initial bid: 2.4¢/m ³ (\$30/aft)	9 (0.50)	9 (0.50)	
	Upper bid: 3.6¢/m ³ (\$45/aft)	5 (0.56)	4 (0.44)	
Bid Set 4	Lower bid: 1.6¢/m ³ (\$20/aft)	7 (0.44)	9 (0.56)	25
	Initial bid: 3.2¢/m ³ (\$40/aft)	9 (0.36)	16 (0.64)	
	Upper bid: 4.9¢/m ³ (\$60/aft)	6 (0.67)	3 (0.33)	
Bid Set 5	Lower bid: 2.0¢/m ³ (\$25/aft)	5 (0.38)	8 (0.62)	18
	Initial bid: 4.1¢/m ³ (\$50/aft)	5 (0.28)	13 (0.72)	
	Upper bid: 6.1¢/m ³ (\$75/aft)	2 (0.40)	3 (0.60)	
Bid Set 6	Lower bid: 2.4¢/m ³ (\$30/aft)	3 (0.23)	10 (0.77)	20
	Initial bid: 4.9¢/m ³ (\$60/aft)	7 (0.35)	13 (0.65)	
	Upper bid: 7.3¢/m ³ (\$90/aft)	1 (0.14)	6 (0.86)	

*Out of the 199 producers that completed survey, 6 respondents refused to answer both WTP questions and 1 refused to answer the second bid level. Twenty-four respondents answered “no” to this third question. Of the remaining 169 respondents, 54 registered “don’t know” responses to one or more of the proposed bid levels. All three groups of respondents were excluded from analysis. In total, 114 respondents were retained for final analysis.

where \mathbf{z} is the vector of variables that measure farm and producer characteristics such as farm location, total irrigated acres, crop mix, year of farming, gross income, education, producers’ awareness of and past participation in conservation programs and producers’ rating of the severity of water shortage in Arkansas. Using equations (1) and (2), the mean WTP can be imputed as (Koss and Khawaja, 2001):

$$E(\text{WTP}) = -\ln[1 + \exp(\alpha + \mathbf{z}'\boldsymbol{\delta})]/\beta \quad (3)$$

The parameters needed to calculate WTP, α , β and δ , are estimated using the method of maximum likelihood estimation (MLE). In MLE, the log likelihood function, the sum of the probabilities of observing each data point in the log form, is maximized. For each observation, a “yes” response to the question “Would you be willing to pay \$___ per acre-foot of water to purchase water from an irrigation district?” means a respondent’s WTP is greater than or equals the amount listed in the question (Hanemann, Loomis and Kanninen, 1991; Koss and Khawaja, 2001). The estimation is done using the STATA statistic software package. Summary statistics of variables are reported in Table 2.

Results and Discussion

Table 3 reports the results of the MLE estimation. If the sign of the estimated coefficient of a variable is positive, it means the variable has a positive effect on the level of WTP. The size of the effect of a variable on WTP is determined by the size of its coefficient as well as the coefficients of other variables. The coefficient of the bid variable is negative and statistically significant at the 1% level, indicating that respondents are more likely to say no to a large bid. A producer located east of Crowley’s Ridge is less likely to say yes to any bid. This is probably because groundwater resources are more abundant in areas east of Crowley’s Ridge and so producers are likely to exhibit lower WTP. The coefficient of respondent’s rating of groundwater shortage in the state is positive and statistically significant at the 5% level, indicating greater willingness to pay for irrigation water when groundwater resources are perceived as scarce. Respondents who indicated awareness of Arkansas’ tax credit program for construction of on-farm surface water infrastructure display a greater likelihood to answer yes to a higher bid. These results highlight the importance of increasing extension efforts to raise awareness of growing and long-term

Table 2. Variable Definitions and Summary Statistics

Variable	Description	Mean	St. Dev.	Min.	Max.
Crowley’s Ridge	Binary variable where 1 = lives in a county to the east (in part or fully) of Crowley’s Ridge, 0 = not	0.3421	0.4765	0	1
Years Farming	Total years of farming experience	30.91	14.41	1	60
Years Farming, Squared	The square of total years of farming experience	1161.35	909.89	0	3,600
Gross Income	Binary variable where 1 = gross income from all sources is greater than \$75,000 and less than or equal to \$150,000, 0=not	0.4123	0.4944	0	1
Percent Farm Income	Percent of gross income from farming	81.69	26.23	0	100
Bachelor’s or Higher	Binary variable where 1 = education greater than or equal to a Bachelor’s degree, 0 = not	0.5614	0.4984	0	1
Total Hectares	Total irrigated in 2015	939.2	774.5	0	4,046.80
Percent Rice	Percent irrigated rice production of total hectares in 2015	27.51	26.42	0	100
Percent Soybean	Percent irrigated soybean production of total hectares in 2015	53.93	27.37	0	100
Awareness of State Tax Credit	Binary variable where 1 = is aware of state tax credit program, 0 = not	0.4825	0.5019	0	1
Conservation, CRP	Binary variable where 1 = has participated in the Conservation Reserve Program, 0 = not	0.4912	0.5021	0	1
Groundwater Shortage	Respondent rating of the severity of water shortage in Arkansas, from 0=no shortage to 5=severe shortage, in the state	2.66	1.96	0	5

Table 3. Maximum Likelihood Estimation Results

	Coefficient	Standard Error
Intercept	-1.6836	1.3816
Bid	-0.0615***	0.0076
Crowley's Ridge	-1.0586**	0.4356
Years Farming	0.2124***	0.0655
Years Farming, Squared	-0.0029***	0.001
Gross Income	0.4595	0.3985
Percent Farm Income	-0.1928	0.7644
Bachelor's or Higher	0.504	0.424
Total Irrigated Hectares	-0.0001**	4.05E-05
Percent Rice	-0.1014	0.9423
Percent Soybean	0.8202	0.9423
Awareness of State Tax Credit	1.1214***	0.4175
Conservation, CRP	-1.1974***	0.4186
Groundwater Shortage	0.2044**	0.0985

***significant at 1%, **significant at 5%, and * significant at 10%

groundwater scarcity in the Delta as well as providing information that explains financial or technical assistance available to farmers who wish to transition to surface water irrigation.

A somewhat unexpected result is that Arkansas producers' WTP for irrigation water from irrigation districts decreases if they have participated in or are currently enrolled in the CRP. Previous studies have shown that producers who participate in conservation programs, such as the CRP, have better access to conservation information and make production decisions based on the impact of their choices in future periods (Lubbell et al., 2013). One possible explanation for this finding is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases. The

squared term of years of farming experience is added to investigate if it has a nonlinear effect on WTP. The estimated coefficients are both statistically significant at 1%. The coefficient of years of farming experience is positive and that of the squared term is negative, revealing an inverted U-shaped relationship between years of farming experience and WTP. The values of estimated coefficients indicate that the turning point is 38. That is, in contrast to findings from previous studies that age is strictly negatively correlated with WTP for irrigation water (Mesa-Jurado et al., 2012), we find that WTP for water from irrigation districts increases with years of farming experience until approximately 38 years of experience, after which, WTP decreases with years of farming experience.

The estimation results are used to derive the willingness to pay for each observation. Of producers sampled, the minimum WTP is \$3.09/acre-foot and the maximum WTP was \$78.98/acre-foot. The mean WTP is \$33.21/acre-foot (Table 4). One important finding is that for a significant share of the producers, the estimated WTP for surface water is likely to be greater than the energy cost they are currently paying to pump groundwater from the Aquifer. The Arkansas Irrigation Use Survey did not collect information on pumping cost by producer. Using the data on the depth-to-groundwater from the Natural Resources Conservation Service (Swaim et al., 2016) and energy prices, we calculate the pumping cost producers are currently paying to pump groundwater out. About 72% of our sample producers use both electric and diesel pumps, 12% uses electric pumps and 13% uses diesel pumps. For most producers, it is more expensive to pump using diesel fuel. The price of diesel used for the calculations is \$3.77/gallon, which is about the 80th percentile of the weekly diesel prices between 1994 and 2016 reported by the US Energy Information Administration. Thus our estimates of pumping cost are on the high end of the distribution of pumping costs. The estimated pumping cost for the Arkansas Delta is \$22.17/acre-foot, which is about the 29th percentile using the distribution of the estimated WTPs. This means 71% of the sample producers have estimated WTPs higher than the estimated average pumping cost.

The comparison is also carried out for Lonoke County, which is located to the west of Crowley's Ridge and has the greatest average depth-to-groundwater in Arkansas. Although the median WTP is lower than the average pumping cost (\$42.03/acre-foot versus \$45.62/acre-foot), 28% of the sample producers have

Table 4. Willingness to Pay (WTP) and Average Groundwater Pumping Cost

Region	Average Depth-to-groundwater ^a	Estimated Cost of Pumping ^b	Estimated WTP	Percentile in the Distribution of Estimated WTPs
Arkansas Delta	12.3m (40.49 ft)	1.8¢/m ³ (\$22.17/acft)	2.7¢/m ³ (\$33.21/acft) ^c	29 th
Lonoke County (greatest average depth-to-groundwater in Arkansas)	25.6m (83.35 ft)	3.7¢/m ³ (\$45.62/acft)	3.4¢/m ³ (\$42.03/acft) ^d	72 th
Mississippi County (lowest average depth-to-groundwater in Arkansas)	4.9m (16.22 ft)	0.7¢/m ³ (\$8.9/acft)	2.0¢/m ³ (\$24.81/acft) ^d	5 th

a. Data on the depth-to-groundwater are obtained from Arkansas Natural Resources Commission (Swaim et al. 2016).

b. Pumping cost is computed using the average depth-to-groundwater and the cost of diesel fuel reported by the Energy Information Administration.

c. Mean WTP is reported.

d. Due to small sample size in each of the two counties, median WTP is reported.

estimated WTPs higher than the estimated average pumping cost in the county with the greatest average depth-to-groundwater. Mississippi County is located east of Crowley’s Ridge, where the average depth-to-ground water is as shallow as 16 feet and pumping costs rarely exceed \$9/acre-foot. The estimated median WTP is \$24.81/acre-foot, much higher than the average pumping cost of \$8.9/acre-foot. Thus, even in areas of the state where groundwater is most abundant, producers’ WTP for surface water is likely to exceed the energy cost paid to pump groundwater from the aquifer.

Conclusions

The most significant finding of this study is that for the majority of the sample producers, their estimated WTPs for surface water are likely to be greater than the average pumping cost of groundwater producers are currently paying. Our study also identifies a set of factors that influence producers’ WTP. For example, higher awareness of water shortage problems seems to predict increases in producers’ WTP for irrigation water. This finding highlights the importance of continued outreach by the extension service to increase awareness of water problems in Arkansas. While producers are aware of growing state-level groundwater scarcity, few producers believe that scarcity is a problem which directly impacts their farm operations.

The finding that participation in the CRP decreases WTP could have important policy implications. While large water savings could be achieved by increasing producers’ awareness of the CRP, such practices may also decrease the level of producers’ WTP for water from irrigation districts. If the downward influence on the WTPs of such programs is to the extent that irrigation districts cannot set the price of surface water to a level that allows them to recover the cost of delivering water, then the financial viability of such projects may be hampered. Similar conflict may also arise between conservation programs that focus on improving irrigation efficiency and programs that focus on conversions to surface water. Both types of programs would positively impact the health of the Aquifer by reducing groundwater use or moving producers towards surface water resources. However, the effectiveness or viability of one program may be negatively influenced by the existence of the other program. If such changes limit the revenue earned by irrigation districts, the financial viability of such projects may also be limited. Policymakers and extension need to take such unintended consequences into account when promoting these programs. For example, conservation programs that focus on improving irrigation efficiency may

be more fruitful in areas where conversion to surface water is not an option (e.g., due to lack of infrastructure).

References

- Alhassan, M., J. Loomis, M. Frasier, S. Davies and A. Andales. 2013. Estimating Farmers' Willingness to Pay for Improved Irrigation: An Economic Study of the Bontanga Irrigation Scheme in Northern Ghana. *Journal of Agricultural Science* 5:31–42.
- Aprahamian, F., O. Chanel and S. Luchini. 2007. Modeling Starting Point Bias as Unobserved Heterogeneity in Contingent Valuation Surveys: An Application to Air Pollution. *American Journal of Agricultural Economics* 89:533–547.
- ANRC. 2015. Arkansas Water Plan Update 2014. Arkansas Natural Resources Commission. Available at: <http://arkansaswaterplan.org/plan/ArkansasWaterPlan/AppendicesUpdate.htm>.
- Flachaire, E. and G. Hollard. 2006. Controlling Starting-Point Bias in Double-Bounded Contingent Valuation Surveys. *Land Economics* 82:103–111.
- Hanemann, M., J. Loomis and B. Kanninen. 1991. Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation. *American Journal of Agricultural Economics* 73:1255–1263.
- Koss, P. and M.S. Khawaja. 2001. The value of water supply reliability in California: a contingent valuation study. *Water Policy* 3:165–174.
- Lee, S.H., J.Y. Lee, D.B. Han and R.M. Nayga. 2015. Are Korean consumers willing to pay a tax for a mandatory BSE testing programme? *Applied Economics* 47:1286–1297.
- Lubbell, M.N., B.B. Cutts, L.M. Roche, M. Hamilton, J.D. Derner, E. Kachergis and K.W. Tate. 2013. Conservation Program Participation and Adaptive Rangeland Decision-Making. *Rangeland Ecology & Management* 66:609–620.
- Mesa-Jurado, M.A., J. Martin-Ortega, E. Ruto and J. Berbel. 2012. The economic value of guaranteed water supply for irrigation under scarcity conditions. *Agricultural Water Management* 113:10–18.
- NASS. 2014. 2012 Census of Agriculture: Farm and Ranch Irrigation Survey (2013). No. AC-12-SS 1, USDA NASS. Available at: http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.
- Swaim, E., T. Fugitt, J. Battreal, C. Kelley, J. Harvey, D. Perry and J. Broach. 2016. Arkansas Groundwater Management and Protection Report for 2015. Arkansas Natural Resources Commission.

Project Title: Investigating Impact of Lead Service Lines in Drinking Water Distribution Systems at the City of Tulsa
Project Number: 2017AR397B
Start Date: 3/1/2017
End Date: 2/28/2018
Funding Source: 104B
Congressional District: AR-3
Research Category: Engineering
Focus Category: Water Quality, Treatment, Water Supply
Descriptors: None
Principal Investigator: Wen Zhang

Publications:

Belcher, K., H. Jiang, R. Foster, and W. Zhang, 2017, Accumulation and Release of Lead by Biofilms in Drinking Water Distribution Systems, AEESP Research and Education Conference, Ann Arbor, MI.

Belcher, K., H. Jiang, R. Foster, and W. Zhang, 2017, Accumulation of Lead by Biofilms in Drinking Water Distribution Systems, Arkansas Water Resources Center Annual Conference, Fayetteville, AR.

Belcher, K., H. Jiang, R. Foster, and W. Zhang, 2017, Accumulation of Lead by Biofilms in Water Distribution Systems, Southwest AWWA annual conference, Oklahoma City, OK.

Belcher, K, 2018 (expected), Interaction between lead and biofilm within Drinking Water Distribution Systems, MS thesis, Civil Engineering, College of Engineering, University of Arkansas, Fayetteville, AR.

Accumulation of Lead by Biofilms in Water Distribution Systems

Kaleb Belcher and Wen Zhang

Department of Civil Engineering, University of Arkansas, Fayetteville, Arkansas

Core Ideas

Biofilm growth is ubiquitous in lead-containing water distribution systems.

Biofilm grown within the water pipes accumulated lead at concentrations as high as 48.39 $\mu\text{g}/\text{cm}^2$ as well as other elements.

No dissolved lead release was observed from biofilm after lead pipe was removed within the pipe loop system.

Executive Summary

Lead accumulation in humans is detrimental at very low doses, especially in developing children. With millions of lead pipes and lead solder used in American homes before the 1980s, it is important to understand the interactions between lead pipes, their respective distribution systems, and the water flowing through them. This study examines the interaction between lead sources and biofilm, using a pipe loop system to determine how biofilms behave in the presence and subsequent absence of lead source. It also provides insight regarding lead activity in premise plumbing systems that have lead segments and how much of a threat these segments pose. A pipe loop with different pipe materials including lead was constructed to simulate water flows and stagnation periods of a typical household. Biofilms from the pipe loop were removed and analyzed for growth, lead concentration, and microbial community structure. In the presence of lead source, biofilms were shown to adsorb lead at concentrations as high as 48.39 $\mu\text{g}/\text{cm}^2$. This demonstrates that biofilms have the capability of accumulating lead in drinking water distribution systems. Lead levels in the biofilm ultimately decreased after the lead source was removed. No dissolved lead was observed releasing from the biofilm. The decrease of lead concentration within biofilm was likely due to detachment of the biofilm from the pipe. Biofilms can be a previously unrecognized source of lead following lead pipe removal. As the lead-laden biofilm detaches over time, a flushing regime and temporary avoidance of drinking tap water is recommended following pipe removal. This will ensure the safety of drinking water regarding lead concentration.

Introduction

Recently, lead (Pb) in the water supply has become a hot button issue following the early 2014 discovery of lead-contaminated drinking water in Flint, Michigan. Many scientists, government workers, and citizens nationwide now have serious concerns that other American communities may be at risk for potential lead contamination in drinking water. While the issue in Flint is believed to have been caused by a failure to use necessary corrosion control in the pipes, lead in distribution systems is a problem ranging across the United States. Before the 1980's, many pipes used lead solder in order to connect lead pipes to copper pipes, and a number of lead pipes are still in use in distribution systems around the nation. This is a serious issue, as research has found that even small amounts of lead can be very hazardous to human health, especially young children in important developmental phases. Due to the severity of the effects of

lead, the EPA has set a Maximum Contamination Level Goal (MCLG) at zero. Achieving this goal would essentially require removing all lead and lead containing parts in the entirety of a drinking water distribution system (DWDS). However, to perform such a removal would be a massive undertaking in economic terms as well as physical labor required. Thus, it is important to learn the consequences of slowly removing lead from DWDSs. Disappointingly, a recent study found that replacing pipes in the system might actually exacerbate the problem due to the fact that in DWDSs, perceptible amounts of lead can be found within soft deposits and solids (St. Clair et al., 2016). We hypothesize another possible source of lead contamination is biofilm that develops throughout the DWDS. Biofilms are a group of cells that aggregate together and often adhere to an external surface by extracellular polymeric substances. In DWDSs biofilms have been shown to be ubiquitous (Berry et al., 2006). The goal of the present project is to discover the role biofilms play concerning lead contamination in DWDSs. It is very important not only to the state of Arkansas, but to society as a whole, to determine if trace amounts of lead are being accumulated and released into the water by biofilm in DWDSs.

Methods

Replaced Pipe Sampling

A 1-ft lead pipe was collected from 1023 Haskell ST, Tulsa, OK 74106 on November 15, 2016. The pipe sample was preserved on ice and delivered to the University of Arkansas lab the next day. To access the biofilm and scale within the pipe, the pipe was cut open and into three equal pieces. Two of the pieces were used for lead analysis in scale and biofilm using ICP-MS. Pipe A was cut longitudinally to allow easy access to scraping the biofilm and scale with a metal spatula. Pipe B was left intact and the biofilm and scale was removed with a sponge that was pushed through the pipe and then sonicated. Following that metal analysis using ICP-MS was performed. The remaining piece was used for DNA analysis following the method below.

Pipe Loop Construction and Operation

Five types of pipe materials are included in the pipe loop: lead pipes ($\frac{3}{4}$ " ID \times 1" OD), PEX-A ($\frac{3}{4}$ "), Copper Type K ($\frac{3}{4}$ " ID \times 7/8" OD), galvanized steel ($\frac{3}{4}$ " ID \times 1" OD), and PVC ($\frac{3}{4}$ " Schedule 40). Within each loop, 12 pieces of 6" long removable pipe sections were installed in the overall pipe loop. The total pipe length per train is 30-ft. The pipe loop configuration is shown in Figure 1 and the actual pipe loop is shown in Figures 2 & 3. After pipe loop construction, the entire system was flushed at high velocity for 30 minutes to ensure that there were no leaks in the system. During the initial operation, the pipe loop was

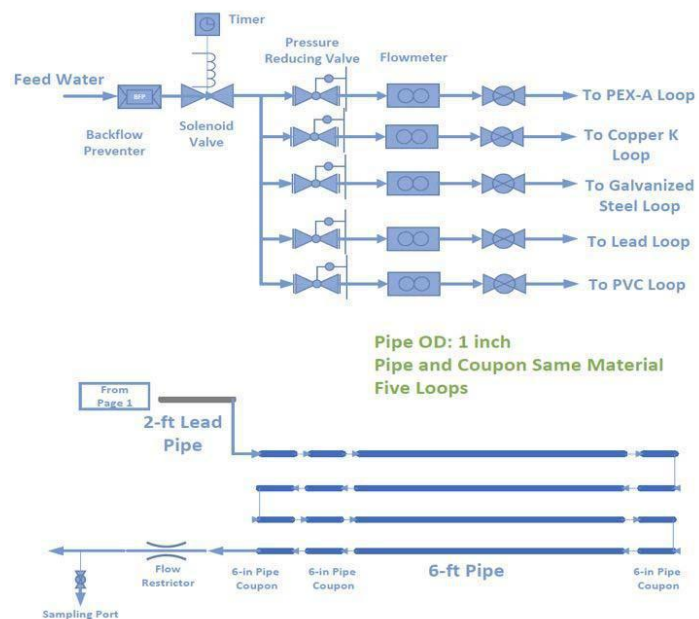


Figure 1: Pipe loop construction configuration.



Figure 2: Pipe loop displaying PEX-A train (on top of pipe loop), Galvanized Steel train (top of loop wall) and Copper-K train (bottom of loop wall).



Figure 3: Pipe loop displaying Lead train (top of pipe wall) and PVC train (bottom of pipe wall).

placed in the A.B Jewell plant, and water had a chloramine residual of 2.75 mg/L. Water in the pipe loop flowed in an intermittent mode at a flow rate of 1.0 gpm during the hours of 6:00am - 9:00 am, 11am – 1:30pm, 4:00pm – 6:30pm, and 9:30pm – 10:30pm. The flow was designed to simulate a typical residential water usage pattern. There was no flow in other time periods and water was allowed to stagnate in the pipes during these times. The pipe loop was operated in two different stages. In Stage one, 2 ft of lead pipe in each train served as the initial source of lead contamination. This stage lasted from January 23, 2017 to September 5, 2017. In Stage two, the 2 ft of lead pipes were removed from all trains and the system continued to operate until October 26, 2017.

Pipe Loop Sampling

Pipe loop samples were collected on February 17, 2017, March 22, 2017, April 21, 2017, July 11, 2017, October 6, 2017, and October 26, 2017. On each sampling day, two 6-inch pipe coupons (duplicates) were collected from each train composed of different pipe materials. Each pipe sample was placed in a one gallon ziploc bag with approximately 80 mL of water from its respective pipe train. The samples were then preserved on ice and transported to the University of Arkansas lab on the same day for processing. Each pipe coupon was sonicated using a Branson Sonifier 3800 (Emerson, Ferguson, MO) for 30 minutes within the collection bag to dislodge the biofilm from the pipe interior. Following the sonication step, the water from each of gallon ziplock bag was filtered through separate 0.22 μm filters (Pall Corporation, Port Washington, NY). Each filter was then dried completely in the oven at 98°C. The filters were preserved in -20°C until subsequent processing.

Metal analysis

Dried filters from the previous step were placed in 20 mL centrifuge tubes for storage and

digestion. Five mL of deionized distilled (DDI) water from a Barnstead Gen pure Pro UV/UF 501311950 (Thermo Fisher Scientific, Waltham, Massachusetts) was added into the centrifuge tube and then sonicated for 30 minutes in a VWR Model 751 Sonicator (Radnor, PA). A solution of 1 mL of H₂O₂, 0.42 mL of HCl and 0.2 mL of HNO₃ was then added to each of the centrifuge tubes. That mixture was digested for 24 hours in a Blue M model M01440A oven (Thermo Fisher Scientific, Waltham, Massachusetts) set at 50 °C. After 24 hours, the mixture was diluted to 10 mL using DDI water. One mL was then removed from the solution and 9 mL of 2% HNO₃ was added to that 1 mL for a final dilution of 10x. Elemental levels were calculated on the 10x dilution using a Thermo Sci. Icap Q (Bremen, Germany) Inductively Coupled Plasma Mass Spectrometer (ICP-MS).

DNA analysis

DNA was extracted for subsequent analyses from the filter containing the biofilm using a soil DNA extraction kit (Power Soil DNA Isolation Kit, Mo-Bio, Carlsbad, CA). The protocol recommended by the manufacturer was followed. DNA extracts were preserved in -20°C until subsequent processing. To quantify bacteria concentration, 16S rRNA was first amplified using PCR. PCR reactions were completed following the procedure used by Walden, Carbonero and Zhang, 2017. The presence of 16S rRNA genes was confirmed by gel electrophoresis. For bacteria community analysis, DNA extracts were submitted to the sequencing facility in Food Science at the University of Arkansas for next generation sequencing. Sequencing and data analysis was performed according to the procedure used by Walden, Carbonero and Zhang, 2017.

Results and Discussion

Replaced Pipe Scale Analysis

Lead concentrations were normalized by surface area ($\mu\text{g}/\text{cm}^2$) as well as the percentage of lead compared to the overall total solids recovered. Results are shown in Table 1. For both pipe samples, Pb was abundant in the deposit collected with concentrations going as high as 472.44 ($\mu\text{g}/\text{cm}^2$). Notice that pipe A has a much lower lead concentration than B. We believe this was caused by the rinsing procedure after pipe A was cut open to remove the metal shavings.

Replaced Pipe Biofilm Growth

Figure 4 is the gel image showing the presence of universal bacteria genes (16S rRNA). It confirmed the biofilm presence within pipelines from the DWDS in Tulsa, OK.

Biofilm Growth

PCR and Gel Electrophoresis showed positive bacterial genes from the pipe coupons, one example is shown from March 22, 2017 in Figure 5. This shows the biofilm growth within the pipe loops.

Biofilm Lead Adsorption

Results from ICP-MS showed each type of pipe in the pipe loop had biofilm that adsorbed lead. The metal

Table 1: Elemental concentrations within deposits collected from the two pieces of removed pipe.

		Lead
Pipe Sample A	Conc. ($\mu\text{g}/\text{cm}^2$)*	22.26
	Distribution (%)	38.71
Pipe Sample B	Conc. ($\mu\text{g}/\text{cm}^2$)*	472.44
	Distribution (%)	70.27

*Surface area for pipe sample A and B is 49.98, and 24.47 cm^2 , respectively.

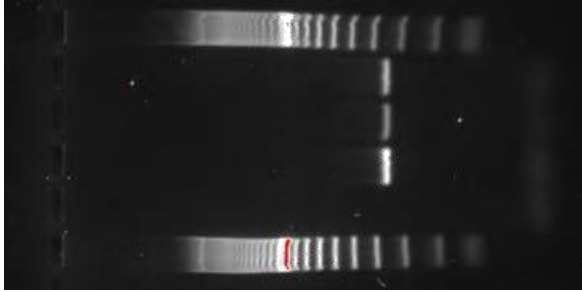


Figure 4: Gel electrophoresis image showing the successful amplification of DNA extracted from lead pipe deposits in the City of Tulsa. The wells contain: ladder, triplicate DNA samples, negative control, and ladder (in vertical order).

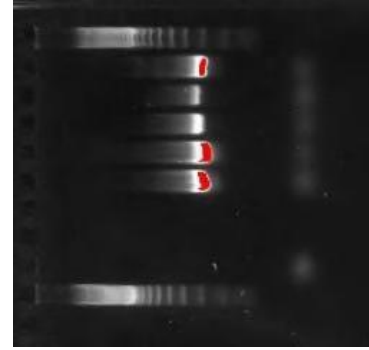


Figure 5: Gel electrophoresis image showing the successful amplification of DNA extracted from biofilms in the pipe samples from the pipe loop on March 22, 2017. The wells contain: ladder, 5 DNA extracts from Galvanized Steel, Copper Type K, Lead, PEX-A and PVC pipes, negative control, and ladder (in vertical order).

concentrations are normalized in two ways – by surface area ($\mu\text{g}/\text{cm}^2$) and by dry weight ($\mu\text{g}/\text{mg}$).

These are shown in Tables 2 and 3. The surface areas for the five pipe materials are 98.00 cm^2 , 91.20 cm^2 , 86.23 cm^2 , 79.67 cm^2 and 112.70 cm^2 for PVC, galvanized steel, lead, PEX-A, and Copper Type K, respectively. The largest adsorption of lead for all materials occurred on October 6, 2017. We speculate this is due to the lead source that was removed in September which dislodged particles of lead or lead scale were then able to attach to the biofilm. The highest reported adsorption of lead was in a lead pipe coupon at $40.18 \mu\text{g}/\text{cm}^2$ and $738.10 \mu\text{g}/\text{mg}$. The largest adsorption recorded for a non-lead pipe coupon was in galvanized steel at $42.77 \mu\text{g}/\text{cm}^2$ and $98.76 \mu\text{g}/\text{mg}$. However, the lead concentration found in the galvanized steel pipe biofilm may have been inflated. A recent study found that the zinc coating in galvanized steel pipes contained up to 2% of lead (Martin et al., 2015). In other pipe materials, the PEX coupon was shown to have adsorbed $11.75 \mu\text{g}/\text{cm}^2$ and the Copper Type K coupon had adsorbed $70.02 \mu\text{g}/\text{mg}$.

Lead Release

The lead concentration in biofilms initially increased after the lead source was removed. This data is shown in Tables 2 and 3. The largest change occurred in the Copper Type K with an increase of $21.44 \mu\text{g}/\text{cm}^2$. We speculate that the removal of the lead source dislodged particulate lead or lead scale, which then attached to the biofilm. During the next sampling period the lead levels in each train decreased.

However, dissolved lead levels in water did not increase during this time. This indicates that the lead may not have released from the biofilm into the water after the lead source pipes were removed; instead, particulate lead was released from biofilm and pipe deposits as biofilm detachment happened. Ultimately if this were a real system the particulate lead or dislodged biofilm would be consumed by human use or enter the sanitary sewer.

Table 2: Lead adsorbed by biofilms measured in $\mu\text{g}/\text{cm}^2$.

Date Collected	Pipe Material				
	Lead	PVC	PEX-A	Steel	Copper-K
17-Feb-17	3.01	0.07	0.04	0.05	0.04
22-Mar-17	5.25	0	0.02	0	0
21-Apr-17	9.16	0.05	0.05	0.02	0.32
11-Jul-17	7.26	0.08	0.03	0.04	0.02
6-Oct-17	23.05	7.57	11.75	10.87	21.44
26-Oct-17	23.5	1.3	0.07	1.41	0.45
26-Oct-17-Long	18.49	0.4	0.34	0.76	1.7

Table 3: Lead adsorbed by biofilms measure in $\mu\text{g}/\text{mg}$.

Date Collected	Pipe Material				
	Lead	PVC	PEX-A	Steel	Copper-K
17-Feb-17	117.94	0.31	0.16	0.7	0.3
22-Mar-17	1565.99	0.65	0.37	0	0.68
21-Apr-17	738.1	9.37	15.23	3.33	36.3
11-Jul-17	29.53	0.4	0.12	0.18	0.09
6-Oct-17	83.52	38.82	57.79	70.02	98.76
26-Oct-17	104.98	8.18	0.33	9.44	1.7
26-Oct-17-Long	54.52	2.08	0.63	2.52	3.24

DNA Sequencing

DNA sequencing was performed on all pipe samples. Microbial communities were determined for each pipe loop material over time. An example of one microbial community is shown below in Figure 6. It shows different pipe material accumulated distinct microbial communities within the biofilm.

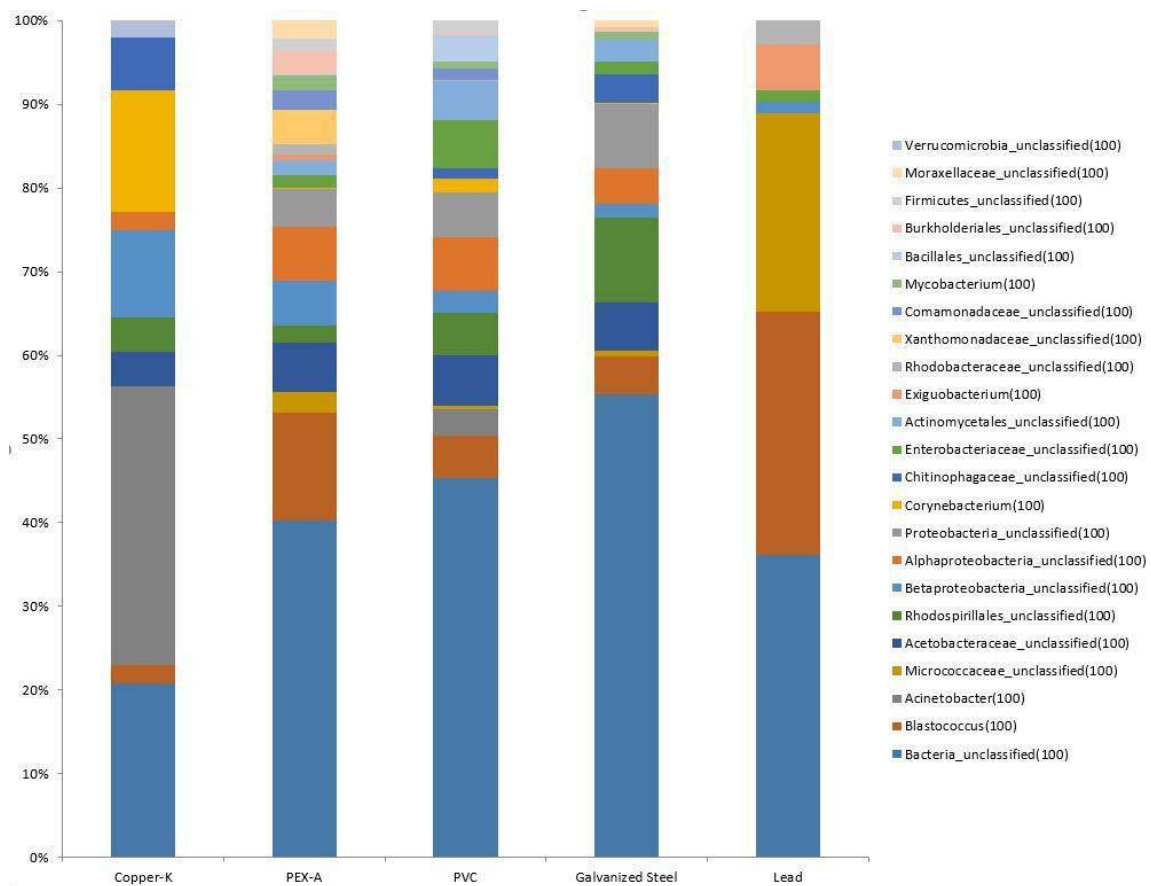


Figure 6: Stacked bar chart of the most abundant species of bacteria present in each pipe coupon from the March 22, 2017.

Conclusions

Scale pipe deposits in the replaced lead pipe from DWDS at the City had lead deposits with concentrations as high as $472.44 \mu\text{g}/\text{cm}^2$. It also showed positive biofilm growth within the replaced pipe.

Biofilm formed within the pipe loop adsorbed lead at varying levels with concentrations as high as $48.39 \mu\text{g}/\text{cm}^2$. Adsorption of lead occurred in all five pipe materials when there was a lead source pipe present. After the removal of the lead source, lead concentration in the biofilms rose on average by $13.45 \mu\text{g}/\text{cm}^2$. Lead levels in biofilm then decreased in the next sampling period, however, no dissolved lead was observed releasing from the biofilm. We recommend continuing this research by conducting further pipe loop tests using other variables such as disinfectant, source water, and treatment processes.

Lead is an ongoing problem at both regional and national level. The present research indicates that lead can be adsorbed into biofilms but no dissolved lead was released back into the water above detection limit. Additionally, a major finding is that when our lead source was removed in all five pipe trains the lead concentration in the biofilm rose briefly. This indicates that when lead pipe is replaced in premise plumbing that certain amount of lead released can be stored for a brief period by the biofilm. Our recommendation is that a flushing regime occurs following lead pipe removal to ensure that all stored lead is removed before continuing usage.

References

- Berry, D., Xi, C., & Raskin, L. (2006). Microbial ecology of drinking water distribution systems. *Current Opinion in Biotechnology*, 17(3), 297-302. doi:10.1016/j.copbio.2006.05.007
- Clark, B. N., Masters, S. V., & Edwards, M. A. (2015). Lead Release to Drinking Water from Galvanized Steel Pipe Coatings. *Environ. Eng. Sci.*, 32(8), 713-721. doi:10.1089/ees.2015.0073
- Sandvig, A. M., Pierson, G. L., Shetty, P., & Boyd, G. R. (2004). Pb in tap water following simulated partial lead pipe replacements. *Journal of Environmental Engineering*, 130(10), 1188-1197. doi:10.1061/(ASCE)0733-9372(2004)130:10(1188).
- St. Clair, J., C. Cartier, S. Triantafyllido, B. Clark, and M. Edwards. (2016). Long-Term Behavior of Simulated Partial Lead Service Line Replacements. *Environ.Eng.Sci.*, 33(1), 53-64.
- Walden, C., Carbonero, F., & Zhang, W. (2017). Assessing impacts of DNA extraction methods on next generation sequencing of water and wastewater samples. *Journal of Microbiological Methods*, 141, 10-16. doi:10.1016/j.mimet.2017.07.007

Project Title: Combined application of nutrient manipulation and hydrogen peroxide exposure to selectively control cyanobacteria growth and promote eukaryote phytoplankton production in aquaculture ponds

Project Number: 2017AR398B

Start Date: 3/1/2017

End Date: 2/28/2019

Funding Source: 104B

Congressional District: AR

Research Category: Water Quality

Focus Category: Water Quality, Nutrients, Treatment

Descriptors: None

Principal Investigator: Amit Kumar Sinha, William Reed Green, Sixte Ntamatungiro

Publications:

Sinha, A.K., M. Eggleton, R. Lochmann. 2018. An environmentally friendly approach for mitigating cyanobacterial bloom and their toxins in hypereutrophic ponds: potentiality of a newly developed granular hydrogen peroxide-based compound. *Science of the Total Environment*. 637-638: 524-537.

Sinha, AK., R. Green, Y.Ramena and J Howe, 2018, Selective suppression of algal bloom in aquaculture ponds with sodium carbonate peroxyhydrate, In *Aquaculture America 2018*, Las Vegas, NV.

Sinha, AK., R. Green, and J Howe, 2018, Mitigating Cyanobacterial Blooms and Cyanotoxins in Hypereutrophic Ponds Following the Application of Environmental-Friendly Hydrogen Peroxide-based PAK® 27 Algaecide, In *Annual Meeting of the Arkansas Chapter of the American Fisheries Society*, Pine Bluff, AR.

Sinha, AK., R. Green, and J Howe, 2018, Controlling noxious algal bloom and their toxins in ponds through the application of hydrogen peroxide based algaecide, In *UAPB Research forum*, Pine Bluff, AR.

Sinha, AK., R. Green, and J Howe, 2018, Restraining cyanobacterial bloom and their toxins in hypereutrophic ponds through the application of hydrogen peroxide based algaecide, In *Rural Life Conference*, Pine Bluff, AR.

Sinha, AK., R. Green, and J Howe. 2018, Mitigating cyanobacterial bloom and microcystins in hypereutrophic ponds following the application of hydrogen peroxide based algaecide, In *Workshop: Arkansas Bait and Ornamental Fish Growers Association Annual Meeting*, Lonoke, AR.

Mitigating cyanobacterial bloom and cyanotoxins in hypereutrophic ponds following the application of a granular hydrogen peroxide-based algaecide

Amit Kumar Sinha¹ and William Reed Green²

¹Asst. Professor, Aquaculture/Fisheries center, University of Arkansas at Pine Bluff, Pine Bluff, Arkansas

²Adjunct Faculty member, U.S. Geological Survey, Little Rock, Arkansas

Core Ideas

Cyanobacterial blooms and their toxins are potential threat to aquatic animals.

Granular H₂O₂ based sodium carbonate peroxyhydrate (SCP) compound was investigated.

SCP at 2.5 and 4.0 mg/L H₂O₂ effectively suppressed cyanobacterial bloom and toxin.

SCP left no footprint of H₂O₂ in water; hence, SCP is an eco-friendly compound.

Executive Summary

To control cyanobacterial blooms and their toxins, the efficacy of a newly developed granular compound (sodium carbonate peroxyhydrate 'SCP', trade name 'PAK[®] 27') containing hydrogen peroxide (H₂O₂) as the active ingredient was investigated. First, the dose efficacy of the SCP that corresponded to 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0 and 8.0 mg/L H₂O₂ was tested for 10 days in small-scale tanks installed in 0.1-acre experimental hypereutrophic ponds dominated by blooms of the toxic cyanobacterium *Planktothrix* sp. SCP ranging from 2.5- 4.0 mg/L H₂O₂ selectively killed *Planktothrix* sp. without major impacts on either eukaryotic phytoplankton (e.g., diatom *Synedra* sp., green algae *Spirogyra* sp. and *Cladophora* sp.) or zooplankton (e.g., rotifers *Brachionus* sp. and cladocerans *Daphnia* sp.). Based on these results, SCP at 2.5 mg/L and 4.0 mg/L H₂O₂ were homogeneously introduced into entire water volume of the experimental ponds in parallel with untreated control ponds. Temporal analysis indicated that *Planktothrix* sp. blooms collapsed remarkably in both 2.5 mg/L and 4.0 mg/L H₂O₂ treatments. Both treatments also were accompanied by an overall reduction in the total microcystin concentration. At 2.5 mg/L H₂O₂, the growth of eukaryotic phytoplankton (*Synedra* and *Cladophora* sp.) increased, but these populations along with zooplankton (*Brachionus* and *Daphnia* sp.) were suppressed at 4.0 mg/L H₂O₂. The longevity of 2.5 and 4.0 mg/L H₂O₂ treatment effects were up to 5 weeks. In addition, the added granular algaecide degraded within a few days, thereby leaving no long-term traces of H₂O₂ in the environment.

Introduction

Cyanobacterial blooms have been increasingly reported and are progressively becoming a major water quality issue in pond, lakes, and river ecosystems throughout the Arkansas states, thus impacting their fisheries resources. There are several strategies suggested to remove cyanobacterial blooms. Reducing nutrient loads (typically phosphorus) to prevent eutrophication is probably the best strategy (Conley et al., 2009; Matthijs et al., 2012; Smith and Schindler, 2009), though it often requires several years for the effect to be realized. Dredging of nutrient-rich sediments from pond bottoms followed by a phosphorus-binding clay treatment is the simplest remedial approach to eliminate phosphorus loads. However, these practices are associated with high operating costs, slow action, and the outcomes are not always predictable or effective (Robb et al., 2003; Van Oosterhout and Lurling, 2011). Additional strategies such as artificial pond mixing also may restrain cyanobacterial populations (Huisman et al., 2004; Visser et al., 1996), but is economically infeasible in most cases. Chemical alternatives including herbicides (e.g.,

diuron), copper-based compounds (e.g., copper sulfate), and alum have been used for many decades. However, there are concerns with lengthy environmental persistence and risks of ecotoxicity to other non-target aquatic biota, including green algae, zooplankton, and fishes (Jancula and Marsalek, 2011). High-frequency sonication is a newer method of selectively bursting gas vesicles and vacuoles in cyanobacteria, which disrupts cell membranes and retards photosynthetic activity (Rajasekhar et al., 2012). Although this technique kills the cyanobacterial blooms by lysing their cells, it has no effect on the toxins. Consequently, following mass cell ruptures, large amounts of cyanotoxins are released into surrounding waters, which often deteriorates rather than resolve the water-quality issues.

In light of the well-documented problems associated with cyanobacterial blooms and their toxins, there is a corresponding need for an environmentally-benign treatment that rapidly restrains the cyanobacterial populations while also destroying their toxins. Recently, hydrogen peroxide (H_2O_2) has been proven useful in selectively reducing cyanobacteria in mixed phytoplankton communities (Barrington et al., 2013; Bauza et al., 2014; Drabkova et al., 2007; Matthijs et al., 2012; Wang et al., 2012). The algaecidal action of H_2O_2 occurs via the formation of free hydroxyl radicals (OH^\cdot) in the solution, which in turn, inhibit electron transport and photosynthetic activity by rendering photosystem II inactive, and thus, causing cellular death. Nevertheless, adding large volumes of pure H_2O_2 solution directly into water bodies poses safety concerns, and also is likely to spill during broadcasting, transportation, and storage. An attractive alternative to traditional H_2O_2 solution is sodium carbonate peroxyhydrate (SCP), which is a relatively new, dry granulated H_2O_2 -based algaecide (USEPA, 2004). When added to water, SCP decomposes rapidly and liberates H_2O_2 and sodium carbonate.

In the present study, our primary goal was to examine the use of this granulated H_2O_2 -based algaecide (SCP) for treating cyanobacterial blooms in ponds. We hypothesized that adding SCP to hypereutrophic experimental ponds would selectively suppress cyanobacterial overgrowth and destroy the associated toxins. We also proposed that SCP added to ponds would degrade within a few days, and that no long-term traces of H_2O_2 would remain. Findings of this study will provide insights into the current knowledge base of effective, rapid, and safe technologies to successfully control cyanobacterial blooms in Arkansas water resources and beyond.

Materials and methods

Experimental site and algal bloom culture

Experimental trials using the granular SCP-based algaecide were performed in a series of ponds located at the Aquaculture Research Station on the campus of the University of Arkansas at Pine Bluff (UAPB). The experiments were performed at two different scales: small-scale trials done in outdoor tanks and full-scale trials conducted in experimental ponds. A total of six experimental ponds (0.1-acre each with average depth of 1.2 m) were filled with shallow well water, and fertilized with an inorganic fertilizer and commercially available de-oiled rice bran to stimulate phytoplankton growth. In early July 2017, water from a nearby hypereutrophic pond (i.e., 'seed stock') was used to inoculate each of the six experimental ponds. Nutrients (inorganic fertilizer and de-oiled rice bran) were added, as needed, throughout the culture phase until hypereutrophic, cyanobacteria-dominated conditions were obtained. Average values and range of the various physico-chemical parameters measured in experimental ponds prior to the SCP treatments are provided in Table 1.

Preparation of SCP dilutions

The SCP-based algaecide used in this study is marketed as SePRO 'PAK[®] 27' (active ingredient ~ 27% H_2O_2 ; USEPA Registration number, 67690-76, SePRO Corporation, Carmel, IN, U.S.A.). The physical properties and characteristics of PAK[®] 27 are outlined in Table 2.

Table 1. Mean values \pm S.E of the physico-chemical and biological parameters of control and the treatment ponds prior to the SCP (PAK[®] 27) application.

	Control	SCP (2.5 mg/L H ₂ O ₂)	SCP (4.0 mg/L H ₂ O ₂)
Water temperature (°C)	24.4 \pm 0.6	25.8 \pm 0.5	24.2 \pm 0.4
Transparency (cm)	19.92 \pm 1.12	20.94 \pm 0.94	18.86 \pm 1.24
pH	8.62 \pm 0.20	8.48 \pm 0.11	8.82 \pm 0.14
Dissolved oxygen (mg/L)	2.84 \pm 0.34	2.76 \pm 0.29	3.04 \pm 0.26
Total hardness (mg/L as CaCO ₃)	187 \pm 12	182 \pm 13	196 \pm 17
Total alkalinity (mg/L as CaCO ₃)	119 \pm 9	102 \pm 12	121 \pm 10
Conductivity (μ S/cm)	385 \pm 18	371 \pm 10	405 \pm 21
Ammonia – N (mg/L)	0.92 \pm 0.08	0.96 \pm 0.12	0.89 \pm 0.14
Nitrite – N (μ g/L)	35.0 \pm 4.2	41.0 \pm 3.8	39.0 \pm 4.2
Nitrate – N (mg/L)	0.37 \pm 0.03	0.43 \pm 0.03	0.39 \pm 0.03
Total Nitrogen (TN, mg/L)	8.06 \pm 0.34	7.96 \pm 0.29	7.79 \pm 0.31
Total Phosphorus (TP, mg/L)	1.71 \pm 0.09	1.76 \pm 0.10	1.72 \pm 0.14
TN:TP	4.71 \pm 0.17	4.52 \pm 0.19	4.53 \pm 0.14
Chlorophyll a (μ g/L)	1002 \pm 84	989 \pm 72	1112 \pm 81
<i>Planktothrix</i> sp. (10 ⁶ cells per mL)	1.09 \pm 0.10	1.11 \pm 0.12	1.08 \pm 0.09

Small-scale outdoor tank experiment

Small-scale tank experiments were performed first to screen for the most appropriate dose of SCP (quantified as H₂O₂ concentrations) for the full-scale pond application. Three circular 75-L tanks were installed in each of the six hypereutrophic algal bloom ponds in early August 2017. Each tank was filled with

water (up to 65 L) from the respective algal bloom ponds. SCP (as PAK[®] 27) at 5.56, 7.41, 9.26, 11.11, 12.96, 14.81, 18.52 and 29.63 mg/L was mixed into each tank to achieve final concentrations of 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0 and 8.0 mg/L H₂O₂ respectively. This design also included one control to which no SCP was added. Each of the eight treatments and the control were conducted in duplicate.

Full-scale pond experiment and sampling

Based on the results of the small-scale tank experiments, which are reported in the Results and Discussion section, concentrations of 2.5 mg/L (low dose) and 4.0 mg/L (high dose) H₂O₂ as SCP were chosen for further study in full-scale ponds. Two ponds were treated with 2.5 mg/L H₂O₂, two ponds were treated with 4.0 mg/L H₂O₂, and the remaining two ponds received no treatments and served as control ponds. The experimental design consisted of first sampling the water on day 1 following the initiation of SCP treatments followed by daily sampling for the next 10 days. This was followed by weekly sampling from week 2 through week 6.

Table 2. Physical and chemical properties of PAK[®] 27.

Ingredient	Property
Sodium Carbonate Peroxyhydrate (active ingredient)	> = 85.0 %
Carbonic acid sodium salt	< =13.0 %
Sodium silicate SiO ₂ /Na ₂ O	< =1.5 %
EPA Registration no.	68660-9-67690
CAS No.	15630-89-4
Physical state	Free flowing white granules
Mean Particle Size	350 – 650 (μ m)
Alkalinity (%Na ₂ CO ₃)	67
Solubility	150 g/L
pH	10.4-10.6 (10.1 g/L)
Bulk density	900-1200 kg/m ³

Source: PAK[®] 27 Technical Data Sheet

Sampling protocols and analytical techniques

All phytoplankton were identified to the lowest practical taxonomic level *via* 200X, 400X, 600X (oil), or 1000X (oil) magnifications by using a 0.1-mm hemocytometer under an optical microscope (Axiostar plus, Zeiss, USA). Zooplankton composition and numbers was determined using Sedgewick Rafter counting cell and viewed at either 100X or 150X. Total microcystin concentrations were determined using Abraxis microcystins assay kit (product No. 520011). Standard water quality parameters were determined through a portable multi-probe field meter (HQ40D portable multi meter, HACH) and HACH assay kits (method details are provided in the Table 3 legends).

Statistical analysis

All data are presented as mean \pm standard error (S.E.). For comparisons among treatment and control groups, one-way completely randomized analyses of variance (ANOVA) were performed; if significant differences were detected, among-treatment differences were assessed using Dunnett's test. Student's two-tailed t-test was used for single comparisons. A probability level of 0.05 was used for rejection of all null hypotheses.

Results and Discussion

Selective toxicity and dose optimization of granular H₂O₂ algaecide (SCP) towards cyanobacterial blooms

The present study tested the feasibility of a commercially available SCP granular algaecide (PAK[®] 27) that would release H₂O₂ when added to the water as a means of selectively eliminating cyanobacteria from mixed phytoplankton communities. In this study, determination of the correct dosage through a small-scale tank experiment was a critical step for the effective application at the full-scale pond level. The tank experiments suggested that the addition of the SCP corresponding to 2.5 mg/L H₂O₂ and greater significantly reduced the dominating cyanobacterium *Planktothrix* sp. population (Figure 1). However, concentrations of 5 mg/L H₂O₂ and greater would not be feasible, as non-targeted eukaryotic phytoplankton communities (e.g., green algae *Spirogyra* sp., *Cladophora* sp. and the diatom *Synedra* sp.) and herbivorous zooplankton (e.g., the rotifer *Brachionus* sp. and cladoceran *Daphnia* sp.) appeared sensitive to these elevated levels (Figures 2 and 3). On the basis of these findings, SCP corresponding to 2.5 mg/L and 4.0 mg/L H₂O₂ were selected for application in experimental ponds to investigate optimal suppression of cyanobacteria without affecting the remaining, non-target plankton community.

Plankton dynamics in the SCP treated ponds

The application of 2.5 mg/L H₂O₂, in the form of SCP in the full-scale experimental ponds reduced the abundance of cyanobacterium *Planktothrix* sp. (Figure 4), whereby other phytoplankton classes (e.g., green algae *Cladophora* sp. and the diatom *Synedra* sp.) exhibited a conspicuous increase in abundance (Figures 5A,5B). This finding suggested that eukaryotic phytoplankton species in the 2.5 mg/L H₂O₂ -SCP treated ponds exploited the cyanobacterial collapse and mobilized the available nutrients, which would otherwise have been rapidly exhausted by the cyanobacteria bloom. This was supported by an initial significant increase in ammonia (Table 3). Another possibility could include the presence of nitrifying bacteria (i.e., oxidizing ammonia to nitrite and to nitrate), based on a gradual increase in nitrite and nitrate in all treated ponds after 3 weeks (Table 3). Furthermore, comparatively greater total phosphorus content in the treated ponds relative to controls was consistent with the reduction in cyanobacterial blooms in treatment ponds, which rendered phosphorus more bioavailable in the water column (Table 3). We also observed that the abundance of herbivorous zooplankton (*Brachionus* and *Daphnia* sp.) strongly declined in the 4.0 mg/L H₂O₂ -SCP applied ponds in contrast to those that received 2.5 mg/L H₂O₂ (Figures 6A,6B).

Parameter	Treatment	Days										Weeks					
		1	2	3	4	5	6	7	8	9	10	2	3	4	5	6	
Dissolved oxygen (mg/L)	Control	2.84 ± 0.21	3.01 ± 0.26	2.38 ± 0.19	2.46 ± 0.23	3.04 ± 0.16	3.41 ± 0.17	2.88 ± 0.28	2.31 ± 0.28	2.34 ± 0.22	2.64 ± 0.22	1.65 ± 0.26	2.01 ± 0.21	2.38 ± 0.16	2.26 ± 0.27	2.04 ± 0.26	
		2.5 mg/L	2.76 ± 0.31	3.02 ± 0.32	2.67 ± 0.33	2.33 ± 0.33	2.90 ± 0.33	3.13 ± 0.35	2.81 ± 0.32	2.32 ± 0.31	2.21 ± 0.31	2.48 ± 0.38	1.75 ± 0.29	2.12 ± 0.28	2.61 ± 0.36	2.78 ± 0.35	2.58 ± 0.35
	4.0 mg/L	3.01 ± 0.24	2.89 ± 0.30	2.99 ± 0.23	2.01 ± 0.23	3.19 ± 0.26	3.21 ± 0.29	2.89 ± 0.30	2.67 ± 0.29	2.52 ± 0.29	2.42 ± 0.35	2.27 ± 0.36	2.32 ± 0.29	2.72 ± 0.36	2.88 ± 0.37	2.70 ± 0.38	
		Control	182 ± 7.8	190 ± 7.8	178 ± 13.2	181 ± 11.7	180 ± 12.9	189 ± 11.5	190 ± 12.2	191 ± 11.9	185 ± 15.1	191 ± 12.5	190 ± 13.0	196 ± 11.3	182 ± 14.7	190 ± 9.9	201 ± 10.2
	Total hardness (mg/L as CaCO ₃)	2.5 mg/L	187 ± 7.7	186 ± 9.2	180 ± 7.6	182 ± 12.3	190 ± 8.2	192 ± 13.2	188 ± 15.8	184 ± 13.3	188 ± 11.6	201 ± 13.2	200 ± 14.4	190 ± 14.4	186 ± 14.6	192 ± 16.0	189 ± 14.9
		4.0 mg/L	196 ± 7.1	192 ± 10.1	189 ± 13.3	190 ± 12.7	183 ± 14.3	190 ± 13.7	185 ± 14.8	189 ± 13.3	186 ± 13.3	188 ± 12.9	201 ± 13.5	204 ± 12.9	190 ± 14.9	201 ± 14.4	205 ± 13.4
Ammonia – N (mg/L)	Control	0.92 ± 0.11	0.91 ± 0.08	0.88 ± 0.11	0.97 ± 0.11	0.91 ± 0.10	0.89 ± 0.14	0.92 ± 0.12	0.88 ± 0.12	0.89 ± 0.11	0.9 ± 0.11	0.92 ± 0.08	0.91 ± 0.10	0.91 ± 0.11	0.86 ± 0.12	0.89 ± 0.11	
		2.5 mg/L	0.96 ± 0.12	0.90 ± 0.12	0.91 ± 0.12	0.88 ± 0.10	0.82 ± 0.11	0.88 ± 0.10	0.90 ± 0.09	0.90 ± 0.11	1.31 ± 0.11	1.34 ± 0.14	1.21 ± 0.11	1.27 ± 0.12	0.98 ± 0.13	1.09 ± 0.12	1.04 ± 0.12
	4.0 mg/L	0.89 ± 0.12	0.88 ± 0.12	0.79 ± 0.09	0.91 ± 0.12	0.94 ± 0.07	1.02 ± 0.11	0.89 ± 0.07	1.22 ± 0.11	1.32 ± 0.11	1.29 ± 0.13	1.23 ± 0.12	1.30 ± 0.12	1.08 ± 0.12	1.07 ± 0.11	1.01 ± 0.08	
		Control	39.2 ± 5.80	41.1 ± 5.61	43.7 ± 5.80	39.5 ± 5.67	37.2 ± 5.67	40.2 ± 6.18	45.5 ± 5.61	46.4 ± 5.73	44.6 ± 8.34	47.1 ± 8.54	52.3 ± 7.71	51.9 ± 5.80	49.4 ± 8.28	47.3 ± 5.67	50.4 ± 6.82
	Nitrite – N (µg/L)	2.5 µg/L	38.6 ± 5.73	37.4 ± 5.61	41.3 ± 5.22	33.5 ± 5.61	28.7 ± 5.73	29.5 ± 5.61	30.3 ± 5.80	28.4 ± 5.47	31.1 ± 8.41	28.3 ± 8.22	29.6 ± 7.83	30.7 ± 6.24	47.6 ± 5.48	42.4 ± 6.62	48.5 ± 6.11
		4.0 mg/L	40.2 ± 5.03	40.1 ± 5.80	39.6 ± 5.99	30.2 ± 6.50	29.4 ± 5.80	30.1 ± 5.73	28.2 ± 5.86	29.8 ± 5.77	28.5 ± 5.86	31.1 ± 5.86	33.2 ± 8.09	29.3 ± 6.88	42.5 ± 6.94	48.3 ± 6.43	46.8 ± 5.67
Nitrate – N (mg/L)	Control	0.43 ± 0.05	0.44 ± 0.05	0.44 ± 0.05	0.45 ± 0.04	0.49 ± 0.04	0.48 ± 0.04	0.47 ± 0.04	0.49 ± 0.05	0.46 ± 0.03	0.46 ± 0.04	0.46 ± 0.03	0.47 ± 0.05	0.47 ± 0.05	0.49 ± 0.04	0.48 ± 0.05	
		2.5 mg/L	0.41 ± 0.02	0.41 ± 0.02	0.39 ± 0.01	0.38 ± 0.03	0.46 ± 0.03	0.34 ± 0.04	0.41 ± 0.03	0.28 ± 0.03	0.31 ± 0.03	0.39 ± 0.03	0.39 ± 0.03	0.41 ± 0.03	0.48 ± 0.03	0.50 ± 0.03	0.47 ± 0.03
	4.0 mg/L	0.39 ± 0.02	0.37 ± 0.03	0.38 ± 0.03	0.37 ± 0.02	0.28 ± 0.03	0.32 ± 0.03	0.40 ± 0.03	0.31 ± 0.05	0.31 ± 0.04	0.35 ± 0.03	0.38 ± 0.031	0.39 ± 0.029	0.47 ± 0.035	0.51 ± 0.026	0.48 ± 0.032	
		Control	0.43 ± 0.05	0.44 ± 0.05	0.44 ± 0.05	0.45 ± 0.04	0.49 ± 0.04	0.48 ± 0.04	0.47 ± 0.04	0.49 ± 0.05	0.46 ± 0.03	0.46 ± 0.04	0.46 ± 0.03	0.47 ± 0.05	0.47 ± 0.05	0.49 ± 0.04	0.48 ± 0.05

Parameter	Treatment	Days										Weeks					
		1	2	3	4	5	6	7	8	9	10	2	3	4	5	6	
Total Nitrogen (mg/L)	Control	8.04 ± 0.39	7.77 ± 0.38	8.11 ± 0.46	7.97 ± 0.34	7.76 ± 0.41	7.87 ± 0.28	8.02 ± 0.31	8.26 ± 0.39	7.97 ± 0.39	8.13 ± 0.41	7.63 ± 0.48	8.03 ± 0.50	8.28 ± 0.47	8.50 ± 0.47	8.16 ± 0.49	
	2.5 mg/L	7.10 ± 0.41	6.96 ± 0.41	8.78 ± 0.43	8.63 ± 0.44	7.48 ± 0.44	8.27 ± 0.45	8.51 ± 0.49	9.22 ± 0.48	9.30 ± 0.47	9.82 ± 0.50	9.75 ± 0.46	9.19 ± 0.46	8.99 ± 0.47	8.67 ± 0.47	8.16 ± 0.48	
	4.0 mg/L	7.79 ± 0.39	7.29 ± 0.37	8.44 ± 0.38	8.46 ± 0.37	6.97 ± 0.28	8.09 ± 0.32	8.95 ± 0.40	9.15 ± 0.31	9.87 ± 0.31	9.76 ± 0.35	9.96 ± 0.38	8.97 ± 0.46	8.16 ± 0.39	8.33 ± 0.51	7.99 ± 0.48	
											*	*	**				
											**	*	**				
Total Phosphorus (mg/L)	Control	1.72 ± 0.13	1.75 ± 0.13	1.78 ± 0.13	1.69 ± 0.13	1.70 ± 0.15	1.70 ± 0.14	1.58 ± 0.14	1.59 ± 0.15	1.59 ± 0.14	1.33 ± 0.14	1.21 ± 0.14	1.17 ± 0.15	1.22 ± 0.15	1.18 ± 0.15	1.08 ± 0.15	
	2.5 mg/L	1.88 ± 0.13	1.84 ± 0.12	1.89 ± 0.12	1.80 ± 0.11	1.82 ± 0.14	1.81 ± 0.11	1.87 ± 0.13	1.71 ± 0.19	1.67 ± 0.09	1.58 ± 0.12	1.53 ± 0.15	1.32 ± 0.13	1.46 ± 0.15	1.35 ± 0.16	1.33 ± 0.15	
	4.0 mg/L	1.73 ± 0.12	2.03 ± 0.14	2.09 ± 0.14	1.72 ± 0.12	1.92 ± 0.09	1.99 ± 0.10	1.80 ± 0.12	1.99 ± 0.19	1.84 ± 0.09	1.59 ± 0.14	1.51 ± 0.16	1.45 ± 0.12	1.53 ± 0.15	1.51 ± 0.16	1.42 ± 0.15	

Values are means ± S.E. Asterisks (*) indicate a significant difference between the treatment groups (n=8) and control (n=8) at the same sampling period (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

Collected water samples were analyzed for total nitrogen (HACH method 10071, 10072), total phosphorus (HACH method 8190), ammonia nitrogen (NH₃-N, mg/L; HACH method 10023, 10031), nitrite-N (HACH method 10207), nitrate-N (HACH method 10206), total alkalinity (mg/L as CaCO₃; HACH method 8203) and total hardness (mg/L as CaCO₃; HACH method 8204).

It is very likely that the oxidative damage induced by a higher dose of 4.0 mg/L H₂O₂ is beyond the tolerance range of these zooplankton groups. This reduction in herbivorous zooplankton might have also been potentially coupled with the reduction of eukaryotic phytoplankton richness that limits the supply of phytoplankton as a food source.

Cyanotoxin degradation and environmental feasibility of SCP based algaecide

A potential risk associated with the massive cyanobacterial lysis is the copious release of internally produced cyanotoxins into the surrounding water (Westrick et al., 2010). For instance, the persistence of cyanotoxins has the potency to kill food fish, cause food safety issues, or adversely affect product quality (Sinden and Sinang, 2016). Hence, the timely control of not merely the cyanobacterial blooms, but also their associated toxins from the culture system is essential. Copper-containing algaecides (e.g., Captain and K-Tea) are effective in controlling cyanobacterial populations; however, evidence suggests that these chemicals cannot mitigate cyanotoxins or microcystin concentrations (Greenfield et al., 2014; Jones and Orr, 1994; Kenefick et al., 1993). This study provides strong evidence that the total microcystin concentrations are dramatically reduced by H₂O₂ applications in the form of SCP-based algaecide (Figure 7). The oxidation of the H₂O₂ fraction of the SCP granules may have catalyzed the production of hydroxyl and hydroperoxyl radicals that induced the oxidative cleavage of microcystins. This process, in effect, degrades microcystins into peptide residues by either modifying the Adda-moiety or breaking the amino-acid ring structure of the microcystins (Antoniou et al., 2008; Liu et al., 2003).

Aquaculturists, water resource managers, and water authorities should consider not only the efficiency, but also the ecological consequences of cyanobacteria bloom prevention and control approaches. In this study, the H₂O₂ added in the form of SCP-‘PAK[®] 27’ rapidly degraded in the water column, usually within 3 to 4 days (Figure 8), which suggests that this product is unlikely to leave any significant environmental footprint. Consequently, the SCP-based algaecide seems to exert minimal detrimental consequences on aquatic food webs compared to other algaecides (e.g., copper-based compounds) that have a more lengthy environmental persistence.

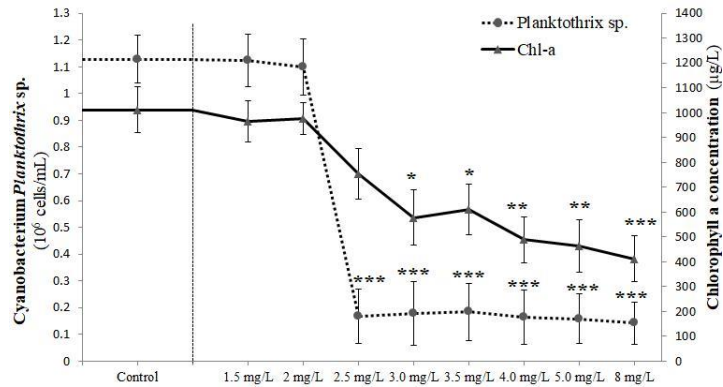


Figure 1. Changes in the cyanobacterium *Planktothrix* sp. abundance (dotted line) and chlorophyll a concentrations (solid line) in tanks after 10 days with different concentrations of H₂O₂ as SCP (PAK[®] 27). Values are means ± S.E. Asterisks (*) indicates a significant difference between the exposure groups (n=6) and the respective control (n=6) (**P* < 0.05; ***P* < 0.01; ****P* < 0.001).

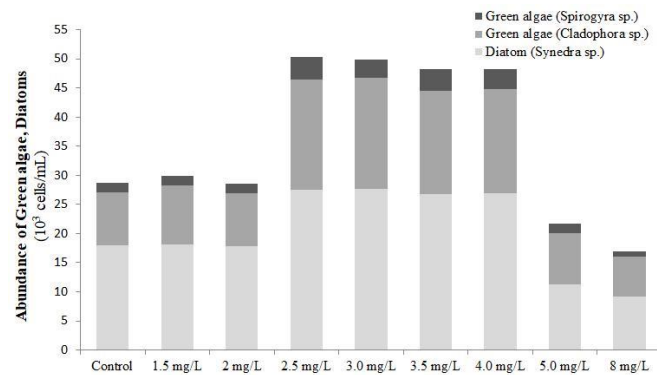


Figure 2. Abundance of green algae (*Spirogyra* sp. and *Cladophora* sp.) and diatom (*Synedra* sp.) in the tanks after 10 days with different concentrations of H₂O₂ as SCP (PAK[®] 27). Data show the means (n=6) of two duplicate tanks per treatment.

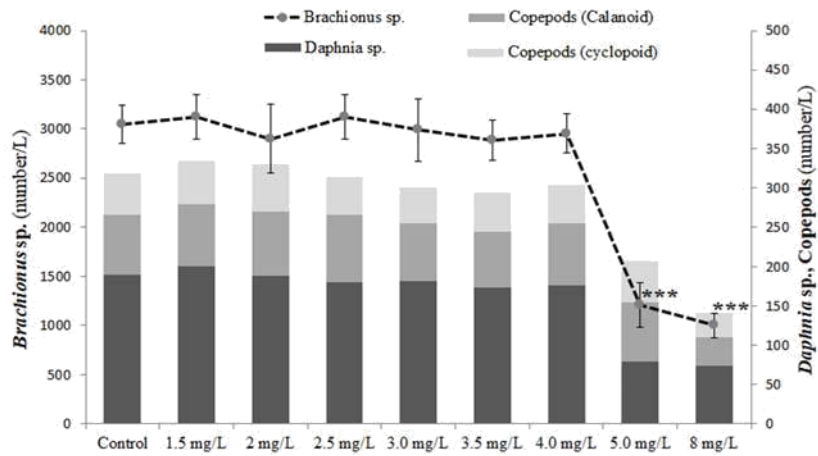


Figure 3. Abundance of zooplankton in the tanks after 10 days with different concentrations of H₂O₂ as SCP (PAK[®] 27). Line graph represents the population dynamics of rotifers (*Brachionus* sp.) while cladocerans (*Daphnia* sp.) and copepods (calanoid, cyclopoid) are illustrated as bar graphs. Data show the means (n=6) of two duplicate tanks per treatment.

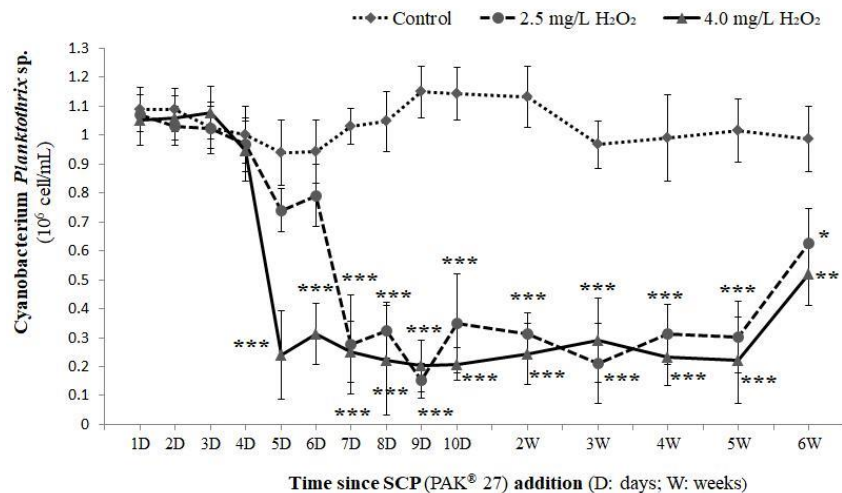


Figure 4. Temporal changes in the cyanobacterial *Planktothrix* sp. abundance in ponds over 6 weeks of treatments with 2.5 mg/L and 4.0 mg/L H₂O₂ as SCP (PAK[®] 27). Values are means \pm S.E. Asterisks (*) indicate a significant difference between the treatment

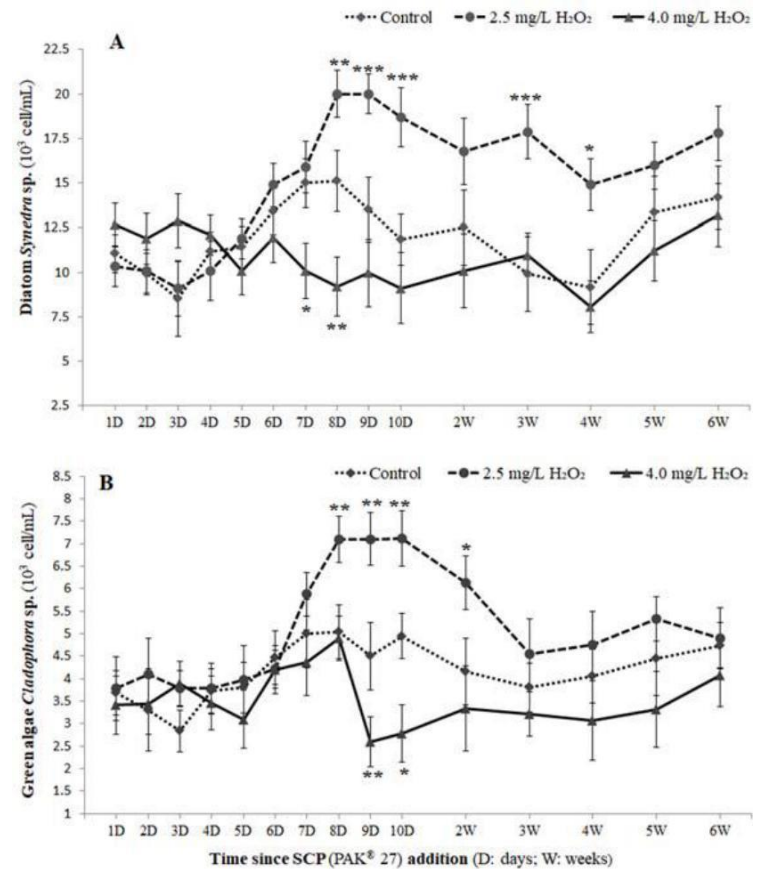


Figure 5. Temporal variations in the dynamics of eukaryotic phytoplankton (A) diatoms *Synedra* sp. and (B) green algae *Cladophora* sp. populations in ponds over 6 weeks of treatments with 2.5 mg/L and 4.0 mg/L H₂O₂ as SCP (PAK[®] 27). Values are means \pm S.E. Asterisks (*) indicate a significant difference between the treatment groups (n=8) and control (n=8) at the same sampling period (* P < 0.05; ** P < 0.01; *** P < 0.001).

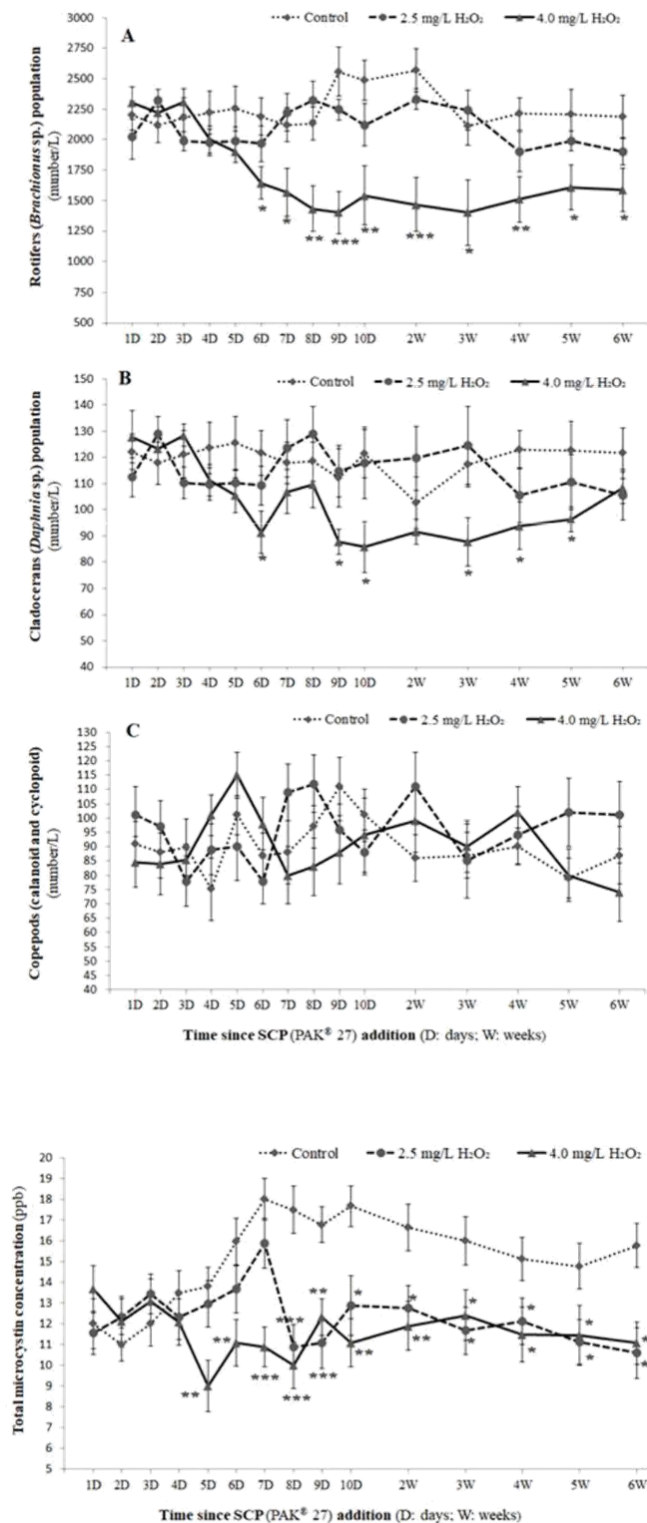


Figure 7. Changes in microcystin concentrations (ppb) in ponds over 6 weeks of treatments with 2.5 mg/L and 4.0 mg/L H₂O₂ as SCP (PAK[®] 27). Values are means ± S.E. Asterisks (*) indicate a significant difference between the treatment groups (n=8) and control (n=8) at the same sampling period (**P* < 0.05; ***P* < 0.01;

Figure 6. Abundance patterns of zooplankton (A) *Brachionus* sp., (B) *Daphnia* sp. and (C) copepods in ponds over 6 weeks of treatments with 2.5 mg/L and 4.0 mg/L H₂O₂ as SCP (PAK[®] 27). Values are means ± S.E. Asterisks (*) indicate a significant difference between the treatment groups (n=8) and control (n=8) at the same sampling period (**P* < 0.05; ***P* < 0.01; ****P* < 0.001).

Conclusions

With the current scenario of increased frequencies of cyanobacterial blooms worldwide, largely due to anthropogenic activities, an environmentally compatible management strategy is crucial that not only controls the blooms, but also their toxins. To address this issue, the efficacy of a newly developed granular H₂O₂ based SCP algaecide (PAK[®] 27) application for full-scale hypereutrophic ponds was assessed following a dose range-finding test in outdoor tanks. The applications of SCP at both 2.5 and 4.0 mg/L H₂O₂ substantially reduced cyanobacteria *Planktothrix* sp. cell numbers. However, given the minimal effects on non-target eukaryotic algae and zooplankton, the 2.5 mg/L H₂O₂ concentration as SCP had practical advantages over the 4.0 mg/L H₂O₂ concentration for reducing cyanobacteria and diminishing the likelihood of recurring cyanobacteria blooms. Furthermore, the present study also revealed that the added H₂O₂ as PAK[®] 27 degrades within a few days, and thus leaves no long-term traces in the environment. Overall, these results suggest that SCP based PAK[®] 27 algaecide is effective at both removing cyanobacterium *Planktothrix* and microcystins, while also being environmentally benign. However, the optimal dosage may also depend on the species composition of the cyanobacteria. In the future, conducting similar experiments with other genera of dominating cyanobacterial blooms (e.g., *Microcystis* or *Anabaena* sp.) will be crucial.

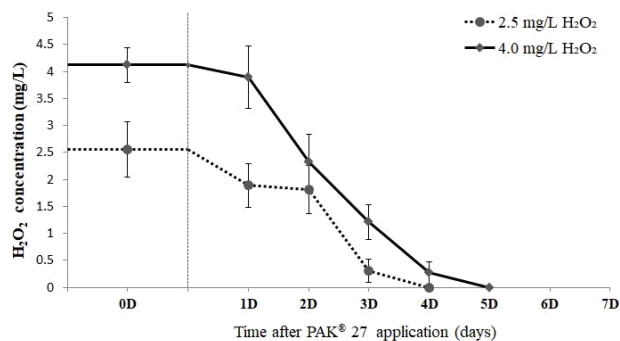


Figure 8. Degradation profile of 2.5 mg/L and 4.0 mg/L H₂O₂ applied as SCP (PAK® 27) in ponds. Values are means \pm S.E (n=8).

References

- Antoniou, M.G., J.A. Shoemaker, A.A. De La Cruz and D.D. Dionysiou. 2008. Unveiling new degradation intermediates/pathways from the photocatalytic degradation of microcystin-LR, *Environ. Sci. Technol.* 42: 8877–8883.
- Barrington, D.J., E.S. Reichwaldt and A. Ghadouani. 2013. The use of hydrogen peroxide to remove cyanobacteria and microcystins from waste stabilization ponds and hypereutrophic systems. *Ecol. Eng.* 50: 86-94.
- Bauza, L., A. Aguilera, R. Echenique, D. Andrinolo and L. Giannuzzi. 2014. Application of hydrogen peroxide to the control of eutrophic lake systems in laboratory assays. *Toxins* 6: 2657-2675.
- Conley, D.J., H.W. Paerl, R.W. Howarth, D.F. Boesch, S.P. Seitzinger, K.E. Havens, C. Lancelot and G.E. Likens. 2009. Controlling eutrophication: nitrogen and phosphorus. *Science* 323: 1014-1015.
- Drabkova, M., W. Admiraal and B. Marsalek. 2007. Combined exposure to hydrogen peroxide and light selective effects on cyanobacteria, green algae, and diatoms. *Environ. Sci. Technol.* 41: 309-314.
- Greenfield, D.I., A. Duquette, A. Goodson, C.J. Keppler, S.H. Williams, L.M. Brock, K.D. Stackley, D. White and S.B. Wilde. 2014. The effects of three chemical algaecides on cell numbers and toxin content of the cyanobacteria *Microcystis aeruginosa* and *Anabaenopsis* sp. *Environ. Mgt.* 54: 1110-1120.
- Huisman, J., J. Sharples, J.M. Stroom, P.M. Visser, W.E.A. Kardinaal, J.M. Verspagen and B. Sommeijer. 2004. Changes in turbulent mixing shift competition for light between phytoplankton species. *Ecology* 85: 2960-2970.
- Jancula, D and B. Marsalek. 2011. Critical review of actually available chemical compounds for prevention and management of cyanobacterial blooms. *Chemosphere* 85: 1415-1422.
- Jones, G.J. and P.T. Orr. 1994. Release and degradation of microcystin following algicide treatment of a *Microcystis aeruginosa* bloom in a recreational lake, as determined by HPLC and protein phosphatase inhibition assay. *Water Res.* 28: 871-876.
- Kenefick, S.L., S.E. Hrudey, H.G. Peterson and E.E. Prepas. 1993. Toxin release from *Microcystis aeruginosa* after chemical treatment. *Water Sci. Technol.* 27: 433- 440.
- Liu, I., L.A. Lawton and P.K.J. Robertson. 2003. Mechanistic studies of the photocatalytic oxidation of microcystin-LR: an investigation of byproducts of the decomposition process. *Environ. Sci. Technol.* 37: 3214- 3219.
- Matthijs, H.C., P.M. Visser, B. Reeze, J. Meuse, P.C. Slot, G. Wijn, R. Talens and J. Huisman. 2012. Selective suppression of harmful cyanobacteria in an entire lake with hydrogen peroxide. *Water Res.* 46: 1460-1472.
- Rajasekhar, P., L. Fan, T. Nguyen and F. A. Roddick. 2012. Impact of sonication at 20 kHz on *Microcystis aeruginosa*, *Anabaena circinalis*, and *Chlorella* sp. *Water Res.* 46: 1473-1481.

- Robb, M., B. Greenop, Z. Goss, G. Douglas and J. Adeney. 2003. Application of Phoslock™, an innovative phosphorus binding clay, to two Western Australian waterways: preliminary findings. *Hydrobiologia* 494: 237-243.
- Sinden, A. and S.C. Sinang. 2016. Cyanobacteria in aquaculture systems: linking the occurrence, abundance and toxicity with rising temperatures. *Int. J. Environ. Sci. Technol.* 13: 2855-2862.
- Smith, V.H. and D.W. Schindler. 2009. Eutrophication science: where do we go from here? *Trends Ecol. Evolut.* 24: 201-207.
- United States Environmental Protection Agency (USEPA). 2004. Registration Eligibility Decision (RED). PAK™ 27. Human and ecological risk assessment for section 3 registration of the end-use product PAK™ 27 for application to lakes, ponds, and drinking water reservoirs. EPA registration no. 68660-9-67690. Office of pesticide programs, biopesticides and pollution prevention division, Washington, DC.
- Van Oosterhout, F and M. Lurling. 2011. Effects of the novel 'Flock & Lock' lake restoration technique on *Daphnia* in Lake Rauwbraken (The Netherlands). *J. Plankton Res.* 33, 255-263.
- Visser, P.M., B.A.S. Ibelings, B.A.R.T. van der Veer, J.A.N. Koedood and R. Mur. 1996. Artificial mixing prevents nuisance blooms of the cyanobacterium *Microcystis* in Lake Nieuwe Meer, The Netherlands. *Freshwater Biol.* 36: 435-450.
- Wang, Z., D. Li, H. Qin and Y. Li. 2012. An integrated method for removal of harmful cyanobacterial blooms in eutrophic lakes. *Environ. Pollut.* 160: 34-41.
- Westrick, J.A., D.C. Szlag, B.J. Southwell and J. Sinclair. 2010. A review of cyanobacteria and cyanotoxins removal/inactivation in drinking water treatment. *Anal. Bioanal. Chem.* 397: 1705-1714.

Project Title: Herbicide Mitigation Potential of Tailwater Recovery Systems in the Cache River Critical Groundwater Area

Project Number: 2017AR399B

Start Date: 3/1/2017

End Date: 2/28/2019

Funding Source: 104B

Congressional District:

Research Category: Water Quality

Focus Category: Water Quality, Water Use, Agriculture

Descriptors: None

Principal Investigator: Cammy Willett, Deborah Leslie

Publication:

Thompson, M.N., C.D. Willett, D.L. Leslie, and E.M. Grantz, 2017, An examination of the presence of dicamba in tailwater recovery systems, In Arkansas Water Resources Center Annual Meeting, Fayetteville, AR

Herbicide Mitigation Potential of Tailwater Recovery Systems in the Cache River Critical Groundwater Area

Cammy D. Willett¹ and Deborah L. Leslie²

¹Assistant Professor, Crop, Soil, and Environmental Sciences Department, University of Arkansas, Fayetteville, AR

²Assistant Professor, Department of Physical Sciences, Arkansas Tech University, Russellville, AR

Core Ideas

Herbicide concentrations were higher and more variable in tailwater ditches than in reservoirs.

Herbicide concentrations peaked in May-June following a “spring flush.”

Recycling irrigation from reservoirs will minimize risk of off-target cross-crop contaminations.

Strategies to use on-farm reservoir water for artificial groundwater recharge should focus on non- growing season.

Executive Summary

Unsustainable water level decline in Arkansas aquifers has led agricultural producers to incorporate ditches and reservoirs into irrigation systems to recover tailwater and store winter-spring precipitation. These tailwater recovery systems offer water-saving benefits, but little is known about how they affect herbicide fate and transport, or the potential implications of these effects on the surrounding landscape. This study initiated a herbicide monitoring record for tailwater recovery systems in the Cache Critical Groundwater Area. Grab samples were collected weekly from April – August 2017 from seven tailwater recovery systems in Craighead and Poinsett counties. Samples were processed by filtration and concentration using solid phase extraction on reverse-phase polymer columns in preparation for analysis by high performance liquid chromatography with photodiode array detection. Target analytes were 2,4-D, clomazone, dicamba, metolachlor, propanil, and quinclorac. Clomazone, metolachlor, and quinclorac were frequently detected in the monitored systems, while 2,4-D, dicamba, and propanil were rarely or never detected. Across compounds, concentrations in ditches were higher, on average, and more variable than in reservoirs. Peak clomazone concentrations were observed in April, with few remaining detections by August. Quinclorac and metolachlor concentrations peaked in June, and these compounds were more persistent, with frequent low-level detections continuing through August. These findings were consistent with expectations that the majority of herbicide transport from fields occurs in a “spring flush” and that relatively large water volumes in reservoirs will “treat” elevated residual herbicide concentrations leaving fields in tailwater and runoff through dilution.

Introduction

Current agricultural groundwater use rates in Arkansas are unsustainable, demonstrated by the drawdown of agriculturally important aquifers, such as the Mississippi River Valley Alluvial, in recent decades (Schrader, 2015; Reba et al. 2017). Continued groundwater decline is predicted as long as irrigation demand exceeds aquifer recharge. In addition to problems of water quantity, agricultural field runoff of sediment, nutrients and pesticides contributes to impaired surface water quality (USEPA, 2009). Herbicide usage in Arkansas and the Midsouth is only anticipated to intensify in the age of herbicide- resistant weeds (Norsworthy et al., 2013; Riar et al., 2013), increasing the risk of elevated herbicide

concentrations in surface and ground waters. These water quality and quantity challenges will limit options for safe and appropriate water use in regions of intensive agriculture without effective mitigation strategies.

In zones of groundwater depletion, such as the Cache Critical Groundwater Area, agricultural producers have begun incorporating tailwater recovery into their irrigation systems by constructing networks of ditches and storage reservoirs (Fugitt et al., 2011; Yaeger et al. 2017). Ditches recapture runoff and tailwater leaving fields, while reservoirs provide capacity to store recaptured tailwater and winter-spring precipitation long-term for growing season irrigation supply. The water-saving benefits of on-farm reservoirs have been established, potentially replacing 25-50% of groundwater irrigation (Sullivan and Delp, 2012). But, little is known about how these systems affect water quality in the surrounding landscape or about the persistence and accumulation of herbicides within them. Beyond the primary objective to reduce reliance on groundwater, tailwater recovery systems offer the potential benefit of conserving water quality in adjacent surface waters by preventing off-site movement of nutrients, sediment, and herbicides through retention and transformation processes. Further, water stored in reservoirs has been proposed as suitable supply water for managed artificial aquifer recharge using structures such as injection galleries (Reba et al. 2015; Reba et al. 2017). But these systems also pose potential risks of cross-crop impacts if residual herbicides are present at levels that could injure non-target crops when applied as irrigation water, and any artificial recharge supply must meet water quality and human health safety standards.

The objective of this study was to initiate a herbicide monitoring data record for tailwater recovery systems located in the Cache Critical Groundwater Area (Figure 1). Data from this study can be used to screen recovered tailwater for herbicide concentrations that could lead to cross-crop injuries during the growing season, characterize quality of water stored in tailwater systems in terms of suitability

Figure 1. Map showing the location of the 7 monitored tailwater recovery systems (A-G) in Poinsett and Craighead counties in Arkansas.



for artificial groundwater recharge, and estimate herbicide loads intercepted by tailwater recovery systems.

Methods

Seven tailwater systems were selected for herbicide monitoring from across the Cache Critical Groundwater Area in Craighead and Poinsett counties (Figure 1). Meteorological data were collected from a weather station on the campus of Arkansas State University. Herbicide application records were collected from producers in early April 2017 and were updated throughout the growing season. Based on this information, broad frequency of use in the region, and anticipated future use, seven herbicides were selected as target analytes: 2,4-dichlorophenoxyacetic acid (2,4-D), 2-[(2-chlorophenyl)methyl]-4,4-dimethyl-1,2-oxazolidin-3-one (clomazone), 3,6-dichloro-2-methoxybenzoic acid (dicamba), 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide (metolachlor), N-(3,4-dichlorophenyl) propanamide (propanil), and 3,7-dichloroquinoline-8-carboxylic acid (quinclorac). The herbicides 2,4-D and dicamba were selected for monitoring based on anticipated future use with the release of dicamba- and 2,4-D-tolerant soybean and cotton cultivars.

Tailwater ditch and reservoir grab samples were collected weekly (April – August 2017) in high density polyethylene bottles. Samples were stored on ice and shipped overnight for processing by the Residue Lab at the University of Arkansas. Upon receipt, samples were stored at 4°C until filtration through a 0.45 µm nylon membrane within 48 hours. Filtered samples were preserved by freezing until analysis by high performance liquid chromatography with photodiode array detection (HPLC-DAD) following concentration by solid phase extraction (SPE). During SPE, samples were concentrated from 200 mL (aqueous) to 8 mL 50:50 acetonitrile:methanol using Strata-X reverse-phase polymer columns. Columns were conditioned with 10 mL 100% methanol, equilibrated with 0.5% phosphoric acid in ultrapure water, and rinsed with a 20% methanol and 0.5% phosphoric acid solution in ultrapure water prior to elution. Eluates were spiked with 100 mg L⁻¹ metazachlor to a known concentration to correct for volumetric variability. Eluates were analyzed for concentrations of the remaining target herbicides using HPLC-DAD with a mobile phase gradient of acetonitrile in 0.1% phosphoric acid ranging from 34-64% over 20 minutes. Clomazone, metolachlor, and metazachlor absorbance were monitored at 195 nm, 2,4-D and dicamba were monitored at 200 nm, propanil was monitored at 210 nm, and quinclorac was monitored at 226 nm. Wavelengths were selected to maximize each compound's absorption intensity. Bulk water sample herbicide concentrations were calculated by multiplying the concentration measured using HPLC by the ratio of the eluate and beginning sample volumes after correcting eluate volume for differences in the measured and expected metazachlor concentration.

Results and Discussion

Clomazone, metolachlor, and quinclorac were frequently detected in tailwater ditches and reservoirs during April – August 2017 (Table 1). The herbicides 2,4-D, dicamba, and propanil were rarely detected or not detected in any of the monitored systems (data not shown). These findings were consistent with producer herbicide application reports. The majority of producers reported applying rice herbicides containing clomazone and/or quinclorac in mid-April 2017, as well as residual herbicides containing metolachlor as late as mid-June. No producers reported applying 2,4-D or dicamba. One producer reported propanil use, though the compound was not detected in that tailwater system. Propanil is known to rapidly degrade in the environment (Kanawi et al. 2016), and these findings suggest that the sampling intensity of the current scheme may not be sufficient to track propanil transport in these systems.

For clomazone, metolachlor, and quinclorac, concentrations were consistently more variable and higher, on average, in tailwater recovery ditches than in reservoirs. This trend was observed both across

all monitored Table 1. Summary systems, statistics and by site each for clomazone, paired ditch, metolachlor, and reservoir, and quinclorac with concentrations the exception measured of Ditch in 2 at Site

C, all ditches and reservoirs during April – August 2017 in the monitored tailwater recovery systems in the Cache

Critical Groundwater Area. The abbreviation “ND” indicates that the herbicide was not detectable.

Site	Structure	Compound	n	Median ($\mu\text{g L}^{-1}$)	Mean ($\mu\text{g L}^{-1}$)	Standard Deviation ($\mu\text{g L}^{-1}$)	Range ($\mu\text{g L}^{-1}$)
A	Ditch	Clomazone	17	ND	3.40	5.75	17.62
A	Reservoir	Clomazone	15	0.66	0.48	0.46	1.33
B	Ditch	Clomazone	16	0.69	1.35	3.00	12.38
B	Reservoir	Clomazone	18	ND	0.08	0.23	0.91
C	Ditch 2	Clomazone	17	ND	0.04	0.16	0.64
C	Ditch 3	Clomazone	16	ND	0.50	1.00	3.00
C	Ditch 5	Clomazone	20	ND	0.53	1.26	5.29
C	Reservoir	Clomazone	20	ND	ND	ND	ND
D	Ditch	Clomazone	15	1.16	7.77	15.96	60.39
D	Reservoir	Clomazone	15	0.25	0.36	0.40	0.98
E	Ditch	Clomazone	16	0.39	1.36	2.58	10.30
E	Reservoir	Clomazone	18	ND	0.03	0.11	0.33
F	Ditch	Clomazone	14	1.57	2.30	3.32	12.88
F	Reservoir	Clomazone	16	1.35	1.35	1.20	3.49
G	Ditch	Clomazone	15	1.52	2.67	3.82	12.34
G	Reservoir	Clomazone	14	1.13	1.34	1.73	7.11
A	Ditch	Metolachlor	17	0.83	1.67	2.36	9.75
A	Reservoir	Metolachlor	15	ND	0.58	1.31	4.30
B	Ditch	Metolachlor	16	ND	0.23	0.65	2.55
B	Reservoir	Metolachlor	18	ND	0.02	0.07	0.32
C	Ditch 2	Metolachlor	17	ND	2.96	5.65	21.90
C	Ditch 3	Metolachlor	16	0.51	2.34	4.39	17.45
C	Ditch 5	Metolachlor	20	ND	1.54	3.85	15.01
C	Reservoir	Metolachlor	20	ND	0.57	0.85	2.10
D	Ditch	Metolachlor	15	1.35	4.61	6.01	19.51
D	Reservoir	Metolachlor	15	0.84	2.50	3.73	10.23
E	Ditch	Metolachlor	16	0.57	2.57	5.40	20.80
E	Reservoir	Metolachlor	18	ND	1.72	5.15	22.06
F	Ditch	Metolachlor	14	ND	0.69	1.25	4.59
F	Reservoir	Metolachlor	16	ND	1.40	2.72	10.17
G	Ditch	Metolachlor	15	1.18	2.35	5.00	20.08
G	Reservoir	Metolachlor	14	0.00	1.06	1.65	3.86
A	Ditch	Quinclorac	17	3.93	5.33	8.81	37.36
A	Reservoir	Quinclorac	15	0.38	0.49	0.58	1.38
B	Ditch	Quinclorac	16	0.65	3.10	6.69	27.08
B	Reservoir	Quinclorac	18	0.43	0.53	0.88	3.91
C	Ditch 2	Quinclorac	17	0.75	0.70	0.52	2.00
C	Ditch 3	Quinclorac	16	1.44	2.29	2.99	12.72
C	Ditch 5	Quinclorac	20	1.22	2.89	4.95	21.94
C	Reservoir	Quinclorac	20	0.94	0.94	0.13	0.61
D	Ditch	Quinclorac	15	0.98	3.13	5.86	18.73
D	Reservoir	Quinclorac	15	0.58	0.83	0.95	2.33
E	Ditch	Quinclorac	16	5.21	10.54	15.87	63.07
E	Reservoir	Quinclorac	19	0.84	1.70	1.63	6.26
F	Ditch	Quinclorac	14	2.94	7.54	13.42	43.35
F	Reservoir	Quinclorac	16	0.59	0.76	0.85	2.06
G	Ditch	Quinclorac	15	7.14	10.19	15.50	59.67
G	Reservoir	Quinclorac	14	1.43	1.43	0.87	2.37

all monitored systems, and for each paired ditch and reservoir, with the exception of Ditch 2 at Site C, where mean quinclorac concentration was low and comparable with the reservoir, and site F, where the average metolachlor concentration was 2 times greater in the reservoir. At Site C, low concentrations of quinclorac and clomazone in Ditch 2 suggest few or no rice production acres in the drainage. However, the reservoir at Site C also aggregates tailwater from Ditches 3 and 5, where quinclorac was detected at high concentrations. At Site F, the ditch has substantial forested riparian land cover that may accelerate or change retention and transformation processes for metolachlor when compared to other ditches. Further, in several of the monitored reservoirs, metolachlor concentrations were more variable than for quinclorac and clomazone, with maximum concentrations that were comparable with ditches. This finding suggests that the factors controlling transport and transformation may be affected differently in tailwater recovery systems for metolachlor than for quinclorac and clomazone.

The finding that residual herbicide concentrations were higher in tailwater ditches than in reservoirs is congruent with the concept that residues are diluted along the flow path by mixing with increasingly large volumes of water with lower residual concentrations, as well as break down over time. While herbicide concentrations in tailwater systems have not been extensively monitored, Mattice et al. (2010) found a similar pattern for clomazone and quinclorac residues within 4 river networks in the region, including the Cache. In that study, concentrations decreased moving downstream, with increasing flow in the rivers. However, the finding that ditches and reservoirs have different magnitudes of herbicide concentrations is in contrast with previous findings for nutrient concentrations and other water quality parameters (Moore et al. 2015). In a 13-month study of another tailwater recovery system in the region, no difference in water quality was observed between ditches and reservoirs.

Clomazone, metolachlor, and quinclorac all exhibited a spring flush trend in the monitored tailwater recovery systems, with concentrations peaking in April – June across all sites (Figure 2). This period coincides with heavy precipitation in the region (Figure 3), immediately following or overlapping the bulk of annual herbicide application. Peak clomazone concentrations were observed in April, with few remaining detections by August. Quinclorac and metolachlor concentrations peaked in June, and these compounds were more persistent, with frequent low-level detections continuing through August.

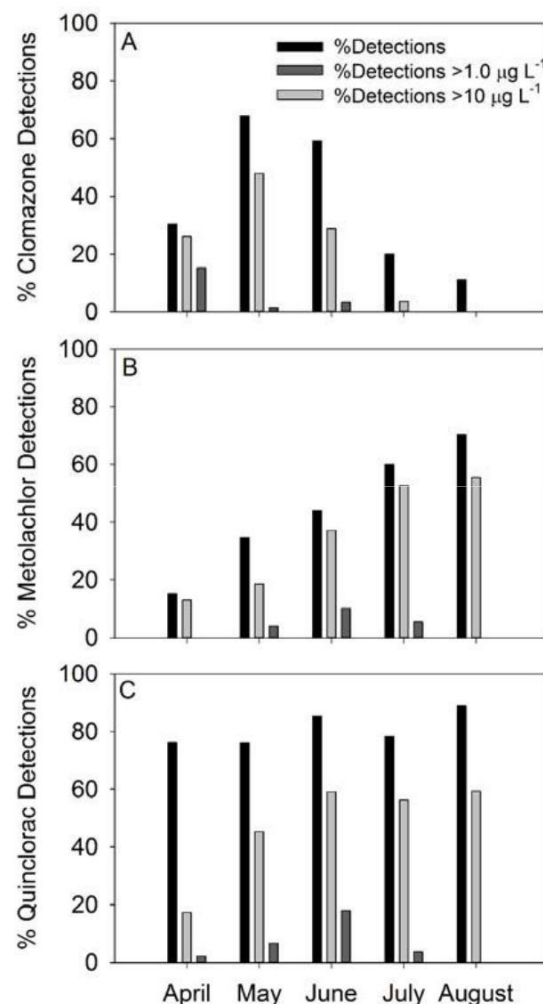


Figure 2. Frequency of all detections, detections > 1.0 µg L⁻¹, and detections > 10 µg L⁻¹, expressed as a percentage of the total number of samples for the month, during the period April – August 2017 for A) clomazone, B) metolachlor, and C) quinclorac.

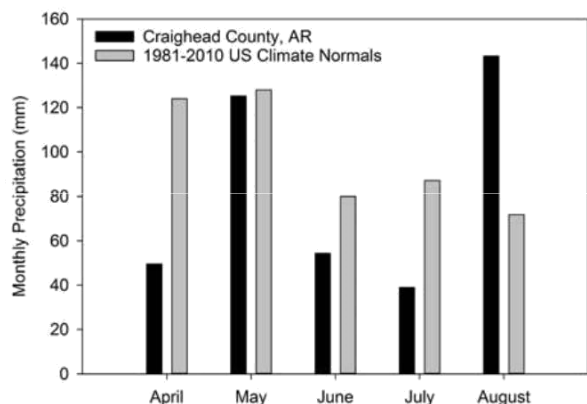


Figure 3. Monthly precipitation measured in Craighead County, Arkansas during April – August 2017 and U.S. precipitation normals for the region averaged over 30 years between 1981-2010 (NOAA, 2018).

Conclusions

Herbicides applied to fields adjacent to tailwater recovery systems were readily detectable in ditches and reservoirs during the 2017 growing season. The highest concentrations were detected during the “spring flush” when precipitation events immediately follow or overlap herbicide application. Concentrations were consistently higher in ditches than in reservoirs, up to an order of magnitude for single events. These findings support the following recommendations to minimize risk of cross-crop contamination when using recovered tailwater for irrigation: 1) source irrigation water only out of reservoirs and 2) always cycle recovered tailwater through the reservoir for treatment of residual herbicides. Before it can be determined if any of the concentrations

detected represent high-risk events for cross-crop contaminations, more information is needed about how common crops like soybean, rice, or cotton respond to off-target exposure to residual herbicides in irrigation water across a range of concentrations. Further, study findings support the current non-growing season focus of proposals to use on-farm reservoirs as supply water for artificial groundwater recharge, as the periodically elevated concentrations of herbicide residues during the growing season may be deemed hazardous by regulatory bodies.

Continued work on the project will assess the non-growing season residual herbicide concentrations in the monitored on-farm storage reservoirs. This study initiated a herbicide monitoring record that provides data needed to assess costs and benefits of tailwater recovery systems, a best management practice with the potential to preserve Arkansas’ groundwater resources into the future. The United States Geological Survey and others can use this dataset to improve models of herbicide fate and transport to include the mitigation potential of tailwater recovery systems to reduce herbicide loads from agricultural lands to the Mississippi River Basin.

References

- Fugitt, D. T., J. L. Battreal, J. Johnston, C. Kelley, M. Ritchey, P. Dotson, J. Harvey, J. Broach, and E. Swaim. 2011. Arkansas groundwater protection and management report for 2010 *Rep.*, 92 pp, Arkansas Natural Resources Commission, Little Rock, AR.
- Mattice, J.D., Skulman, B.W., Norman, R.J., and E.E. Gbur, Jr. 2010. Analysis of river water for rice pesticides in eastern Arkansas from 2002 to 2008. *J. Soil Water Conserv.* 65:130-140.
- Moore, M.T., J.R. Pierce, and J.L. Farris. 2015. Water-quality analysis of an intensively used on-farm storage reservoir in the northeast Arkansas delta. *Arch. Environ. Contam. Toxicol.* 69:89-94.
- NOAA. 2018. 1981-2010 U.S. Climate Normals. National Oceanic and Atmospheric Administration, Washington, D.C., <https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data>. Accessed 2018, April 26.
- Norsworthy, J.K., J. Bond and R.C. Scott. 2013. Weed management practices and needs in Arkansas and Mississippi rice. *Weed Technol.* 27:623-630.

- Kanawi, E., Van Scoy, A.R., Budd, R., and R.S. Rjeerdema. 2016. Environmental fate and ecotoxicology of propanil: a review. *Toxicol. Environ. Chem.* 98:689-704.
- Reba, M.L., K. Kahill, J. Czarnecki, J. Rigby and J. Farris. 2015. Early findings from artificial recharge efforts of the Mississippi river valley alluvial aquifer. p. 1. *In* Early findings from artificial recharge efforts of the Mississippi river valley alluvial aquifer. 2015 ASABE annual international meeting, 2015. American Society of Agricultural and Biological Engineers.
- Reba, M.L., Massey, J.H., Adviento-Borbe, M.A., Leslie, D., Yaeger, M.A., Anders, M. and J. Farris. 2017. Aquifer depletion in the Lower Mississippi River Basin: Challenges and Solutions. *Journal of Contemporary Water Research and Education.* 162:128-139.
- Riar, D.S., J.K. Norsworthy, L.E. Steckel, D.O. Stephenson and J.A. Bond. 2013. Consultant perspectives on weed management needs in midsouthern United States cotton: A follow-up survey. *Weed Technol.* 27:778-787.
- Schrader, T.P. 2015. Water Levels and Water Quality in the Mississippi River Valley Alluvial Aquifer in Eastern Arkansas, 2012. U.S. Geological Survey Scientific Investigations Report 2015-5059, 63 p., United States Geological Survey, Washington, D.C.
- Sullivan, M.E. and W.M. Delp. 2012. Water Conservation Planning: How a Systems Approach to Irrigation Promotes Sustainable Water Use. *In* NABC Report 24. Water Sustainability in Agriculture, pp. 145- 159.
- USEPA. 2009. National Water Quality Inventory: Report to Congress 2004 Reporting Cycle. EPA 841-R-08-001, 43 p., Office of Water Regulations and Standards, United States Environmental Protection Agency, Washington, DC.
- Yaeger, M.A., Reba M.L., Massey J.H., and M.A.A. Adviento-Borbe. 2017. On-farm irrigation reservoirs in two Arkansas critical groundwater regions: A comparative inventory. *Applied Engineering in Agriculture.* 33: 869-878.

Project Title: Regionalizing agricultural field evapotranspiration observations
Project Number: 2017AR400B
Start Date: 3/1/2017
End Date: 2/28/2018
Funding Source: 104B
Congressional District: 3
Research Category: Climate and Hydrologic Processes
Focus Category: Irrigation, Conservation, Agriculture
Descriptors: None
Principal Investigator: Benjamin RK Runkle

Publications:

Reba ML, BN Fong, TG Teague, BRK Runkle, K Suvočarev, 2018, Eddy Covariance Measurements of Carbon Dioxide and Water Fluxes In Mid-South US Cotton, In Summaries of Arkansas Cotton Research 2017, Arkansas Agricultural Experiment Station Research Series, AR.

Liang, L, BRK Runkle, BB Sapkota, ML Reba, 2018 (in preparation), Mapping Rice Fields in the Mississippi Alluvial Valley Using Google Earth Engine and Multi-Date Training Sample Normalization, Remote Sensing of the Environment.

Fong BN, ML Reba, TG Teague, BRK Runkle, K Suvočarev, 2018 (in preparation), Eddy covariance measurements of carbon dioxide and water fluxes in mid-south US Cotton, Agriculture, Ecosystems & Environment.

Runkle BRK, K Suvočarev, ML Reba, 2017, Rice irrigation strategies: Alternate wetting and drying and methane reductions, In Mississippi Water Resources Conference, Jackson, MS.

Suvočarev K, ML Reba, BRK Runkle, 2017, Surface Renewal Satellite Towers for Gap-Filling Eddy Covariance Sensible Heat Flux, In 2017 FLUXNET workshop, Berkeley, CA.

Suvočarev K & F Castellvi, 2017, The surface renewal method and its application for GHG measurements over irrigated crops, Invited presentation at the GHG Flux Workshop: From Photosystems to Ecosystems, Potsdam, DE.

Suvočarev K, F. Castellví, J. Cavero, M.Reba, Runkle BRK, 2017, The surface renewal method independent from calibration and wind measurements: Possibilities for application over irrigated crops for sensible and latent heat flux estimation, In the GHG Flux Workshop: From Photosystems to Ecosystems, Potsdam, DE.

Suvočarev K, M Fischer, JH Massey, ML Reba, BRK Runkle, 2017, The surface renewal method for better spatial resolution of evapotranspiration measurements, In the American Geophysical Union Fall Assembly, New Orleans, LA.

Runkle BRK, K Suvočarev, ML Reba, 2017, Geoscience research helps rice farmers mitigate climate change and world hunger, In the American Geophysical Union Fall Assembly, New Orleans, LA.

Runkle BRK, K Suvočarev, ML Reba, 2017, Testing climate-smart irrigation strategies to reduce methane emissions from rice fields, In the American Geophysical Union Fall Assembly, New Orleans, LA.

Fong B., A. Adviento-Borbe, M.L. Reba, B.R.K. Runkle, K. Suvočarev, 2017, Carbon dioxide emissions and energy balance closure before, during, and after biomass burning in Mid-South rice fields, In the American Geophysical Union Fall Assembly, New Orleans, LA.

Fong B., M.L. Reba, T. Teague, BRK Runkle, 2018, Carbon dioxide and Eddy Covariance measurements in mid-South cotton, In Cotton Agronomy, Physiology & Soil Conference of the 2018 Beltwide Cotton Conferences, San Antonio, TX.

Runkle BRK, ML Reba, K Suvocarev, C Reavis, 2018, Evapotranspiration and CO2 dynamics in AWD irrigated rice production, In the Rice Technical Working Group, Long Beach, CA.

Reavis, C, 2017, Evaluating Methods for Quantifying Evapotranspiration in Arkansas Rice, MS Thesis, Biological and Agricultural Engineering, University of Arkansas, Fayetteville, AR, 48 pp.

Kosana Suvočarev & Mark Isbell, presentation to Citizen's Climate Lobby regional meeting Ft. Smith, AR, February 17, 2018, Greenhouse gas emissions and sustainable rice farming. **Advance press for this event also featured an interview with Kosana Suvočarev on local radio stations.

Regionalizing agricultural field evapotranspiration observations

Benjamin R.K. Runkle¹

¹Assistant Professor, Department of Biological & Agricultural Engineering, University of Arkansas, Fayetteville, Arkansas

Core Ideas

Growing season evapotranspiration estimates of between 616-785 mm have been made for production-scale rice fields in Lonoke County, Arkansas, for the years 2016-17.

Growing season evapotranspiration estimates of 555-615 mm have been made for production-scale cotton production fields in Mississippi County, Arkansas.

The surface renewal method, a potentially cheaper and more adaptable strategy of providing direct observations of the evapotranspiration flux, is within 10-20% of more standardized eddy covariance estimates.

The surface renewal method performs better after the canopy cover develops, guiding future research directions.

Executive Summary

This project aimed to quantify evapotranspiration (ET) estimates in different agricultural production systems in Arkansas as part of a broader strategy to understand and improve upon the over-consumption of groundwater in the state. The project team directly observes ET in a cotton and several rice fields over different growing seasons. These measurements are taken with the eddy covariance method, compared to the Penman-Monteith model, and are also taken with a more experimental method called “surface renewal”. Growing season ET is determined to be 567-636 mm in the rice fields and 555-615 mm in the cotton field. The Penman-Monteith model over-estimated ET, with estimates ranging from 752-835 mm. The surface renewal method was within 10-20% of eddy covariance estimates, encouraging its broader adaptation as a more cost-effective ET observation method. Quantifying ET will be helpful to quantify the dynamics of the crop water use. By knowing the water use dynamics we can follow up with questions about how to save water and associated pumping costs. The project findings are contextualized through inclusion in a growing, multi-institution network named Delta-Flux, which will be used to develop climate- smart and water-saving agricultural production.

Introduction

Rice and cotton agriculture together use approximately 50% of Arkansas’s irrigation water; unfortunately Arkansas’s groundwater supplies are being unsustainably applied to irrigate fields (Reba et al., 2013; ANRC, 2014). To understand this water use better and to create targeted water management solutions that preserve both food and water security, estimates of evapotranspiration (ET) are necessary for different Arkansas row crops. ET is the dominant part of the growing season water balance and is directly tied to plant primary production and growth. ET is therefore also an indicator of the landscape’s cycling of water, carbon, and energy and a key link between field function and performance. Over- application of irrigation water contributes to groundwater depletion, changing surface water base flow regimes, and has real energy costs due to its pumping requirement. ET is difficult to directly observe, and

to determine constrained state-wide estimates of water use. Thus, we need to improve and reduce costs in ET measurement systems in order to have better measurement resolution across different crops and across the whole aquifer-withdrawing region. Using additional and/or alternative observations of ET allows researchers to make predictions of irrigation scheduling that have a scientific basis in how they represent expected crop dynamics.

This work builds on USGS 104B grants in both FY2015 and FY2016 to study the hydrological implications of increased water use efficiency – with a focus in rice production. These projects have generated the intriguing finding (from the FY2015 award) that total evapotranspiration (ET) from an AWD field is similar or even slightly greater than a reference, continuously flooded field. This response may be due to the strong ability of rice roots to pull water from the soil matrix and from the relatively short length of the dry down period (approximately 11 days). The FY2016 award demonstrated the potential of the FAO-56 version of the Penman-Monteith equation for ET to adequately and accurately simulate observed ET. This equation seems to significantly outperform the relatively simpler Hargreaves model currently used in Arkansas’s irrigation scheduling tools. We recognized a need to work beyond rice, as it represents less than half the irrigation water used in Arkansas and any solution to water withdrawal issues will come from a concerted, multi-crop effort.

In this work, we therefore measure ET in production-scale rice and cotton fields in Arkansas. We observe and model ET rates, partition ET into its two constituent parts (evaporation and transpiration), and compare ET measured in different years. We also test a novel ET measurement strategy as a step toward implementing a potentially cheaper and more scalable method to observe ET under many different land management regimes. This new strategy is a micrometeorological method called “surface renewal” (Paw U et al., 1995) and is based on detecting and quantifying ramp-like structures seen in the turbulent transport of H₂O or other scalars into the atmosphere. It is compared to the more common and expensive, eddy covariance method (Baldocchi, 2003) whose observations we have presented in the previous years’ reports.

We focus on fields already under potentially water-saving irrigation practices. In cotton, pivot irrigation has been shown to halve irrigation water use while increasing yield, relative to more traditional furrow irrigation practices (Reba et al., 2014). In rice, the Alternate Wetting and Drying (AWD) style of irrigation (Lampayan et al., 2015), especially when applied on zero-grade fields, can save 40% of water applications (Hardke, 2015; Henry et al., 2016). AWD can also serve as a carbon-offset credit option (ACR, 2014), and its implementation expenses may partially be paid for through the Natural Resources Conservation Service’s Environmental Quality Incentives Program (EQIP).

Methods

We measured water vapor fluxes as observations of evapotranspiration by the eddy covariance (EC) method (Baldocchi, 2003) of deriving the turbulent transport from landscape to atmosphere. These flux terms are then modeled by the Penman-Monteith equation (Monteith, 1981) as implemented in FAO document 56 (Allen et al., 1998). In brief, the measurement procedure uses a sonic anemometer to measure the wind vector components and an infrared gas analyzer (IRGA) to measure CO₂ and H₂O concentrations. We then derive an observational data-stream and gap-filling it using an artificial neural network, as documented in our previous report (Runkle, 2017). As before, the dual crop coefficient method within the FAO56 procedure is used to calculate separate crop coefficients used to convert reference evapotranspiration (ET_0) into transpiration and evaporation: $E = K_b ET_0 + K_e ET_0$. The part modified by K_b is the estimated transpiration and the part modified by K_e is the estimated evaporation. These coefficients are adjusted for the higher relative humidity conditions present in the US Mid-South following the FAO 56 protocol. The reference evapotranspiration rate was calculated using methods also outlined in FAO 56 as part of the Penman-Monteith method.

Surface renewal (SR) estimates of ET were generated using the IRGA's time series of H₂O concentration to detect recurrent ramp structures. The ramp characteristics were detected by structure function analysis (van Atta, 1977). These characteristics are then processed with horizontal wind speed in a calibration-free approach (Castellví, 2004) that iterates a solution by deriving friction velocity, H₂O flux, and atmospheric stability parameters. These ET estimates are gap-filled using the same neural network strategy applied to the EC observations.

Site description: This research is performed at two privately farmed, adjacent rice fields (34° 35' 8.58" N, 91° 44' 51.07" W) outside of Humnoke, Arkansas, and a cotton field near Manila, Arkansas (35° 53' 14" N, 90° 8' 15" W).

The rice fields are zero-graded and their size is approximately 350 m wide from north to south and 750 m long from east to west (i.e., 26 ha each). One field was managed with continuous flooding (CF) during the rice growing season and the other with AWD management practice, facilitating a direct comparison of the two types of systems with minimal spatial separation. The sites are not tilled and are flooded for two months in winter for duck habitat and hunting. The dominant soil mapping unit in this area is a poorly-drained Perry silty clay. In 2016 the fields were drill-seed planted 23 April and harvested 13 September. In 2017 the fields were drill-seed planted on 9-10 April and harvested 26-27 August. The fields are surface irrigated through perimeter ditches; in 2016 an Alternate Wetting and Drying irrigation strategy was used on both fields; in 2017 a continuous flood was established in both fields on 17 May and held until 4 August.

The pivot-irrigated, 63 ha cotton field had a cover crop eliminated by a mixture of Glyphosphate, Dicamba and Firstshot approximately three weeks before planting. The DeltaPine 1518B2XF cotton variety was planted at a rate of 118,610 seeds ha⁻¹ (48,000 seeds ac⁻¹). In 2016, cotton was planted on 8 May and harvested 10 October while in 2017, cotton was planted on 19 May and harvested 30 October.

Results and Discussion

The observed ET by eddy covariance (EC) in rice was relatively consistent across the measurement fields and growing seasons (*Figure 2; Figure 1*). In the northern field at Humnoke, ET ranged from 567-608 mm and in the southern field ET at Humnoke, ranged from 594-636 mm. In all cases, the Penman-Montieth FAO-56 model over-estimated ET, with estimates ranging from 752-835 mm. This overestimation was consistent across the growing season. This over-estimation may result from higher crop coefficients – derived from their global synthesis – than necessary in Arkansas under water-efficient or higher humidity conditions. Following the FAO-56 method of partitioning growing season ET into its constituent parts, evaporation and transpiration, transpiration represented 23-35% of the seasonal total ET flux. The partition between these terms follows the seasonal growth cycle, with more transpiration during later vegetative and early reproductive stages.

The cotton field evapotranspiration rates were similar to the rice fields, with measured values of 555-615 mm (*Figure 4*). ET increased after emergence likely due to higher transpiration activity, greater water applications or rainfall, and higher air temperatures. ET later decreased after physiological cutout during boll maturation, likely due to lower plant water needs. Likely due to the higher relative humidity and greater cloud cover (reducing incoming solar radiation), these ET estimates are lower than in other regions. For example, a two-year study in Texas using weighing lysimeters found ET of 739-775 mm in full irrigation conditions; compared to 578-622 mm under a deficit irrigation strategy that also reduced field yields by 10-50% (Howell et al., 2004).

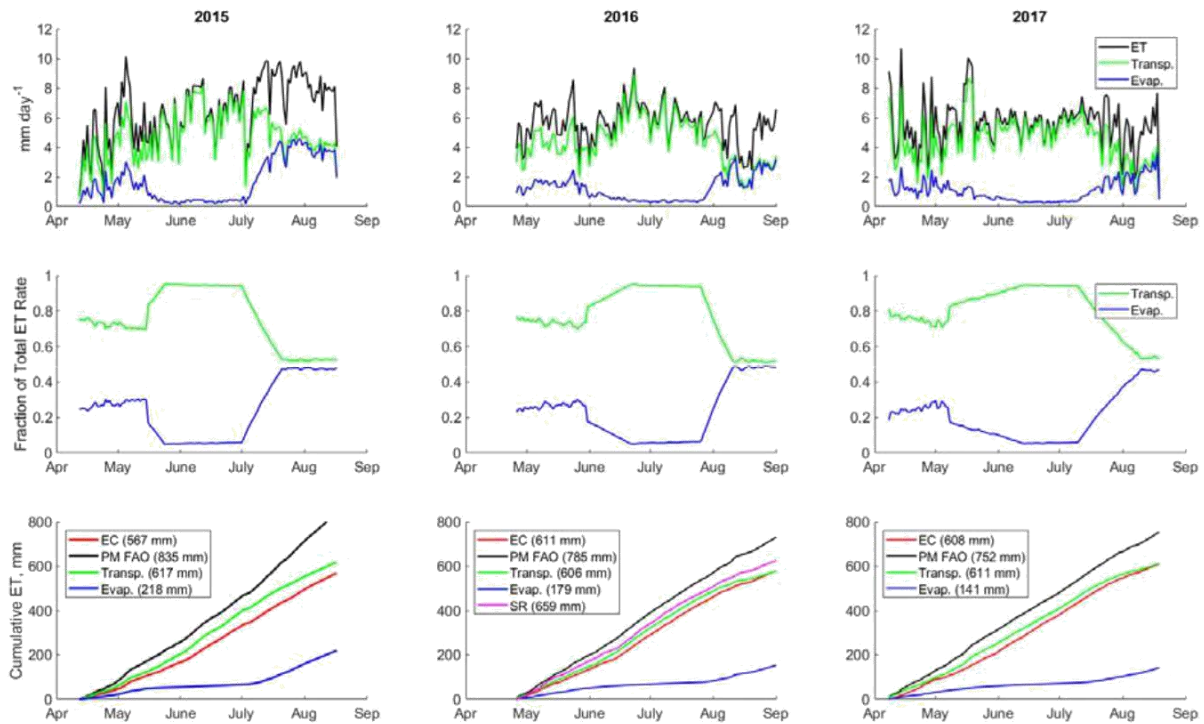


Figure 2: ET measured and modeled at the northern rice field in Humnoko (2015-17). The top six figures use the Penman Monteith model (PM FAO) to estimate ET and its partition into evaporation and transpiration components. Note the surface renewal observations are presented in for 2016 in the lower panels.

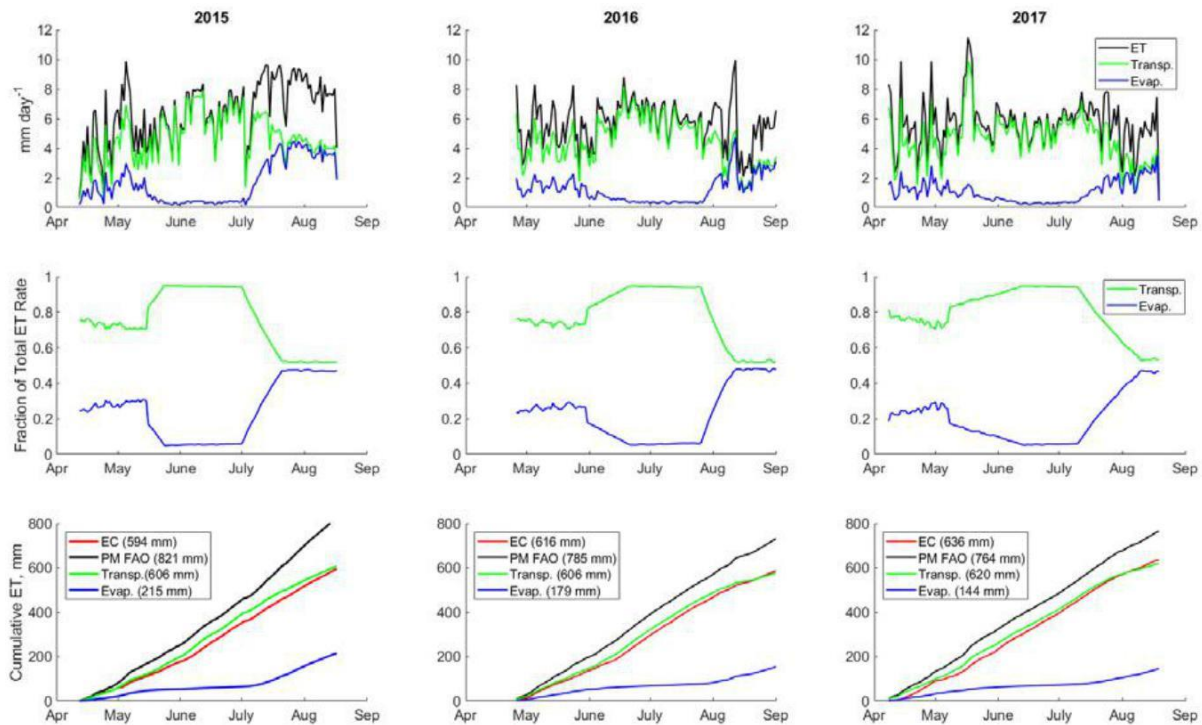


Figure 1: ET measured and modeled at the southern field in Humnoko (2015-17), and otherwise similar to Figure 1, though for this field we do not present the surface renewal data in 2016.

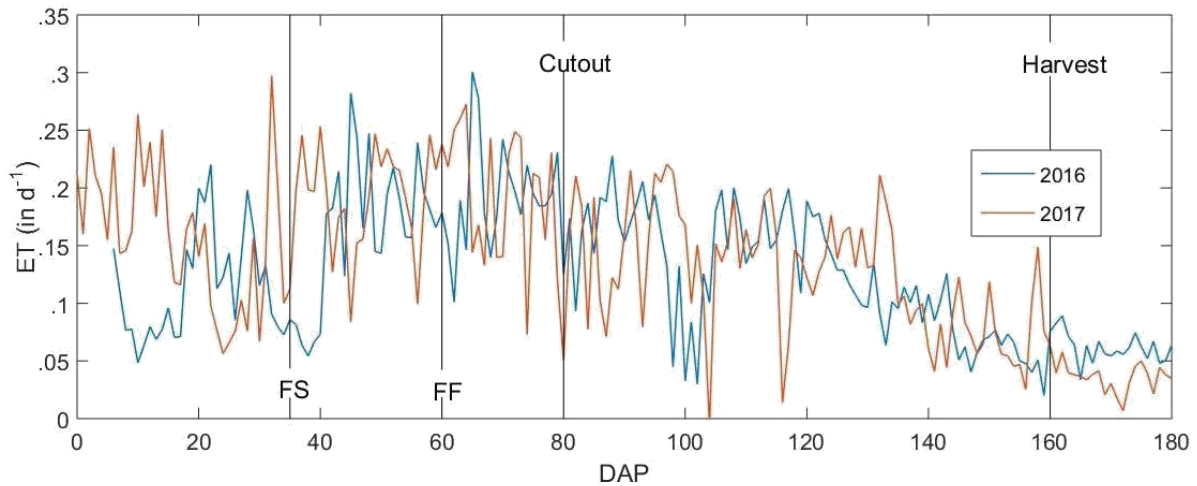


Figure 4: Daily crop evapotranspiration (ET) during 2016 and 2017 cotton growing seasons presented against days after planting (DAP). FS is first week of squaring, FF is first week of flowering, and cutout is physiological cutout or nodes above white flower equal to 5.

The surface renewal estimates are presented for the northern rice field for 2016 as these were the most complete time series (*Figure 3*). This method performed well – when gap-filled, its cumulative estimate of ET was very similar to the EC method (660 mm vs. 616 mm). On a one-to-one comparison, the methods agree well. Most of the over-estimation of SR relative to EC is largest earlier in the season, prior to full canopy development. Reasons may include the larger effective measurement height (with less surface roughness and greater effective eddies) and changes in canopy interference with turbulent structures. While corrected for density fluctuations, it may be that the concentration signals under high evaporative fluxes are challenging to interpret with the structure functions that have been more rigorously tested under temperature, rather than water vapor, time series.

Conclusions

The project finds good agreement between methods for estimating ET and more carefully partitions ET between transpiration and evaporation. Total ET shows less year-to-year variability. Similar to our previous work, we find that ET is largely controlled by transpiration during the peak growing season. We see little impact from irrigation style on the magnitude of ET fluxes, indicating minimal potential reduction to crop yield (due to the link between the carbon and water cycles through stomatal transfer of both CO₂ and H₂O). Work is ongoing to enhance the ability of the Penman-Monteith method to adequately

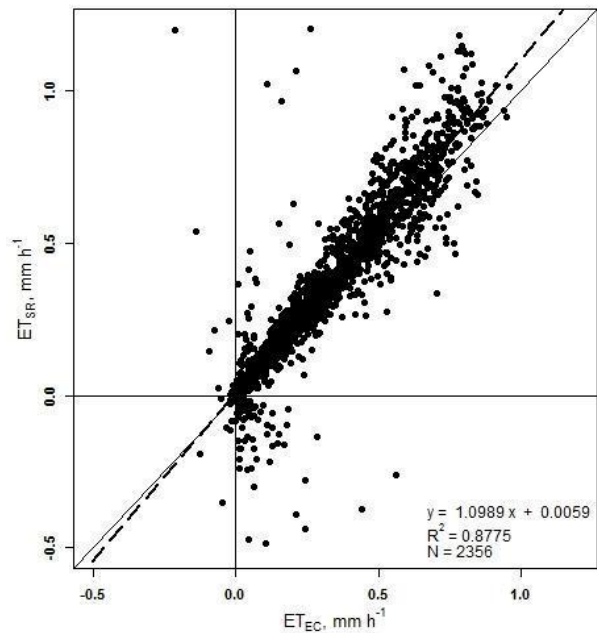


Figure 3: EC measured by surface renewal (SR) as compared to eddy covariance (EC) methods, in the northern rice field in Humnoke (2016).

represent ET in these land cover types. We will work to determine crop coefficients for rice derived from local measurements rather than the global values found in the FAO56 handbook. The ET measurements from the Arkansas cotton fields support this approach, as these measurements also indicated lower ET than in Texas, in part due to the greater cloudiness and higher humidity of the mid-south vs. other cotton-growing regions.

Local, regional, and national benefits:

The site-based data is helpful to guide farmer decisions on water application to their fields. It is also contextualized through inclusion in the growing network named Delta-Flux (Runkle et al., 2017) for climate-smart agriculture. This multi-institution network, is composed of a suite of eddy covariance measurement towers on multiple crop and land cover types. The most representative crops and landscapes of the Lower Mississippi Alluvial Plain will be monitored for their water use, potentials for the decrease in water applications to the fields and carbon sequestration possibilities. The scientists involved represent the USGS, USDA, and higher education institutions. The group is beginning to work with USGS partners on the MERAS groundwater model to contribute our ET datasets to their regional modeling initiatives. Additionally the locally-calibrated mechanistic relationships we are working to develop will offer predictive strategies upon which to strengthen irrigation planning tools. Being part of the Ameriflux and Fluxnet network, our measurements contribute to the global database for landscape types that have historically not been represented for their ET rates and CO₂ fluxes.

References

- ACR, 2014. Voluntary Emission Reductions in Rice Management Systems - Midsouth Module, version 1.0, American Carbon Registry, Winrock International, Little Rock, Arkansas.
- Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. FAO Irrigation and Drainage Paper No. 56 Crop evapotranspiration (guidelines for computing crop water requirements). FAO Rome 1–300.
- ANRC, 2014. Arkansas Water Plan Update 2014, Arkansas Natural Resources Commission (<http://www.arwaterplan.arkansas.gov/plan/ArkansasWaterPlan/2014AWPWaterPlan/AWPFinalExecutiveSumm.pdf>).
- Baldocchi, D.D., 2003. Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: past, present and future. *Glob. Change Biol.* 9, 479–492.
- Castellví, F., 2004. Combining surface renewal analysis and similarity theory: A new approach for estimating sensible heat flux. *Water Resour. Res.* 40, W05201.
- Hardke, J.T., 2015. Trends in Arkansas Rice Production, 2014, in: Norman, R.J., Moldenhauer, K.A.K. (Eds.), B.R. Wells Arkansas Rice Research Studies 2014, Research Series. Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville., pp. 11–22.
- Henry, C.G., Hirsh, S.L., Anders, M.M., Vories, E.D., Reba, M.L., Watkins, K.B., Hardke, J.T., 2016. Annual Irrigation Water Use for Arkansas Rice Production. *J. Irrig. Drain. Eng.* 142, 05016006.
- Howell, T.A., Evett, S.R., Tolk, J.A., Schneider, A.D., 2004. Evapotranspiration of full-, deficit-irrigated, and dryland cotton on the Northern Texas High Plains. *J. Irrig. Drain. Eng.* 130, 277–285.
- Lampayan, R.M., Rejesus, R.M., Singleton, G.R., Bouman, B.A.M., 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Res.* 170, 95–108. <https://doi.org/10.1016/j.fcr.2014.10.013>
- Linquist, B.A., Anders, M., Adviento-Borbe, M.A., Chaney, R. I., Nalley, L. I., da Rosa, E.F.F., van Kessel, C., 2015. Reducing greenhouse gas emissions, water use and grain arsenic levels in rice systems. *Glob. Change Biol.* 21, 407–417. <https://doi.org/10.1111/gcb.12701>
- Monteith, J.L., 1981. Evaporation and surface temperature. *Q. J. R. Meteorol. Soc.* 107, 1–27.

- Paw U, K.T., Qiu, J., Su, H.-B., Watanabe, T., Brunet, Y., 1995. Surface renewal analysis: a new method to obtain scalar fluxes. *Agric. For. Meteorol.* 74, 119–137.
- Reba, M., Teague, T., Vories, E., 2014. A retrospective review of cotton irrigation on a production farm in the Mid-South. *J. Cotton Sci.* 18, 137–144.
- Reba, M.L., Daniels, M., Chen, Y., Sharpley, A., Bouldin, J., Teague, T.G., Daniel, P., Henry, C.G., 2013. A statewide network for monitoring agricultural water quality and water quantity in Arkansas. *J. Soil Water Conserv.* 68, 45A-49A. <https://doi.org/10.2489/jswc.68.2.45A>
- Rogers, C.W., Brye, K.R., Norman, R.J., Gbur, E.E., Mattice, J.D., Parkin, T.B., Roberts, T.L., 2013. Methane Emissions from Drill-Seeded, Delayed-Flood Rice Production on a Silt-Loam Soil in Arkansas. *J. Environ. Qual.* 42, 1059–1069. <https://doi.org/10.2134/jeq2012.0502>
- Runkle, B., 2017. Partitioning rice field evapotranspiration into evaporation and transpiration components; Arkansas Water Resources Center Annual Technical Report FY2016, <https://arkansas-water-center.uark.edu/publications/annual-reports-104b.php>.
- Runkle, B.R.K., Rigby, J.R., Reba, M.L., Anapalli, S.S., Bhattacharjee, J., Krauss, K.W., Liang, L., Locke, M.A., Novick, K.A., Sui, R., Suvočarev, K., White, P.M., 2017. Delta-Flux: An Eddy Covariance Network for a Climate-Smart Lower Mississippi Basin. *Agric. Environ. Lett.* 2.
- Sudhir-Yadav, Gill, G., Humphreys, E., Kukal, S.S., Walia, U.S., 2011. Effect of water management on dry seeded and puddled transplanted rice. Part 1: Crop performance. *Field Crops Res.* 120, 112–122.
- van Atta, C., 1977. Effect of coherent structures on structure functions of temperature in the atmospheric boundary layer. *Arch. Mech. Stosow.* 29, 161–171.

Information Transfer Program Introduction

Information transfer activities are an integral component of the Arkansas Water Resources Center's (AWRC) mission. AWRC provides water resources information to the user community, including researchers, students, water resources planners and managers, environmental consultants, environmental advocacy entities, lawyers and the general public. The AWRC accomplishes this mission primarily through the following activities:

1. Annual water research conference
2. Monthly electronic newsletters
3. Websites for the Center and to publish and archive newsletter stories
4. Reports and fact sheets
5. Social media
6. Other news outlets
7. Peer-reviewed publications, presentations at scientific conferences, and student degrees

Project Title: Arkansas Water Resources Center - Information Transfer
Project Number: 2017AR401B
Start Date: 3/1/2017
End Date: 2/28/2018
Funding Source: 104B
Congressional District: 3
Research Category: Not Applicable
Focus Category: Education, Water Quality, Management and Planning
Descriptors: None
Principal Investigator: Brian E. Haggard, Erin Scott

Publications:

Scott, E.E. and B.E. Haggard, 2017, Water News, March Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, April Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, May Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, June Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, July Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, August Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, September Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, November Newsletter, Arkansas Water Resources Center.

Scott, E.E. and B.E. Haggard, 2017, Water News, February Newsletter, Arkansas Water Resources Center.

Austin, B.J., E. Scott, others, and B.E. Haggard. 2017. Unconventional natural gas development did not result in detectable changes in water chemistry (within the South Fork Little Red River). *Environmental Monitoring and Assessment* 189:209-222.

Brennon, R., A. Sharpley, others, and B.E. Haggard. 2017. Linking soil erosion to instream dissolved P cycling and periphyton growth. *Journal of the American Water Resources Association* 53(4):809-821.

Grantz, E., B.E. Haggard, and J.T. Scott. 2017. Censored data can inflate or obscure trends in analyses used for water quality target development. *Environmental Monitoring and Assessment* [Submitted]

Harmel, R., K. King, others, and B.E. Haggard. 2018. Measuring edge-of-field water quality: Where we have been and the path forward. *Journal of Soil and Water Conservation*. 73(1): 86-96.

Heeren, D.M., G.A. Fox, others, and B.E. Haggard. 2017. Impact of macropores and gravel outcrops on phosphorus leaching at the plot scale in silt loam soils. *Transactions ASABE* 60(3):823-835.

Lasater, A.L., and B.E. Haggard. 2017. Sediment phosphorus flux at Lake Tenkiller, Oklahoma: How important are internal sources? *Agricultural and Environmental Letters* 2:170017.

Longing, S.D., L.A. Mack, and B.E. Haggard. 2017. Bioassessment of four karst springs at Hobbs State Park – conservation area with a focus on diving beetle (Dytiscidae: Hydroporinae) species of concern. *Journal of Arkansas Academy of Science* 71:1-8.

McCarty, J.A., M.D. Matlock, J.T. Scott, and B.E. Haggard. 2017. Four risk indicators for prioritizing smaller watersheds to improve water quality. *Transactions ASABE* [Submitted]

Scott, E., M. Leh and B.E. Haggard. 2017. Spatiotemporal variation in exceedances of bacterial water quality standards and the relationship with pasture land cover. *Journal of Water and Health* 15.6:839-848.

Sharpley, A.N., B.E. Haggard, L. Berry, J. Burke, K. Brye, M.D. Daniels, T. Glover, T. Kresse, P. Hays, and K.W. VanDevender. 2017. Nutrient concentrations in Big Creek correlate to regional watershed land use. *Agricultural and Environmental Letters* 2:170027

Simpson, Z.P., and B.E. Haggard. 2018. Optimizing the flow-adjustment of constituent concentrations via LOESS for trend analysis. *Environmental Monitoring and Assessment* 190(2): 103.

Joint Study Committee, 2017. Final report to the Governors from the Joint Study Committee and Scientific Professionals: Summary, technical summary and recommendations. AWRC Technical Report MSC 384, 72 pp.

Austin, B.J., J.B. Payne, S.E. Watkins, and B.E. Haggard. 2017. How to collect your water sample and interpret the results for the poultry analytical package. AWRC Fact Sheet FS-2017-01

Austin, B.J., M. Daniels, and B.E. Haggard. 2017. How to collect your water sample and interpret the results for the domestic analytical package. AWRC Fact Sheet FS-2017-02

Austin, B.J., L. Espinoza, C. Henry, M. Daniels, and B.E. Haggard. 2017. How to collect your water sample and interpret the results for the irrigation analytical package. AWRC Fact Sheet FS-2017-03

Haggard, B. 2017. Illinois River TMDL – what’s happened, and where we are going? Arkansas Society of Professional Engineers, Hot Springs, Arkansas.

Haggard, B. 2017. Serving at the Governor’s Request – The Joint Study Committee. National Institutes of Water Resources Annual Meeting, Washington, D.C.

Haggard, B. 2017. Harmful Algal Blooms. 2nd Biennial Forum on Forestry and Drinking Water, DeGray Lake Resort, Arkansas.

Austin, B. and B. Haggard. 2017. Oklahoma Clean Lakes and Watershed Association Annual Conference, Stillwater, Oklahoma.

Austin, B., S. Patterson and B. Haggard. 2017. University Council on Water Resources Annual Meeting, Fort Collins, Colorado.

Haggard, B. 2017. University Council on Water Resources Annual Meeting, Fort Collins, Colorado.

Lord, M. and B. Haggard. 2017. Oklahoma Clean Lakes and Watershed Association Annual Conference, Stillwater, Oklahoma.

Reavis, Megan Amanda, 2017, The Potential for Phosphorus Release from Floodplain Soils: Temporal Variability and Management Strategies, MS Thesis, Biological and Agricultural Engineering, University of Arkansas, Fayetteville, AR, 2615. <http://scholarworks.uark.edu/etd/2615>.

Project Title: Information Transfer Program

Project Team: Brian E. Haggard, Arkansas Water Resources Center
Erin E. Scott, Arkansas Water Resources Center

Introduction:

A key component of the Arkansas Water Resources Center's (AWRC) mission is the transfer of water resources information to the user community within Arkansas and the region. This community of users includes researchers, resource planners and managers, environmental consultants, environmental advocacy entities, lawyers, and the public. The transfer of information was accomplished through the following outlets:

1. Annual water research conference
2. Monthly electronic newsletters
3. Websites for the Center and to publish and archive newsletter stories
4. Reports, fact sheets, and the Arkansas Bulletin of Water Research
5. Social media
6. Other news outlets
7. Peer-reviewed publications, presentations at scientific conferences, and student degrees

The dissemination of water resources information through the outlets listed above reaches a broad audience throughout Arkansas and neighboring states.

Annual Water Research Conference:

Over 150 people attended the annual water conference held in July 2017. The conference theme was "Protecting Water Supplies for People and the Environment". This year, we partnered with the Arkansas Chapter of the American Water Resources Association to hold their annual symposium in conjunction with our conference.

The conference was geared toward a regional audience, as speakers traveled from Arkansas and surrounding states to talk about the following topics:

- Source water protection
- Science and policy in the Illinois River Watershed Current research from the U.S. Geological Survey Water management for agricultural irrigation
- Water quality in agriculture
- Urban watershed management
- Dam safety and water supply issues

Speakers and attendees came from Arkansas, Oklahoma, Texas, Louisiana, Mississippi, and even Canada to share their ideas and insights about pressing water issues that we all face. This was a valuable venue for water researchers and managers to learn from, network, and collaborate with professionals from throughout the region, sharing ideas about the successes and challenges of managing our water resources.

Eighteen students presented their research during the poster presentation session. Undergraduate students in the Ecosystems Services Research Experience for Undergraduates (EcoREU) program, funded by the National Science Foundation, presented the work completed during their 10-week summer project under a faculty advisor. Graduate students also presented their research, many of whom received funding through the 104B program.

Monthly Electronic Newsletters:

The AWRC distributed monthly electronic newsletters to several hundred people from local and state agencies, municipalities, academia, non-profit organizations, consulting firms, students, and many other stakeholders. Electronic newsletters continue to be a valuable means of distributing important information related to water resources. The open rate is about 35% on average, much higher than the national average for Mailchimp newsletters.

The Center published news articles on current research being done throughout the State, especially projects funded through the USGS 104B program, activities of the Water Center, the USGS, and other organizations, funding opportunities, and other timely water-related news. The AWRC populates a section of the newsletter for “Upcoming Events” to highlight not only Center-related events and activities, but also those of other local or national organizations such as ADEQ, ANRC, Beaver Watershed Alliance, Illinois River Watershed Partnership, and the US EPA. AWRC also updates a “Jobs” section each month aimed to provide recent graduates or early career people some guidance and examples of current job openings related to water science and engineering.

Websites:

The AWRC website (arkansas-water-center.uark.edu) is the primary portal for stakeholders to access important and useful water resources information. During this past year, Center-staff have worked to improve the usability of the website and the availability of water resources information. The website serves as a platform to provide:

- Immediate electronic availability of almost all AWRC publications
- A warehouse of raw data provided as water-data reports associated with research and monitoring projects
- Information about water research being conducted by the Water Center director, students, and staff, as well as research we fund through the USGS 104B program
- Information about submitting a water sample to the AWRC Water Quality Laboratory
- Information on upcoming conferences and funding opportunities, especially USGS 104B and 104G grants, and other events.

Maintenance of the AWRC website is a critical component of the AWRC’s information transfer program.

The Center also maintains a website (WaterCurrents.uark.edu) devoted to publishing and archiving stories from the electronic newsletters. Housing news articles on a designated website enhances searchability and aesthetic quality of important news and information.

AWRC publication materials are also available on ScholarWorks@UARK (scholarworks.uark.edu), the institutional repository for the University of Arkansas. The benefits of publishing on ScholarWorks include enhanced visibility, availability, and impact of our work as the information is open access and available to users around the world. Approximately 250 publications are available through ScholarWorks including:

the Arkansas Bulletin of Water Research, technical reports dating as far back as 1973, and our fact sheets. During the last year, over 300 downloads have been done by users around the globe.

Reports, Fact Sheets, and the Arkansas Bulletin of Water Research:

AWRC published 1 technical report on the Center's website during this past project year (March 2017-February 2018). Our technical reports include water research and monitoring reports from projects funded by state or local water organizations, as well as reports by scientists not related to the Center to make available valuable information in addition to or in lieu of peer-reviewed articles. Water-data reports are published on AWRCs website and provide easy access to years-worth of Center-related water quality monitoring data associated with the data collected for the technical reports. These data reports are available to the public and can be accessed as neatly-organized Microsoft Excel data files.

The Center also developed and published 2 fact sheets during the last year. Our fact sheets provide information to stakeholders, especially those who submit water samples to the AWRC Water Quality Lab for analysis. The lab offers analytical "packages" that include parameters of interest for various intended uses. These uses include aquaculture, livestock watering, poultry watering, domestic, and irrigation. Fact sheets are associated with each of the analytical "packages" and describe how a water sample should be collected, and how people can interpret their lab results. Fact sheets on reporting limits, method detection limits, and censored values and on laboratory quality control are also available to allow people to become better informed about the process we go through to produce scientifically defensible water quality data.

The Center produced and published the inaugural issue of the Arkansas Bulletin of Water Research, in which all completed 104B projects from the previous year were included. The Bulletin was developed to allow anyone conducting research relevant to Arkansas water issues to publish their results, making them available to stakeholders and other researchers throughout the State. The Bulletin is a great avenue to publish results that might not stand alone in a national or international journal, yet are extremely valuable to stakeholders in Arkansas. The Bulletin is also meant to communicate applied research findings that people of various specialties can understand, and we encourage authors to write in a relatively casual way.

Social Media:

The AWRC continues to expand its presence on social media. During this past year, staff utilized Facebook, Twitter, and Instagram to disseminate information about the activities of the Center including funding opportunities, conference materials, and research findings. Facebook followers continue to grow as the Center currently has 605 likes and followers, about 100 more than this time last year. "Boosting" posts to advertise monthly electronic newsletters continues to increase viewers, where we "reach" approximately 2,000 people for each post. Social media has been valuable outlet to network and share ideas and stories among water stakeholders and organizations. The Center shares posts from other water or water-related organizations about current news or upcoming events.

Other News Outlets:

The AWRC continues to coordinate with communications staff at the University of Arkansas, University Relations Department, and the Division of Agriculture to increase the Center's reach and inform the greater public through additional news outlets. The Center has also used Arkansas Newswire as an outlet to disseminate information about student job opportunities, conferences, and other relevant information. These outlets have the potential to reach tens of thousands of people including faculty, staff and students at the University of Arkansas.

Publications, Presentations and Degrees:

When soliciting research proposals through the USGS 104B program, AWRC emphasizes several objectives, including the future publication of research results in peer-reviewed scientific literature. During this past year, 21 publications have been submitted or accepted into peer-reviewed scientific journals. These publications are listed within each project report or in the section for publications from previous project years.

AWRC also emphasizes the presentation of research results at local, national and international meetings and conferences, and the support of graduate research assistants. During this past year, 29 oral and poster presentations were given by student and faculty researchers at conferences around the country. Additionally, 6 graduate students either successfully completed their graduate studies and have published their thesis or dissertation, or are expected to graduate in coming years.

Center director Brian Haggard authored and co-authored various invited and submitted presentations at regional and national conferences. He also served as a technical advisor for the Illinois River Watershed TMDL Model, the Big Creek Research and Extension Team, the USEPA Region VI Nutrient Criteria Development, the Poteau Valley Improvement Authority, the Beaver Watershed Alliance, and the Illinois River Watershed Partnership.

During the past year, the Center cosponsored and helped organize various events including the Beaver Watershed Alliance annual symposium, the Arkansas State University Soil and Water Education Conference, the Arkansas chapter of the American Water Resources Association annual symposium and state meeting, and the South Central Geological Society of America annual meeting.

Summary:

One of the primary missions of the AWRC is the transfer of information to water resources stakeholders. Through the use of an annual water conference, electronic newsletters, maintenance of the websites, publication of reports and fact sheets, engagement through social media, use of additional news outlets, and scientific publications and presentations, AWRC continues to reach a broad audience throughout Arkansas and even the Nation. The Center has helped to ensure that water resources managers have the information necessary to help guide important management decisions.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	12	0	0	0	12
Masters	8	0	0	0	8
Ph.D.	3	0	0	0	3
Post-Doc.	2	0	0	0	2
Total	25	0	0	0	25

Notable Awards and Achievements

Project 2017AR400B: PI Runkle was part of the 2018 Rice Technical Working Group Distinguished Rice Research and/or Education Team Award for “Advancing irrigation management practices to achieve sustainable intensification outcomes”, alongside Merle Anders, Michele Reba, Christopher Henry, Joseph Massey, Jarrod Hardke, Arlene Adviento-Borbe, Steve Linscombe, Dustin Harrell, and Bruce Linnquist.

Project 2017AR401B: 2017 UCOWR Service Award – Board Member Recognition for Brian Haggard

Project 2017AR401B: 2017 Illinois River Watershed Partnership – Golden Paddle Award – Research and Technical Support, Brian Haggard

Publications from Prior Years

1. 2010OK192G ("Scale Dependent Phosphorus Leaching in Alluvial Floodplains") - Articles in Refereed Scientific Journals - Heeren, D.M., G.A. Fox, C.J. Penn, T. Halihan, D.E. Storm, and B.E. Haggard. 2017. Impact of macropores and gravel outcrops on phosphorus leaching at the plot scale in silt loam soils. *Transactions of the ASABE*, 60(3): 823-835.
2. 2015AR369B ("Creating an annual hydroecological dataset in forested Ozark streams") - Conference Proceedings - Dodd, A.K., D.R. Leasure, D.D. Magoulick, and M.A. Evans-White. 2017. Stream metabolism in two dominant north Arkansas flow regimes. *Society for Freshwater Science Meeting*, Raleigh, NC.
3. 2015AR369B ("Creating an annual hydroecological dataset in forested Ozark streams") - Articles in Refereed Scientific Journals - Dodd, A.K., D.R. Leasure, D.D. Magoulick, and M.A. Evans-White. (in prep). Flow regime influence on ecosystem structure and function in the Ozarks. *Freshwater Science*.
4. 2015AR373B ("Does environmental context mediate stream biological response to anthropogenic impacts?") - Articles in Refereed Scientific Journals - Baker, L., Evans-White, M.A., Entrekin, S. 2018. Basin risk explains patterns of macroinvertebrate community differences across small streams in the Fayetteville Shale, AR. *Ecological Indicators*, Volume 91, August 2018. Page 478- 479, ISSN 1470-160X, <https://doi.org/10.1016/j.ecolind.2018.03.049>.
5. 2015AR374B ("Runoff Water Quality from Managed Grassland Amended with a Mixed Coal Combustion Byproduct") - Dissertations - Burgess-Conforti, J.R. 2016. Liming characteristics of a high-Ca dry flue gas desulfurization by-product and its effect on runoff. MS Thesis. *Crop, Soil, and Environmental Sciences*, University of Arkansas, Fayetteville, AR.
6. 2015AR374B ("Runoff Water Quality from Managed Grassland Amended with a Mixed Coal Combustion Byproduct") - Articles in Refereed Scientific Journals - Burgess-Conforti, J.R., D.M. Miller, K.R. Brye, L.S. Wood, and E.D. Pollock. 2016. Liming characteristics of a high-Ca flue gas desulfurization by-product and a Class-C fly ash. *J. Environ. Protec.* 7:1592-1604
7. 2015AR374B ("Runoff Water Quality from Managed Grassland Amended with a Mixed Coal Combustion Byproduct") - Articles in Refereed Scientific Journals - Burgess-Conforti, J.R., D.M. Miller, K.R. Brye, and E.D. Pollock. 2017. Plant uptake of major and trace elements from soils amended with a high-calcium dry flue gas desulfurization by-product. *Fuel*. 208:514-521.
8. 2015AR374B ("Runoff Water Quality from Managed Grassland Amended with a Mixed Coal Combustion Byproduct") - Articles in Refereed Scientific Journals - Burgess-Conforti, J.R., K.R. Brye, D.M. Miller, E.D. Pollock, and L.S. Wood. 2017. Dry flue gas desulfurization by-product effects on plant uptake and soil storage changes in a managed grassland. *Environ. Sci. Pollut. Res.* 25(4) 3386-3396.
9. 2015AR374B ("Runoff Water Quality from Managed Grassland Amended with a Mixed Coal Combustion Byproduct") - Articles in Refereed Scientific Journals - Burgess-Conforti, J.R., K.R. Brye, D.M. Miller, E.D. Pollock, and L.S. Wood. 2018. Land application effects of a high-calcium dry flue gas desulfurization by-product on trace elements in runoff from natural rainfall. *Water Air Soil Pollut.* 229(34).
10. 2016AR383B ("Partitioning rice field evapotranspiration into evaporation and transpiration components") - Conference Proceedings - Suvočarev K, Greer S, Sadler J, Wood JD, Bhattacharjee J, Reba ML, Runkle BRK, 2017, Surface renewal application and examination over different AmeriFlux landscapes, In 2017 Joint NACP and AmeriFlux Principal Investigators Meeting, North Bethesda, MD.
11. 2016AR383B ("Partitioning rice field evapotranspiration into evaporation and transpiration components") - Conference Proceedings - Runkle BRK, Suvočarev K, Reba ML, 2017, Scaling up measurement systems to test climate-smart rice irrigation strategies, In 2017 Joint NACP and AmeriFlux Principal Investigators Meeting, North Bethesda, MD.

12. **2016AR383B ("Partitioning rice field evapotranspiration into evaporation and transpiration components") - Conference Proceedings - Runkle BRK, Suvočarev K, Reba ML, 2017, Rice irrigation strategies: Alternate wetting and drying and methane reductions, In 2017 Mississippi Water Resources Conference, Jackson, MS.**
13. **2016AR385B ("Investigating Fate of Engineered Nanoparticles in Wastewater Biofilms") - Conference Proceedings - Walden, C., and W. Zhang, 2017, Investigating fate of Silver Nanoparticles in Wastewater Biofilms, In AEESP Research and Education Conference, Ann Arbor, MI.**
14. **2016AR385B ("Investigating Fate of Engineered Nanoparticles in Wastewater Biofilms") - Dissertations - Walden, Connie, 2017, Investigating Fate of Silver Nanoparticles in Wastewater Biofilms, PhD Dissertation, Civil Engineering, College of Engineering, University of Arkansas, Fayetteville, AR.**
15. **2016AR387B ("Biological and ecological consequences of sub-lethal ion concentrations on microbial and macroinvertebrate detritivores.") - Conference Proceedings - Huggins, B., Brass, A. Entrekin, S. and Gifford, M, 2017, Influence of Common Salt Concentrations on Detritivore Respiration, In Arkansas Academy of Science, Conway, AR.**
16. **2016AR387B ("Biological and ecological consequences of sub-lethal ion concentrations on microbial and macroinvertebrate detritivores.") - Articles in Refereed Scientific Journals - Entrekin, S., B. Howard-Parker, M.A. Evans-White, and N. Clay. 2018 (submitted). Salt type matters: Ion concentration and identity differentially altered growth and resource-use efficiency of a common freshwater detritivore (Plecoptera) at sub-lethal levels. *Freshwater Biology*.**