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Kentucky Water Resources Research Institute Annual Technical Report FY 2015

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Kentucky Water Resources Research Institute, University of Kentucky

Kentucky Water Resources Research Institute Annual Technical Report FY 2015

Introduction

The 2015 Annual Technical Report for Kentucky consolidates reporting requirements for the Section 104(b) base grant award into a single document that includes: 1) a synopsis of each student research enhancement project that was conducted during the period, 2) citations for related publications, reports, and presentations, 3) a description of information transfer activities, 4) a summary of student support during the reporting period, and 5) notable awards and achievements during the year.

No funds were requested for general program administration activities. However, travel funds were provided to support the participation of the director and associate director in the annual meeting of the National Institutes for Water Resources in Washington, DC from February 8-10, 2016.

Research Program Introduction

The activities supported by the Section 104(b) program funds and required matching are interwoven into the overall program of the Kentucky Water Resources Research Institute. Additional research, service, and technology transfer activities were funded through a variety of other sponsors. The Kentucky River Authority supported watershed management services in the Kentucky River basin and a small grant program to fund local grassroots watershed organizations. The National Institute of Environmental Health Services supported research translation activities through the Superfund Public Outreach Program and the development of ground water remediation processes for potential use at contaminated sites. The Kentucky Department for Environmental Protection supported 4 students through their Environmental Protection Scholarship Program.

The Institute's Committee on Research and Policy considered 19 proposals for student research enhancement grants for support through 104(b) 2015 funding. Ten projects were selected. The projects were conducted at the University of Kentucky (6), Murray State University (2), Western Kentucky University (1), and Eastern Kentucky University (1). The projects represented faculty and students from a variety of discipline areas including geosciences (3), biology (2), civil engineering (2), plant and soil sciences (1), biosystems and agricultural engineering (1), and forestry (1). The goal of this approach is to support a number of student-based efforts representing a variety of discipline areas at numerous educational institutions throughout the state to develop and support a broad research capacity related to water resources. Many state agencies are experiencing a significant loss of personnel in their environmental programs through retirements and it is critical that undergraduate and graduate students are well trained and available to fill this void. A total of 13 students were supported through the 104(b) program (1 PhD student, 8 masters students, and 4 undergraduate students; 10 male, 3 female). Reports for the ten 2015 student research enhancement projects follow.

Sinkhole probability mapping: Integrating human impacts and natural processes in conjunction with LiDAR to predict karst subsidence

Basic Information

Title:	Sinkhole probability mapping: Integrating human impacts and natural processes in conjunction with LiDAR to predict karst subsidence
Project Number:	2015KY239B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 3 & 4
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Methods, Geomorphological Processes
Descriptors:	None
Principal Investigators:	Junfeng Zhu

Publications

1. Pierskalla, Jr.,W.P. and Junfeng Zhu, 2015, Incorporating Human Impacts and Natural Processes to Assess Sinkhole Risk, in Geological Society of America, Abstracts with Programs, 47(7), p. 625.
2. Perskalla, Jr., W.P. and Junfeng Zhu, 2016, Incorporating Human Impacts and Natural Processes to Assess Sinkhole Risks, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 69.

Sinkhole Probability Mapping: Integrating Human Impacts and Natural Processes in Conjunction with LiDAR to Predict Karst Subsidence

Project and Research Objectives

Land use planners rely on maps of existing karst hazards to make decisions regarding development and environmental regulations. Maps of subsidence risk are based primarily on the lithology of the surface and subsurface. Current karst risk maps for Kentucky do not accurately reflect the distribution of sinkholes (Figure 1). This lack of knowledge can lead to developing property at high risk of subsidence in areas that are listed as moderate to low risk.

In Kentucky, 50% of the state is underlain by karst terrain (Carey et al., 2008) and sinkholes cause over $20 million damage annually (Currens, 2012). Engineers, hydrologists, and government agencies in Kentucky have been studying subsidence and attempting to predict future sinkhole locations for decades (Dinger and Rebmann, 1986; Veni and Crawford, 1988; Currens et al., 2005; Dinger et. al., 2007). Currently, there is no effective method of determining sinkhole risk in karst areas other than the existing maps of sinkholes, many of which have not been field verified. We propose that by integrating human and geologic factors that influence sinkhole collapse and subsidence we can reduce future sinkhole damages by improving sinkhole risk assessment. Available information on geologic units, land use, development, drainage, and soil types can assist in predicting future sinkhole risk.

Recent LiDAR sinkhole mapping has allowed us to locate more sinkholes with higher accuracy. For example, Zhu et al. (2014) located almost four times as many sinkholes in previously mapped areas using LiDAR and field verification showed an 88% accuracy in these new maps (Figure 2). This improved sinkhole coverage allows us to better understand the spatial distribution of existing sinkholes and provides needed data for accurate evaluation of sinkhole risk.

Methods and Procedures

We use the Floyd's Fork watershed in north central Kentucky as the study area (Figure 2), which has been extensively mapped for sinkholes with the use of LiDAR and field investigations (Zhu et al., 2014). Several applications are essential for the analysis of the spatial data in this process, including the Random Forest™ machine learning algorithm and Environmental Systems Research Institute’s ArcMap program (ESRI, 2015). By compiling data using machine learning techniques, and ESRI’s ArcMap we can create a sinkhole risk map based on a variety of geomorphologic features.

Random Forest (Breiman, 2001, Breiman and Cutler, 2004) is a classifier consisting of a collection of decision trees where random vectors are replaced at each node of the tree, and each tree casts a vote for the most popular class generating a list of variable importance. This random replacement of variables creates less variance in the data without a corresponding increase in bias. Using machine learning enables us to incorporate various human and natural features to generate high-quality sinkhole risk maps with greater accuracy than existing maps.

To determine sinkhole risk, we used the area density of existing sinkholes per grid (the higher the density, the higher the risk of sinkholes). The grid density was determined by using Carter Coordinates (KGS, 2002). Using a one-half minute Carter grid, the study area was divided into 783 cells, roughly 3000 feet per side. Based on calculated area density of LiDAR-derived sinkholes, we classified sinkhole risk for each grid into one of three categories; 1 (low), 2 (moderate), and 3 (high), respectively (Figure 3).

We determined the variables to be used in training the Random Forest algorithm by consideration of risk factors for sinkhole development (lithology, forest cover, developed land, barren land, soil drainage, and stream length were chosen as possible high potential risk factors). The lithologic variables include limestone, dolomite, clay, and shale. These variables are the primary factors influencing sinkhole development. The National Land Cover Database (NLCD) was used to quantify data from land use types (Homer et al., 2015). Various factors were aggregated into just three categories for the data set (Table 1). Water and wetlands were discarded because standing water indicates little or no drain in the depression. This decision also eliminates man-made wetlands and ponds. Barren land has the broadest selection by defining it simply as open land that has little or no alteration and only scrub vegetation (not trees). The dataset was randomly divided into two groups: 587 records were used for training and 195 were used for testing in the Random Forests algorithm.

Principle Findings and Significance

The results of this research are promising. The Random Forest results reveal that limestone and dolomite rank first and third in variable importance (Table 2). This ranking seems to corroborate the effectiveness of the algorithm as karst terrain is defined by the presence of carbonate lithologies. Forested lands are the second highest ranked risk factor. Several conditions may explain this. First, the new sinkhole data generated through LiDAR resolved a large percentage of sinkholes within forested areas that were previously unknown. Second, forested areas typically have less alteration from the original topography compared with other land uses. Third, often these forested lands are the least desirable for agriculture and development. Barren land and development are the next two highest variables, respectively. Undisturbed barren land may indicate a high subsidence potential due to the identification of many previously unreported smaller depressions. Development may be high risk due to the tendency of developers to work around existing land features and avoid building directly on known sinkholes, thereby preserving some of the original density of sinkholes. Additionally, field checking in developed areas documented a notable preservation of sinkholes for use as natural drainage within high to medium density development. This practice may add risk by intentionally channeling additional water flow into areas already at risk.

These preliminary results help define which variables are the best predictors of sinkhole risk and they exhibit some promising correlations. Even with high overall error rates of 41% for the training data set and 35% for the testing data set (Table 3), these results can still suggest potential high-risk factors for sinkhole development for land use planners.

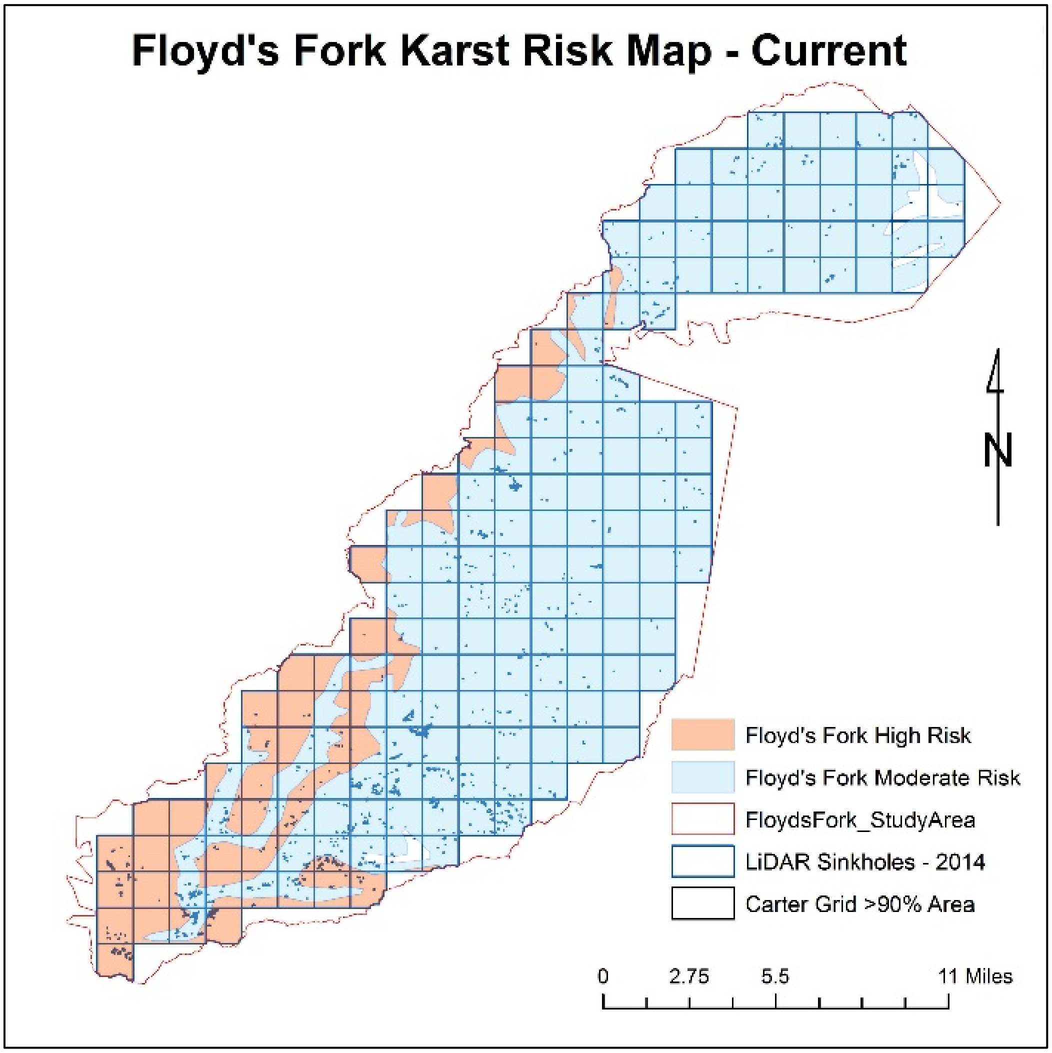

Figure 1. Floyds Fork watershed in north central Kentucky. New sinkhole database mapped to current karst risk map. Many sinkholes appear in moderate karst zone and some high risk areas have no sinkholes. (Sinkhole map from Zhu,2014)(Karst risk modified from KGSGeoportal, Paylor and Currens, 2002).

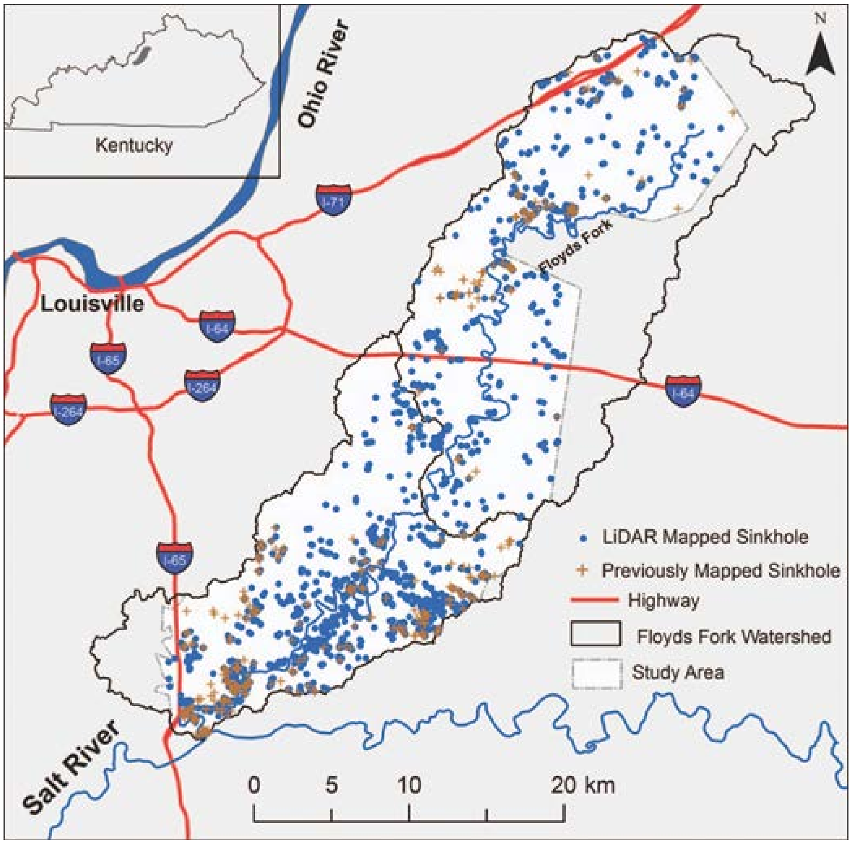

Figure 2. Older sinkhole maps with new sinkhole data added (Zhu et al., 2014).

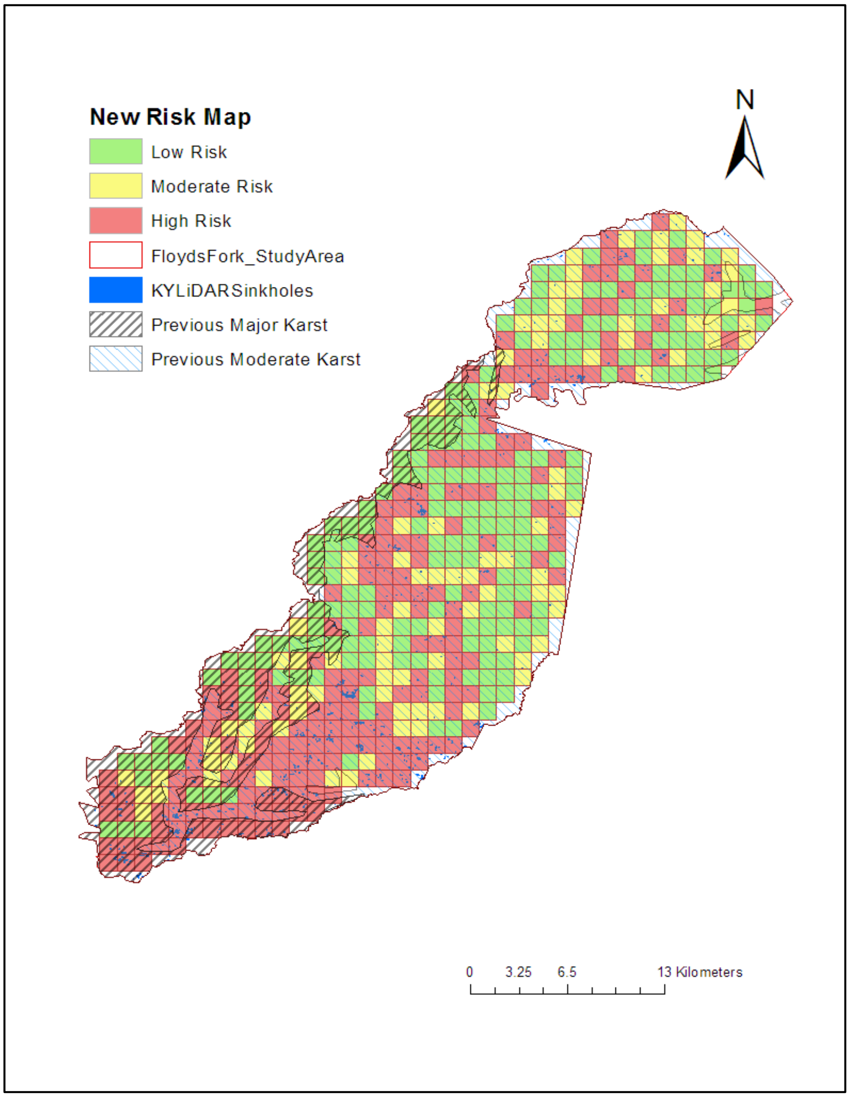

Figure 3. New risk map based on LiDAR-derived sinkholes over old karst risk map

Table 1. Class aggregation table for land uses.

Class	Includes Value	NLCD Category
Forests	41, 42, 43	Deciduous, Evergreen, Mixed
Developed	22, 23, 24	21-Developed Open space moved to Barren
Barren	31, 81, 82, 21, 71	Barren Land, Pasture, Crops, Open Developed Land, Grassland
Wetlands	11, 12, 90, 95	Open Water, Perennial Ice, Snow, Woody Wetlands, Emergent Wetlands

Table 2. The normalized importance of variables tested.

_LIMESTONE	100.00
_FOREST	91.50
_DOLOMITE	83.28
_BARREN	66.35
_DEVELOPED	62.36
_WELLDRAINED	45.80
_STREAM	38.45
_SHALE	34.54
_QAL	30.15
_POORLYDRAINED	25.31
_CLAY	18.45

Table 3. Confusion Matrix for a) training and b) test data.

a) Training Set Confusion Matrix (OOB)

Class	1	2	3	Row Total	Users Accuracy
1	284	73	87	444	64%
2	12	4	8	24	17%
3	29	30	60	119	50%
Column Total	325	107	155	587	
Overall Accuracy:	87%	4%	39%		59%

b) Test Set Confusion Matrix

Class	1	2	3	Row Total	Users Accuracy
1	93	28	21	142	65%
2	4	2	6	12	17%
3	3	7	31	41	76%
Column Total	100	37	58	195	
Overall Accuracy:	93%	5%	53%		65%

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Long term effects of forestry best management practices on hydrology and water chemistry in three Appalachian headwater catchments

Basic Information

Title:	Long term effects of forestry best management practices on hydrology and water chemistry in three Appalachian headwater catchments
Project Number:	2015KY240B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 6
Research Category:	Water Quality
Focus Category:	Surface Water, Hydrology, Sediments
Descriptors:	None
Principal Investigators:	Carmen Agouridis

Publication

1. Wright, K., C. Agouridis, and C. Barton, 2016, Long-Term Effects of Forestry Best Management Practices on Hydrology and Water Chemistry in Three Appalachian Headwater Catchments, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 81.

Long-Term Effects of Forestry Best Management Practices on Hydrology and Water Chemistry in Three Appalachian Headwater Catchments

Problem and Research Objectives

Riparian zones provide a buffer between upland management scenarios and the stream. The importance of riparian zones in maintaining hydrologic function, filtering upland derived sediment, utilizing upland derived nutrients, maintaining in-stream and near-stream temperature profiles, and providing habitat and corridors for aquatic and terrestrial fauna has been identified but not well quantified, particularly for headwater stream systems (NCASI, 1999a). Because of their small size, headwater streams are quite sensitive to anthropogenic disturbances such has harvesting which can cause larger runoff volumes, higher peak flows, and decreased water quality (Reeves, 2012; Richardson and Danehy, 2007). Most forestry best management practices (BMPs) are designed to decrease sediment transport resulting from soil erosion. Soil erosion and subsequent suspended sediment in surface waters is considered by many as one of the largest environmental concerns in the U.S. today (USEPA, 1992). Erosion of organic and nutrient rich surface soil also decreases forest productivity (Pritchett and Fisher, 1987). Transport of sediment to streams and subsequent sedimentation leads to loss of stream habitat and altered steam hydrology (NCASI, 1999a; 1999b). Although sediment transport is a main concern associated with forest harvesting, nutrient transport and impacts on stream temperature and carbon distribution are also important (Arthur et al., 1998; Hornbeck and Edwards, 1990). While research has examined the short term effectiveness of forestry BMPs (Arthur et al., 1998; McClure et al., 2004; Witt et al., 2011), research on the long-term effects on these BMPs is quite limited (Burt et al., 2015). As such, a thorough investigation into the long-term effectiveness of forestry BMP use is needed, particularly with respect to riparian buffers, to provide a framework of understanding of how such BMPs can protect headwater streams systems thus leading to better forestry management practices.

In 1982, a study was initiated to evaluate BMP effectiveness on three streams (A, B and C) in the Field Branch watershed in the University of Kentucky's Robinson Forest, which is a teaching, research and extension experimental forest located in the Cumberland Plateau of eastern Kentucky. Treatments included a control or reference watershed, a watershed with a 50-ft buffer along the perennial stream segment, and a watershed that was harvested completely to the stream bank without BMPs (i.e. logger's choice). An overview of initial results by Arthur et al. (1998) concluded that the harvested sites recovered within approximately four years of the harvest and that forestry BMPs reduced impacts of stream discharge and nutrient fluxes. Although the preliminary conclusions were intriguing from a BMP effectiveness standpoint, little is known about the long-term significance that BMP implementation may have on water yield and quality. Preliminary field observations indicate that the hydrology of the completely harvested watershed differs from the control watershed even after a 30 year period.

Very little is known about the long-term ramifications of BMP use, especially pertaining to riparian buffer zones. Monitoring has continued in the ABC watersheds since harvest was initiated in 1983. This long-term record presents a unique opportunity to examine potential differences in water yield and water chemistry attributes. As such, we compiled all hydrologic and water quality data collected over the last 30 years in these watersheds and assessed how these variable have changed during that period. The objectives of the study were as follows:

1. Evaluate the storm hydrograph characteristics of the paired watersheds to determine significant pairwise differences and long-term trends.
2. Analyze monitored pollutant concentrations on the paired watersheds by comparing flow-weighted mean concentrations (FWMC) to determine significant pairwise differences and long-term trends for the monitored time periods.

Methodology

The study site consists of three headwater streams and riparian zones located in the University of Kentucky's Robinson Experimental Forest. Robinson Forest is located in the Cumberland Plateau Physiographic Region and is centrally positioned in Appalachia and drains to the North Fork of the Kentucky River (Figure 1). The mixed mesophytic forest consists mainly of second growth hardwoods 80-100 years in age.

The three watersheds include an unharvested control ("WSA", Control, 16.1 ha), a second watershed with best management practices (BMPs) applied that included a 15.2 m (50 ft.) unharvested zone near the stream ("WSB", BMP watershed, 11.2 ha), and a third watershed that was harvested without strict BMPs with harvesting occurring up to the stream edge and slash left within the stream and riparian zones ("WSC", No BMP watershed, 10.5 ha). Table 1 contains additional information on WSB and WSC. The BMP and No BMP watersheds were harvested in 1983. The harvesting of the BMP and No BMP watersheds consisted of a complete silvicultural clearcut. Commercial sawtimber logs were removed from the sites and all stems <5 cm dbh were cut and left on site (Arthur *et al.*, 1998). Prior to harvest, all watersheds were 70+ years in age and the overstory was dominated by oaks (*Quercus* spp.; 39% of overstory density), hickories (*Carya* spp.; 17% of overstory density), and yellow poplar (*Lirodendron tulipifera* L.; 15% of overstory density) (Overstreet, 1984).

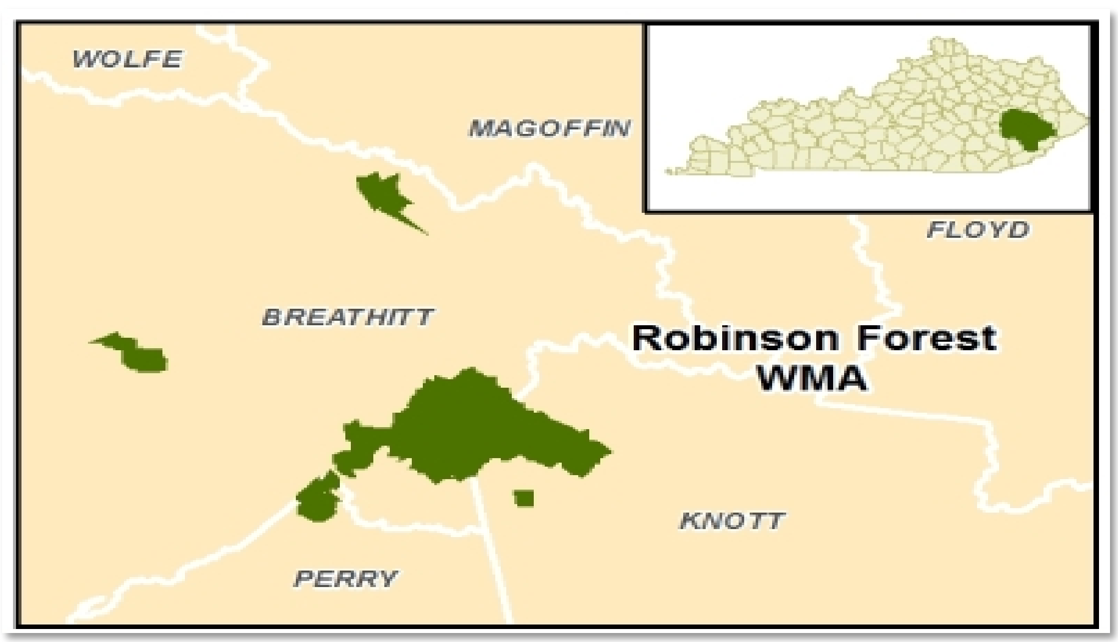
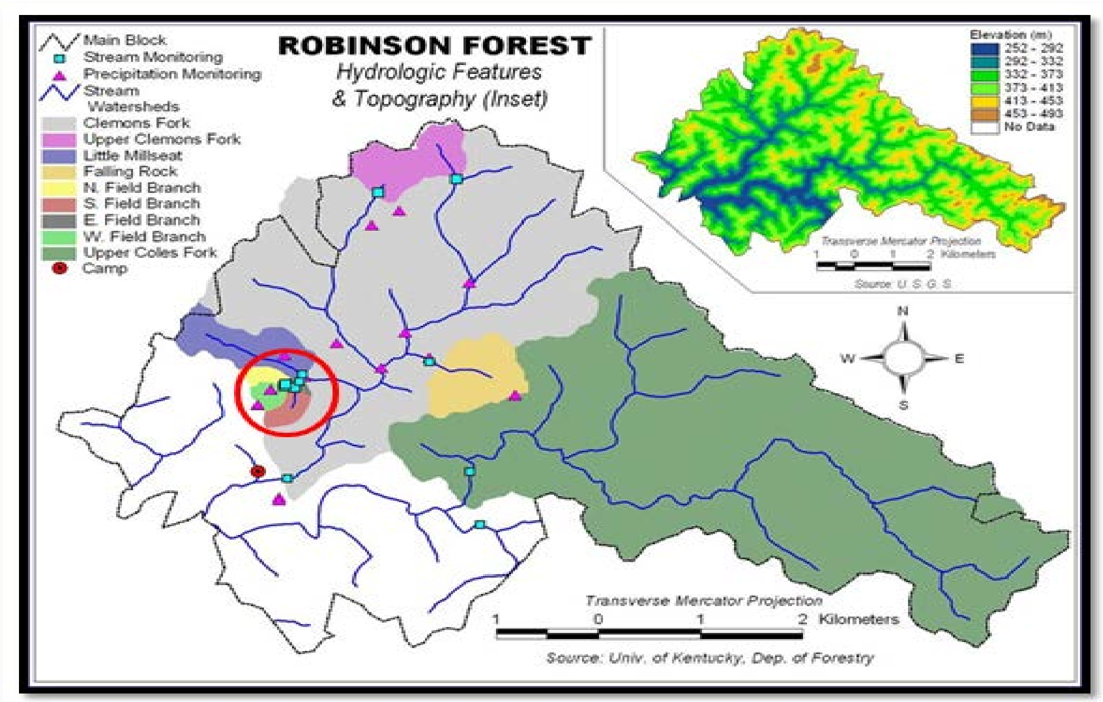


Figure 1. (a) Robinson Forest location map.



(b)

Figure 1. (b) WSA, WSB and WSC location map

Table 1. Harvest management practices for WSB and WSC.

Watershed	Harvest Management Practices
WSB	– 15.2 m undisturbed riparian zone on either side of the stream – Roads seeded with fescue after logging was complete – Logging roads constructed at less than 10% grade – Log skidder kept on roads – Broad-based dips used as water control structures on roads – Logging debris kept out of streams
WSC	– Logs repeatedly skidded downhill – Roads left bare after logging was complete – No buffer strips were left around streams – Trees felled into and across streams

Hydrology and Water Chemistry Monitoring

Each watershed contains an H-flume equipped with stage height recorders for continuous discharge measurements. Discharge has been continuously monitored since 1982. Weekly stream water samples are analyzed in the field for pH, conductivity, dissolved oxygen, and temperature using field instruments (most recently a YSI 556 Environmental Monitor). Suspended sediment, total dissolved solids, turbidity, alkalinity, nitrate, ammonium, total nitrogen, sulfate, calcium, magnesium, potassium, sodium and total organic carbon were also collected weekly and analyzed in the University of Kentucky Forestry Department water quality lab using standard methods (APHA, 1992).

Weather (precipitation, relative humidity, temperature, wind speed and direction, solar radiation) was continuously monitored within the study site using, most recently, a Campbell Scientific weather station. An open precipitation collector, situated near the weather station, was used to assess ionic inputs in precipitation.

All data generated during the last 30 years has been stored in computer files (MS Excel) housed at the University of Kentucky, Department of Forestry. All files are backed-up on the Department's server and hard copies of stream charts and laboratory notes are archived in the Department. Dr. Barton is the current custodian of the data set. A bulk of the work performed for this project was processing and interpreting the data set.

Data Analysis and Interpretation

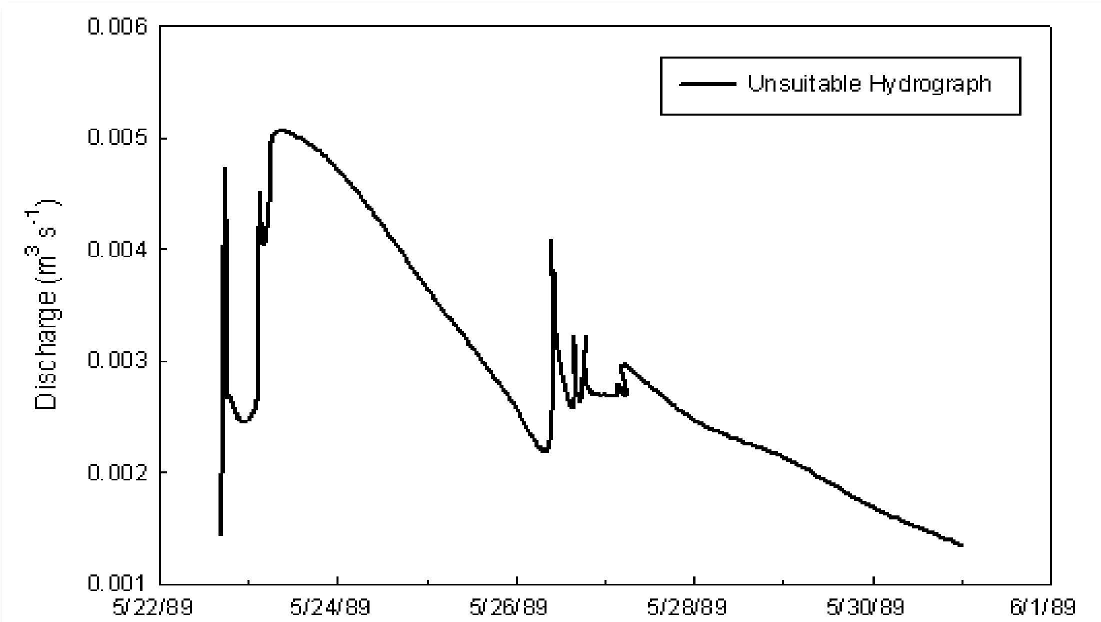
The analysis period for the project was separated into two contiguous time periods: 1982-1993 and 2002-2008 (WSC 2005-2008). Extended equipment failure limited the ability to perform a continuous analysis. Precipitation data were used to identify storms and subsequently hydrograph responses across watersheds. Storms were defined as being equal to or greater than 11 mm; gaps in precipitation larger than three hours were separated into different events. This led to a total of 555 hydrographs from each watershed: 345 from 1982-1993 and 210 from 2002-2008. A digital recursive filter was utilized to separate hydrograph baseflow from stormflow. Of these 555 hydrographs, we deemed 190 acceptable (e.g. single peak) from the 1982-1993 period and 104 from the 2002-2008 period (Figure 2). This subset was used to analyze for differences between WSA, WSB and WSC with respect to stormflow and baseflow.

The stormflow characteristics analyzed included peak flow (Qp), storm volume as a percentage of rainfall ([Q/P]%), and curve number (CN). Significant statistical differences of the previous hydrograph characteristics were evaluated on a yearly basis by a one-way analysis of covariance (ANCOVA) with precipitation depth and growing season (April 20-October 26) serving as covariates.

Principal Findings and Significance

Curve Number

For CN, statistical differences between WSA and WSC were observed in 1984, 1985, 2006, and 2007 with average CN's (λ=0.05) in WSC of 91, 79, 88, and 81, respectively; average CN's in WSA were 82, 70, 80, and 75, respectively. Statistical differences between WSA and WSB only occurred in 1985 with WSB having an average CN of 78 while WSA's was 70. The average CN of WSA, WSB, and WSC pre-harvest was 76 while post-harvest WSA had an average CN of 78, WSBs was 81, and WSCs was 82. Figure 3 shows the mean annual CN values for each watershed.



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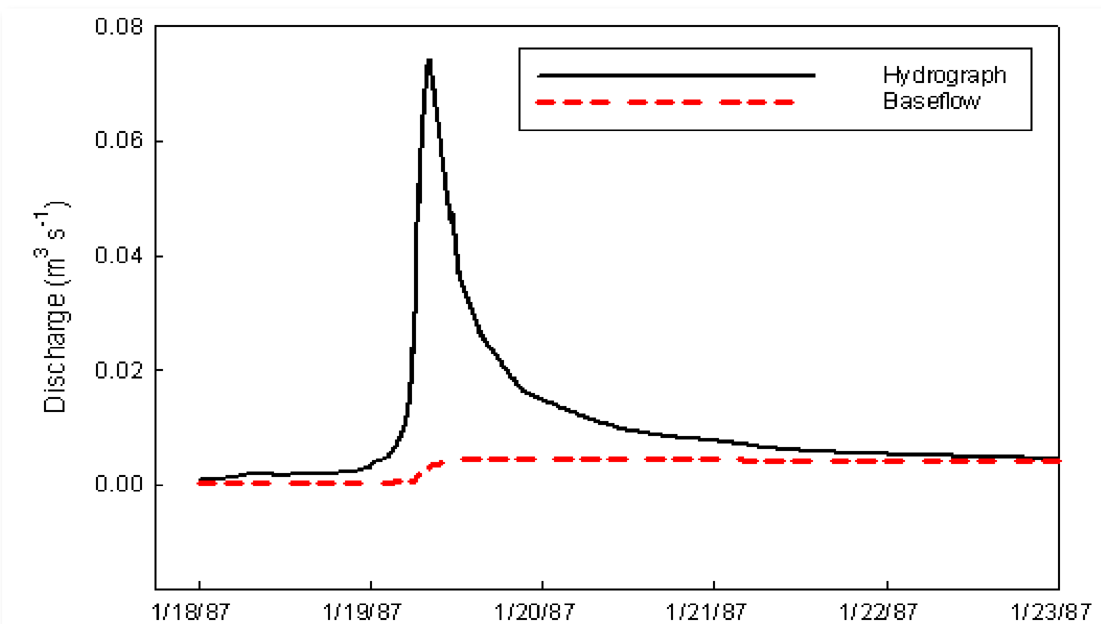
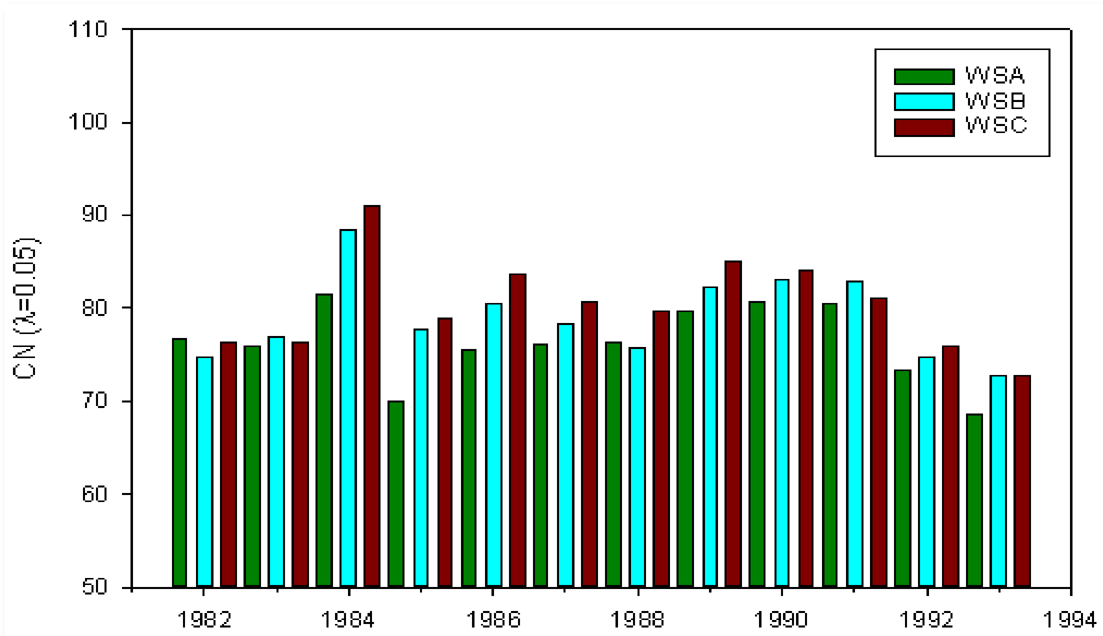


(b)

Figure 2. Examples of (a) unsuitable and (b) suitable hydrographs.



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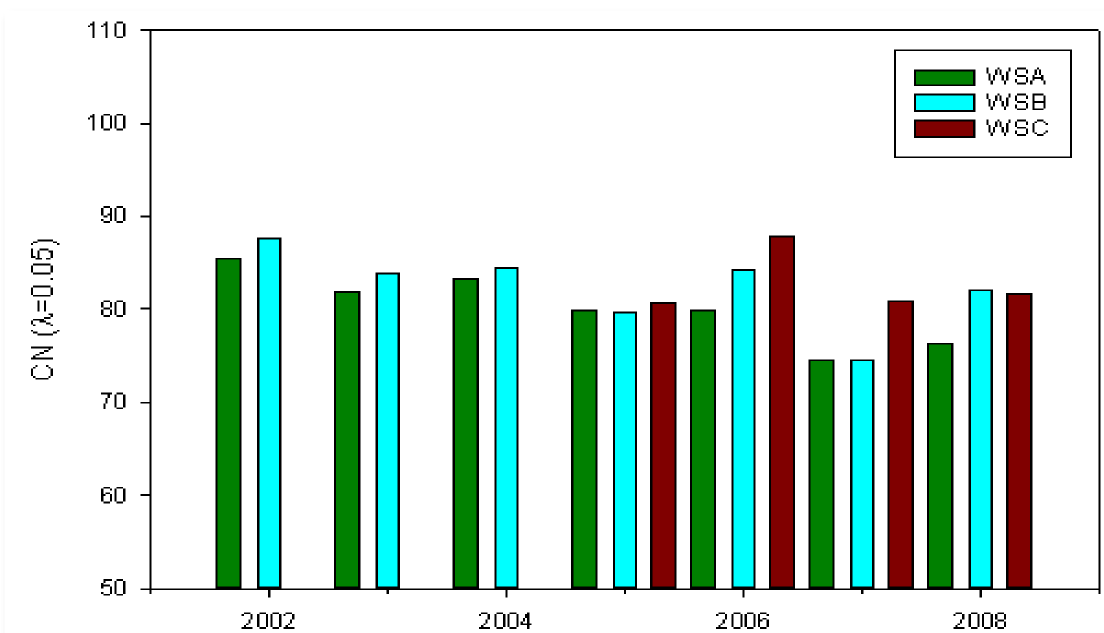

(b)

Figure 3. Mean annual CN (l=0.05) for WSA, WSB and WSC for (a) 1982-1993 and (b) 2002-2008.

Baseflow and Stormflow

For baseflow and stormflow, results from the statistical analysis indicate large differences in baseflow between WSA and WSC in 1985 and 2007 (Figure 4). The total yearly baseflow was 1.3 times as much in WSC in 1985 and 1.6 times as much in 2007. Although not statistically significant, total yearly baseflow in 2006 and 2008 was 2.7 and 2.1 times higher in WSC compared to WSA. Significant statistical differences were also found between WSA and WSB in 1985; total yearly baseflow was 1.4 times greater than WSA. More significant variations were seen in stormflow between the watersheds throughout the study. Statistically significant differences were seen between WSA and WSC in 1984, 1985, 2006 and 2007 with total yearly stormflow in WSC being greater by 2.3, 2.5, 3.1, and 1.4 times respectively higher. This trend was significant throughout the study with stormflow in WSC being on average 2 times higher than WSA post-harvest during both analyzed time periods. Statistically significant differences were also seen in stormflow between WSA and WSB in 1985 where WSB was 2.2 times higher than WSA. Stormflow remained somewhat elevated post-harvest in WSB, it was on average 1.8 times higher than WSA in the first analyzed period and 1.4 times higher in the second.

Peak Discharge

For peak discharge, no statistical differences were found throughout the study period across the watersheds (Figure 5). There were marginal differences between the watersheds and no discernible trends in the data. The main difference was seen in 1993 when the average storm peak flow for WSC was much higher. This difference mainly came from one event (July 13, 1993) when the peak flow in WSC was 15 times higher than WSA and 16 times higher than WSB. In the second time period these differences become even less noticeable and the watersheds have nearly identical results for most years.

Storm Volume

For the average storm volume as a percentage of rainfall [Q/P]%, significant statistical differences between WSA and WSC were observed in 1984, 1985, 1989, 2006, and 2007, with average [Q/P]% for WSC being 56%, 25%, 47%, 38%, and 14% respectively compared to WSA average [Q/P]% being 35%, 12%, 28%, 19%, and 7% (Figure 6). Statistical differences between WSA and WSB were only present in 1985; average [Q/P]% for WSB was 23% compared to WSA’s 12%.

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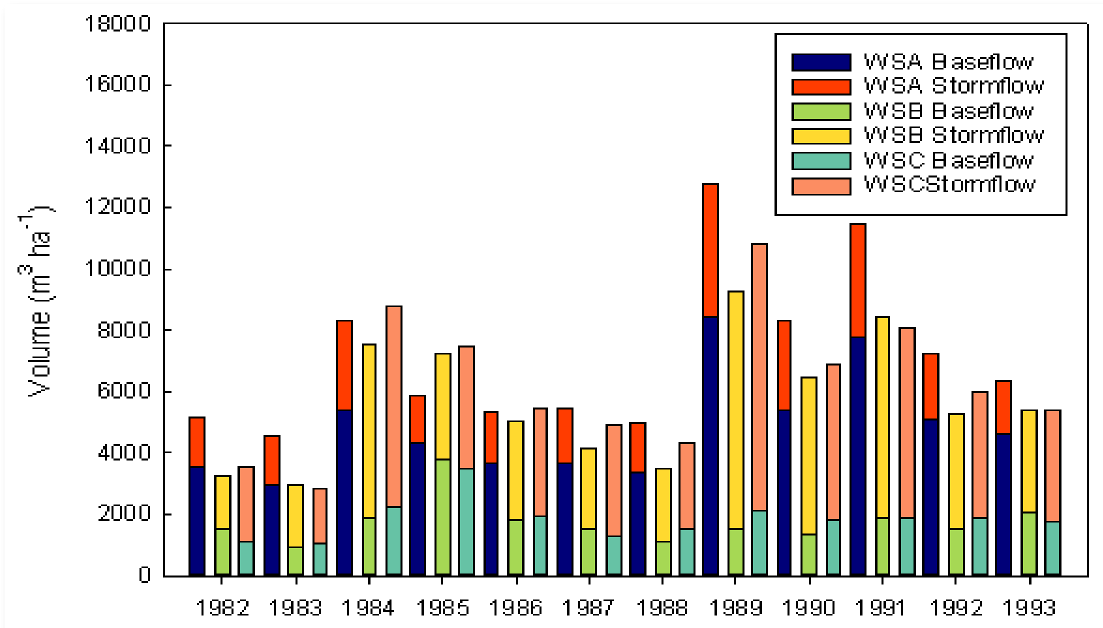

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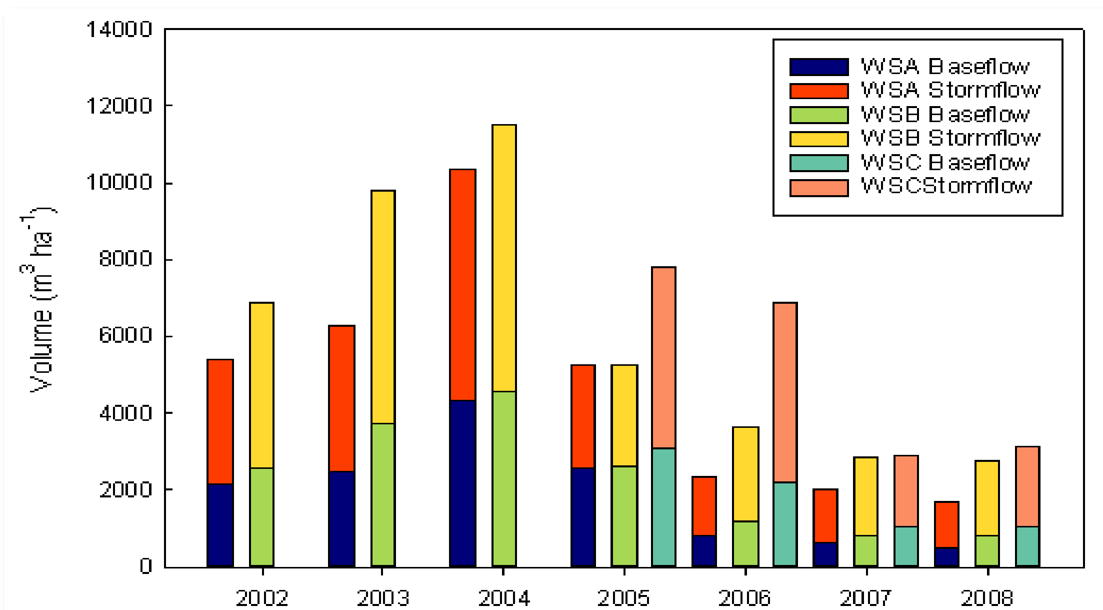
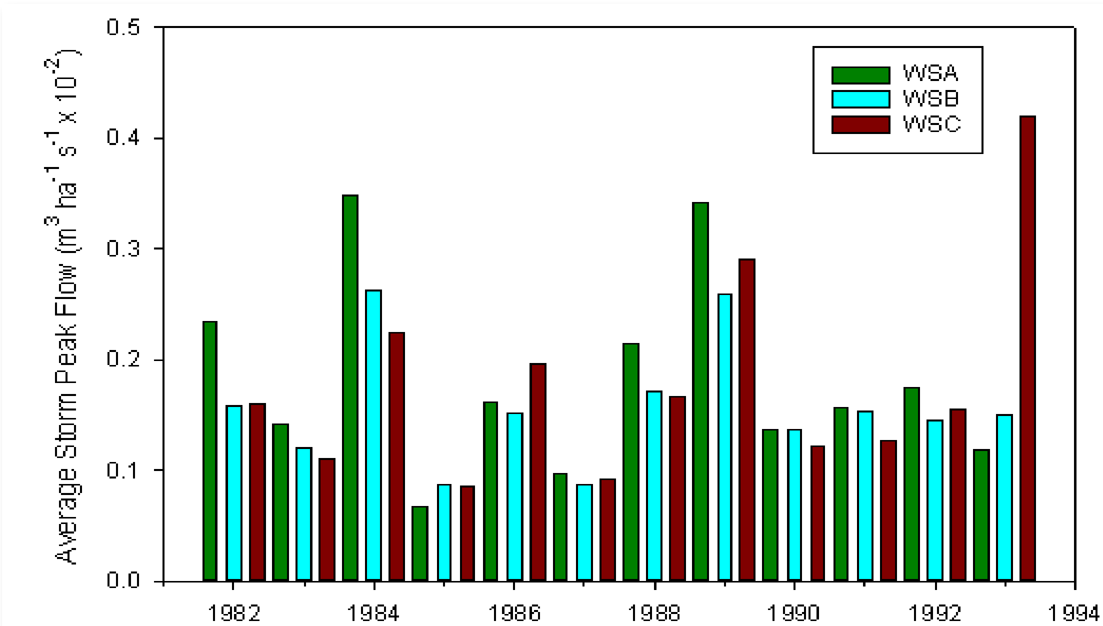


(b)

Figure 4. Annual baseflow and stormflow volumes for WSA, WSB and WSC for (a) 1982-1993 and (b) 2002-2008



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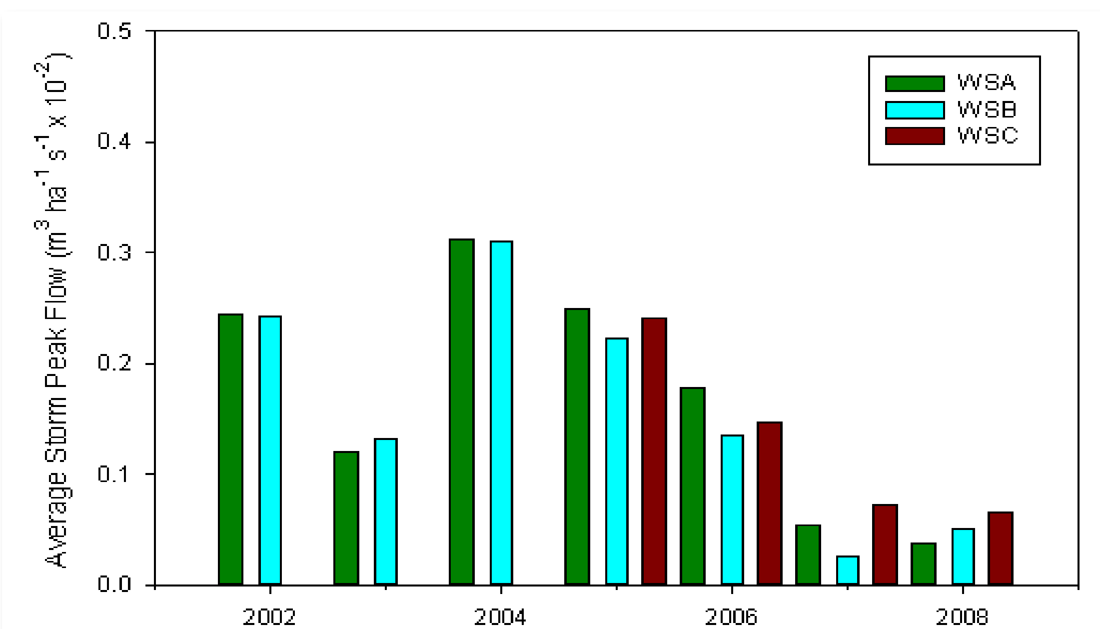

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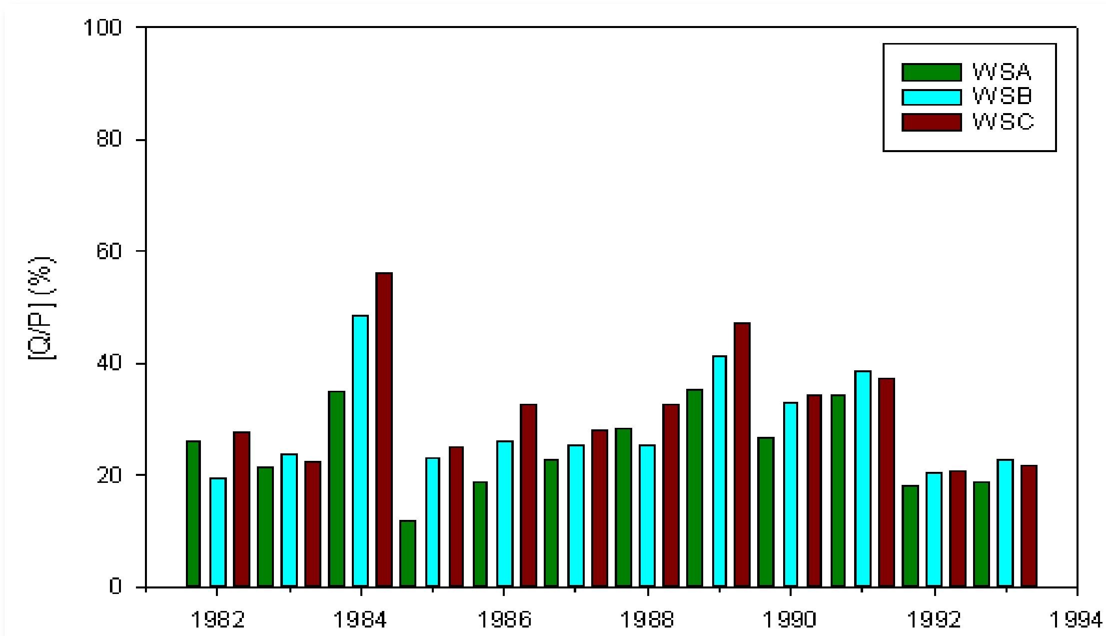
Figure 5. Average storm peak discharges for WSA, WSB and WSC for (a) 1982-1993 and (b) 2002-2008.



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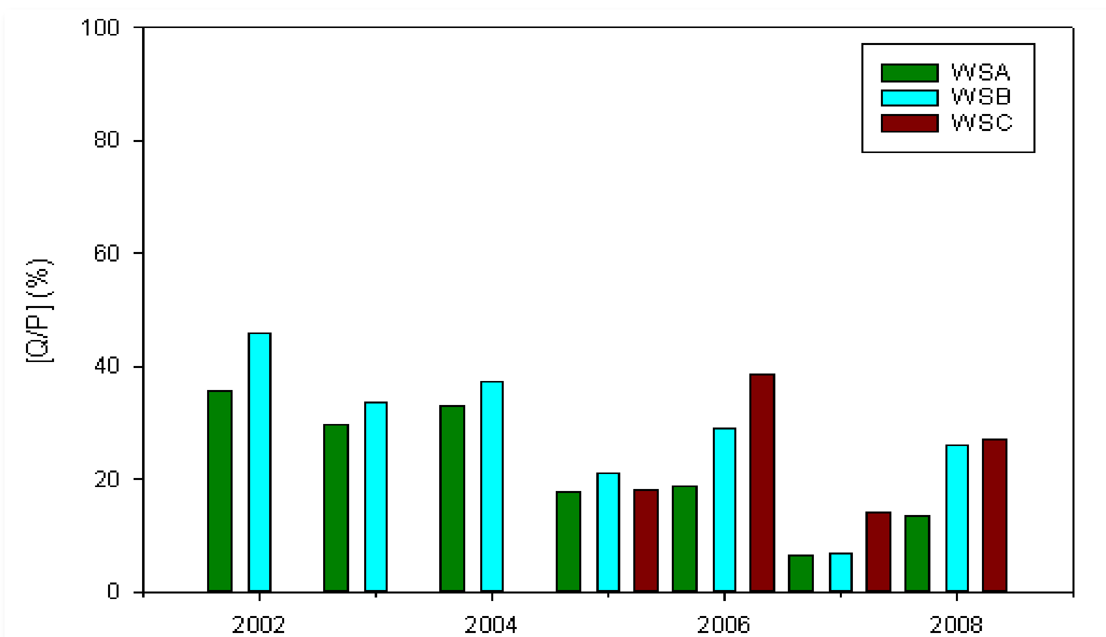

(b)

Figure 6. Average storm volumes for WSA, WSB and WSC for (a) 1982-1993 and (b) 2002-2008.

Water Quality

Statistical analysis for water quality constituents is undergoing analysis, so no statistical results are presently available. However, from Figures 7-16, it can be seen that most constituents for the harvested watersheds became elevated post-harvest and steadily aligned back with the control. The most notable of these variations is nitrate. The concentration of nitrate peaks for the two harvested watersheds in 1984 where it is 8 times higher than WSA; from 1988 onward these differences become negligible.

Principle Findings and Significance

From the analysis that has been done thus far it is clear that BMP implementation had a significant impact at mitigating some of the negative consequences that occur after harvesting. With the exception of stormflow, all of the evaluated hydrograph characteristics were aligned or nearly aligned with the control by the end of the study. Conversely, many of the hydrograph characteristics in WSC were still elevated at the end of the study 25 years after harvest. These results suggest that implementing forestry BMPs is critical to protecting the hydrology and water quality of forested headwater streams.

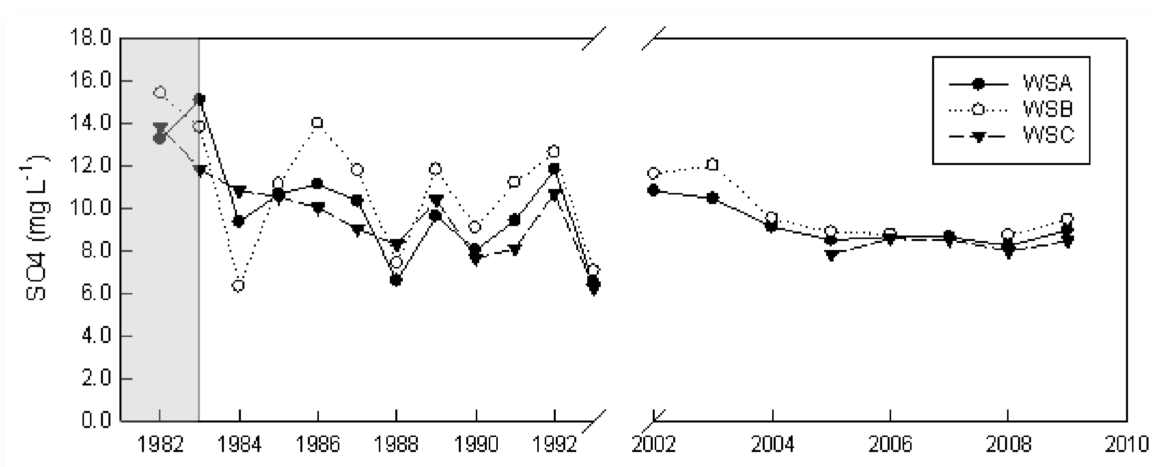

Figure 7. Average annual SO_4 concentrations for WSA, WSB and WSC.

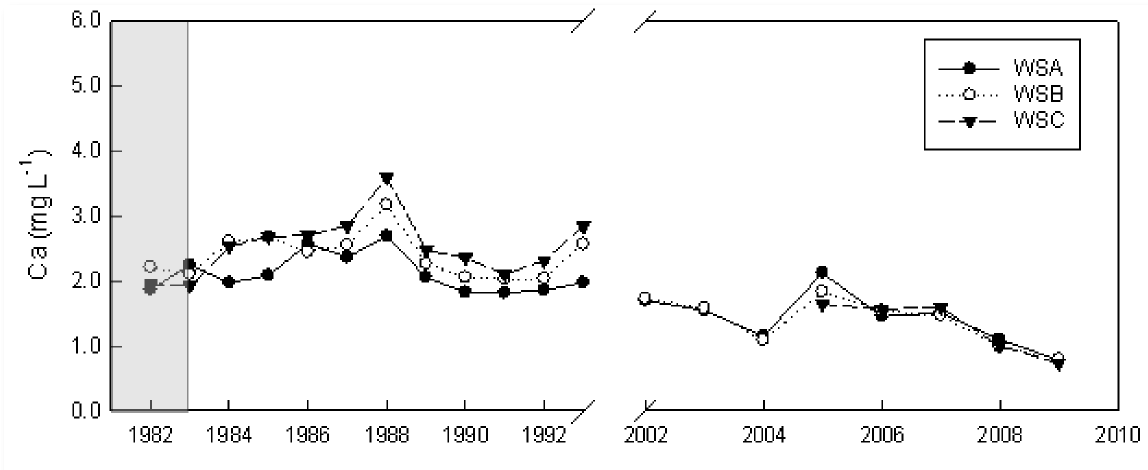

Figure 8. Average annual Ca concentrations for WSA, WSB and WSC.

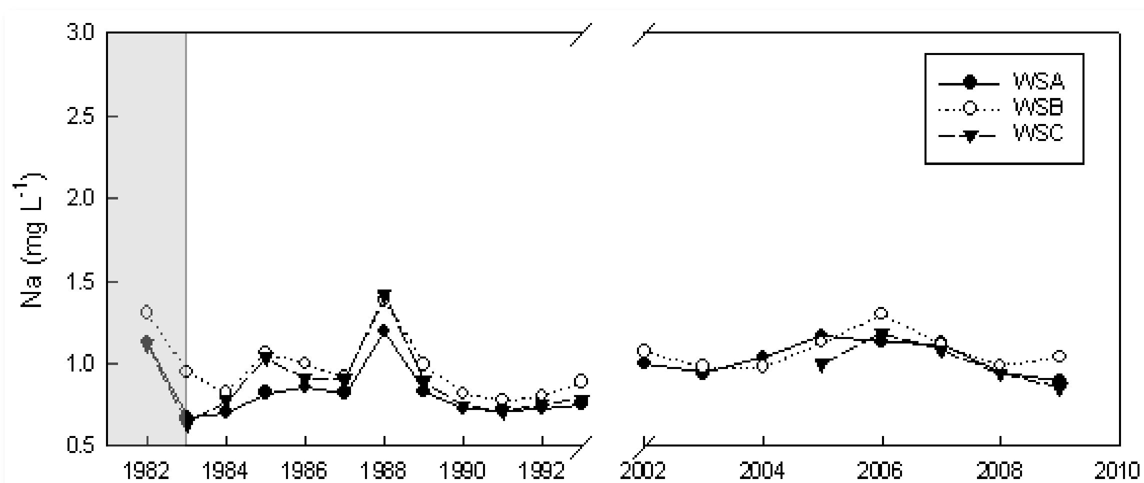

Figure 9. Average annual Na concentrations for WSA, WSB and WSC.

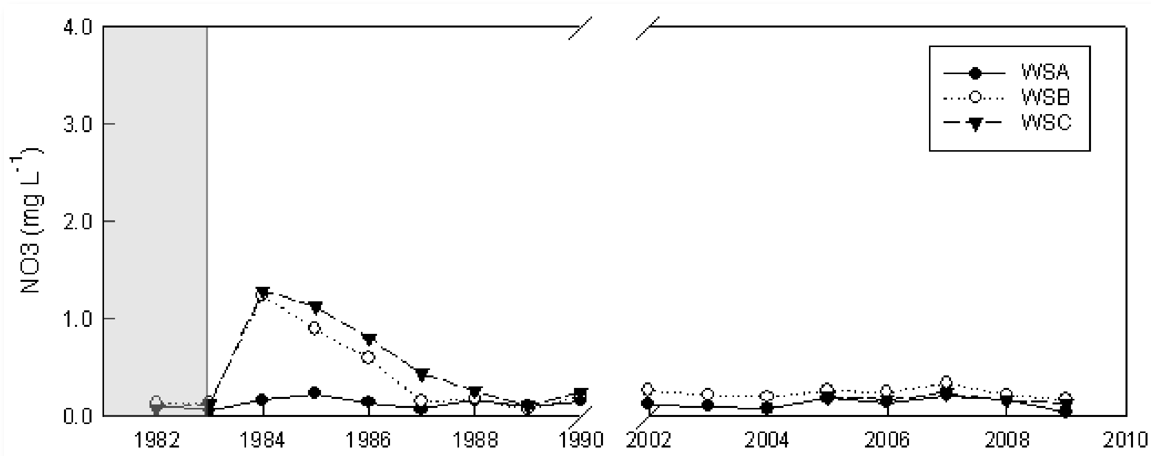

Figure 10. Average annual NO_3 concentrations for WSA, WSB and WSC.

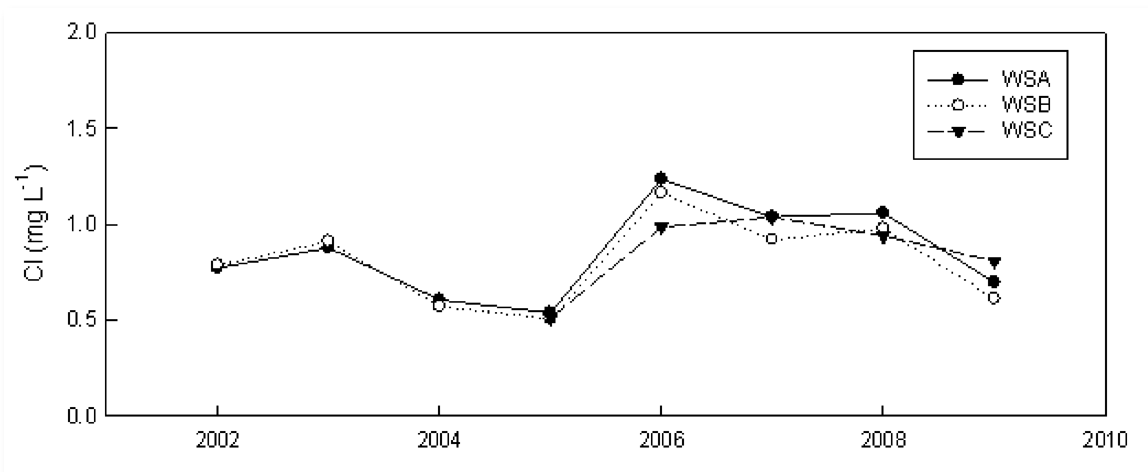

Figure 11. Average annual Cl concentrations for WSA, WSB and WSC.

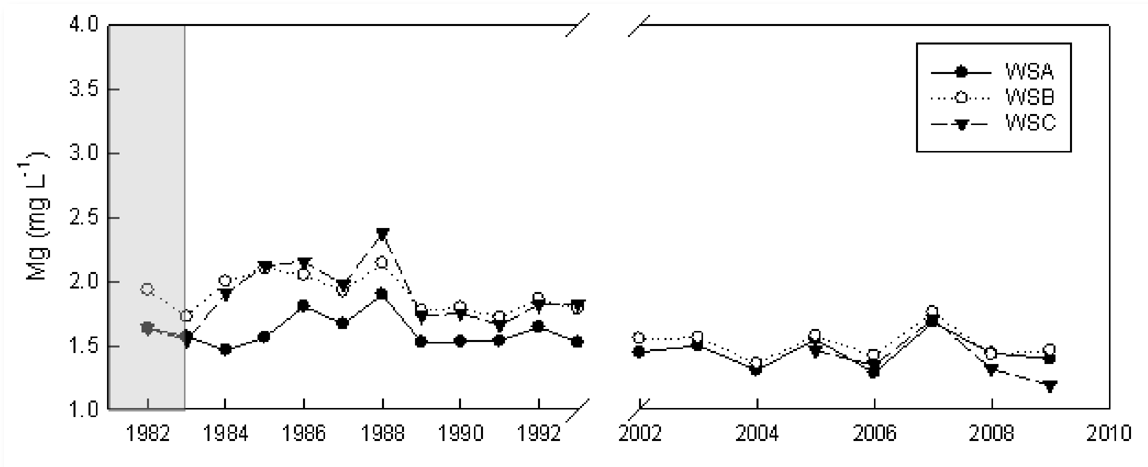

Figure 12. Average annual Mg concentrations for WSA, WSB and WSC.

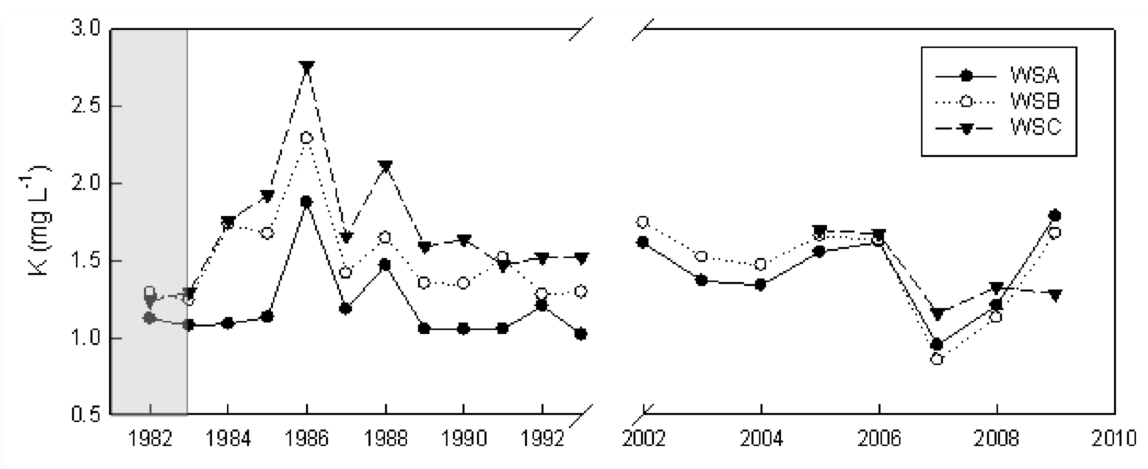

Figure 13. Average annual K concentrations for WSA, WSB and WSC.

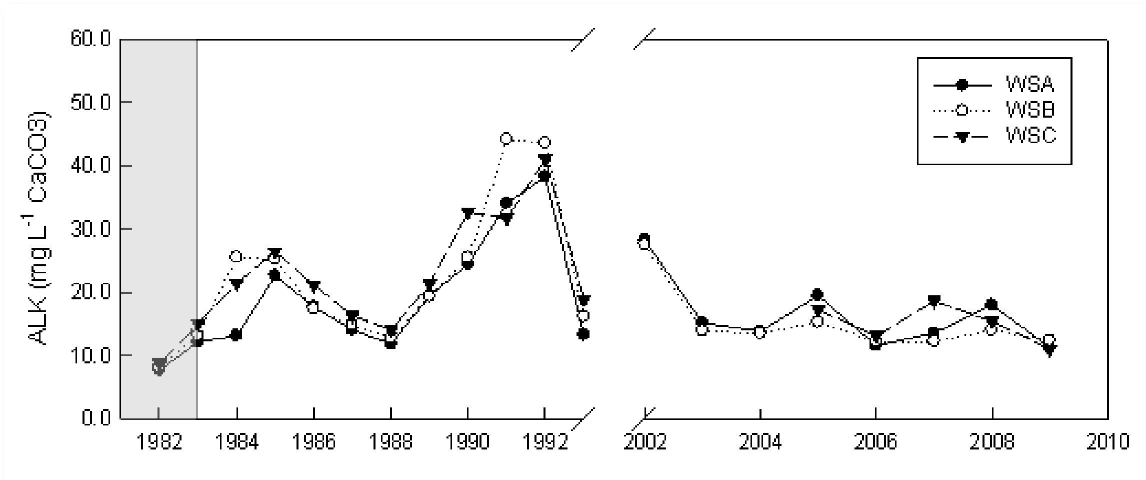

Figure 14. Average annual alkalinity concentrations for WSA, WSB and WSC.

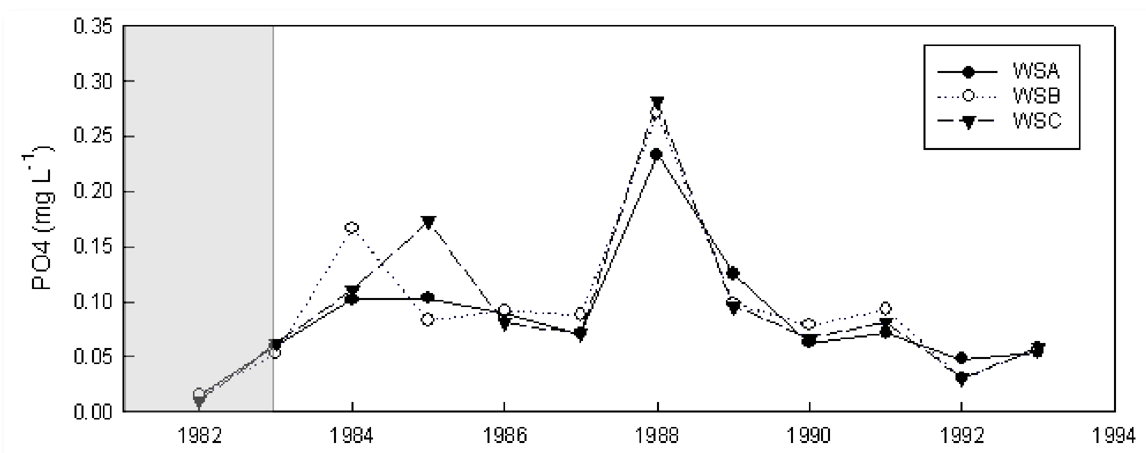

Figure 15. Average annual PO_4 concentrations for WSA, WSB and WSC.

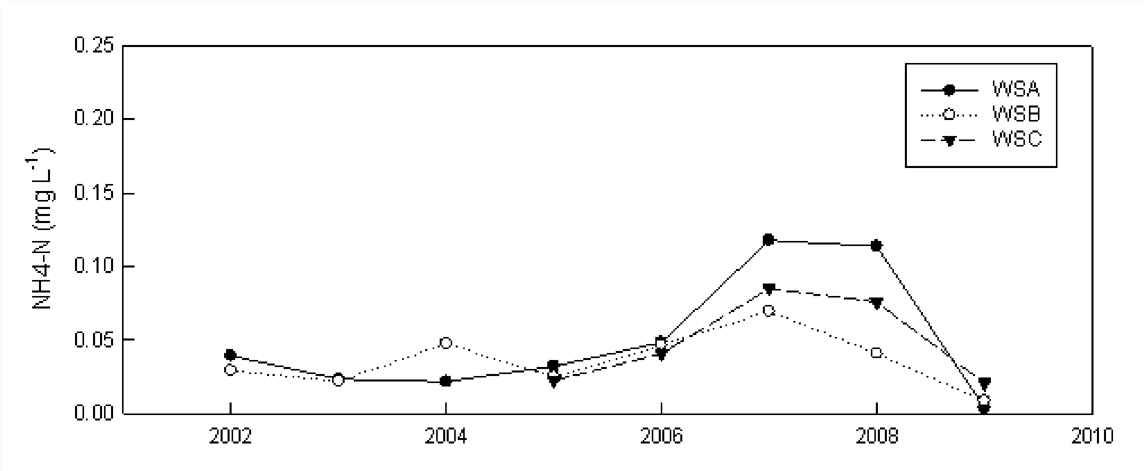

Figure 16. Average annual NH_4 concentrations for WSA, WSB and WSC.

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Geospatial evaluation of sewer gas to indoor air pathways relevant for vapor intrusion

Basic Information

Title:	Geospatial evaluation of sewer gas to indoor air pathways relevant for vapor intrusion
Project Number:	2015KY241B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 3 & 6
Research Category:	Ground-water Flow and Transport
Focus Category:	Toxic Substances, Groundwater, Water Quantity
Descriptors:	None
Principal Investigators:	Kelly G Pennell

Publication

1. Willett, E. and K. Pennell, 2016, Geospatial Evaluation of Sewer Gas to Indoor Pathways Relevant for Vapor Intrusion, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 57.

Geospatial Evaluation of Sewer Gas to Indoor Air Pathways Relevant for Vapor Intrusion

Problem and Research Objectives

Aging sewer lines are a major challenge for modern cities. Cracked, broken, or otherwise deteriorated sewer lines can be penetrated by water from outside the sewer. The unintentional entering of groundwater or runoff (e.g. inflow and infiltration (I&I)) into sewer systems is a well-known management challenge due to both the increased volume of water being transported by the sewer, as well as the larger volume of water that requires treatment. A less known, but important, challenge associated with aging sewer lines is when contaminated water and vapors enter the deteriorated sewer lines near hazardous waste sites. In this situation, the sewer system can serve as a preferential pathway transporting contaminated water and vapors long distances. Deteriorated sewer components provide pathways for contaminated groundwater and vapors to enter (and leave) the sewer system (Figure 1).

Smoke testing verifies leaks in sewer

Source: City of Denham Springs (http://www.cityofdenhamsprings.com/newsletter31.html)

Separated sewer pipe

Source: City of Palo Alto (http://paloaltofreepress.com/city-hides-broken-gas-and-water-lines-clogged-sewers/)

Rootlets

Source: Yorba Linda Water District (https://www.ylwd.com/your-sewer-service/tips-to-save-lines/)

Figure 1. Deteriorated sewer components

Deteriorated sewer lines are not only a concern outside of homes, but also within homes because plumbing fixtures are often poorly maintained. In most buildings, plumbing traps prevent sewer vapors from directly venting to the indoor air. Therefore, in buildings where plumbing is appropriately installed and maintained, sewer gas infiltration is less likely. However, if traps and/or drains become dry, or if joints and fittings are not properly working, sewer gas vapors can enter indoor spaces at concentrations that pose health risks.

The sewer gas to indoor air pathway was previously shown to be important during vapor intrusion field studies in Massachusetts (Pennell et al, 2013), Denmark (Riis et al, 2010), and Pennsylvania (Hawkins, 2008). This research project investigates the sewer gas to indoor air pathway relevant for vapor intrusion scenarios by evaluating available GIS maps of sewer lines and geospatial information about hazardous waste sites within Kentucky, particularly Fayette

County. Maps delineating areas where contaminated groundwater (and vapors) from hazardous waste sites may be entering aging sewer lines have been generated. These maps illustrate which areas are most susceptible for sewer systems to act as preferential pathways for transporting hazardous waste contaminants long distances from the original hazardous waste sites.

Sewer gas is a generic name for a complex mixture of gases and airborne agents that result from the natural process of the decomposition of organic materials in sewage. Typically, the agents of human health concern are sulfide (H_2S), ammonia (NH_3), methane (CH_4), and to a lesser extent, carbon dioxide (CO_2). Public health risks due to these exposures are focused on acute toxicity and physical hazards resulting from explosions and, rarely, asphyxiations (ATSDR 2004). In cases where contaminated groundwater and/or vapors from a hazardous waste site are able to penetrate a sewer main, the sewer gas may also contain hazardous waste chemicals.

In additional to groundwater, illegal sump pump connections and roof downspouts add rainwater to the sewer system. Several previous studies have reported a history of dry-cleaning-related operations discharging contact water, as well as free-phase solvents to municipal sewers (e.g. State Coalition for Remediation of Drycleaner Sites, 2010). If solvent-laden material is present within a sewer line, it can result in volatile organic chemical (VOC) vapors in the sewer head-space, and it can also result in contamination surrounding the sewer line. Vroblesky et al (2011) documented the effect of leaky sewers allowing tetrachloroethene to contaminate soils adjacent to sewer lines.

Figure 2a shows the various pathways by which VOC vapors could enter a sewer. Aside from solvent-laden sludge materials serving as a source of vapors, contaminated vapors in the vadose zone can enter the sewer through deteriorated joints and/or cracks in the piping. In addition, if the sewer line is located below the groundwater table, contaminated groundwater could also enter the sewer through deteriorated joints and/or cracks. Any volatile chemicals present in the liquid within the sewer water could then partition into the vapor phase under appropriate environmental conditions. It should be noted that vapor phase partitioning would include chemicals present in the wastewater itself and/or from the chemicals present in contaminated groundwater that may infiltrate into the sewer and mix with the wastewater already within the sewer.

Once VOCs are present in the sewer, they can potentially enter an indoor space by many routes, including plumbing fixtures. Figures 2b and 2c show how the vapors within the sewer are typically contained within the sewer pipe via water traps associated with plumbing fixtures and drains. The traps prevent vapors from directly venting to the indoor air. Therefore, in buildings where plumbing is appropriately installed and maintained, sewer gas infiltration is unlikely. However, if traps and/or drains become dry, or if the wax that seals the connection between the toilet and the sewer is not properly working, sewer gas vapors may enter the indoor air space.

Methodology

Physical addresses were obtained from the Kentucky Department of Environmental Protection (KYDEP) for many hazardous waste sites in Kentucky that have ongoing groundwater contamination plumes. Using this data, a Geographic Information System (GIS) sewer map was superimposed onto the hazardous waste site locations within Fayette County. The GIS sewer map was obtained online from the Kentucky Infrastructure Authority.

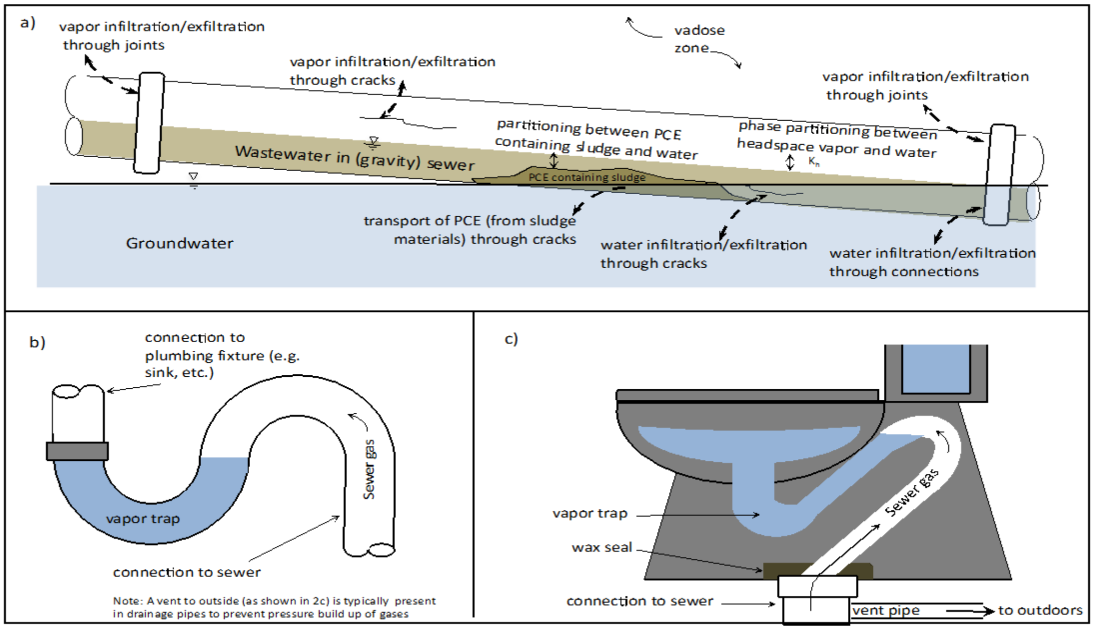

Figure 2. Sewer gas to indoor air pathways for VOCs (specifically shown for PCE) Source: Pennell et al., 2013

This map was then evaluated to determine the following attributes:

- Regulatory description
- Regulatory status (active, managed)
- Material of nearest sewer main adjacent to each site
- Construction date of adjacent sewer main
- Pipe diameter of adjacent sewer main
- Distance between each site and the nearest sewer main

A formal request was made with the Lexington Division of Water Quality to obtain the addresses of home and business owners who have called to report instances of indoor sewer gas odor. This information, when combined with the hazardous waste site and sewer line data, would provide rationale that sewer gas is able to enter indoor air spaces. Thus, if it can be shown that the connected sewer system is breach by contaminated water or vapors, then the likelihood of the indoor air spaces being contaminated is increased. The sewer odor report data has not yet been received.

GIS sewer line maps for other Kentucky counties were downloaded online from the Kentucky Infrastructure Authority. GIS sewer line maps for Jefferson County were obtained from the Louisville and Jefferson County Metropolitan Sewer District (MSD) through the Louisville/Jefferson County Information Consortium (LOJIC). Hazardous waste sites and sewer mains for other Kentucky counties, including Jefferson County, have not yet been geospatially evaluated.

Principal Findings and Significance

The generated map spatially displays areas where the sewer gas to indoor air pathway has the greatest potential to result in exposure risks. Figure 3 shows the locations of Fayette County hazardous waste sites with the sewer map superimposed. There are currently 13 active or managed hazardous waste sites in the county.

Figure 3. Fayette County active and managed sites, with sewer lines overlaid

This figure shows the distribution and general locations of active and managed hazardous waste sites and sewer lines within the county. Figure 4 shows a sample attribute table used to determine information of interest at one of the sites.

The attribute data collected for each sewer line of interest were used to assess areas of concern for increased VOC exposure risks. While the generated map spatially displays areas where the sewer gas to indoor air pathway has the greatest potential to negatively impact health, this information has also been tabulated in a single, easy to read table. Table 1 provides the recorded geospatial attributes for a sample of the contaminated sites within Fayette County.

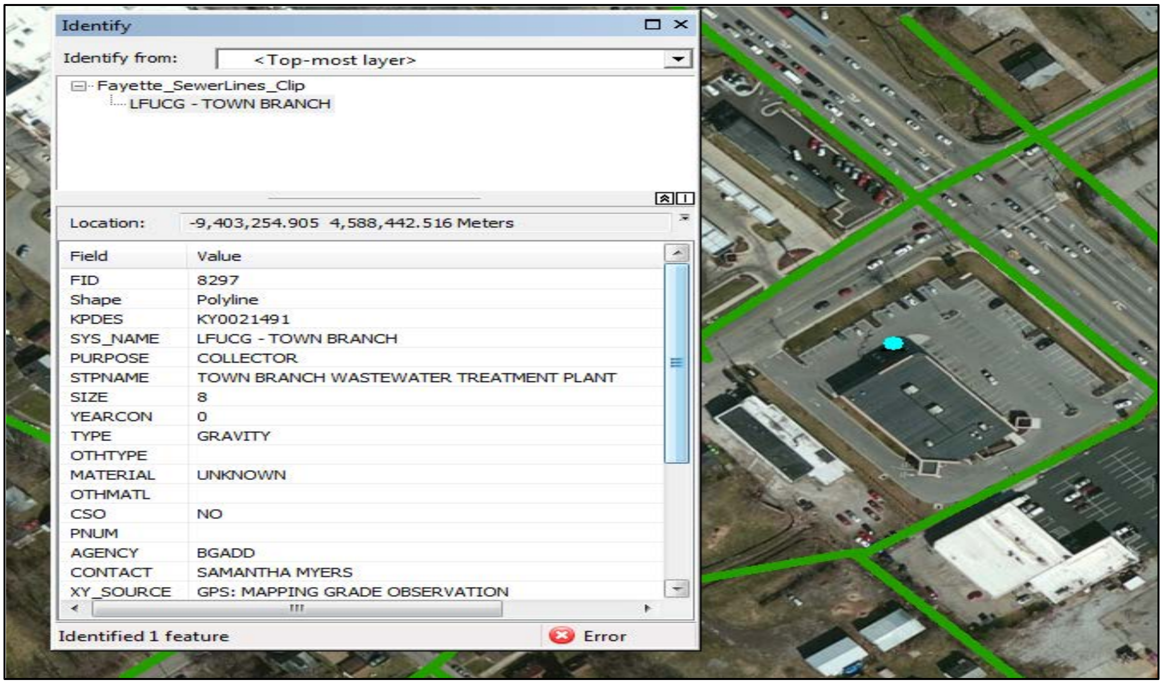

Figure 4. Attribute data of sewer line proximal to hazardous waste site

Table 1. Geospatial data for sample of contaminated sites within Fayette County

Site Name	Regulatory Description	Site Status	Sewer Material	Year Constructed	Distance to Sewer Main (m)*
Federal Medical Center	State Superfund	Active	PVC	2000	514
Crossroads Concord Custom Cleaners	State Superfund	Active	VCP	1970	28.5
Marathon Petroleum Co. LP – Lexington Terminal	Petroleum Cleanup	Active	PVC	Not given	35.8
Concord Custom Cleaners No. 087	State Superfund	Active	PVC and Ductile Iron	Not given	65.4
Link-Belt Construction Equipment Co.	State Superfund	Managed	VCP	2001	47.6
Tobacco States Chemical Co.	State Superfund	Managed	PVC	1930	16.9
Early Bird Cleaners	State Superfund	Managed	Not given	Not given	51.7

Note: PVC = polyvinyl chloride; VCP = vitrified clay pipe
*distance from the physical address not the plume edge.

There are numerous hazardous waste site locations that demonstrate potential for contaminated groundwater and vapors to enter aging and deteriorating sewer lines. “Aging” sewer lines can be defined here as those sewer lines constructed 30 or more years ago. Using this criterion, there are at least five aging sewer lines proximal to hazardous waste sites in Fayette county. For six of the 13 sites, there was no attribute data available for the year of construction for the adjacent sewer lines. Sewer material information was available for all but one adjacent sewer line.

The map generated illustrates which areas are most susceptible for sewer systems to act as preferential pathways, carrying hazardous contaminants long distance from the source locations. Aging sewer lines are more susceptible to deterioration, regardless of material. Moreover, the smaller the distance between each source location and the adjacent sewer main, the greater the probability for contaminated water (and vapors) to enter the deteriorated sewer. For homes connected to the sewer system with faulty plumbing fixtures and drains, this sewer gas to indoor air pathway may elevate the exposure risk of indoor air contamination.

The researchers plan to follow up with state and local officials for additional information to supplement the geospatial analysis. Supplementary information includes the sewer lines in Kentucky (with special emphasis on Louisville and Lexington) that are most susceptible to being breached by water and/or vapors, as well as locations of sewer gas entry into homes and buildings. Additionally, a record review will be conducted at KYDEP about specific hazardous waste sites that are of interest, based on the maps generated as part of this project. This enhanced analysis will then be used to provide recommendations for which geographic areas in the county appear most susceptible to the sewer gas to indoor air pathway resulting in increased indoor air VOC exposure risks.

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Toward rapid detection of Phytophthora cinnamomi and P. ramorum in Appalachian streams

Basic Information

Title:	Toward rapid detection of Phytophthora cinnamomi and P. ramorum in Appalachian streams
Project Number:	2015KY242B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 5
Research Category:	Biological Sciences
Focus Category:	Invasive Species, Methods, Surface Water
Descriptors:	None
Principal Investigators:	Chris Barton

Publication

1. Sena, Kenton, Ellen Crocker, Tyler Dreaden, and Chris Barton, 2016, Towards Rapid Detection of Phytophthora cinnamomi in Appalachian Streams, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 35-36.

Toward Rapid Detection of *Phytophthora cinnamomi* and *P. ramorum* in Appalachian Streams

Problem and Research Objectives

Invasive forest pathogens represent one of the most worrisome threats to forest ecosystems today. The 20th century saw the devastating extirpation of American elm and American chestnut from Appalachian forests, both at the hands of invasive pathogens. Currently, Appalachian forests are threatened by invasive pests such as emerald ash borer and hemlock wooly adelgid, and new potentially devastating pathogens are on the horizon. Among these, *Phytophthora cinnamomi* (already present in Appalachian forests) and *P. ramorum* (currently in California, but not yet in Appalachia) are particularly disconcerting pathogens of chestnut and oak species. These species are soil borne pathogens but are transmitted as zoospores by streams (Peterson et al. 2014). Streams thus represent both an important conduit for pathogen dispersal as well as an opportunity for assessment of pathogen presence in a given watershed (e.g., Reeser et al. 2011, Hwang et al. 2008).

Conventionally, *Phytophthora spp*. are detected from streamwater by baiting in-stream with susceptible plant material (e.g., rhododendron or chestnut leaves), culturing plant infection lesions on selective media (e.g., PARPH), and identifying to species using morphological characteristics and/or genetic sequences. Stream-based detection assays for P. ramorum are well-established, but conventional stream detection for P. cinnamomi has proven less effective. Researchers have suggested that P. cinnamomi zoospores are "poor swimmers," and thus less commonly baited from streamwater than soil (Steve Oaks, personal communication). This project was initiated to evaluate the efficiency of a novel stream-based detection assay employing a molecular genetics method (qPCR) from filtered streamwater samples. Conventional baiting methods will only detect viable and motile zoospores—dead or compromised zoospores will be unable to both colonize bait material and survive harsh conditions of selective media. In contrast, our proposed method should improve detection capability by permitting detection of dead and viable nonculturable zoospores, as long as the DNA is intact.

Methodology

Weekly streamwater samples (2 x 1L samples) were collected from four watersheds in the University of Kentucky Robinson Forest: Little Millseat, Clemons Fork, Coles Fork, and Falling Rock. Samples were refrigerated and filtered as soon as possible using vacuum filtration and 3μm nitrocellulose filters (Nuclepore Track-Etch Membrane, by Whatman). Filters were frozen until they could be further processed.

Phytophthora cinnamomi was isolated from soils in Robinson Forest, where *P. cinnamomi* infection of American chestnut was previously documented (Rhoades et al., 2003).

Soil samples were baited using rhododendron leaves, cucumbers, and pears; infection lesions were cultured on PARPH media and colonies resembling *Phytophthora spp*. were isolated through several passes in V8 agar. This baiting and culturing stage resulted in a total of six isolates, which were used to establish a *Phytophthora* culture collection. We extracted DNA from all six isolates and sequenced the ITS fingerprint region. Sequences of all six isolates were identical to each other, and demonstrated high identity to published sequences of *P. cinnamomi* available on GenBank and low identity to closely related *Phytophthora spp*.

After confirming that our isolates were *P. cinnamomi*, we tested the molecular genetic detection assay published by Engelbrecht et al. (2013) for sensitive and specific detection of *P. cinnamomi* from *Persea americana* rootstocks. We extracted DNA from isolates using a commercial DNA extraction kit (MoBio Ultra Clean Microbial kit) and amplified DNA using the nested LPV3 primers published by Engelbrecht et al. (2013). This assay is ongoing. After confirming that primers and thermocycling conditions are effective for amplifying DNA from *P. cinnamomi* isolates, we will test the method on DNA extracted from filtered water samples. Briefly, DNA will be extracted from filtered streamwater samples using an appropriate DNA extraction kit (MoBio Power Water DNA Isolation Kit), and DNA will be amplified using the nested LPV3 primers published by Engelbrecht et al. (2013). The method will be calibrated for quantification using a standard curve prepared from serial dilutions of a zoospore suspension. After validating this method on filtered streamwater samples, the method will be applied to the filtered samples stored in the freezer and to additional samples collected over the upcoming year. This assay will permit us to evaluate seasonal variation in P. cinnamomi abundance in streamwater. Additionally, this assay will be compared to conventional stream-baiting and culturing to evaluate efficiency and sensitivity.

In addition, *Phytophthora ramorum* is a soilborne oomycete pathogen of concern, particularly in California and southern Oregon. To investigate the utility of this detection method for *P. ramorum*, Sena is collaborating with Rizzo Lab at UC Davis in May 2016, where conventional baiting methods will be compared with our novel filtered streamwater method to evaluate relative sensitivity and efficiency.

Principal Findings and Significance

P. cinnamomi was successfully isolated from soil in Robinson Forest, in eastern Kentucky. Isolate identity was confirmed by sequencing the ITS fingerprint region and comparing to published sequences on GenBank.

A collaboration with Rizzo Lab at UC Davis was established to permit evaluation of our detection assay for *P. ramorum* in California.

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Investigation of source, fate, and transport of sediments in a karst dominated watershed

Basic Information

Title:	Investigation of source, fate, and transport of sediments in a karst dominated watershed
Project Number:	2015KY243B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 6
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Hydrology, Sediments
Descriptors:	None
Principal Investigators:	James F. Fox

Publications

1. Husic, Admin, J. Fox, C. Agouridis, J. Currens, S. Workman, W. Ford, and C. Taylor, 2016, Data and Model Investigation of a Fluviokarst System in the Bluegrass Region: Water, Sediment, and Carbon Interactions, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 13.
2. Husic, Admin, 2015, Sediment Organic Carbon Fate and Transport in a Fluviokarst Watershed in the Bluegrass Region, MS Thesis, Department of Civil Engineering, College of Engineering, University of Kentucky, Lexington, Kentucky, 171 p.

Investigation of Source, Fate, and Transport of Sediments in a Karst Dominated Watershed

Problem and Research Objectives

The erosion, deposition, and transport of fine sediments is a primary source of pollution in many watersheds. Sediment can have deleterious impacts on the aquatic ecosystem and the quality of drinking water. The sediment problem is particularly difficult in karst dominated watersheds due to the general lack of available historical knowledge and prediction tools for karst systems. Over 25% of the world obtains its water from karst aquifers and approximately 40% of Kentucky is underlain by karst topography (Fleury, 2009). Karst is a solutionally dissolved landscape that is dominated by secondary porosity *via* fractures and conduits that produce low-resistance pathways for flows within karst aquifers. Karst aquifers can transport sediment orders of magnitude faster than porous aquifers as a result of the high hydraulic conductivity of karst though the many complex pathways in karst conduits. There is a great need to focus on new research and method advancement for the source, fate, and transport of fine sediments and other contaminants in karst dominated watersheds.

Our research project aims to support eventual development of numerical models for karst aquifers, experimental representations of karst processes, and field-based investigation techniques. The methods utilized will be used to advance the scientific theory and engineering methods for predicting surface-subsurface interactions in coupled stream and conduit drainage networks.

Based on our new field and laboratory results, it is the intention to ultimately create a numerical model that works well as a predictor of the water and sediment interactions in mature karst landscapes. We believe that this model will be transferrable to other karst watersheds/aquifers with similar properties (e.g., rock era, solubility, presence of large conduits). Specifically, we chose the Cane Run watershed as a testbed for theory and method development due to the i) pronounced surface and subsurface physical coupling, ii) the extensive historical dataset available, and iii) the environmental significance of Cane Rune to the Bluegrass Region given that the karst network provides drinking water to the city of Georgetown.

The following research scope outlines the overall research plan:

1) A framework using conceptual models is needed to help understand the physical and hydro-biogeochemical processes occurring in the Cane Run testbed. The conceptual model was framed using previous research in the basin and models in the literature, however, we have added sediment losses due to upwelling and diversion of subsurface waters using sediment mass balance formula.
2) Our research identifies sediment exchange between the subterranean conduits and surface channels by using a coupled unsteady flow stream reach model with a subsurface pipe-network model. A numerical model will ultimately be developed that can quantify flow magnitude and direction in karst networks as well as sediment transport capacity. The implementation of this research scope in the current project, while including flow, was more focused on sediment transport and modeling of erosion and deposition processes in the subsurface karst. Development of a more involved, coupled hydraulic model is an on-going research investigation.

3) A new field-based tracer fingerprinting method with isotope analysis was used to analyze sediment source and fate in the Cane Run system. Sediment samples were processed through extensive preparation and isotope analysis and then discretized based on the signatures of samples from different sources using Bayesian statistical methods.
4) A new field-based sensor network using wireless environmental sensors will be eventually created to collect data and validate models. We will be applying wireless velocity bend sensors that can calculate time-averaged velocity and turbulence for karst swallets; the sensors were previously developed by Stewart, Fox, and Harnett (2012). Field investigation of swallets has been completed, but the implementation of sensors is planned for the fall of 2016.
5) Scaled experiments of the karst system will be performed in the hydrosystems laboratory to fundamentally advance the scientific theory related to karst hydraulics. We aim to understand karst processes by creating experiments with knowledge that can be transferred from the laboratory to the field. Plans for the implementation of this research scope are for the spring of 2017.

Methodology

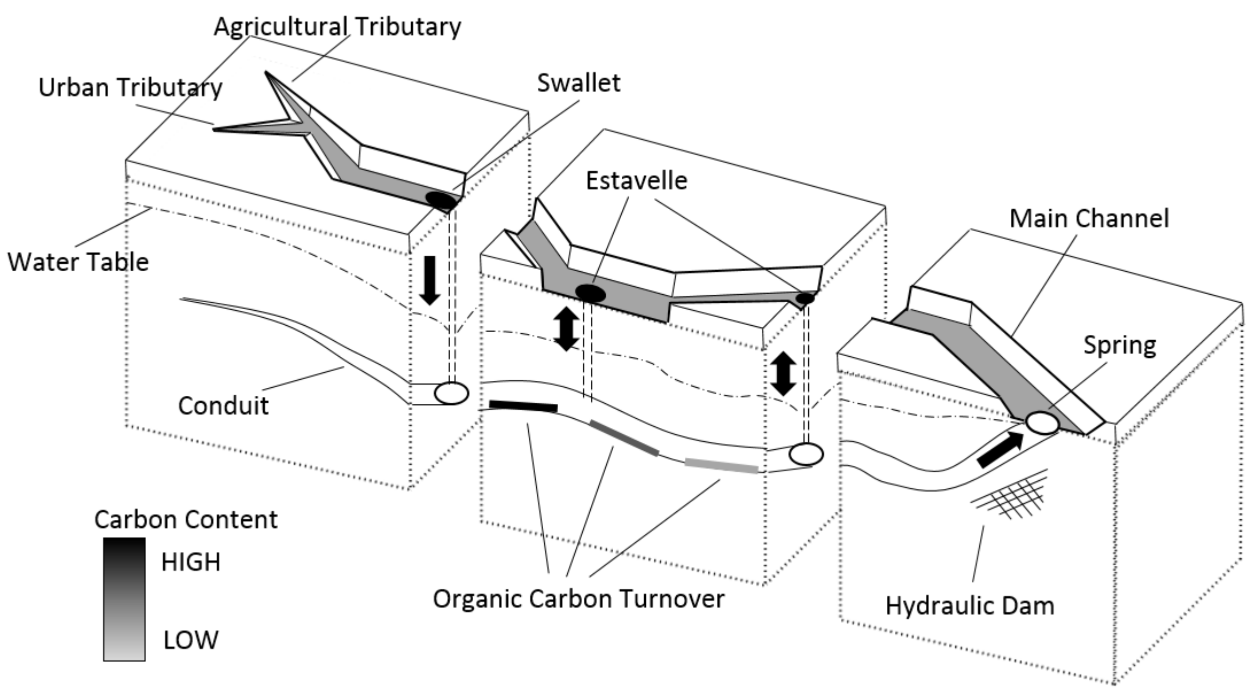
We have helped gather several years of continuously monitored data around the Cane Run watershed that will be vital to the calibration of future models as well as for inferences on the behavior of the drainage network. We have also collected weekly *in situ* sediment trap samples for several years at four locations in the Cane Run subbasin. Our collaborators, including the Kentucky Geological Survey, use a highly instrumented network (e.g., flowmeters, turbidity meters, automated pump samplers, well stage recorders) for surface and subsurface water and sediment measurements. Finally, natural biogeochemical tracers including stable carbon isotopes are being used to investigate source to sink pathways. Much of the sediment has already undergone innovative isotope methods in conjunction with the University of Arkansas Stable Isotopes Lab. In order to get a better understanding of the hydraulics occurring in natural karst networks, scale models will be created in the hydrosystems lab at UK. Experiments for both the hydraulics and the field-based sensors will be performed using a recently reconstructed flume.

We will develop a coupled open channel and pipeflow network numerical model for simulation on hourly to monthly time scales spanning karst watersheds on the order of 10 to 100 square kilometers. The model will be coded in the MATLAB numerical computing environment because of its ubiquitous application in engineering. Spatial analysis such as determining subbasins, finding contributing areas, and determining topographical gradients will be performed using ArcGIS. The numerical model will be based on the fundamental conservation of mass, momentum, and energy equations. Continuity, Manning's Equation, and the Extended Bernoulli Equation are the governing equations. The numerical model will couple several different processes such as hydrologic surface streamflow, subsurface hydraulic pipeflow in networks, groundwater flow, and sediment transport mechanisms. The coupling of the surface-subsurface network will use appropriate time-lags for inputs and outputs to the surface and subsurface network as determined by the rate information travels. The sediment transport model will be coupled to the flow model and simulate erosion and deposition within the surface fine-grained laminae (SFGL). In addition, biogeochemical organic carbon reactions will be modeled using a first-order model.

Principal Findings and Significance

A conceptual model of water, sediment, and sediment carbon transport within a coupled surface-subsurface karst drainage network has been developed (see Figure 1, Husic et al., 2016a). Connective pathways (e.g., swallets and estavelles) linking surface streams and subsurface pathways promote the pirating of terrestrially-derived sediment into the subsurface. The transport carrying capacity of the subsurface conduit is limited due to an adverse downstream hydraulic gradient causing carbon-rich sediment to fall out of suspension. During temporary deposition, epilithic heterotrophic bacteria act to oxidize labile sediment; the karst conduit becomes a biologically active pathway for sediment organic carbon in the fluvial continuum. Upon re-suspension of the SFGL sediment, the depleted carbon is exported by the conduit and recharged back into surface streams. A numerical model was constructed based on this conceptual model (Husic et al., 2016b). Physically based sediment processes coupled with biogeochemical carbon transformation processes were coupled together and applied in a karst setting for the first time.

Figure 1: Conceptual model of sediment and water transport in fluviokarst.



Results of this research show that the sediment transport carrying capacity of the phreatic karst water is orders of magnitude less than surface streams during storm-activated periods promoting deposition of fine sediments in the subsurface karst. The sediment transport carrying capacity of the conduit is sustained, on average, 2.5 times longer than the capacity in surface tributaries. The sustained energy promotes resuspension of fine sediments long after hydrologic events; numerical modelling suggests that 46% of the sediment conveyed by the karst pathway is during periods when no surface stream flow is present. Flow results indicate a one day residence time for surface-derived karst water whereas carbon results show a one year residence time for sediment. The significance of the sediment trapping mechanism in phreatic karst aquifers should not be overlooked when estimating organic matter stocks and carbon transformation in fluviokarst streams.

The surficial fine grained laminae occur in the subsurface karst system, much like surface streams, and includes deposition of a fine sediment layer coating the cave floor. Unlike surface streams, the light-limited conditions of the subsurface karst promote constant heterotrophy within an aerobic environment that promotes microbial oxidation leading to net degradation of sediment organic carbon. In addition to limited light availability, the subsurface conduit has a mean annual temperature of 2 to 3°C warmer than surface streams in the region resulting in exponential microbial growth rate (White et a., 1991). Data and modeling results point towards a 27.6 to 29.7% loss of sediment carbon due to temporary storage in the subsurface karst. The net loss of sediment carbon for the karst conduit contrasts the 50% enrichment in sediment carbon observed in a neighboring surface stream due to the sequestration of in-stream generated algal carbon (Ford and Fox, 2014).

Sediment fingerprinting was performed in the karst watershed using a stable carbon isotope ($\delta^{13}C$). Fingerprinting showed a statistical difference between inputs and outputs to the karst system (p-value $< 1\times10^{-6}$). In addition, sediment source unmixing was also performed using $\delta^{13}C$: the dominant sources of sediment organic carbon to the subsurface are derived from litter and soil. Another innovative component introduced in this model is the equilibrium exchange rate of sediment during net zero deposition/erosion. The equilibrium exchange rate improved model performance and helped extend our knowledge of karst system behavior. The numerical methods described above can be built upon in future studies related to sediment behavior in karst and even non-karst systems.

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Controlled drainage in western Kentucky: Mitigating water stress and reducing nutrient loss to surface waters in grain crop production

Basic Information

Title:	Controlled drainage in western Kentucky: Mitigating water stress and reducing nutrient loss to surface waters in grain crop production
Project Number:	2015KY244B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 1
Research Category:	Ground-water Flow and Transport
Focus Category:	Agriculture, Nutrients, Groundwater
Descriptors:	None
Principal Investigators:	Carrie Knott, Ole Wendroth

Publication

1. Snyder, Ethan and Carrie Knott, 2016, Controlled Drainage in Western Kentucky: Mitigating Water Stress and Reducing Nutrient Loss to Surface Waters in Grain Crop Production, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 27.

Controlled Drainage in Western Kentucky: Mitigating Water Stress and Reducing Nutrient Loss to Surface Waters in Grain Crop Production

Problem and Research Objectives

The four objectives of this project were to compare the effects of controlled and free tile drainage on 1) water quality (nitrate, phosphate, total N, total P, and turbidity concentration in wastewater), 2) outflow rate of agricultural wastewater, 3) crop yield and yield components between fields, and 4) the effect of drainage tile spacing on water table height, soil hydrology, and crop yield within the field in both controlled drainage (CD) and freely drained (FD) plots.

Methodology

To determine the effect of controlled tile drainage on grain crop yield, experiments were conducted in two fields in Muhlenberg county Kentucky 2014 and 2015. The fields are similar in soil type (Belknap silt loam), size, and slope and are separated by only a small drainage ditch. Agricultural drain tiles were installed at 50 foot intervals in both fields in 2000. Each field is drained to a single main tile line outlet that flows into a larger surface drainage ditch to the south west edge of the crop fields. The cooperating producer manages both fields according to University of Kentucky recommendations for a corn, wheat, and double crop soybean crop rotation.

Controlled drainage structures manufactured by Agri Drain of Adair, IA were installed at the main tile outlet of each field below the soil surface. In one field (treated field), the controlled drainage structure was managed by inserting plastic gates into the structure to raise the level of the water table in the field. Gates could also be removed from the controlled drainage structure to export water from the treated field. In the treated field, controlled drainage structures were opened only before field operations such as planting, spraying, or harvest were to take place so that compaction would not affect present or future crops. In the second field (untreated control field) the controlled drainage structure was left fully open all year in order to simulate a normal subsurface tile drained field.

Corn was planted in both fields in early May 2014 and harvested in September. Winter wheat was planted in fall 2014 and harvested in June 2015. No treatment was applied to the winter wheat crop so that wheat yield would not be affected by high soil moisture levels through the winter months. Double crop soybean was planted in the wheat stubble in both fields in July 2015 and harvested October 2015.

Grab water samples were taken in order to determine differences in the amounts of nitrogen and phosphorous leaving the field through each tile drainage system at two sampling times: May 15, 2014 and August 14, 2015. Sixteen ounce plastic sample containers, pre-washed with 1N sulfuric acid, were provided by McCoy and McCoy Laboratories of Madisonville, Kentucky. The containers were held under the stream or drip of water flowing from the respective main tile line outlet until the container was full. All water samples were kept on ice during transport to the laboratory. The samples were analyzed for nitrate as N, nitrite as N, orthophosphates as P, phosphate calc analyte, total phosphorous, total Kjeldahl nitrogen, and total nitrogen calc analyte.

Grain yield was determined at the plot level from sixteen locations in each field by hand harvesting corn and soybean in 2014 and 2015, respectively. The sixteen locations were 0 ft., 12.5 ft., 25 ft., and 37.5 ft. from a respective drainage tile. Hand harvest of corn was conducted September 24, 2014 by removing every ear from corn plants in 10 ft. of 2 rows at each of the 16 locations. Harvest corn ears were weighed. Corn kernels were shelled from the ear to determine grain moisture with a Dickey-John Grain Analysis Computer (GAC) 2100. Total grain yield was adjusted to 15% moisture for each plot. Soybean hand harvest was conducted November 2 and 3, 2015 by cutting every plant from 5 foot wide by 10 foot long areas at each of the 16 locations. Soybean plants were placed into burlap bags, transported to the University of Kentucky's Western Kentucky Research and Education Center, and hand fed through a small plot combine to separate soybean seed from all other aboveground biomass. Soybean seed samples were weighed and analyzed for grain moisture with a GAC 2100. Grain yield was adjusted to 13.5% moisture for each plot. The producer also completed yield estimates at the field level from both the control and treated fields by weighing total grain from each field separately after harvest with a combine.

Principal Findings and Significance

We originally proposed that water quality testing would be completed each month and/or after each significant rain event within the year. Unfortunately, the graduate student that began work on this study had health issues that prevented completion of the study and each tile line outlet was sampled just once in 2014. A second graduate student picked up the study beginning mid-summer 2015, but only one grab sample was collected from each field. There was very little rainfall through the fall of 2015, therefore, no samples were collected during this period. Additionally, in fall 2015 our farm cooperator asked that we no longer collect water quality data from this site.

No strong conclusions could be made from the four water quality grab samples that were collected for the study (Table 1). It appears that nutrient levels in drainage water were very similar between the treated and control fields when both fields were allowed to flow freely. When the 2014 samples were collected, both fields were draining freely due to saturated soil conditions that would have had negative impacts on corn yield had the water been allowed to stay in the field. When the 2015 water quality samples were collected, the treated field had all gates installed into the controlled drainage structure and the water flow from the main tile outlet was merely a drip. The drainage structure was open for the control field at the time of the 2015 water quality samples and a steady stream of water was flowing from the main tile outlet. Higher levels of nutrients were found in the control field's water sample than in the treated field's water sample in 2015 as shown in Table 2.

The results of the grain yield measurements indicate that implementing controlled drainage has the opportunity to increase grain crop yields in the state of Kentucky. Our study showed a 9% increase in hand harvested grain yield and a 12% increase in producer estimated yield when the drainage tile was closed in the controlled drainage field (Table 3).

If repeated, this study would be of value to producers growing grain crops on tile drained soils in Kentucky and other areas of the country with soil types similar to Belknap silt loam. The study has shown after only two years of corn and soybean yield data that conservation of water through the use of controlled drainage can positively influence grain crop yield at our site in Kentucky. On average the most limiting factor for grain crop yield in Kentucky is water. Many producers in the state are controlling this water deficit that their crops sometimes experience with pivot irrigation. However, not all areas of the state have access to adequate amounts of water for pivot irrigation. In areas of Kentucky where pivot irrigation is not an option, controlled drainage looks to be a possible alternative system to increase water availability to grain crops and in turn increase yield.

Table 1. Results from water quality samples taken May 15, 2014 from controlled drainage (CD) and freely drained (FD) field.

Analyte	**Result**	
	CD	**FD**
Nitrate as N	**18.7 mg/L**	**13.7 mg/L**
Nitrite as N	**Not detected**	**Not detected**
Orthophosphate as P	**0.1 mg/L**	**0.09 mg/L**
Phosphate calc analyte	**0.34 mg/L**	**Not detected**
Phosphorus-Total	**0.11 mg/L**	**0.07 mg/L**
Total Kjeldahl nitrogen	**Not detected**	**Not detected**
Total nitrogen calc analyte	**19 mg/L**	**14 mg/L**
Turbidity	**2.78 NTU**	**2.43 NTU**

Table 2. Results from water quality samples taken August 14, 2015 from controlled drainage (CD) and freely drained (FD) fields.

Analyte	2015 Result	
	CD	FD
Nitrate as N	0.4 mg/L	5.9 mg/L
Nitrite as N	Not detected	Not detected
Orthophosphate as P	Not detected	0.07 mg/L
Phosphate calc analyte	Not detected	0.31 mg/L
Phosphorus-Total	Not detected	Not detected
Total Kjeldahl nitrogen	Not detected	Not detected
Total nitrogen calc analyte	Not detected	5.9 mg/L
Turbidity	1.19 NTU	0.96 NTU

Table 3. Percent grain yield for the controlled drainage (CD) field expressed as a percentage of the freely drained (FD) control field for the hand-harvested and producer-harvested grain yields.

Treatment	Hand-Harvested Yield	Producer Estimated Yield
	% of Control	% of Control
CD field	109	112
FD field (control)	100	100
P-value	0.0163	0.0292

Examinng the impacts of valley fills on stream water quality and amphibian and macroinvertebrate communities in southeastern Kentucky

Basic Information

Title:	Examinng the impacts of valley fills on stream water quality and amphibian and macroinvertebrate communities in southeastern Kentucky
Project Number:	2015KY245B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 5
Research Category:	Water Quality
Focus Category:	Water Quality, Ecology, Toxic Substances
Descriptors:	None
Principal Investigators:	Stephen Richter

Publications

1. Bourne, John, 2015, Examining the Impacts of Valley Fills on Amphibian and Aquatic Insect Communities in Southeastern Kentucky, MS Thesis, Biology Department, College of Arts and Sciences, Eastern Kentucky University, Richmond, Kentucky, 80 p.
2. Bourne, John and Stephen Richter, 2016, Examining the Impacts of Valley Fills in Stream Ecosystems on Amphibian and Aquatic Insect Communities in Southeastern Kentucky, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky p. 39.

Examining the Impacts of Valley Fills on Stream Water Quality and Amphibian and Macroinvertebrate Communities in Southeastern Kentucky

Problem and Research Objectives

The specific objective of this research was to determine the impacts of valley fills on aquatic ecosystems of Appalachia by comparing impacted streams with reference streams in southeastern Kentucky. This was measured and compared in terms of water and habitat quality, and in abundance and diversity of stream salamander and aquatic insect communities. This research also evaluated the differences in the level of selenium between reference and valley-fill streams. The original objectives of this research included measuring the accumulation of a suite of metals and contaminants in collected water samples and in the tissue of stream salamanders, this was reduced and a greater concentration was placed on measuring the accumulation of selenium in water samples and stream salamander tissue.

Methodology

In the spring of 2014 (March-June) the investigators developed methodology for evaluating streams for water and habitat quality, salamander richness and abundance; and aquatic insect richness, abundance, and percent E.P.T. taxa (Ephemeroptera, Plecoptera, Trichoptera). Sampling occurred in eight reference quality streams in state preserves and national parks throughout southeastern Kentucky. In the spring of 2015 (March-June) sampling occurred in five reference headwater streams and ten headwater streams impacted by valley fills that are geographically paired. This represents a departure from the original proposal which stated five of each treatment would be sampled.

Reference sites (RS) consisted of mature, forested first-order headwater streams considered to be some of the best quality headwater streams in the region based on discussions with personnel from the Kentucky Division of Water, Kentucky State Nature Preserves, and Kentucky Natural Lands Trust. Stream catchment size varied from 2.46-3.52 sq. miles in RS and 1.69-4.23 sq. miles at valley fill sites. The forest stands were at least 70 years old, including old-growth forest, and the headwaters of the streams and sampled stream reaches were within national and state protected area boundaries. Valley fill sites consisted of first-order streams, with sampled stream reaches located within 500 meters of the valley fill site. Sampled valley fill streams were located in second-growth forest of varying maturity, geographically located within 15 km of reference sites. Within each stream, a 100-m transect was positioned and habitat sampling occurred four times in 1-month intervals in the spring (March–June) of 2015, while collection of salamanders occurred three times in 1-month intervals (April-June 2015), with aquatic insects (March 2015) and water sample (May 2015) collection consisting of a single sampling event. Water samples taken for metal analysis only required a 15- ml sample vs. a 250-ml sample as stated in the proposal.

Habitat Sampling

The dominant mesohabitat, cover types, canopy closure, water depth (cm), stream width (m), and water temperature were measured at three sampling points corresponding to the upper, middle, and lower points of each reach (i.e. at 0, 50, and 100 m) per sampling event. At each point, the proportion of dominant mesohabitat types (run, riffle, and pool) and cover types (silt, sand, gravel, pebble, cobble, boulder, muck, and detritus) were estimated based on a view looking directly down upon the stream (Jung, 2002; Wood and Williams, 2013). The amount of canopy closure was visually estimated using a spherical densiometer. Environmental variables including the pH, conductivity, and dissolved oxygen, were also recorded at the upper, middle, and lower (i.e. 0-, 50-, and 100-m) point of each reach per sampling event using an YSI 556 Multi-probe meter (Yellow Springs Instruments; Yellow Springs, Ohio). Collection of water samples for metal analysis consisted of collecting 10 ml of stream water approximately 2 cm below the surface from three points (i.e. 0, 50, and 100 m) of each sampling reach. Water samples were placed immediately on ice and chilled no longer than 48 hours before acidifying samples with the addition of 100 µL of concentrated HNO_3.

Salamander Sampling

Within each stream, a 10-m reach that included the mesohabitat of a run, riffle, and pool was intensively sampled with all cover objects being searched for salamanders. Immediately upstream of the 10-m reach a 40-m reach was less intensively sampled with one cover object of at least 65 mm searched at every meter point of the reach. Within this 50 m, salamander abundance sampling also consisted of a 1-m terrestrial component on both sides of the stream to quantify adult salamanders utilizing the immediate habitat surrounding the stream in which all rocks and cover objects of at least 65 mm length and width were searched within the 10-m reach and at each 1-m point in the upstream 40-m reach. For each individual captured, the age class (larvae or adult), species identification, and whether the individual was captured within the stream or within the terrestrial sampling component was recorded.

Salamander Selenium Analysis

To standardize sampling, the tail of salamanders were removed 20 mm above the tip using a sterile blade and weighed, following rinsing with stream water and body condition measurements (Bergeron et al., 2010b). An attempt was made to collect 15 tail clips from each stream site to be used in metal analysis. However, due to the low abundances found at several valley-fill sites less than 15 tail clips were collected. A total of 165 tail clips were taken and used in selenium analysis. The clipped tail was kept cool at 4 C^o before being lyophilized and the dried weight was recorded (Bank et al., 2005). Clipped tails were then digested in 750 µL of trace metal grade nitric acid HNO_3 in fluoropolymer digestion vessels using a microwave digestion system (MARS-5, CEM) according to U.S. EPA method 3052 (U.S. E.P.A., 1996). After digestion, the samples were brought to a final volume of 15ml with >18 MΩ deionized water. Analytical method blanks and the standard reference material TORT-2 lobster heptopancreas (National Research Council of Canada, Ottawa, ON) were included in each digestion batch. Selenium analysis was performed on diluted samples through Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) according to U.S. EPA method 6020a (U.S. E.P.A., 1998).

Aquatic Insect Sampling

Aquatic insects were sampled (March 2015) with four replicate Surber samples (0.09 m^2, 600 µm mesh) randomly stratified along the 100-m stream reach. All Surber samples were collected within the thalweg of a riffle mesohabitat within the stream. Collected aquatic insects were separated by site into polyethylene bags and preserved in 70% ethanol before being transported to the laboratory for identification to Family using keys in Aquatic Insects of North America (4^{th} edition; R.W. Merritt, K.W. Cummins, and M.B. Berg).

Principal Findings and Significance

We expected that valley fills within streams would negatively impact stream quality and salamander and macroinvertebrate communities. We also expected that the water quality of sampled streams would be correlated and predict for salamander and aquatic insect communities, thus providing valuable predictive information for how to best conserve Kentucky streams and there biota. Results of this study have followed our original hypotheses as water and habitat quality was found to be significantly lower in valley-fill streams, and a less abundant and diverse community of salamander and aquatic insects has been observed at valley-fill streams. This research has found that these communities appear to be predicted by low conductivity, low amounts of silt, and a higher percentage of canopy closure around a stream. These factors were not found at valley-fill sites that had 21x greater conductivity, 13x greater presence of silt in the stream, and by a significantly lower amount of canopy closure at the sampled stream site. Significantly higher levels of selenium were detected at valley-fill sites for both collected water samples and salamander tissue samples, including levels that exceed threshold levels set by the EPA.

Results from this study provide further evidence of depressed aquatic insect and salamander communities, and impaired habitat and environmental quality in streams impacted by valley fills. Previous studies have evaluated salamander (Wood and Williams, 2013; Muncy et al., 2014) or aquatic insect communities (Pond et al., 2008; Pond 2010), or environmental characteristics (Metts et al., 2012), but to date we know of no studies that have evaluated these parameters simultaneously in these systems. By approaching the issue of the health of Appalachian streams through multiple research questions, this study provides a broader understanding of the effects of valley fills on the health of salamander and aquatic insect communities and highlights the reduction in valley-fill stream quality and function.

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Relationships between water quality and the fish community in Kentucky Lake

Basic Information

Title:	Relationships between water quality and the fish community in Kentucky Lake
Project Number:	2015KY246B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 1
Research Category:	Biological Sciences
Focus Category:	Surface Water, Water Quality, Methods
Descriptors:	None
Principal Investigators:	Timothy Spier

Publication

1. Spier, Timothy, Allison DeRose, Bradley Hartman, 2016, Does Light Penetration Affect the Pelagic Fish Community in Kentucky Lake, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 79.

Relationship Between Water Quality and the Fish Community in Kentucky Lake

Problem and Research Objectives

Kentucky Lake provides a valuable recreational and commercial fishery for the Western Kentucky region, and an understanding of the water quality of Kentucky Lake is essential to properly manage this ecosystem. The availability of light is a crucial water quality parameter, since light is necessary for photosynthetic organisms. Light is also essential for sight-feeding organisms, such as small fish. Many things can degrade water quality and reduce the availability of light in the water. Reduced light penetration can have cascading, long-lasting effects on the rest of the aquatic ecosystem. Thus, studying the water quality of Kentucky Lake and the existing fish community can lead to greater understanding of the current ecosystem.

Most fish species are zooplanktivorous during some portion of their life cycle. While a few species are zooplanktivorous as adults (such as the invasive Bighead Carp *Hypophthalmichthys nobilis*), most all native fish species in Kentucky Lake are only zooplanktivorous during their juvenile life stage. The juvenile life stage is critical for fish species, and excess mortality during this life stage can have lasting effects on the fish community. Juvenile fish must eat constantly (because they are only eating small zooplankton which do not have much energy) so that they can grow to a size which makes them less vulnerable to predation. These small, young fish are mostly sight feeders, so any change in water quality which reduces light penetration could have a disproportionate influence on the zooplanktivorous juvenile fish.

Although factors such as temperature are most often thought to control year class strength in young fish, few studies have looked at how water quality influences juvenile fish. For example, little is known how light penetration affects young fish, even though these fish are very reliant upon light for sight feeding. Sampling small, juvenile fish and coordinating those samples with other ongoing water quality sampling should lead to a greater understanding of the dynamics of the Kentucky Lake ecosystem and its relationships with water quality.

This project will study the relationship between water quality including light penetration on small, pelagic, juvenile fish in Kentucky Lake. The Hancock Biological Station (HBS) of Murray State University collects bi-weekly water samples at several locations in Kentucky Lake. Sampling of the small, pelagic fish community will be coordinated with the HBS water quality sampling in order to look for effects on these small fish. Specifically, turbidity and Secchi depth samples will be compared to trawl samples of juvenile fish to determine how reduced light penetration may affect these fish.

Methodology

Trawl sampling for small, pelagic fish will be conducted at two of the HBS sampling locations at the same time that HBS conducts its water quality sampling. One site will be in a large embayment, and the other site will be in the main channel. The embayment site is more protected from the wind than the channel site, so a large difference in light penetration should exist between the two sites. Since the small, pelagic fish we seek tend to be found in the upper portion of the epilimnion, we must use a surface trawl to collect these fish. Sites will be sampled bi-weekly. All fish catch will be identified and measured (length and weight). The numbers, biomass, and species composition of the fish catch will be compared to water quality data obtained by HBS.

Currently, we are still unable to sample fish because we have not yet received the surface trawl. Benthic trawling commenced in September 2015. However, after only a few samples, we snagged the benthic trawl on the bottom and were unable to retrieve it. Thus, we have no benthic trawl results and we are still waiting for the surface trawl, so we have not yet completed the fish sampling.

Principal Findings and Significance

The surface trawl was ordered but still has not been received. The manufacturer has sent part of the trawl and indicates that the remaining parts should be coming soon. Benthic trawl sampling commenced in September 2015, and very few samples were obtained before this trawl was lost. Too few deep samples were taken to report any preliminary findings.

Since the original plan was to conduct a shallow trawl bi-weekly from March through August (12 trips), we still plan to obtain at least 12 samples once the entire shallow trawl net is available. The regualar HBS water quality sampling continues, so we will be able to coordinate our trawling with their water sampling. We will eventually be able to examine the effect of light penetration on small, pelagic, juvenile fishes in Kentucky Lake.

Measuring water quality and subsurface restoration effects along Obion Creek floodplain, western Kentucky

Basic Information

Title:	Measuring water quality and subsurface restoration effects along Obion Creek floodplain, western Kentucky
Project Number:	2015KY247B
Start Date:	3/1/2015
End Date:	2/29/2016
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Congressional District:	KY 1
Research Category:	Water Quality
Focus Category:	Geochemical Processes, Nutrients, Water Quality
Descriptors:	None
Principal Investigators:	Gary E. Stinchcomb

Publications

1. Casselberry, A. and G. Stinchcomb, 2015, Buried Soils as an Important Control of C Storage along Human-Impacted Landscapes in Kentucky, USA, in Geological Society of America, Abstracts with Programs, 47(7), p. 598.
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3. Stinchcomb, G. A. Casselberry, and A. Smith, 2016, Buried Soils are an Important Chemical Interface Controlling Mineral Weathering and Solute Gradients along River Corridors, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 55.

Measuring Water Quality and Subsurface Restoration Effects Along the Obion Creek Floodplain in Western Kentucky

Problem and Research Objective

This project was designed to examine how riparian restoration affects surface and subsurface water quality along the Obion Creek restoration complex in western Kentucky. This research objective was challenged by access issues. Thus, we formulated an additional research objective focused on soil moisture and pore-water quality as related to the growth and maintenance of xero-hydric flatwood (XHF) bottomland habitats in Clarks River National Wildlife Refuge (CRNWR).

The CRNWR research objective is to examine how the physical and mineralogical properties of soils affect the pore-water dynamics in the near surface horizons of an XHF site. This study proposes to compare an XHF site with other non-XHF habitats to better understand how soil pore-water dynamics compare between XHF and non-XHF sites, which will add value to best management practices for restoring XHF habitats at human-impacted sites.

Methodology

Access proved to be a challenge for installing porous-cup lysimeters along a portion of the Obion Creek restoration complex. Because of this challenge, we redirected our water-quality study to an XHF site along the east fork of the Clarks River, within the Clarks River National Wildlife Refuge. Samples were not taken using a direct core method, rather using a hand-held bulk density core sampler. Six porous-cup lysimeters were installed at depths ranging from 0.16 to 1.88 m below the forest floor. Pore-water chemistry was analyzed using wet-oxidation, flow injection analysis colorimetry and electrochemistry. Because the Hancock Biological Station's isotope mass spectrometer was not operational during the performance period, carbon isotope samples of soil organic matter were prepared and shipped to the Baylor University stable isotope laboratory.

Principal Findings and Significance

Obion Creek study site: Although lysimeters were not installed at the Obion Creek restoration complex as planned, the soil coring results show that a substantial carbon (C) stock exists below the floodplain surface within buried alluvial and wetland soils (Fig. 1) (Casselberry and Stinchcomb, 2015). This is significant in that many models of carbon cycling and storage do not factor underground variability in C stocks due to soil burial. Future work will hope to resolve how depth trends of dissolved organic carbon (DOC) at the Obion site vary with respect to the buried soils.

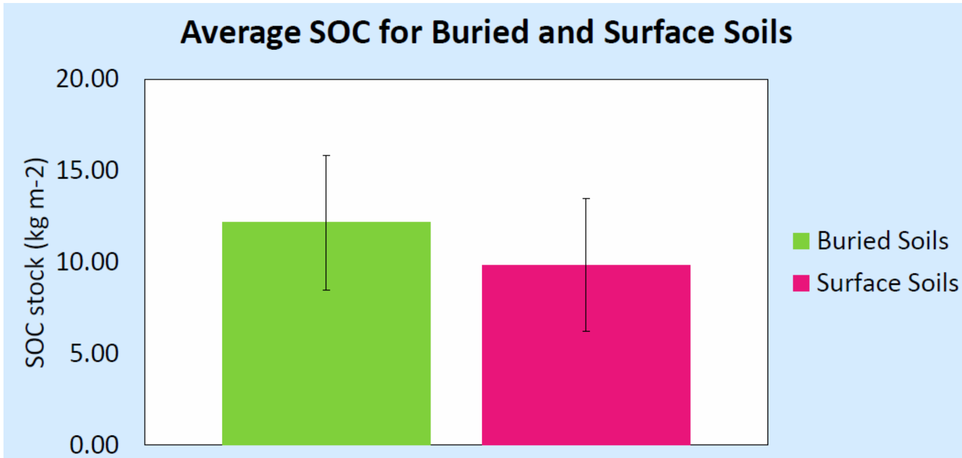

Figure 1. Average soil organic carbon (SOC) stock calculations for buried and surface soils. Error bars are standard deviation (2-sigma) of the data. These calculations are based on a transfer function that relates Loss on Ignition (LOI) and soil textural data to SOC weight %.

Clarks River study site: Physical characterization of the Clarks River XHF soil shows a pronounced lithologic discontinuity at ~1.0 m below the forest floor (Fig. 2). This abrupt change in soil texture and structure coincides with a buried soil with vertic (shrink-swell) features. Pore-water chemistry shows an increase in chloride (Cl^-) below the lithologic discontinuity, within the buried soil. This is inferred to show a decrease in the flow of water. Thus, this buried soil may influence perched water and strong water potential gradients. We plan to further assess the water potential characteristics of the CR1 profile. Overall, physical data and pore-water chemistry are intriguing and we hypothesize that this lithologic discontinuity affects aqueous geochemical gradients that may act to supply and limit nutrients to XHF habitats.

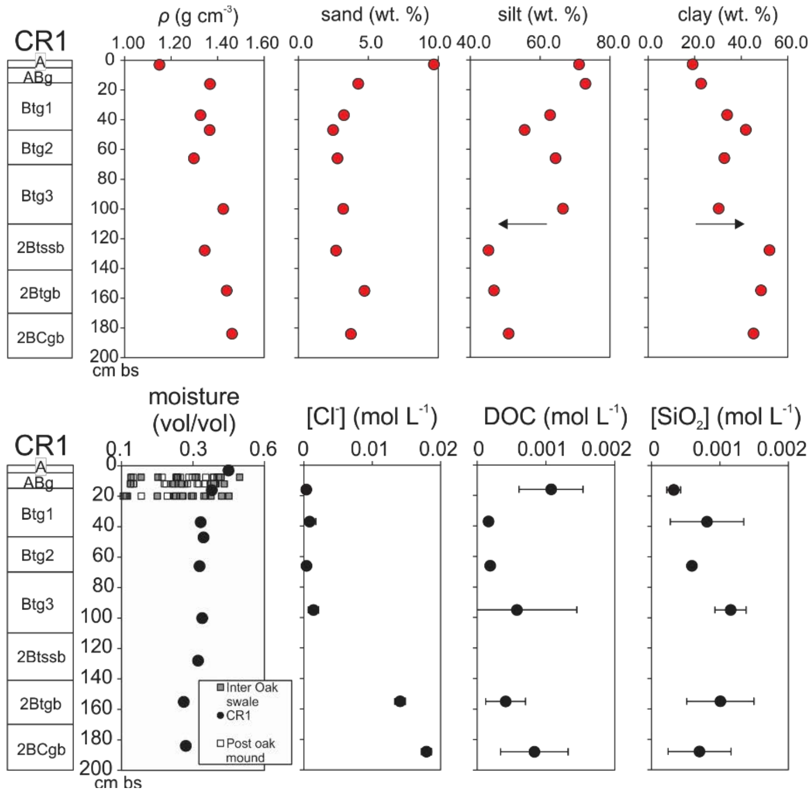

Figure 2. Results from the Clarks River xero-hydric flatwood site. UPPER: Soil physical characterization showing lithologic discontinuity at ~100 cm below surface (bs). This corresponds to a buried soil. LOWER: Pore-water chemistry showing increase in Cl^- and variable DOC with depth, especially in relation to lithologic discontinuity. Note that soil moisture data was collected using Time Domain Reflectometry (TDR) (white and gray circles) and also measured during core extraction (black circles).

Investigating karst hydrology influences on harmful algal blooms in two Kentucky lakes

Basic Information

Title:	Investigating karst hydrology influences on harmful algal blooms in two Kentucky lakes
Project Number:	2015KY248B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 2
Research Category:	Ground-water Flow and Transport
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Jason Polk

Publications

1. Schaefer, Robert, 2016, Development of a Methodology for Evaluating the Influences of Karst Hydrogeology on Freshwater Harmful Algal Blooms in Kentucky Lakes, MS Thesis, Department of Geography and Geology, Ogden College of Science and Engineering, Western Kentucky University, Bowling Green, Kentucky, 76 p.
2. Schaefer, Robert, J. Polk, and K. McClanahan, 2015, Analyzing Possible Influences in Karst Regions Contributing to Harmful Algal Bloom Occurrences in Freshwater Lakes, in Geological Society of America, Abstracts with Programs, 47(7), p. 724.
3. Schaefer, Robert and Jason Polk, 2016, Sourcing and Dynamics of Karst Hydrologic Inputs on Harmful Algal Bloom Occurrences in Kentucky Lakes, in Proceedings Kentucky Water Resources Annual Symposium, Kentucky Water Resources Research Institute, Lexington, Kentucky, p. 15-16.

Investigating Karst Hydrology Influences on Harmful Algal Blooms in Two Kentucky Lakes

Problem and Research Objectives

A problem exists in central Kentucky lakes with the occurrence of harmful algal bloom (HAB) formation. Blooms are forming in several waterways and reservoirs. HABs are an issue because of blue-green algae (cyanobacteria), which can bloom in high enough density to produce several life-threating toxins. To further complicate the issue, the waterways in which these cyanoHABs are forming, occur within karst areas. Karst landscapes present a special issue when it comes to water resource management, due to the interconnectedness between the surface and subsurface, particularly within the context of water quality problems.

As these blooms pose a threat to humans, wildlife, and the surrounding environment, local resource managers need help designing a plan to combat this complex problem. To address this issue, a multifaceted study was undertaken in an effort to better understand the impacts of karst inputs to the two lakes under variable land use and meteorological conditions. The research objectives for this study included characterizing the nutrient loadings and bacterial inputs on water quality at karst inputs to Nolin and Rough River Lakes; determining at high resolution changes in water geochemistry in conjunction with these inputs; determining if the karst hydrology's influence on the lakes' water quality is influencing possible HAB occurrence, particularly during storm events; and developing a sampling strategy from these data to perform high-resolution baseline and storm event sampling within other basins to examine the contamination potential during variable flow conditions. We sought to answer the questions of whether the current monitoring and land use practices are able to capture the parameters that influence HAB development and if the influences of karst inputs and potential changes in seasonality or storm events also contribute to contaminant input through groundwater.

Methodology

A Geographic Information System (GIS) was used in conjunction with USGS data to develop a landuse/land cover map for the watersheds (Nolin and Rough River Lakes) to help establish sampling locations. Karst hydrologic inputs (derived from KGS geologic maps and existing core data from the area) were also utilized. Once potential inputs were identified, they were mapped in conjunction with historic cell count data from the USACE. Then, appropriate sampling sites that complement the USACE sampling sites were determined. With this information, four sampling sites were identified at each lake. Three sites within the lake and one at the tailwaters of the dam. A high-resolution monitoring and sampling (bi-weekly) study was then undertaken for seven months (August 2015 to March 2016) to identify possible changes in nutrient and bacterial inputs to the lakes that characterize the occurrences of HABs, along with the changes in nutrient and bacteria inputs from karst-derived sources.

A YSI 556 multiparameter handheld data collection device was used for grab samples for the basic geochemical parameters: pH, specific conductance (SpC), temperature, and dissolved oxygen (DO). On a bi-weekly basis, surface water samples were collected by hand. The water samples were analyzed at the WKU HydroAnalytical Lab for *E. coli* and at the WKU Advanced Material Institute for anions (nitrates, phosphates), cations (micronutrients – trace metals). HAB testing was conducted by the USACE, as per KDOW recommendations. Rainfall and weather data were downloaded from NOAA and CoCoRaHS online databases. Discharge data for each lake's dam was provided from the USACE to help with loading calculations to better gain an understanding of the influence the lakes may have on downstream communities. Due to funding constraints and policy changes, it was necessary to drop the storm sampling component of the study.

Nitrate isotope samples were sent to the Central Appalachians Stable Isotope Facility (CASIF) and processed using the denitrifier method (Sigman et al. 2001, Casciotti et al. 2002). This method involves processing the sample with a specific culture of bacteria, which reverts the nitrate into di-nitrous oxide (N_2O), for the ^{15}N isotopic analysis, and carbon dioxide (CO^2), for the ^{18}O analysis. These gases are then analyzed with a ThermoFinnigan Gasöench + PreCon trace gas concentration system interfaced to a ThermoScientific Delta V Plus isotope-ratio mass spectrometer. The resulting ratios of $^{18}O/^{16}O$ and $^{15}N/^{14}N$ (denoted as $\delta^{18}O$ and $\delta^{15}N$ respectively) are then put into a modified mixing model from Kendal et al. (2007). This mixing model allows for the delineation of the NO_3 sources.

Collectively, these data were plotted for each lake to determine the potential inputs from the selected study sites with regard to the nutrient and bacterial loadings each week and during the chosen storm events to compare them with the occurrence of HABs in the lakes. Additionally, an analysis of land uses in the watersheds corresponding with the potential source of the contaminants that contribute to HABs was performed. Analysis of these time series data using descriptive statistical treatments helped determine the relationships between the contaminants and HABs in correspondence with land use and storm events, as well as sourcing of the nitrates, which is an important component of determining the groundwater influence on HAB formation.

Principle Findings and Significance

The data reveal there is a detectable karst influence at both lakes. The level of this influence varied from site to site. This influence is seen in the calcium (Ca^+) and magnesium (Mg^+) cation data. At both lakes, the cations show a strong presence and a spike is seen in the Nolin River Lake (NRL) dataset around modified Julian Date 397 (Feb. 1, 2016) in Ca^+ and Mg^+ levels, thereby indicating a flush of storage water from the karst aquifer (Figure 1a-e). The same spike can be seen in the anion data during the same period, but at a different site. The cation and anion data at Rough River Lake (RRL) tell a similar story. The elevated Ca^+ and Mg^+ levels indicate karst influence as well. The nitrate (NO_3) shows an interesting trend that also appears in the Nolin data (Figure 1b) in the apparent seasonality of NO_3 concentrations. This could be due to the inactivity of the biota in the soils once atmospheric temperatures are low enough. These processes typically reduce the amount of nitrate entering the groundwater system through the process of denitrification; however, in a karst system, the water is held warmer than the air temperature in the winter. This can be seen in the RRL hydrograph when the temperature of the water is added to the graph.

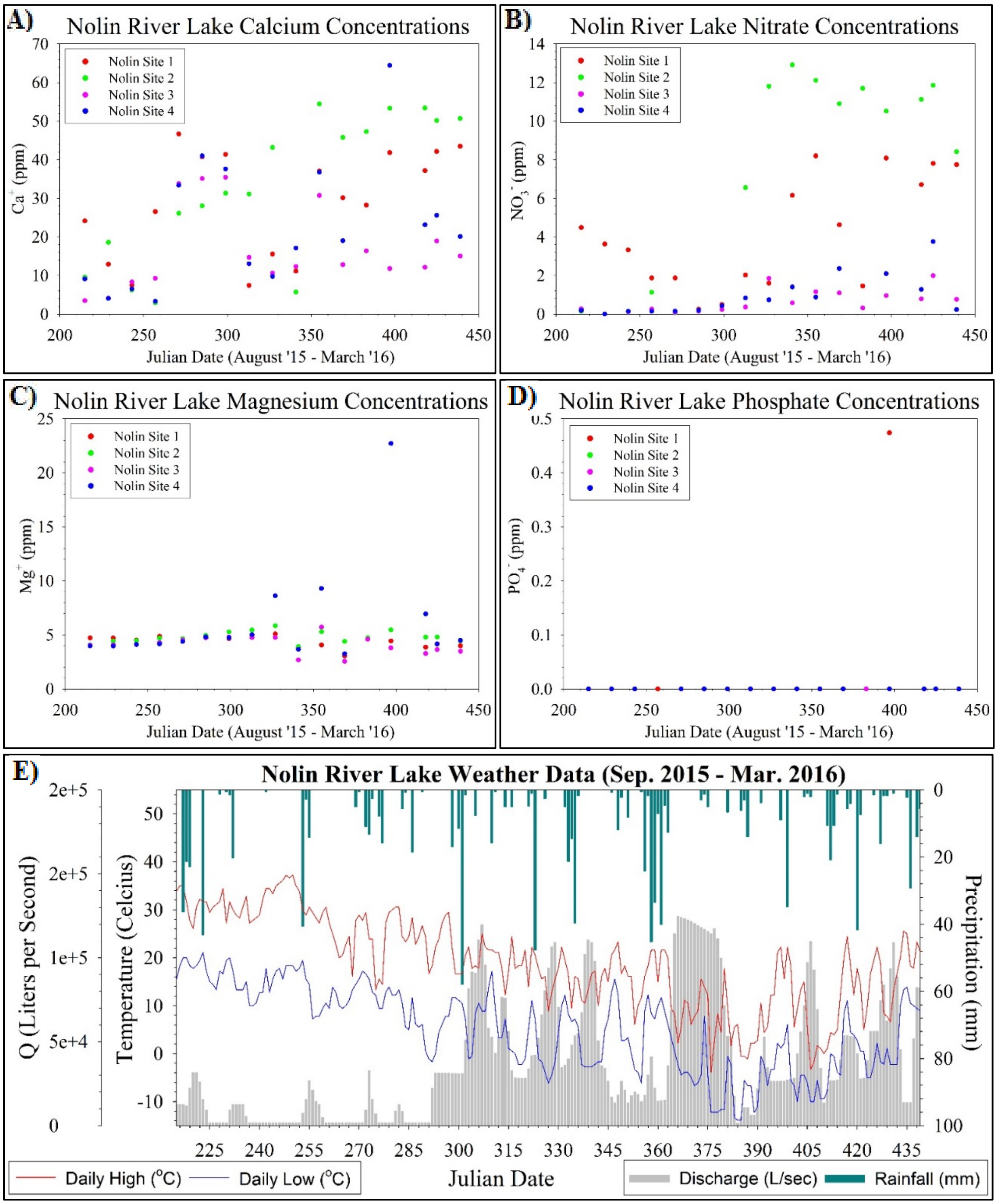

Figure 1: The a) Ca^{+}; b) NO_3; c) Mg^{+}; and d) PO_4 concentrations at the NRL sites during the study; e) the corresponding hydrograph for the same time period.

The water at the sites was consistently warmer than the atmospheric highs (Figure 2). The phosphate (PO_4) data show a flat line at zero. No PO_4 was detected in the system at RRL.

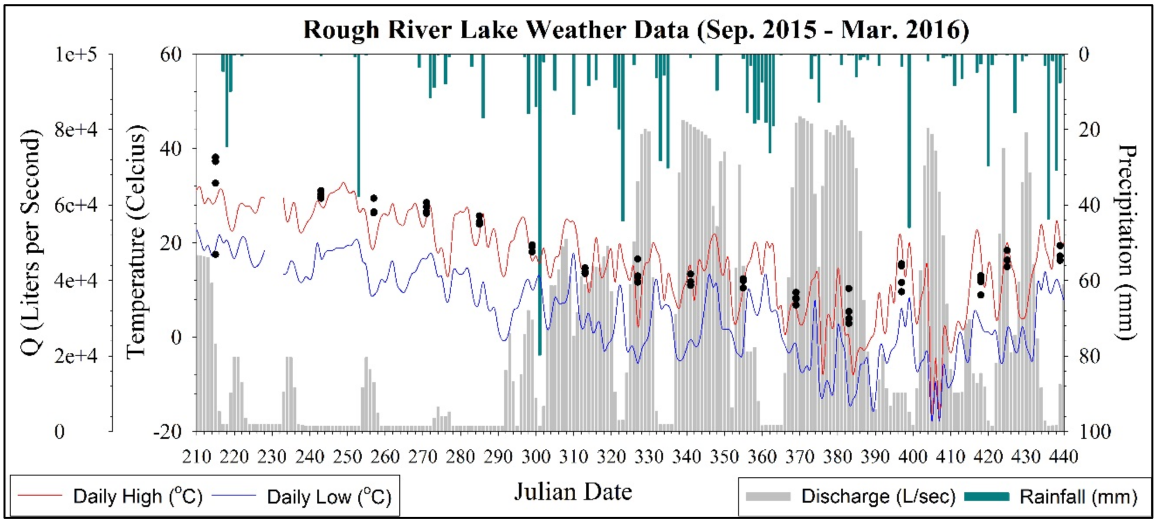

Figure 2: The RRL hydrograph. Water temperatures for the RRL sites are denoted in black.

Not all of the nitrate (NO_3) isotope data are currently available from the lab (still in process); however, trends can be seen in the first run of the isotope data. At NRL, the NO_3 entering the system in the late summer, early fall time period seems to be a mix of ammonia (NH_4) rich fertilizers and septic/animal waste sources (Figure 3a). Given the mix of land use that occurs across the drainage basin of NRL, these results make logical sense; however, one would expect to see a bit more of an urban influence if the water entering the system were only from surface drainage as the urban centers within the basin dominate the landscape. This mix of land use sources also aids in showing how the sinkhole plain plays a role in the watershed's nutrient concentrations, drainage, and pollutant transport. RRL's isotopes show a different story. The NO_3 isotope values there are largely coming from NO_3 rich fertilizers (Figure 3b). The landuse around RRL is also mixed, but the local agriculture is dotted with documented sinkholes. Given the low levels of denitrification indicated in the data, it lends further support to the rapid introduction of the fertilizers to the system through karst transport.

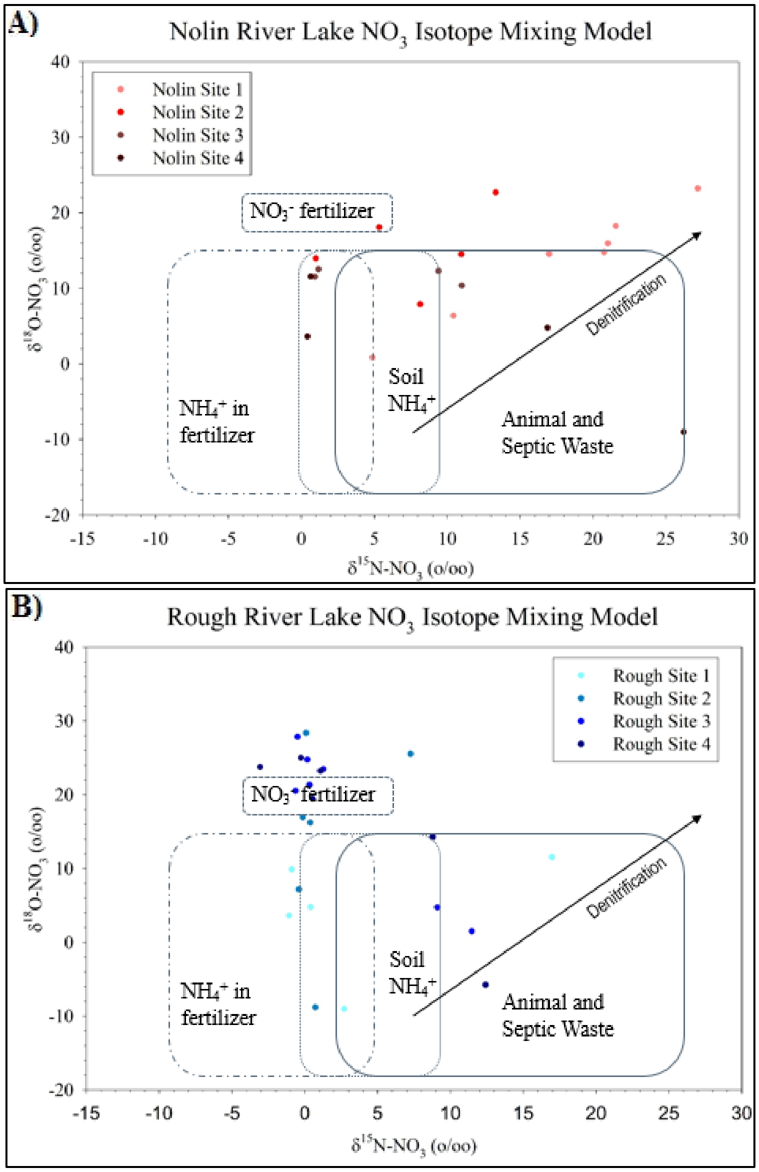

Figure 3: Isotopic ratios as plotted in a modified mixing model from Kendal et al. 2007. The values in a) NRL indicate the NO_3 detected in the system are from mixed land use sources with a heavy influence from NH_4 fertilizers and animal/septic waste. The NO_3 isotopes from b) RRL, indicate NO_3 fertilizers are a dominant source from the land use within RRL's watershed.

In the future, these results are going to be used to help inform the formation of best management practices (BMP's) for each lake in regards to nutrient limitation strategies. Limiting the nutrient sources is one of the best ways to combat HAB formation (Pearl et al. 2001, Wetzel 2001). These BMPs will be disseminated to the USACE as well as the public with the help of the KDOW and "Friends of" NPO's at each lake. The results of this study have helped the USACE in developing and implementing a sampling strategy to clearly identify the inputs potentially contributing to HABs and to create best management practices in preventing their occurrence, with two advanced monitoring sites already setup a the two study sites based on this study's recommendations. Only with the support of all of the stakeholders can the problem of cyanoHAB formation be fully addressed.

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Information Transfer Program Introduction

Information transfer activities are an important part of the overall program of the Kentucky Water Resources Research Institute. There are two main components, and annual symposium and the institute web sites. The institute also participates in and supports numerous other technology transfer activities throughout the year.

2015 Kentucky informaton transfer project

Basic Information

Title:	2015 Kentucky informaton transfer project
Project Number:	2015KY249B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KY 6
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Lindell Ormsbee

Publication

1. Proceedings Kentucky Water Resources Annual Symposium, 2016, Kentucky Water Resources Research Institute, Lexington, Kentucky, 90 p.

Kentucky Information Transfer Project (2015KY249B)

Problems and Objectives

The Water Resources Research Act requires that Institutes or Centers shall:

1) plan, conduct, or otherwise arrange for competent applied and peer reviewed research that fosters -

(A) improvements in water supply reliability

(B) the exploration of new ideas that -

(i) address water problems; or

(ii) expand understanding of water and water-related phenomena;

(C) the entry of new research scientists, engineers, and technicians into water resources fields; and

(D) the dissemination of research results to water managers and the public.

2) cooperate closely with other colleges and universities in the State that have demonstrated capabilities for research, information dissemination, and graduate training in order to develop a statewide program designed to resolve State and regional water and water related land problems.

Each institute shall also cooperate closely with other institutes and other organizations in the region to increase the effectiveness of the institutes and for the purpose of promoting regional coordination.

Kentucky information transfer activities are conducted in support of these objectives.

Methodology

Information transfer activities are an important part of the overall program of the Kentucky Water Resources Research Institute. There are 2 main components, an annual symposium and the Institute's web sites. The Institute also participates in and supports other technology and information transfer activities throughout the year.

The Associate Director develops the program for the Annual Water Resources Symposium. Presentations in both platform and poster format allow researchers and practitioners to share progress on planned, ongoing, and completed water-related activities throughout the Commonwealth each year. Recipients of the 104(b) student research enhancement grants are required to present the results of their projects at the symposium.

The Information Specialist Senior assists with posting program announcements and the proceedings volume for the symposium on the web site. She develops and maintains content for several web sites including the main Institute page at: www.uky.edu/waterresources/. Links for additional sites describing projects and activities (for example, volunteer sampling results and watershed pages for the Kentucky River basin) are provided on the main web site. Research translation to make results accessible for a variety of audiences is a major goal for all of the technology transfer activities of the unit.

The Institute cooperates closely with other groups and agencies in planning additional technology transfer activities in the Commonwealth. These efforts included support for seminars/lectures, support for other web sites, and open houses during Earth Science Week and Engineering Day. Institute staff members serve a variety of support roles on technical committees and advisory panels for agencies and volunteer organizations to help disseminate relevant information about ongoing activities and research results.

Principal Accomplishments and Activities

Kentucky Water Awareness Month is an educational program of the University of Kentucky Cooperative Extension Service, Environmental and Natural Resources Issues (ENRI) Task Force (the Associate Director of KWRRI serves on this group). The program promotes overall water awareness for citizens of Kentucky During May each year. Materials are developed by a committee at the state level and distributed to all of the 120 county extension offices in the state. Individual county agents are encouraged to tailor the program to fit their county's specific needs and to use the materials to enhance their program efforts. The materials remain available throughout the year for use by classroom teachers, 4-H volunteers, and others interested in water issues through the ENRI internet site: www.ca.uky.edu/enri/ The Task Force is also working to encourage Project WET training for extension agents across the Commonwealth. A separate educational program for local elected officials is also under development to inform them of potential water resource issues in local communities.

Water Week, October 19-23, 2015, was a week-long series of events designed to inform faculty, staff, and students on the University of Kentucky campus of the importance of water in the environment. This was the second year of this annual fall event. The project was a collaborative between the College of Agriculture, Food, and the Environment, the College of Arts and Sciences, the College of Engineering, the Kentucky Geological Survey, the Tracy Farmer Institute for Sustainability and the Environment, and the Kentucky Water Resources Research Institute. Featured events for 2015 included: "Conversations on Conservation" including two film shorts, a panel discussion, and lunch on Monday; a film screening and panel discussion on "Swim for the River" on Tuesday evening; a career panel including dinner and a panel discussion with industry experts on Wednesday; a seminar ("Global Water Sustainability" by Bridget Scanlon from the University of Texas at Austin) on Thursday afternoon; and a daylong transdisciplinary design workshop with a water theme was held in the School of Arts & Visual Studies on Friday. In addition, a field trip and stream restoration work day in the Cane Run watershed targeting participants from Fayette County middle schools was also sponsored as part of the 2015 Water Week. These events were organized by a multidisciplinary group of researchers working toward the advancement of water-related research and education at the University of Kentucky.

An open house was held on Wednesday evening 10/14/15 in association with Earth Science Week. This event was co-sponsored with the Kentucky Geological Survey. KWRRI staffed a water exhibit for the elementary, middle school, high school students, and their parents who attended the event (approximately 200 people).

Engineers Day, or E-Day, is a celebration of everything engineering has to offer at the University of Kentucky. From building bridges to discovering new medications to writing the software that powers our cell phones, engineers and computer scientists do the things that make the 21st-century world work. The 2016 E-Day celebration at the University of Kentucky in Lexington was on Saturday, Feb. 27, from 9 a.m. to 1 p.m. E-Day comes at the end of Engineers Week, an annual event sponsored by a coalition of more than 100 professional societies, major corporations and government agencies dedicated to promoting math and science literacy and ensuring a diverse and well-educated future engineering workforce. KWRRI staffed an Enviroscape exhibit demonstrating sources of nonpoint source pollution for participants at the event.

Cyberseminars provided through the Consortium for the Advancemnt of Hydrolgoic Sciences, Inc. were made available of the University of Kentucky Campus for interested faculty, staff, students, and local professionals. The initial University of Kentukcy membership in CUAHSI was underwritten by the KWRRI.

The Kentucky Water Resources Annual symposium was held on March 28, 2016. Although the date of the symposium fell outside of FY2015, most of the planning and preparation for the event occurred during the fiscal year. An opening plenary session focused on lead issues in Flint, Michigan ("Working with Flint Residents: Lead Discovery and Citizen Science in the Flint Water Crisis," Min Tang, doctoral candidate in the Department of Civil and Environmental Engineering at Virginia Tech University). This was followed by a session including 20 poster presentations. Two concurrent sessions provided time slots for 24 oral presentations to round out the program. The noon luncheon provided an opportunity for presentation of annual awards acknowledging outstanding contributions in the areas of Water Research, Water Practice, and Water Quality. Approximately 120 people attended the meeting. Abstracts for all of the presentations were distributed to participants on the day of the meeting: Proceedings of the Kentucky Water Resources Annual Symposium, 2016, Kentucky Water Resources Research Institute, Lexingtonm KY, 90 p. The full proceedings document is also available online through a link on the institute web site: www.uky.edu/waterresources/ The document includes contact information for all of the authors and presenters. Symposium attendees also received a list of attendees providing basic contact information for each individual who pre-registered for the symposium. Attendees included researchers, personnel from local, state, and federal agencies, undergraduate and graduate students, participants from volunteer groups and NGOs, and members of the general public. Conference registration fees are kept low through partial subsidy of symposium expenses (using 104(b) technology transfer and matching funds) to ensure accessibility to individuals from all potential audiences. All of the 104(b) student research enhancement projects funded through the Institute during FY2015 presented their results at the symposium.

Maintenance of the institute web site provides open access for those interested in the activities of the Institute. The site also provides additional links to related sites and information maintained by others. Creation and maintenance of the web site are ongoing throughout the year. Links on the site provide direct access to the Kentucky Center of Excellence for Watershed Management, the University of Kentucky Superfund Research Center, the Kentucky Research Consortium for Energy and Environment, the Kentucky River Watershed Watch, the Tracy Farmer Institute for Sustainability and the Environment, the Environmental Research and Training Laboratory, and the Kentucky Geological Survey.

As a part of the University of Kentucky Superfund Research Program, the Kentucky Water Resources Research Institute planned 5 seminars for employees in the Kentucky Department for Environmental Protection.

2015 Superfund Seminar Series

Anna Hoover, PhD, University of Kentucky, March 11, 2015, **Better engaging communities: Moving beyond cardinal rules**

Bruce A. Stanton, PhD, Dartmouth College, April 8, 2015, **Arsenic: A global public health crisis - How safe is our water?**

Kelly Pennell, PhD,University of Kentucky, December 1, 2015, **Update of the sewer gas to indoor air pathway for vapor intrusion sites**

Isabel Escobar, PhD, University of Kentucky, January 13, 2016, **From membrane biofouling to control of aquaporin channels**

M. Hope Lee, PhD, Pacific Northwest National Laboratory, February 17, 2016, **TCE fate and transport evaluation for Paducah groundwater: Attenuation mechanisms**

All of these brown-bag luncheon seminars were held at the Kentucky Department for Environmental Protection Training Room, 300 Fair Oaks Drive, Room 301D, Frankfort, KY, *Co-Sponsored by the UK-Superfund Research Program, the Kentucky Water Resources Research Institute, and the Kentucky Division of Waste Management (Kentucky Department for Environmental Protection).*

Over the past two or three years, the KWRRI has worked with colleagues across Southeastern Athletic Conference institutions to propose a water-themed symposium. The primary goal of this academic conference-type event is to address a significant scholarly issue utilizing the range of disciplinary strengths of all SEC universities in a manner that expands opportunities for collaboration among SEC faculty and administrators and draws national attention and participation to the Southeast region. This event is also intended to display the research and innovation of SEC institutions for an audience of academicians, government officials and other stakeholders. The university presidents and provosts ultimately accepted our proposal and planning is ongoing for the regional event to be held in Starkville Mississippi on March 27-28, 2017.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	0	4
Masters	8	0	0	0	8
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	13	0	0	0	13

Notable Awards and Achievements

2015KY248B (Polk) - Robert Schaefer was recognized as the outstanding presenter in his section of the Western Kentucky University Student Research Conference in 2016 (Best Oral Presentation)