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Challenges to integrating human and natural systems: An assessment of the Cache River Watershed

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NSF IGERT PROGRAM IN WATERSHED SCIENCE AND POLICY

A report in fulfillment of the NSF IGERT Program requirements

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Chapter 1: Introduction

Human activities can cause a number of ecological problems relating to water quality, wetland function and shifts in biodiversity; there is strong evidence of such impacts in the Cache River basin (Demissie and Xia, 1991; Demissie et al., 2008). Both restoration-oriented and economically-driven land use activities operate in the context of agricultural and conservation policy at national and sub-national scales that impact production markets and subsequently, land use choices. Anthropogenic impacts, particularly in agricultural regions, have detrimental effects on ecosystem functioning in watersheds and structural alterations to waterways disrupt natural geomorphologic processes. In order to address ecological impairments, physical rehabilitation is essential. Environmental concerns, however, need to be balanced with socioeconomic development, flood damage mitigation, public health, and other interests. This report explores one such altered system, contributes new information about its ecological state, and delineates recommendations and research needs to guide future watershed decision-making.

The Cache River watershed, located in southernmost Illinois, is noted for its ecological diversity and rich cultural history. For centuries, the region's bottomlands, wetlands, and streams have provided valuable ecosystem services to the region’s inhabitants. More recently, outdoor recreational opportunities including canoeing, hiking, hunting, and fishing have gained popularity. The region also supports over 100 state and federally threatened or endangered species, and contains Ramsar designated wetlands of international importance (Mankowski, 1997).

Historically, the watershed contained bottomland forest, freshwater resources, and swampland teeming with biodiversity (Mankowski, 1997). However, during the westward expansion of European settlers, the physical and ecological systems of the watershed were significantly altered, largely due to logging practices and the extensive draining of the wetlands for agricultural purposes (Duram et al., 2004). The most drastic change to the hydrological system has been the disconnection of the upper and lower portions of the watershed in 1915 which segmented the river. Today, largely due to socio-political and economic obstacles and despite efforts to restore and protect large portions of land, the system remains both ecologically and hydrologically altered.

Since the 1970s, interest has grown in transitioning the Cache River to a more natural state. Land acquisitions by state and federal agencies and non-governmental organizations within the basin have increased significantly. Public land acquisition for ecological restoration has been one management strategy employed in the watershed in the last 30 years, but can preclude practices that conflict with other stakeholder preferences, such as the maintenance of drainage systems. Additionally, incentive-based programs, funded through the U.S. Farm Bill, are a significant conservation land use management strategy (Adams et al., 2005; Dunn et al., 1993; Ferris and Siikamaki, 2009). There are now over 100,000 acres (including private lands) protected through conservation efforts.

Today, planning continues through the coordinated efforts of the many stakeholders in the watershed and has resulted in public outreach and education programs, ecological monitoring, innovative scientific research, and targeted actions to address degradation. Potential issues associated with physical restoration activities the river to promote healthier ecosystem function can be controversial. Stakeholder concerns include fears of flooding from communities, agricultural landowners, and the drainage district. Given the dynamics of the cultural, political, and ecological status of the Cache River watershed, it is critical that sound science be used to guide holistic and adaptive restoration practices that can address the wide range of stakeholder needs and priorities.

Paying particular attention to interrelatedness of human and natural systems, this report seeks to identify and bridge gaps in current knowledge surrounding the processes in the watershed and inform future land and water management decisions in the basin.

In this report we:

1. Compile and present an integrated, comprehensive review of the current and historical status of the Cache River Watershed,
2. Identify gaps in the current research and information on the Cache River Basin, and
3. Present original research to further the understanding of major challenges within the basin faced by land owners and managers including:
    - Evaluating the effectiveness of restoration practices (i.e., riffle weirs) on upper Cache River through comparing before and after cross-sectional and longitudinal channel profiles,
    - Delineating current distribution of cane for future restoration implications,
    - Evaluating spatial and temporal trends in macroinvertebrate and fish assemblages and water quality parameters.

The final chapters of this report present data-driven recommendations for management-related decisions on private and public lands within the watershed, as well as highlight gaps in information and identify needs for further research. These management recommendations are based on the research and literature review presented, coupled with new research that has been collected and analyzed specifically for this report. Through multi-disciplinary analysis, this report aims to provide a source of discussion and information for the many stakeholders involved in the management of the Cache River basin.

Chapter 2: Cultural and Physical Landscape Settings of the Cache River Watershed

The Cache River Watershed encompasses a variety of physical, cultural, and biotic characteristics. Physical aspects of the basin are diverse and range from farm land to forested wetlands. Relative to other watersheds of Illinois, the biological diversity is high and this is a function of a unique convergence of different ecosystem types. The culture of the watershed can be described as rural or small town and while many residents are multi-generational family farmers, health care professionals and educators are among the most prevalent professions. Agriculture is the dominant land use in the basin and the region is also home to people with some of Illinois' lowest incomes and education levels, creating a complex economic and political space for ecological and watershed-specific management. This chapter describes the cultural and physical landscapes of the Cache River Watershed and sets the stage for further exploration and analyses in subsequent chapters.

Background

Since the Cache River is a tributary of the larger Mississippi River and was accessible by water, parts of it were settled earlier than the rest of the state. In the early 1800s, settlement of the Cache River Watershed continued as commercial and industrial development expanded west. Sawmills were established in the mid-1800s and beginning around 1870, the timber industry grew rapidly producing raw materials used for steamboats, railroads, and construction. The most notable business in the region of that time was operated by the Main Brothers, who owned a box and lumber company and harvested much of the cypress and tupelo trees within the watershed (Pulaski County Board of Commissioners, 1987). Throughout the 19th century, lumber was the major industry and economic driver in the area (Illinois Natural History Survey, 1997).

As timber resources began to dwindle, the decrease in lumber and the recognition of the region's fertile soils incited a shift in the culture within the watershed. Settlers began recognizing the potential within the region for agricultural production. Seasonal flooding from the Ohio River presented the biggest obstacle for agriculture and by 1905 the Cache River Drainage Commission began discussions of an extensive artificial drainage system to develop thousands of acres of land. This coincided with the federal government's promotion of the "reclamation of the land" (Illinois Natural History Survey, 1997). Developmental pressures and pursuit of agricultural production opportunities lead to the complete diversion of the river and ditching for the drainage of wetlands.

To further facilitate ease of timber transportation and maintain drainage for agriculture, a large ditch known as the Post Creek Cutoff was constructed in 1915 (Cache River Watershed Resource Planning Committee, 1995). Essentially, the Post Creek Cutoff drains the Cache River and its eastern tributaries into the Ohio River at a point further upstream than the natural outlet, cutting off the river flow to the lower Cache River to allow drainage and development (Figure 2.1). Well-drained soils in the upper portion of the Cache River Watershed are more conducive to agricultural production. In the 50 years following the construction of the Post Creek Cutoff, numerous other major drainage alterations were made. The long-term impacts of these hydrologic alterations combined with land use changes include erosion, incision, gully formation, increased soil drainage, reduced base flows, and increased flood potential in several areas (Demissie et al., 1990; Demissie et al., 2008).

In light of recognition that the Cache River ecological systems were threatened due to these land use choices, people began to preserve remaining forest land late in the 20th century. A new sub-culture of environmental awareness and interest in restoration of the natural areas in the watershed emerged. Public agencies and local citizens, motivated by environmental concerns, promoted land acquisition for restoration (Davenport et al., 2010). Forests and wetlands along the river were restored, while parks and conservation areas were developed by both state and federal agencies. Today, the region remains rural, including a dozen communities with populations between 500 and 5,000 people. Racial and property-ownership divisions among residents are noted, particularly in the lower Cache River region. Power and influence in environmental decision-making is concentrated among landholders (Adams, 2005).

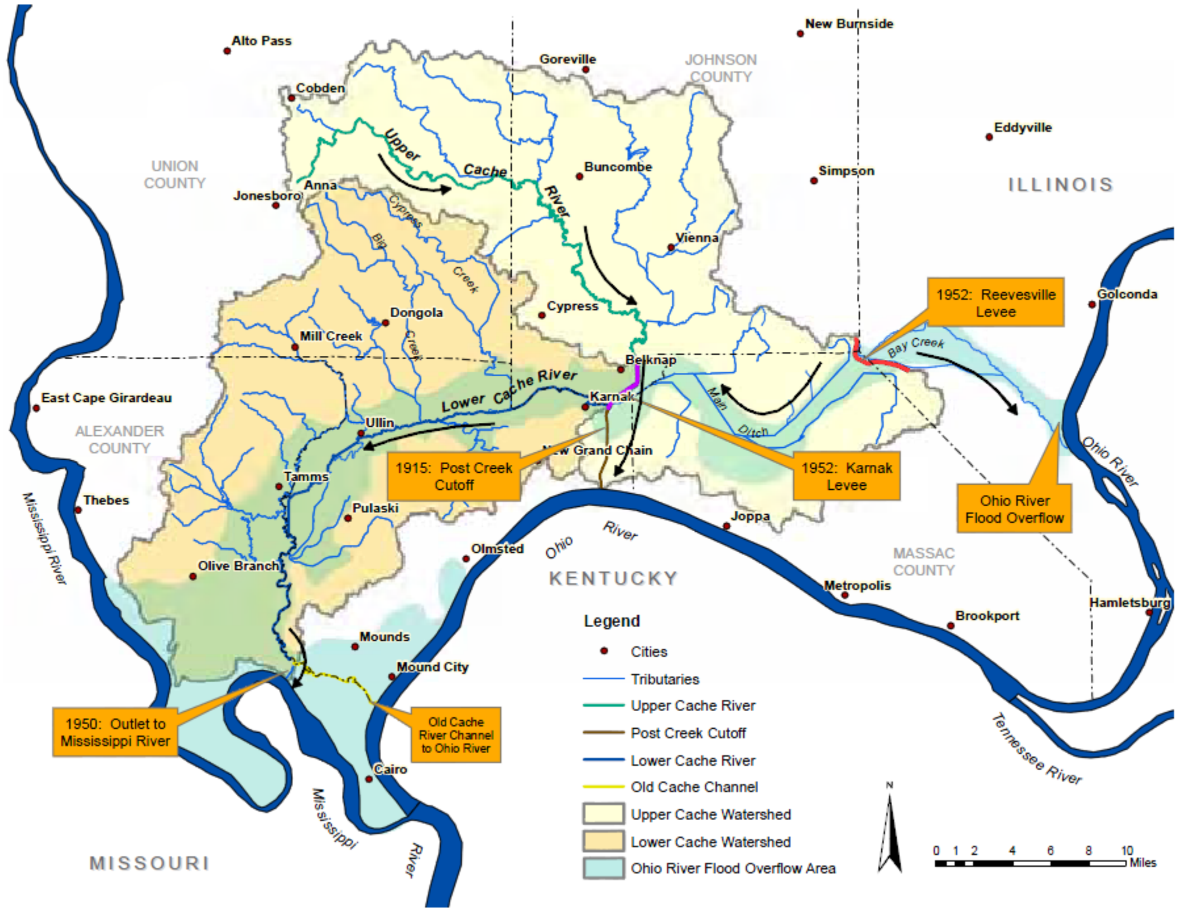

Figure 2.1. Major historical drainage alterations have greatly impacted the lower and upper Cache River (Demissie et al., 2008).

Today, land management decisions are driven by numerous stakeholders including landowners, governmental bodies, and organized interest groups (Table 2.1). The interest groups vary from volunteer-run organizations to structured collaborations made up of government agencies and non-profit organizations. The Citizens Committee to Save the Cache River (CCSCR) is dedicated to the preservation of the river. This group of local landowners, hunters, and non-governmental organizations formed in the late 1970s in response to agricultural drainage of the wetlands, which compromised angling and hunting activities. Another citizens' group, The Friends of the Cache River Watershed, formed to protect their heritage and the natural amenities the river and wetland system provides their communities. The Cache River Wetlands Joint Venture Partnership (JVP) is a collaborative group consisting of Ducks Unlimited (DU), Illinois Department of Natural Resources (IDNR), The Nature Conservancy (TNC), USDA Natural Resources Conservation Service (NRCS), and US Fish and Wildlife Service (USFWS). This partnership was formed in 1991 and has coordinated to obtain 60,000 acres of land from private ownership. While the JVP has promoted environmental protection and ecological restoration in the Cache River Watershed, interests such as agricultural drainage and flood control activities also continue to play a major role in watershed management decisions.

Table 2.1. There are numerous stakeholders who play roles in the management of the Cache River Watershed.

Stakeholder	**Interest/Role in the Cache River Watershed**
Academic Researchers	Conducts scientific research and contributes data useful to other stakeholders in the watershed
Agriculture Industry/Farmers	Farmers and land owners own, rent, or operate the land for both large and small scale agricultural production
Big Creek, Cache River and Cairo Drainage Districts	Local bodies formed for the purpose of draining ditching, and improving land for agricultural and sanitary purposes and authorized to build and maintain drains and levees, and to tax land within their boundaries
Citizens Committee to Save the Cache	Local citizens' organization collaborating to bring national attention to the Cache River wetlands
Ducks Unlimited, Incorporated (Part of JVP)	Private non-profit organization focused on conserving, restoring and managing wetlands and associated habitats for North American waterfowl, wildlife and people
Farm Bureau	County-based institution which aims to promote agricultural interests such as flood mitigation and product transportation.

Friends of the Cache River Watershed	Area citizens focused on environmental restoration and education in the area and promoting local issues
Illinois Department of Natural Resources (Part of JVP)	Provides leadership for the restoration, management, and protection of wildlife, populations, and their habitats for the purposes of providing citizens and visitors of Illinois with a quality environment
The Nature Conservancy (Part of JVP)	Private non-profit organization that strives to preserve the plants, animals and natural communities that represent the diversity of life on by protecting the lands and waters they need to survive
Local Business/Tourism Operators	Strives to increase tourism and recreation in the watershed
Local Government Officials	Influences land use and water management decisions (agricultural income, enrollment of land in CRP and WRP programs, creation of the wildlife refuge, and the tourism industry)
Local Soil and Water Conservation Districts	Implements state programs and helped develop the first Cache River Management Plan. SWCDs also have board members who are landowners living in the Cache River watershed
Illinois Environmental Protection Agency	Contributes data and research useful to other stakeholders in the watershed and enforces state and federal regulations and the CWA
Illinois State Water Survey	Conducts scientific research and contributes data useful to other stakeholders in the Cache River Watershed
USDA Natural Resources Conservation Service (Part of JVP)	Strives to help citizens conserve, maintain, and improve natural resources and environment (USDA's technical assistance agency in the conservation of soil, water, and all other natural resources on private lands)
US Army Corps of Engineers	Provides flood risk management, environmental stewardship, other authorized civil works, and emergency operations within areas of operation

US Fish and Wildlife Service (Part of JVP) Cypress Creek National Wildlife Refuge	Strives to further the conservation of wetlands, aquatic resources, wildlife and fish habitat and contribute to a cooperative effort for the economically and environmentally responsible management of floodplain lands within the river corridor
Recreationalists	Hunters, anglers, and general recreationalists utilize the area for sport, leisure, and recreation

Physiographic regions

The Cache River watershed is located at the convergence of five physiographic provinces (Figure 2.2) (Mankowski, 1997), including the Gulf Coastal Plain, Interior Low Plateaus, and Ozark Plateaus provinces, and is just south of the Central Lowlands province. Physiographic provinces are defined by geologic structures and are further divided into sections, including the Coastal Plains Mississippi Alluvial Plain, Coastal Plains East Gulf Coastal Plain, Interior Low Plateaus Shawnee Hills, and Ozark Plateaus Salem Plateau, and Central Lowlands Till Plain.

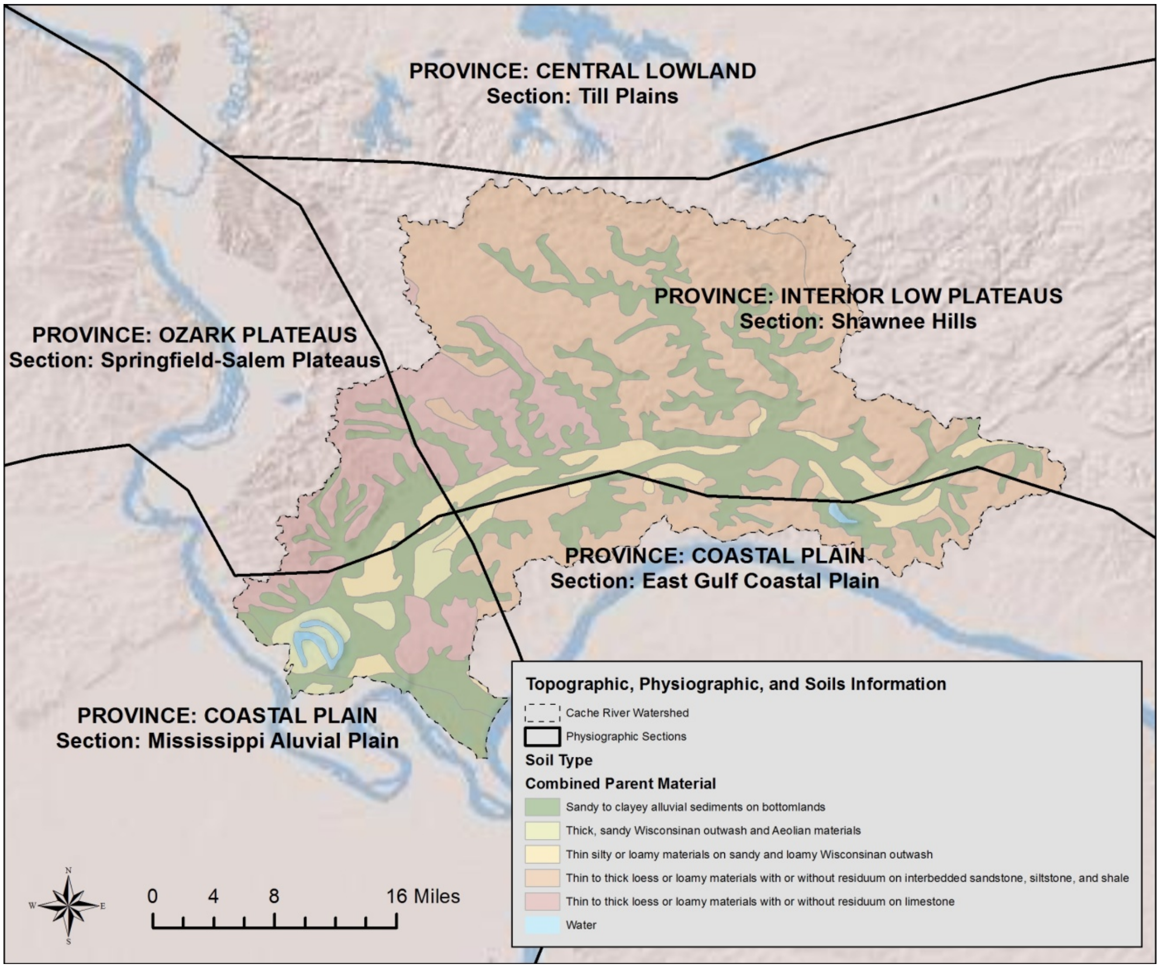

Figure 2.2. The convergence of five physiographic sections in the Cache River Watershed create a diverse physical landscape while the differing soil types allow for varied land uses (Leighton et al., 1948; Fehrenbacher, 1984; ESRI, 2011).

The Coastal Plains Mississippi Alluvial and East Gulf Coastal Plain sections make up most of the southernmost area of Illinois. The province is characterized by low hills and broad river bottomlands. The hills are maturely eroded to form gently sloping knolls and ridges. The upland is partially buried and certain segments are isolated due to glacial outwash and alluvium extending far up the tributary valleys.

The Interior Low Plateaus Shawnee Hills section comprises the northern half of the watershed. A continuous ridge extending across the state was formed by the Pennsylvanian cuesta, which is a sloping plain terminated on one side by a steep slope. In many areas, the ridge has been eroded into hills and valleys; however, some flat uplands remain on narrow ridge crests throughout the length of the escarpment. A plateau on Mississippian rocks to the south is maturely dissected and the larger valleys are alluvial (Demissie et al., 1990).

The Ozark Plateaus Salem Plateau section lies in a small western portion of the watershed. The section includes a discontinuous upland along the southwest boundary of Illinois. Compared to the Shawnee Hills section, Salem Plateau has more rugged hills, closer drainage texture, and higher elevations, including bluffs. While small remnants of flat upland surface remain, much of the plateau is dissected by highly developed, dendritic drainage patterns (Demissie et al., 1990).

The Central Lowlands Till Plain section is located just north of the watershed. Most of the area is level to gently rolling till-plain with broad bottomlands, associated terraces, and meander scars along major river valleys. Overlaying the plain is a series of low, undulating ridges (McNab and Avers, 1994).

Geomorphology

The Cache River valley was formed through repeated glacial advances that caused scouring to limestone bedrock and refilling with glaciofluvial sediments. The valley was once heavily influenced by the Ohio and Mississippi River drainages, but channel and floodplain modification for navigation and flood control structures now limit those influences.

The Ohio River, which historically flowed through what is now the Cache River Valley, later shifted south to its present location. The glacial advances caused the Ohio River to shift, leaving a wide, flat alluvial valley fed by small, steep watersheds to the north (Esling et al., 1989). The Cache River moved into the former channel and course of the Ohio River. Later advances of the glaciers carried sediment that blocked Cache River tributaries, forming temporary glacial lakes. Sediment deposition from the lakes left many flat landscapes, some of which later became the current-day wetlands (Gough, 2005).

Topography

There are two distinct drainage patterns in the Cache River Watershed. The uplands of the Interior Low Plateaus Shawnee Hills section are hilly and rise to an elevation of about 800 feet above mean sea level (msl). Drainage is flashy due to the quick drop of elevation in the watershed. As the Cache River leaves the Shawnee Hills downstream, the terrain begins to flatten around the town of Belknap. In this long, alluvial, bottomland drainage, movement of floodwater through the valley is very slow. These conditions have historically supported the development of natural wetlands. The Cache River continues westward towards the Mississippi River, and enters at an elevation of 280 ft (Cache River Watershed Resource Planning Committee, 1995; Bhowmik et al., 1997).

Soils

The Cache River watershed includes five soil associations that are well documented by the Soil Conservation Service in cooperation with the Illinois Agricultural Experiment Station (Figure 2.2).

Most of the soils in the floodplain, streams and wetlands are formed in stratified clayey to sandy loess alluvium on nearly level to gently sloping areas. The soils are generally poor to well drained, and contain low to medium organic content. Problems associated with these soils can include flooding, wetness, and low fertility. Additional types of soils are fragmented along the Cache River and in the south-eastern region of the watershed. These soils are generally well drained with low to moderate available water capacity, which makes them highly susceptible to water erosion and drought conditions.

In upland areas of the watershed, consisting mostly of agricultural, forested, and range land uses, soils are formed on gentle to steep slopes. The sloping topography, streams, and tributaries provide substantial drainage in these areas. Problems associated with these soils can include susceptibility to erosion, low organic content, low fertility, and low available water capacity (Parks and Fehrenbacher, 1968).

Climate

The Cache River Basin is located in the temperate zone, characterized by warm and humid summers and cool to cold, wet winters. Since 1937, temperatures have ranged from -15°F to 108°F, but average 58°F year-round (National Weather Service, 2011). Between 1970 and 2000, southern Illinois received an annual average of 49 inches of rain and 10 inches of snow. Within the Cache River Basin, the rainy season starts in March and extends through June, with monthly averages of 4 to 5 inches (National Weather Service, 2011). Major rainfall events and flooding are not uncommon in January and February, although about 75% of floods occur during March, April, and May (Mankowski, 1997).

Hydrology

The Cache River drains 737 square miles; however, due to the fragmentation of the river, the upper Cache River drains 368 square miles and typically enters the Ohio River at river mile 957.8 while the lower Cache River generally drains 358 square miles to the Mississippi River at river mile 13.2. Although not common, there are exceptions to this drainage pattern, such as the lower Cache River flowing into Post Creek Cutoff and the upper Cache River flowing into the lower Cache River. An additional 11 square miles is drained through the original confluence of the Cache River with the Ohio River at river mile 974.7 (Bhowmik et al., 1997). One long-term gage is located on the upper Cache River, of which the data shows strong seasonal patterns with high variability (Figure 2.3) (United States Geological Survey, 2011b). The impacts of structural changes and land use to hydrology are explored in more detail in Chapter 3.

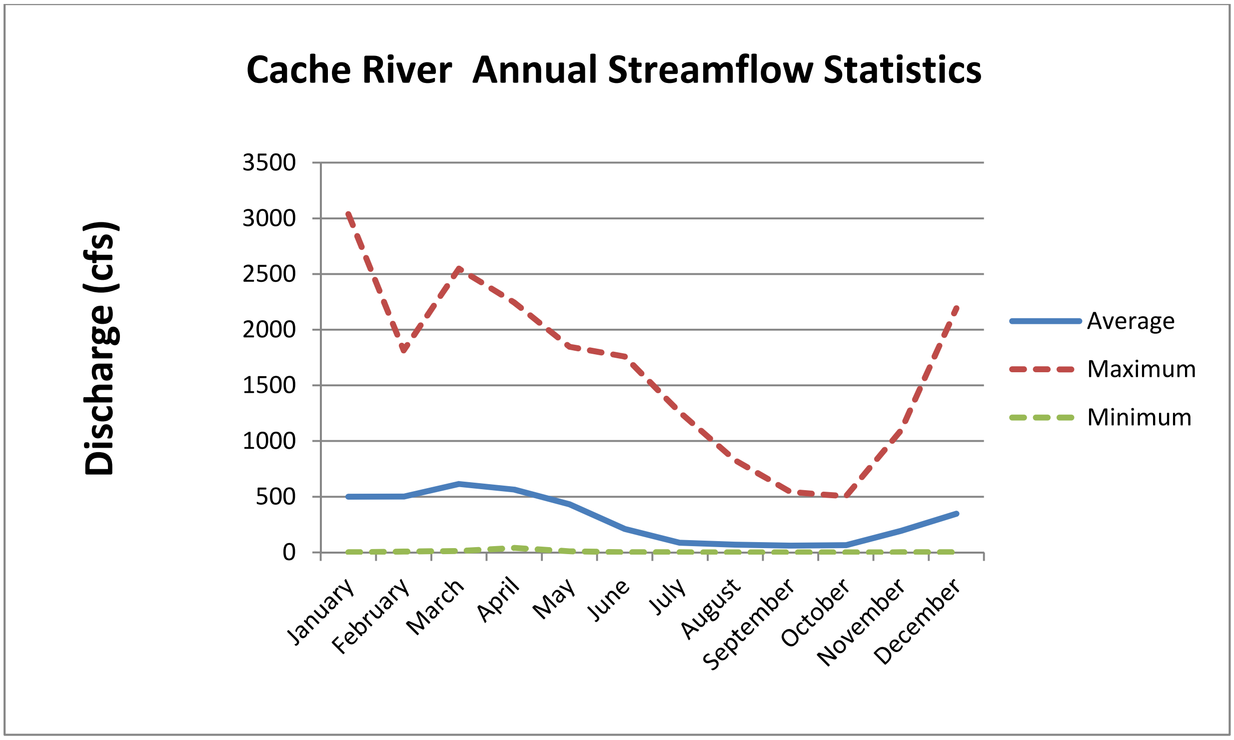

Figure 2.3. Annual streamflow statistics derived from data taken at the Forman gage station, 1923-2010, show seasonal patterns and high flow variability in the Cache River Watershed (United States Geological Survey, 2011b).

Biota

Due to its location at the intersection of the five physiographic provinces, the Cache River system harbors high biological and ecological diversity. The watershed is host to numerous natural community types, including floodplain forests, swamps, flatwoods, upland forests, barrens, prairies, glade, and cliff communities (Mankowski, 1997). These community types are complex, rich in biodiversity, and provide numerous habitats. In 1994, the Ramsar Convention on Wetlands, a United Nations treaty that promotes national protection and international support for the conservation of the world's wetlands, recognized the Cache River wetland system as a Ramsar Wetland of International Significance. The basin supports over 120 species of native breeding birds, 89 species of native and non-native freshwater fish, 34 crustacean species, 430 species of other aquatic macroinvertebrates, 43 species of reptiles, 32 amphibian species, and 52 species of mammals (Mankowski, 1997). Among these are 40 plant and 37 animal species that are state-endangered, 7 plant and 20 animal species that are state-threatened, and 7 federally-endangered animal species (Mankowski, 1997; Guetersloh, 2002). In addition, non-native plant and animal species are threatening to reshape the 20 natural community types within the Cache River basin (Henry and Davey, 2010). A complete list of species found in the basin is provided in Mankowski (1997) and Guetersloh (2002).

The Cache River system contains 7 miles of biologically significant streams (BSS) as determined by IDNR (Figure 2.4) (Illinois Department of Natural Resources, 2008). Biologically significant streams are stream reaches that support populations of state and federally listed threatened and endangered species and contain high fish and mussel diversity (Illinois Department of Natural Resources, 2011).

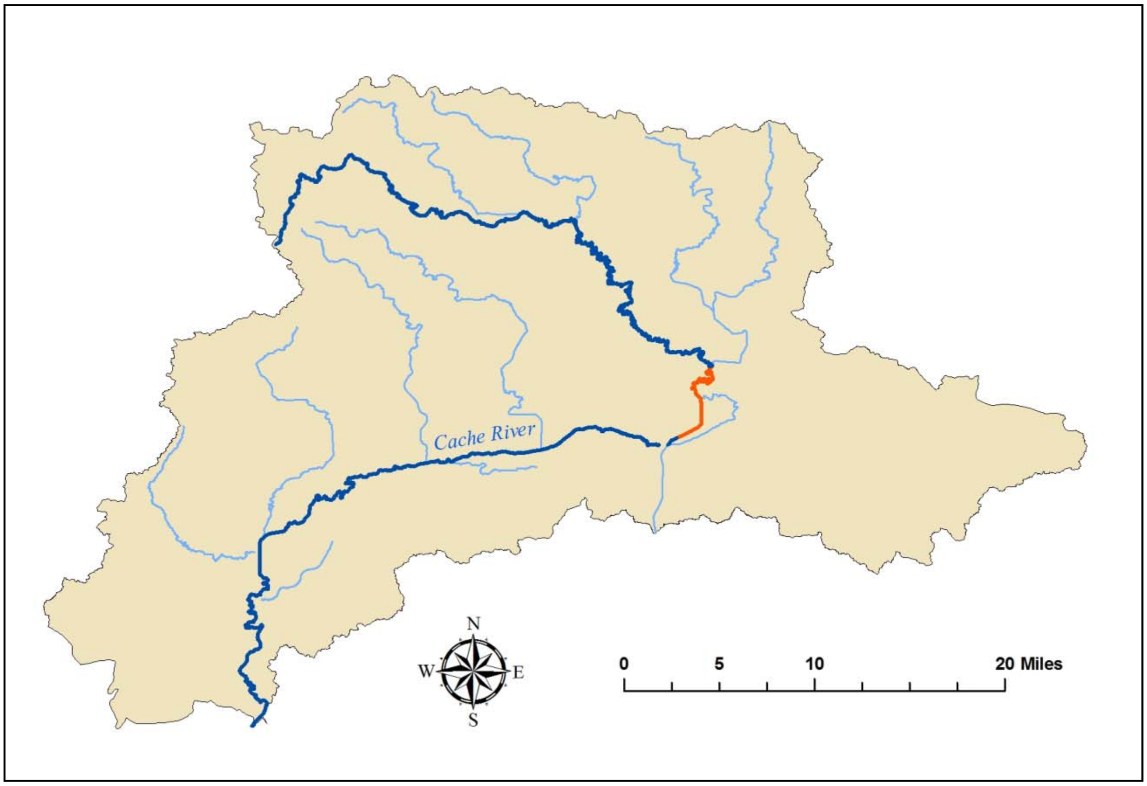

Figure 2.4. The Cache River Watershed includes 7 miles of biologically significant streams, indicated by orange.

Prior to 1800, ~80% of the watershed was forested. Additionally, prairies existed in bottomlands and dry uplands, barrens and springs were common, and there were ~5,300 acres of biologically diverse swamps and wetlands in the basin. This vegetation structure has changed significantly since settlement. Logging and drainage practices, land clearing for agriculture, as well as changes in fire regimes have removed or dramatically altered forest and wetland ecosystems. Although much has been done to restore floodplain forests, only 700 acres remain in their pre-settlement condition, and only 240 acres of swamp and wetlands remain today (Mankowski, 1997).

The majority of the United States freshwater is from groundwater and approximately 25% of that groundwater is located in cave and karst regions. Cave systems are studied information on natural resources, evolution and human history. The organisms that inhabit these systems contain valuable data relevant to climate change (Cave and Karst Program: National Park Service, 2007) and are sensitive to environmental degradation and pollution. In Johnson and Union Counties, there are a total of 43 caves within the Cache River watershed boundaries (Mankowski, 1997). These caves provide unique habitat for diverse and highly specialized species such as the cave salamander (*Eurycea lucifuga*) and the spring cave fish (*Forbesichthys agassizi*) (Mankowski, 1997). These highly adapted organisms reveal valuable information about evolutionary responses, providing valuable clues to current climate change (Cave and Carst Program: National Park Service, 2007). To date, a total of 117 species have been identified within the cave systems (Mankowski, 1997).

Water Supply

The majority of water usage (65%, not including power usage) in the Cache River Watershed counties is for agricultural irrigation and public water supply (Table 2.2). In Massac and Pulaski counties, public water supply is drawn solely from groundwater, and Johnson County, in particular, relies heavily on private groundwater wells. Massac County ranks 14 out of the state's 102 counties in total irrigated acres. Massac County ranks eight for total water use in the state largely due to the presence of a power plant just outside of the watershed. Massac County ranks 39th when power plant withdrawals are omitted.

Table 2.2. Water usage sectors in the Cache River Watershed include public supply, irrigation, golf courses, livestock, mining and power generation (United States Geological Survey, 2005).

County Name	% Population Served by Groundwater (Public Supply)	% Population Served by Surface Water (Public Supply)	Amount Used for Public Water Supply (Mgal/day)	Irrigation			Amount Used for Livestock (Mgal/day)	Amount Used for Mining (Mgal/day)	Amount Used for Power Generation* (Mgal/day)	Total Amount Used (Mgal/day)
				Amount Used for Irrigation (Mgal/day)	Crop Acreage Irrigated (in thousands)	Golf Course Acreage Irrigated (in thousands)				
Alexander	51.53	37.41	1.83	2.89	3.35	0	0.03	0.02	0	4.86
Johnson	17.54	18.60	1.12	0.09	0.12	0.04	0.26	0.39	0	2.63
Massac	79.29	0.00	2.93	5.33	7.64	0.04	0.19	0.35	616.39	630.88
Pulaski	63.73	0.00	.26	1.19	1.76	0.02	0.08	0.58	0	2.33
Union	49.88	11.87	1.27	0.99	1.36	0.02	0.2	0.27	0	3.4
Illinois	**25.47**	**65.71**	**1701.17**	**503.88**	**435.14**	**24.44**	**37.90**	**25.47**	**11753.21**	**15183.67**

*While the power plant in Massac County is located outside the Cache River Watershed, it is included in this table because it represents a large portion of the total county usage.

Land Use

The Cache River Watershed contains 14 of the 21 National Land Cover Classifications designated by USGS (United States Geological Survey, 1992) (Figure 2.5). Of the 14 land cover types, three are dominant in the basin. Deciduous forest, cultivated crops, and pasture/hay comprise over 85% of the watershed. Deciduous forest makes up a third of the watershed. Cultivated crops and pasture/hay combined make up almost half of the watershed, making agriculture the dominant land use. Corn and soybeans are by far the most dominant cultivated crops, comprising 99% of the watershed's agricultural production. Developed land is the next highest land use, covering about 8% of the watershed; however, two-thirds of developed land is classified as open area. Therefore, intense development is very low. Roughly 5% of the watershed is considered wetlands, while open water covers only 1.3% of the basin (United States Department of Agriculture, 2010).

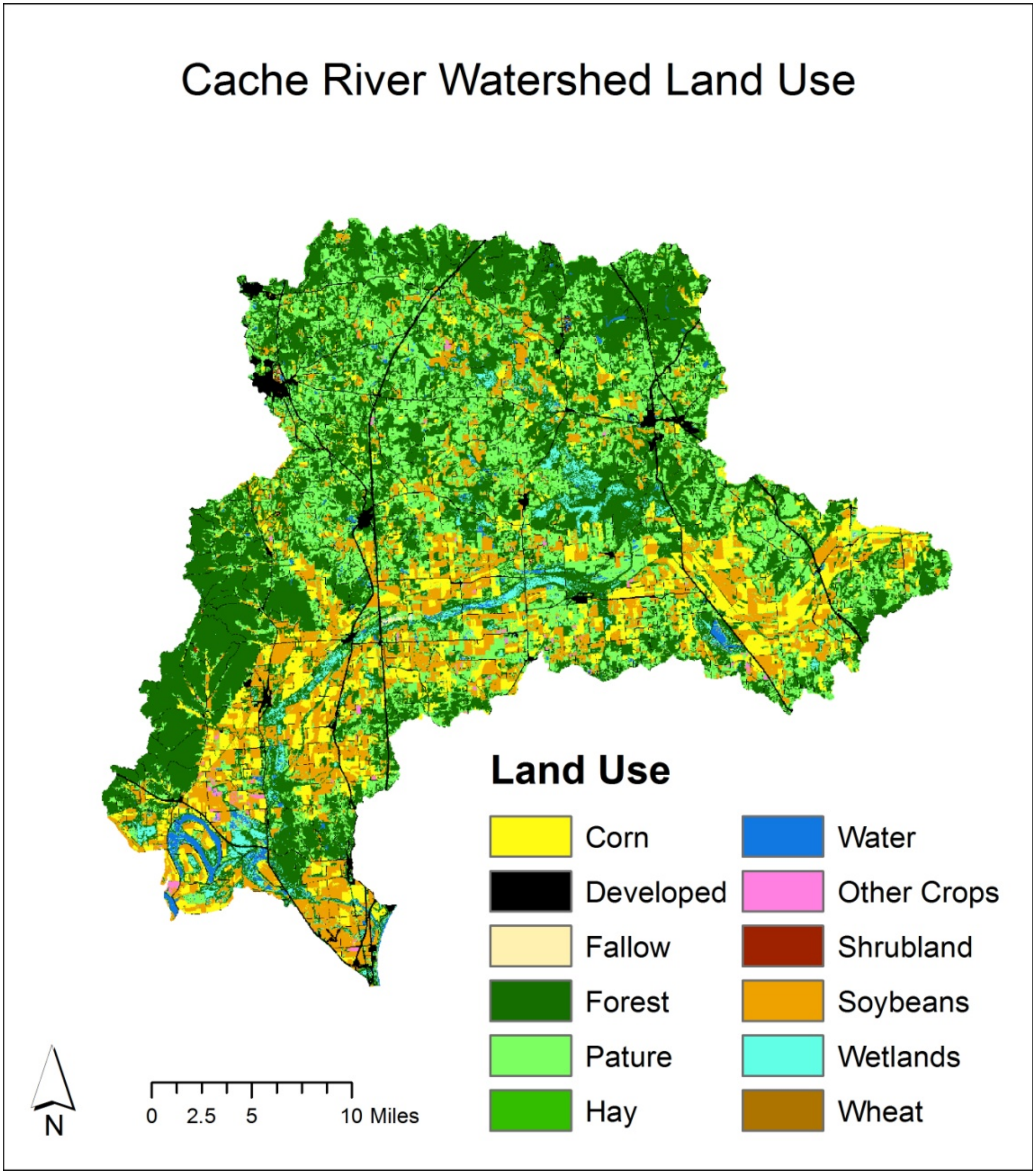

Figure 2.5. Dominant land uses in the Cache River Watershed include corn, pasture, soybeans, forest and wetlands (United States Department of Agriculture, 2010).

Enrollment acreage in the U.S. Farm Bill land conservation retirement programs, as well as public owned lands, impact distributions of land uses. Public land comprises 11% of land in the watershed

(Mankowski, 1997) (Figure 2.6). Cache River Watershed enrollments in Wetland Reserve Programs (WRP) vary widely by county (Table 2.3). Conservation Reserve Program (CRP) enrollment increased in the watershed counties since the program's inception in the 1980s, but has declined since 2006 (Figure 2.7).

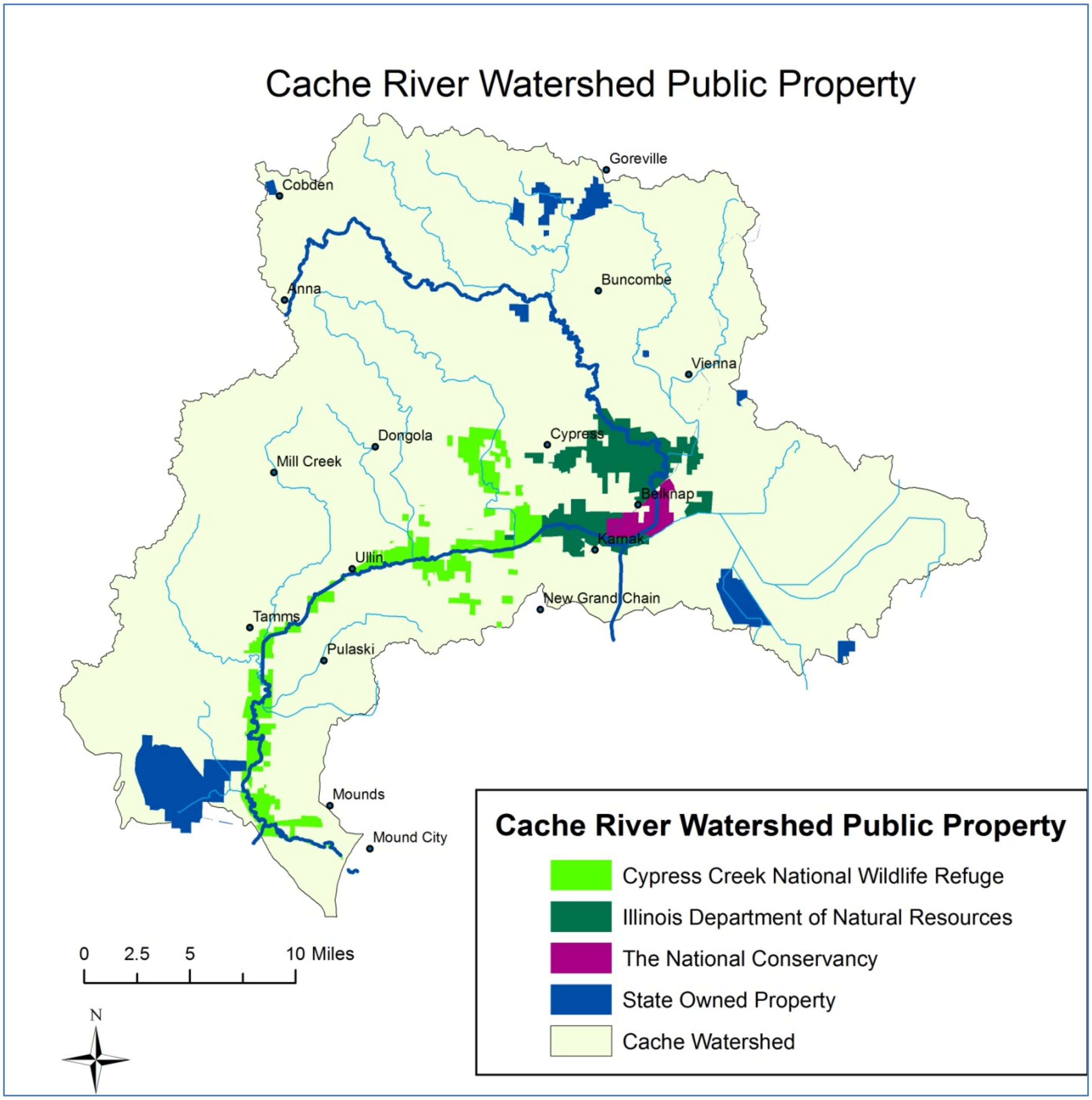

Figure 2.6. The Cache River Watershed contains public lands managed by several different agencies.

Table 2.3. Within the Cache River Watershed, Wetland Reserve Program enrollment is highest in Union County and lowest in Massac County (Wachter, 2011).

County	Acreage	Easements
Union	7,063.3	38
Alexander	5,477.7	23
Pulaski	1,945.6	10
Johnson	4,424.0	8
Massac	151.1	1
Total	19,061.8	80

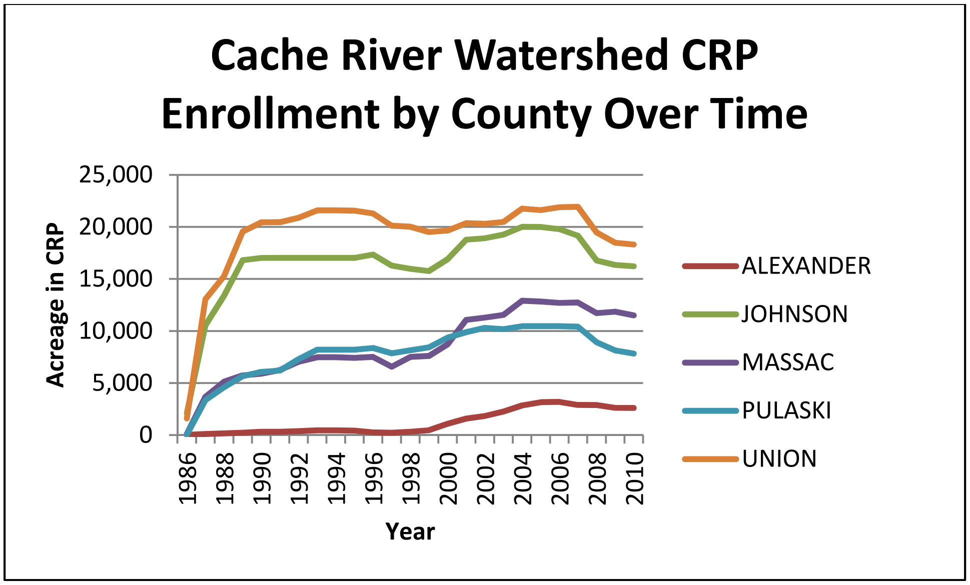

Figure 2.7. CRP enrollment has increased in each county in the Cache River Watershed over time, but total enrollment acreage in the region has decreased since 2006 (U.S. Farm Service Agency, 2010).

Geography

The Cache River Watershed drains portions of six different counties. The watershed area in Pope County makes up a very small portion, representing ~1% of its total area. The rest of the watershed is fairly evenly distributed among the other five counties, with all counties contributing between 14% and 24% of total basin drainage area (Table 2.4).

Table 2.4. The Cache River Watershed (WS) includes portions of six counties (US Census Bureau, 2009; ESRI, 2011).

County	Sq. Miles	Sq. Mi. in WS	% of county in WS	Acres of WS	% of WS	Population
Johnson	350.41	185	53%	118,400	24%	13,730
Union	424.68	184	43%	117,760	24%	18,005
Pulaski	212.86	159	75%	11,760	21%	6,218
Alexander	248.79	127	51%	81,280	17%	7,914
Massac	258.57	103	40%	65,920	14%	14,970
Pope	381.51	4.5	1%	2,880	1%	3,991
Total	1,876.82	762.5	41%	488,000	100%	64,828

The headwaters of the Cache River are located near the city of Anna. Anna is the largest city in the watershed, although a small portion lies outside the watershed boundaries (Table 2.5). The next largest city is Cairo; however, most of the city of Cairo lies outside the watershed borders. There are 17 populated places associated with Cache River Watershed. Eight lie on the border, while nine are completely inside the border (United States Geological Survey, 2011a). Vienna is the largest city completely within the watershed (US Census Bureau, 2009).

Table 2.5. Among the populated places in the Cache River Watershed, Anna is the largest community with a population of just over 5000 people (Illinois State Geological Survey, 2000).

City	County	Population	Within WS*
Anna	Union	5,043	Partial
Cairo	Alexander	3,660	Partial
Jonesboro	Union	1,905	Partial
Vienna	Johnson	1248	Full
Cobden	Union	1,152	Partial
Mounds	Pulaski	1,121	Partial
Goreville	Johnson	992	Partial
Dongola	Union	802	Full
Ullin	Pulaski	758	Full
Tamms	Alexander	721	Full
Mound City	Alexander	681	Partial
Karnak	Pulaski	613	Full
Pulaski	Pulaski	292	Full
Cypress	Johnson	238	Full
New Grand Chain	Pulaski	228	Partial

Buncombe	Johnson	203	Full
Belknap	Johnson	121	Full
Mill Creek	Union	84	Full

*Watershed

The cities nearest the Cache River channel are Belknap, Karnak, Ullin, and Tamms. With the exception of Belknap, these communities are all within one tenth of a mile from the river. Mound City is located on the Ohio River and is near the historic mouth of the Cache River, below the Lower Cache River diversion levee. It should also be noted that none of the populated communities listed lie within Massac County (Figure 2.8).

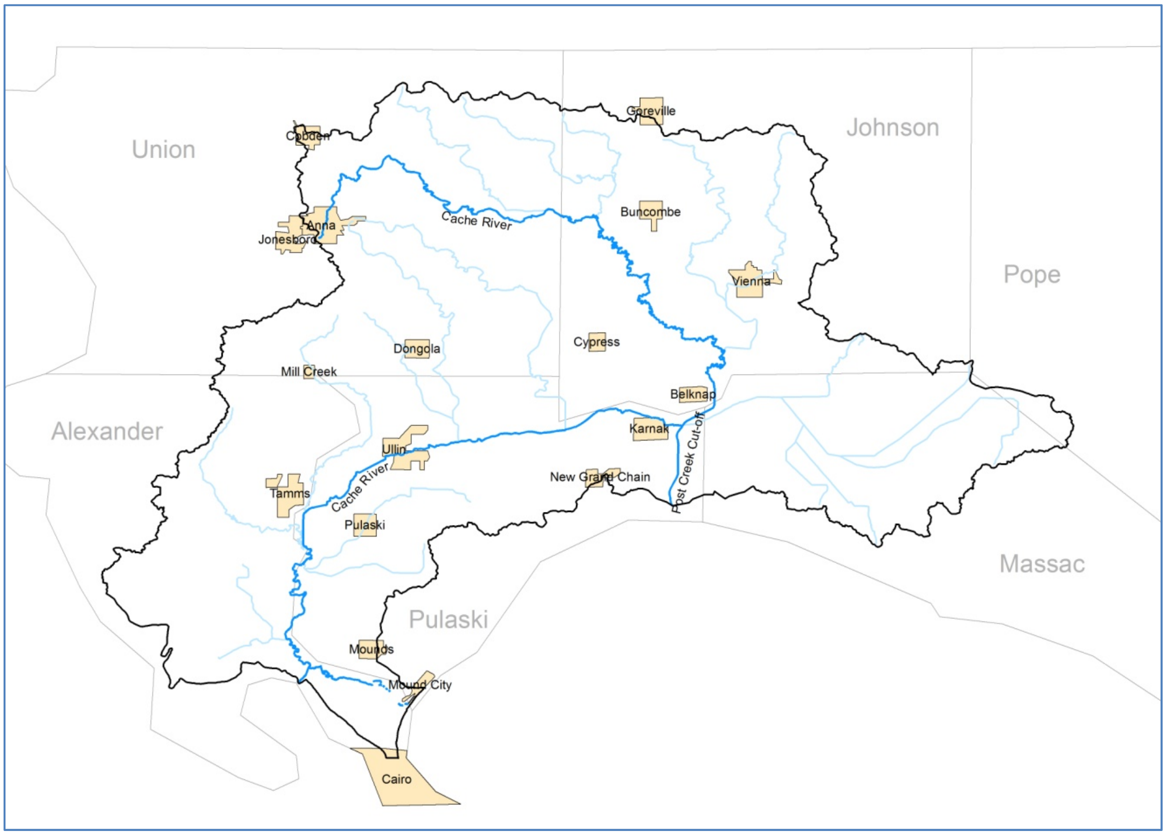

Figure 2.8. Communities of the Cache River Watershed are located in the uplands, lowlands and along the main stem of the Cache River (Illinois State Geological Survey, 2000; Simley and Carswell Jr, 2009).

Socioeconomics

Population has remained fairly constant from 1990 to 2010 in the counties of Union and Massac (Figure 9). Pulaski and Alexander Counties have seen 22.3% and 14.5% decreases in population since 1990, while Johnson County's population has increased by 20.3%. Comparatively, the state of Illinois saw an increase in population of 11.3% in the same 20 year time span, indicating substantial influx into Johnson County and higher than average emigration of the watershed's southwestern counties of Pulaski and Alexander.

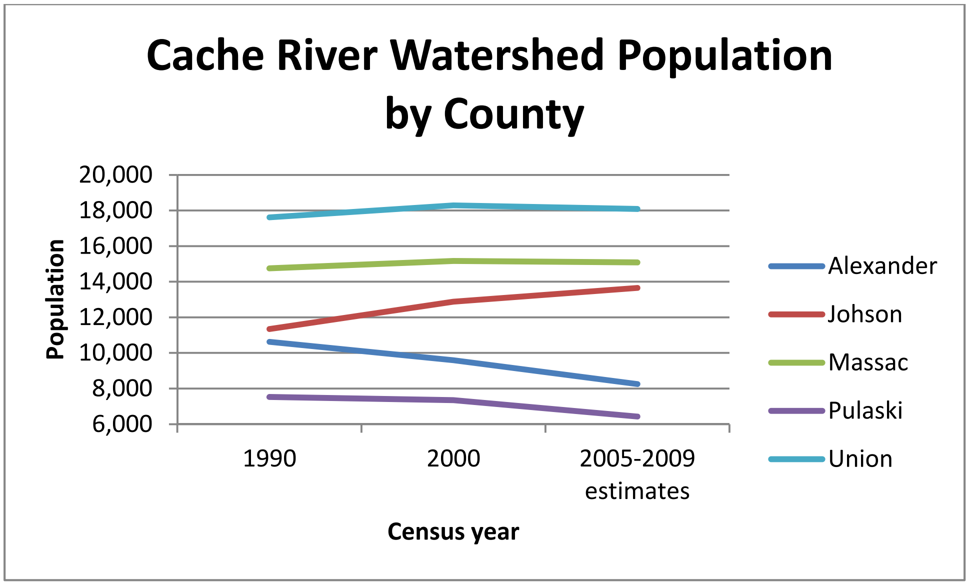

Figure 2.9. Population in Cache River Watershed counties remained stable or decreased in all but one county from 1990 to 2009 projections (U.S. Bureau of the Census, 2009).

Education

Cache River counties have seen steep declines in percentages of their populations without a high school degree over the last 20 years (Table 2.6), yet all five counties consistently rank higher than the state in terms of the percentage of people over 25 years of age lacking a high school diploma. Similarly, college degree attainment in all Cache River counties is lower than the percentage of the state's population holding a bachelor's degree (Table 2.7). While Union County has the highest percentage of its population holding a bachelor's degree, it has one of the two highest percentages of its population without a high school diploma, suggesting educational stratification among the residents.

Table 2.6. The percent of the population in Cache River Watershed counties without a high school degree has decreased in all counties since 1990.

County	1990	2000	2010*
Alexander	40.3	33.0	23.2
Johnson	33.8	32.9	21.3
Massac	34.7	23.5	16.8
Pulaski	40.2	29.3	23.6
Union	35.8	25.2	23.5
State of Illinois	23.8	18.6	14.3

*US Census projections based on 2005-2009 figures

Table 2.7. Percent of the population in Cache River watershed counties with a bachelor's degree has increased in all counties since 1990.

County	1990	2000	2010*
Alexander	7.8	6.9	9.8
Johnson	9.1	11.7	14.1
Massac	8.0	10.7	13.3
Pulaski	7.1	6.1	10.0
Union	10.9	15.8	17.9
State of Illinois	21.0	26.1	29.8

*US Census projections based on 2005-2009 figures

Income and Poverty

The median household income has increased in each Cache River watershed county since 1990, yet has remained below the state average for each of the last three censuses (Figure 2.10). Johnson County's average median income increased substantially since 2000 and is now projected to be $54,011, nearly equal that of the state's average of $55,222. The average median incomes of the other four counties range between $28,775 and $38,237. The percentage of Johnson County's population without a high school degree fell most sharply during the same time it saw a notable increase in average median incomes. Poverty levels in each county are higher than that of the state as a whole (Figure 2.11). In addition, while poverty levels fell in each county and the state from 1990 to 2000, with the exception of Alexander County, each saw an increase in poverty levels over the last 10 years.

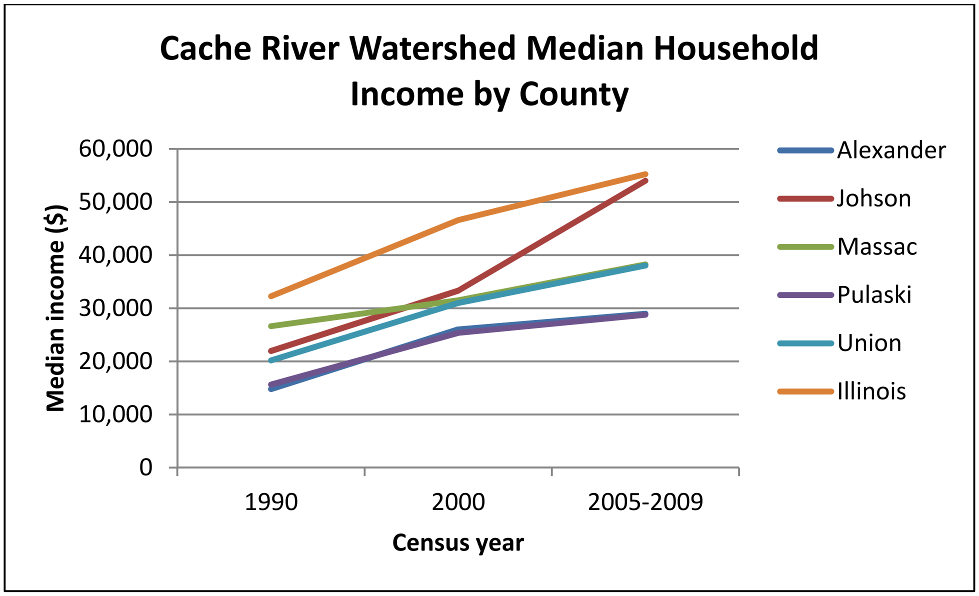

Figure 2.10. Illinois state median household income was higher in each census than all five Cache River Watershed counties for the same years (U.S. Bureau of the Census, 2009).

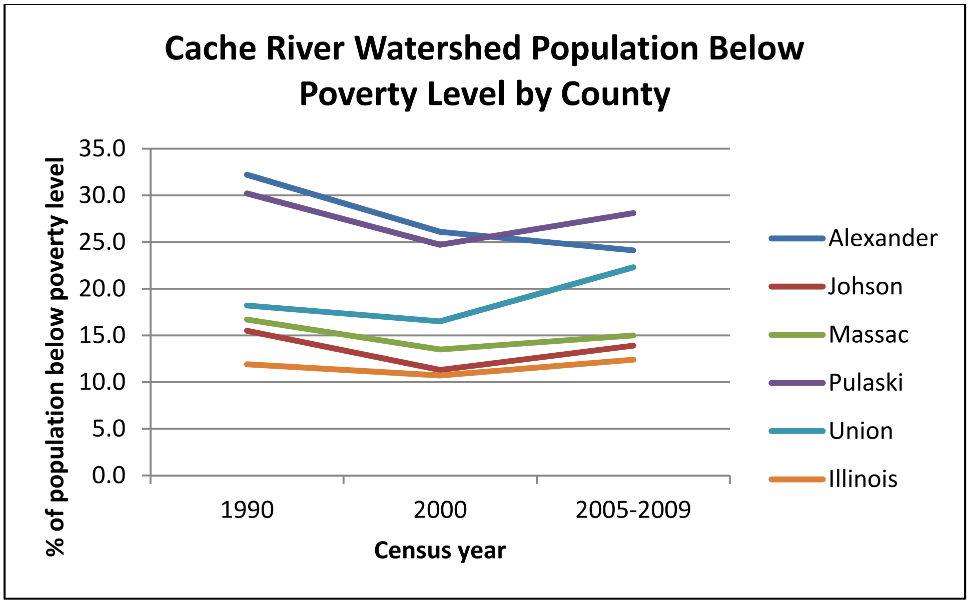

Figure 2.11. Percent of each Cache River Watershed county's populations which is below the poverty level are consistently higher than the percent of the Illinois state population below the poverty line (U.S. Bureau of the Census, 2009).

Employment

Conventional wisdom holds the Cache River watershed to be reliant on agriculture as a primary economic driver; however, employment trends show this to be overstated. Although agriculture is the principal land use in the basin, none of the Cache River counties have a high proportion of their population in agricultural employment. Distribution of employment by sector reveals a population heavily rooted in service sector jobs in education, recreation, government, and healthcare. The dominant sectors vary in each county and are defined by their major employer. For example, the large casino and state park explain why the Arts, Entertainment and Recreation sector is dominant in Massac County (Table 2.8). Similarly, Pulaski County has a thriving community college, while Anna, in Union County, has both a county and state mental hospital.

Table 2.8. The top five employment sectors vary for the Cache River counties (United States Department of Labor, 2011).

County	Rank	Industry Sector	Establishments	Employees	% Pop
Massac	1	Arts, Entertainment, and Recreation	4	794	14.8
	2	Health Care and Social Assistance	28	585	10.9
	3	Manufacturing	8	384	7.1
	4	Education Services	12	382	7.1
	5	Accommodation and Food Services	36	361	6.7
Pulaski	1	Education Services	5	539	26.0
	2	Public Administration	13	235	11.3
	3	Services	16	146	7.0
	4	Professional Scientific & Technical Svc	3	138	6.7
	5	Manufacturing	5	129	6.2
Union	1	Health Care and Social Assistance	45	1,924	33.1
	2	Wholesale/Retail Trade	54	757	13.0
	3	Education Services	9	567	9.7
	4	Manufacturing	15	319	5.5
	5	Accommodation and Food Services	35	299	5.1
Alexander	1	Public Administration	10	462	20.7
	2	Health Care and Social Assistance	8	399	17.8
	3	Education Services	4	275	12.3
	4	Transportation and Warehousing	10	159	7.1
	5	Manufacturing	7	136	6.1

Johnson	1	Public Administration	15	800	27.9
	2	Education Services	8	358	12.5
	3	Accommodation and Food Services	16	206	7.2
	4	Professional Scientific & Technical Svc	11	183	6.4
	5	Health Care and Social Assistance	13	171	6.0

Unemployment levels in the Cache River Watershed were historically much higher than aggregate state levels between the early 1980s and the end of the century when these levels generally began to coincide with state trends. Since 2007, all five Cache River county unemployment rates have been rising steadily while the state rate is declining (Figure 2.12).

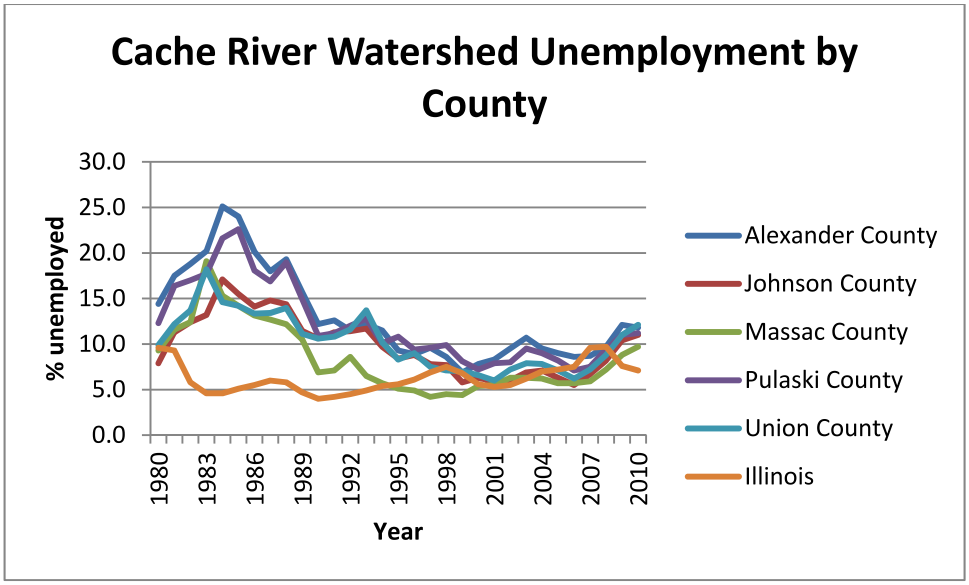

Figure 2.12. Cache River Watershed county unemployment has generally decreased over time, yet has been increasing since 2007 (Illinois Department of Employment Security, 2011).

Property taxes

Fifty-eight percent of aggregate Cache River Watershed county property tax bases were derived from farm land in 1999 (Figure 2.13). By 2008, this property tax class made up only 21.0% of regional property taxes. Residential property taxes showed the reverse trend, increasing from 26.2% to 49.1% over the same time period. Industrial property taxes also showed a notable increase from 7.7% to 18.0% of property taxes from 1999 to 2008.

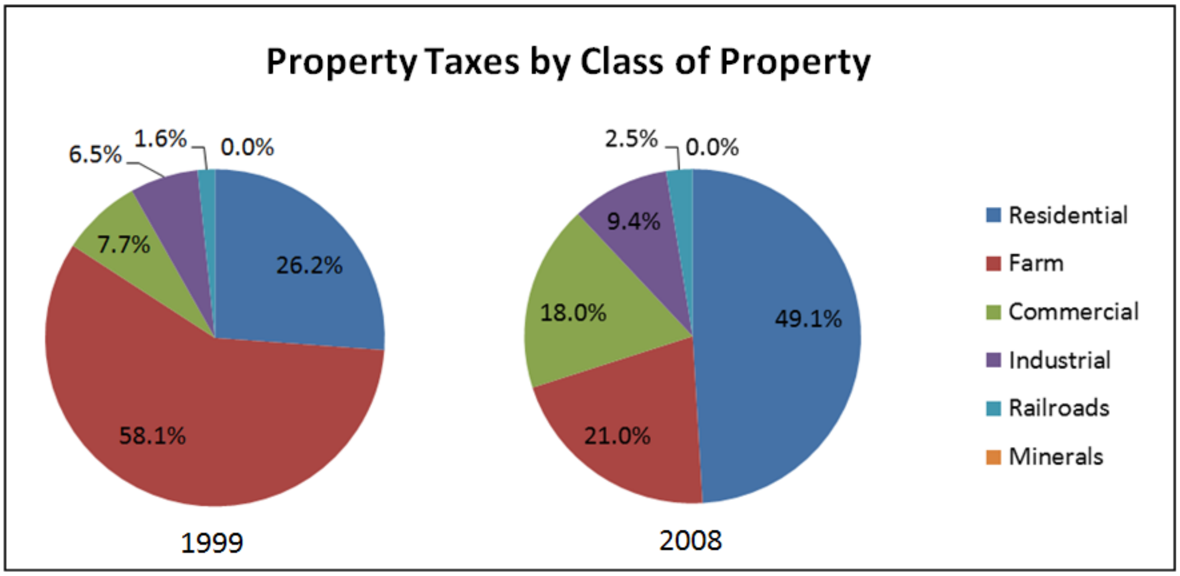

Figure 2.13. Property tax bases in Cache River Watershed counties have shifted from agricultural to residential property class between 1999 and 2008 (Illinois Department of Revenue, 2011).

Summary

Due to its location at the junction of four physiographic provinces, the Cache River watershed has considerable habitat heterogeneity and associated biodiversity. Humans have greatly altered the landscape, largely for agricultural purposes. These alterations have resulted in a highly modified river and altered forest and wetland ecosystems within the watershed.

Population is increasing in Johnson County, while the rest of the region faces declining populations. The percentages of county residents over 25 years old who have obtained bachelor's degrees and those not holding a high school diploma reflect a population with lower educational attainment rates than state averages. When compared to state statistics, the Cache River region's income levels and poverty rates indicate lower socioeconomic statuses. Similarly, unemployment in the Cache River Watershed counties is rising in a state with declining unemployment rates. Socioeconomic trends reflecting county population, educational attainment, income levels, and unemployment trends show the Cache River region to have formidable challenges.

Watershed management in conditions of ecological and water quality impairment, coupled with socioeconomic challenges, need be informed by sound science and interdisciplinary collaboration to address the variety of stakeholder interests and environmental complexities. While this chapter presents these physical, ecological and social characteristics of the watershed separately, human and natural systems are interwoven and interdependent (Figure 2.14). Feasible and effective solutions can only be identified through the understanding of the functions of and interactions between these systems in the watershed. Therefore, the emphasis of the next chapter is to explore how the different aspects of the Cache River Watershed interact so that there is a better understanding of the complexity of the challenges faced. Through analysis of previous research efforts, causes of existing social, physical, and biological settings in the watershed and impacts of these characteristics on natural systems in the basin can be more thoroughly understood and opportunities for future management decisions discerned.

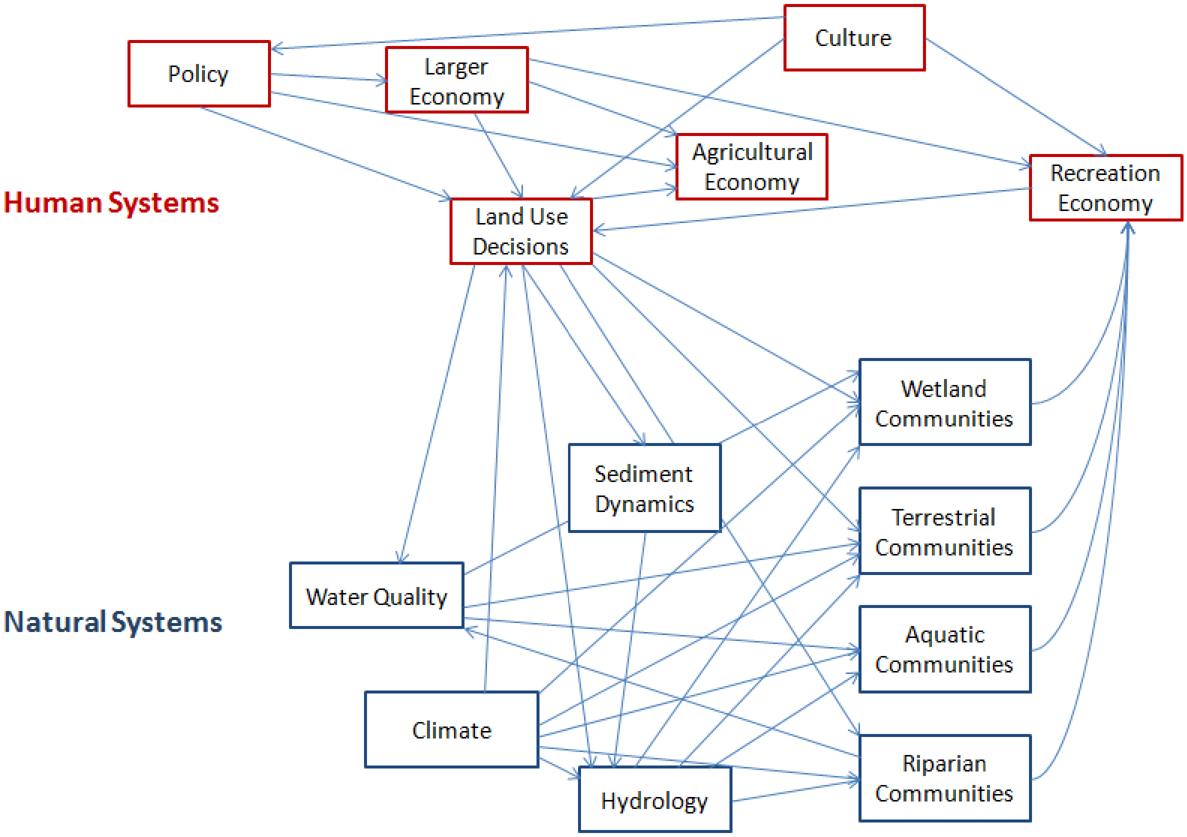

Figure 2.14. Concept map of the relationship of the human and natural system processes are illustrated to convey the reciprocal impacts between and among components of each dynamic system.

Chapter 3: Literature Review

Overview

The ecological integrity of a watershed is inextricably linked to and impacted by land use decisions and associated human activities occurring within the basin. These choices affect the functions and resilience of human and natural systems including: water quantity and quality, flow regimes of waterways, and habitat quality for all life, as well as economic and community development within the watershed. Land use decisions, including structural changes to waterways, are made through a myriad of pressures and incentives, including government programs with economic incentives, regulations, climate changes, and cultural norms. If the goal of managers and stakeholders is to provide the best possible environment for human communities as well as ecosystems in the Cache River Watershed, they must consider all factors involved in land use decisions (Euliss et al., 2008). Concurrently, however, is the necessity of a thorough understanding of the physical, chemical, and biological parameters of the system and expanding valuation of ecological health to human communities (Loomis, 2005).

The potential of ecological restoration to enhance tourism and generate economic benefits in the Cache basin has been noted (Beck et al., 1999; Caudill, 2008), highlighting one way by which the enhancement of ecological integrity has the potential to be symbiotically beneficial to human communities in the region. More broadly, however, the value of natural capital, and the goods and services humans derive from it, should be recognized and incorporated into decision-making to avoid the overuse and exploitation of common-pool resources (Lant et al., 2008). By recognizing the intrinsic and non-market value of environmental goods and services, decision-makers can more accurately incorporate the benefits to society of healthy functioning ecosystems (Ruhl et al., 2007). Noted benefits of ecological integrity include: economic and cultural benefits, recreational opportunities, and health benefits associated with high air and water quality.

Policies and management choices can promote ecosystem service provision by aligning agricultural commodity production with incentive structures that encourage ecosystem service provision (or discourage ecosystem disservice provision) (Wossink and Swinton, 2006). The valuation of ecosystem services to human populations is crucial to understanding their benefits to society and conducting research on the most effective ways to protect and restore ecosystem health (Costanza et al., 1997; Daily et al., 2000). Valuation of ecosystem services within watersheds is particularly complicated in light of the multiple and interacting services produced by the systems such as nutrient cycling, habitat provision, and carbon sequestration. However, due to the complexities and abundance of economic services supplied by wetland systems, attempts to apply econometric valuation to watershed restoration have shown the social value of restoration to outweigh costs (Jenkins et al., 2010). Prioritization of management activities based on stakeholder ranking and information exchange without monetization has also been proposed to simplify watershed management (Randhir and Shriver, 2009).

Research can inform policy and management decisions that are symbiotically beneficial to both human and natural systems. Ecological impairment is a reflection of land use choices and human activities that altered the structure and functioning of natural landscapes in the Cache River Basin. Scientific understanding of ecosystem functions, paired with an awareness of the costs and benefits of watershed management choices, can inform policy choices and land-based activities in order to define and achieve social and environmental goals. In all systems, including the Cache River Watershed, consideration of the interwoven processes is critical to prospects for sound watershed management (Shields et al., 2010). Human impacts on ecological integrity and the subsequent feedback effects of impairment on human systems is emphasized in watershed management plans in the Sacramento and Rhine river basins

(International Commission for the Protection of the Rhine, 2009; Heirman and Knecht, 2010). Similar explorations are required to inform basin management decisions in the Cache River Watershed. To determine further research needs in the Cache River Basin, this chapter seeks to delineate a thorough assessment of relevant literature covering land use choices and activities, their subsequent impacts on ecological integrity, and restoration efforts in the basin.

Land use decisions

Land use in the Cache River Watershed has changed dramatically in the past 200 years. Past decisions were primarily driven by the economic and political landscapes of the time, which often led to inefficient and suboptimal choices (Duram et al., 2004). For example, land deforested for agricultural use in the Cache region was selected based on location, rather than soil quality. Technological advances also led to the ditching and draining of lands, which could not have been employed for agricultural uses, prior to these developments. Later in the 20th century, new pressures to reduce erosion led to the expansion of land-based, incentivized USDA programs such as CRP in the watershed while, at the same time, economic pressures demanded the intensification of farming practices. It was also found that economic pressures were influential in land use changes throughout the 200 year study period, which included the initial harvesting of timber through the transfer to agricultural practices during the 20th century (Duram et al., 2004).

Climate also played a role in the land use changes in the watershed. The dry period during the 1930s allowed for much easier draining of the wetlands. By 1938, much of the forest and wetlands had been removed and, therefore, transformed the culture of much of the watershed as economic activities transitioned from industrial timber harvesting to private agricultural production. Challenges abound in balancing socioeconomic and development interests with ecological preservation and restoration; private land employed for income generating purposes such as agricultural production many times conflicts with initiatives to withdraw acreage from production to retire for conservation purposes (Duram et al., 2004).

While agriculture is less dominant in the Cache River Watershed than other watersheds in Illinois, it plays a significant role in land use decisions. There are a variety of agricultural practices in the watershed, ranging from small hobby farms to larger commercial enterprises (Kraft and Penberthy, 2000). However, there is also spatial heterogeneity of agricultural activities in the watershed. The upper section of the watershed contains primarily small farms while the lower section is dominated by the large commercial farms (Adams, 2005). These larger farms with fewer owners can have a significant impact on ecological restoration. According to Adams (2005), this consolidation of ownership can create a "ruling elite" scenario where a few residents hold much of the decision making power.

Government policy plays a role in land use decisions through various programs (Lant et al., 2005) and has affected land use change in the Cache River Watershed. For example, publically-owned parks, reserves and wildlife refuge areas have been created, which can be managed for ecological integrity through conservation measures. Private lands present additional challenges in terms of watershed management in that land owners are generally compensated for opportunity costs of agricultural production or other income-generating activities if they incur income loss or costs associated with restoration activities. However, conservation programs such as CRP and WRP have improved efforts to conserve private land and have been shown to be ecologically beneficial beyond their intended purpose while providing income to participating landowners.

Wetlands created through WRP have proven to be significant in providing for ecosystem services such as wildlife habitat (Rewa, 2005). Wetlands enrolled in WRP can also provide services such as carbon sequestration (Euliss et al., 2006; Ferris and Siikamaki, 2009). However, these wetlands are not always managed to maximize these services. Therefore, it has been suggested that the management must be conducted within the parameters of the ecosystem processes, as well as the political realities of a given area (Euliss et al., 2006).

The CRP program, initially intended for soil preservation, provides other ecosystem services (Dunn et al., 1993). Conservation programs such as CRP are often appealing to landowners because of the economic incentives and the ability to withdraw from the program over time. On CRP land, the Farm Service Agency has reported reductions of nitrogen and phosphorus in runoff, along with soil erosion reductions, and the ability of the retired agricultural land to sequester carbon (Ferris and Siikamaki, 2009). While the CRP program does not establish permanent easements, the effects of placing land in CRP can be seen even after removal from the program (Roberts and Lubowski, 2007). In a 2007 study, Roberts and Lubowski predicted 42% of CRP lands would not return to crop production after CRP enrollment ended, and suggested putting an emphasis on recruitment over renewal. However, economic factors play an important role in recruitment and renewed enrollments. For example, higher crop prices and profit margin pressures have been documented to keep farmers from initially putting or re-enrolling land into CRP (Secchi and Babcock, 2007; Secchi et al., 2008)), along with the maximum acreage and dollar limitations of the program itself (Lant et al., 2005). Though it is difficult to discern at the watershed scale due to the way land use data is generally collected by political boundaries, there is evidence of commodity price influences in the Cache River watershed. Prices for soybeans and corn have increased while, as stated earlier, the total acres of CRP have declined in recent years in Cache River Watershed counties (Figure 2.4). During this same time, the percent of acreage for corn and soybeans has increased while pasture and grasslands have decreased (CRP lands would likely be classified as pasture or grasslands in the Cropland Data Layer (Figure 3.1)) (United States Department of Agriculture, 2010).

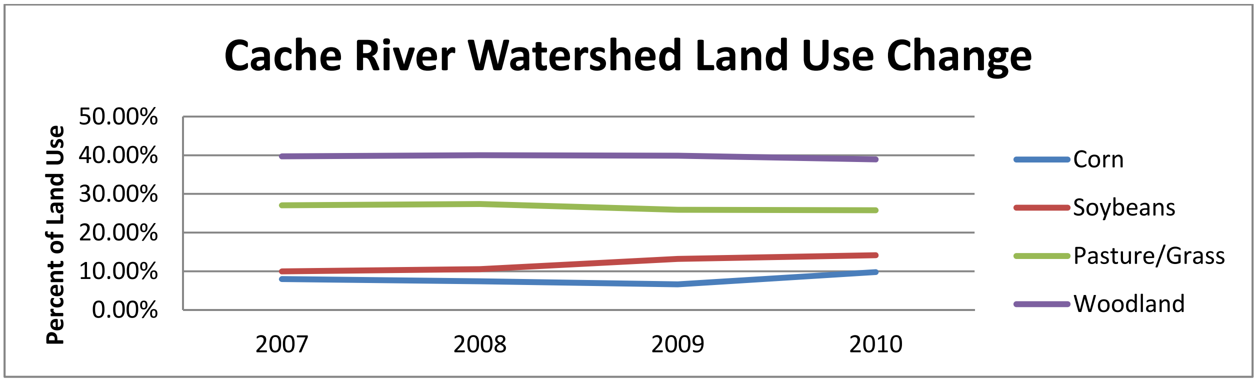

Figure 3.1. Changes in land use indicate an increase in crop acreage and a decline pastures and grasslands in recent years.

While studies have shown Farm Bill conservation programs to result in enhanced ecosystem service provision in heavily agricultural wetland systems (Brinson and Eckles, 2010), their benefits may not be fully realized due to temporal delay in enrollment and observed impacts (Davie and Lant, 1994) and they are often temporary. Within the Cache River Watershed, there were also pressures to protect land in a more permanent fashion through government acquisition. Initially, private landowners resisted government intervention and feared the loss of property rights, which was amplified by the lack of communication between government officials and those potentially impacted by proposed conservation activities. Despite these challenges, significant amounts of land were acquired for conservation purposes (Adams et al., 2005; Davenport et al., 2010).

Land was acquired from only willing sellers to form Cypress Creek National Wildlife Refuge (CCNWR) (United States Fish and Wildlife Service, 1996). To encourage land owners to sell their land, revenue sharing with local governments partially offsets property tax losses incurred. A potential economic benefit through increased recreation in the parks further justifies these expenditures.

The perception of wetlands and other natural areas can vary among watershed constituents (Davenport et al., 2010). Agencies often focus on the physical and biological aspects of preservation, while the general population may look more towards the cultural and economic benefits such as recreation, development, and aesthetics. While efforts were made to cooperate with and include local landowners in developing the Cypress Creek National Wildlife Refuge (CCNWR) through the creation of the Resource Planning Committee, differences in perception continue to be a source of contention (Davenport et al., 2010). Adams and others (2005) also emphasize "legitimacy" in the creation of the refuge. In the view of commercial farmers, the Resource Planning Committee was not a true representation of the Cache River Watershed community because land owners were hand selected by Soil and Water Conservation and Nature Conservancy representatives (Adams et al., 2005). Therefore, those who would make the larger proportion of land use decisions affecting the watershed (large commercial farms) felt disconnected from the planning process.

The CCNWR was authorized on June 26, 1990, through the Emergency Wetlands Resource Act of 1986. A management plan was developed for the CCNWR in 1996 by a diverse committee representing Federal and state agencies, non-governmental organizations, universities and local citizens. Six goals and objectives were developed in the plan: resource protection, habitat restoration, resource management, dynamic partnering/cooperative action, environmental education, and wildlife dependent recreation. According to the plan for the refuge, land use decisions play a large role in the management of the refuge and should be based on scientific results; therefore, access to quality scientific research should be a priority for managers. In addition, managers should employ adaptive management practices to better use current and future research. The land use choices implemented by the refuge include wetlands, forests, and shrubland. The plan also calls for leaving 10% of the refuge land in agricultural production. Some of the agricultural lands use grasses to stabilize erosion, while others improve fertility and help to control noxious weeds (United States Fish and Wildlife Service, 1996).

The formation of the refuge and the state-owned reserves continues to be controversial. In a 2010 study, one of the burdens which locals perceive to have incurred is the loss of property tax base.

Another concern noted by local interviewees is the unrealized economic benefits from the formation of the parks. One respondent indicated that cooperation in economic development between commercial and environmental interests would go a long way in legitimizing the parks (Davenport et al., 2010).

Impacts of Land Use Decisions

Channelization and Sediment Dynamics

Many processes are fundamental to the formation and evolution of channels. In alluvial channels, these processes are consistently occurring at micro-scales to reestablish a hydraulic equilibrium that is destabilized by various natural and anthropogenic disturbances. While the effects of natural disturbances are usually quickly remediated by geomorphic responses, effects of human-induced disturbances can take an indefinite period of time to adjust by the same processes. The result of these disturbances, including channelization, may be a rapid degradation of the physical, biological, and chemical processes which regulate the ecological health of the system (Darby and Simon, 1999). Channelization of streams and rivers includes straightening, widening, dredging, bank stabilization, and clearing or snagging operations (Demissie and Xia, 1991).

The history of the Cache River Watershed is a prime example of how human-induced disturbances can alter natural hydraulics and hydrology within a system. The physical changes made in the watershed have reduced the effectiveness of many vital ecological processes and threaten the biodiversity in the watershed. Natural drainage of the watershed prior to 1915 is shown in Figure 3.2. Streams and creeks in the uplands of the watershed drained south into the Cache River valley and then slowly west towards the Ohio River (Demissie et al., 1990). Flooding from the Ohio River into the Cache River valley towards the Mississippi River was a common occurrence, approximately every 10 years (Gough, 2005).

Additionally, occasional flooding of the Mississippi River backed up into much of the valley. Flooding from both of these sources and the relatively flat terrain of the valley created many swampy areas.

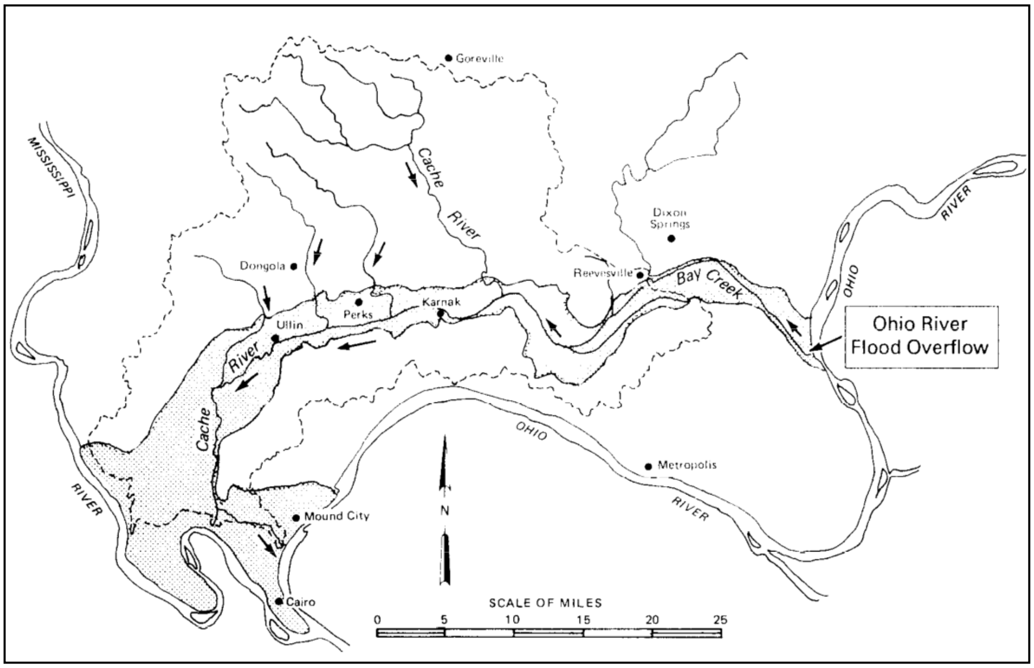

Figure 3.2. Natural drainage and flow pattern of the Cache River prior to 1915 (Bhowmik et al., 1997).

In the 1800s, channelization had begun in the Cache River watershed as a result of commercial and industrial interests. Drainage, levee construction, logging, and intensive agriculture brought complex hydraulic and hydrologic changes. Perhaps the most dramatic change to the hydrology of the River occurred with the completion of the Post Creek Cutoff, draining the Cache River and its eastern tributaries into the Ohio River 35 to 40 miles further upstream than the natural outlet (Figure 3.3). The cutoff, along with later completion of the Karnak/Cache River Levee, bisecting the river and watershed. In 2002, a breach of the Karnak/Cache River Levee reestablished a slight connection between the lower and upper Cache Rivers. Floodwaters from the upper Cache and Ohio Rivers now back up westwardly into the lower Cache River.

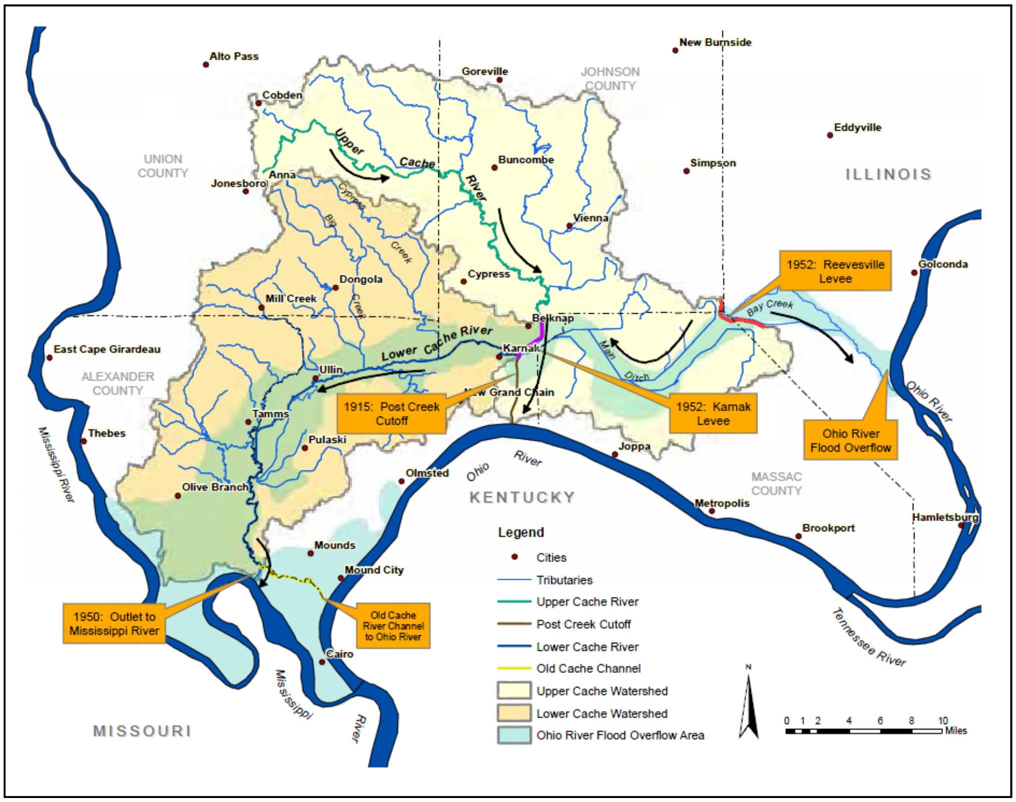

Figure 3.3. Historical major drainage alterations and current drainage pattern of Lower and Upper Cache River watersheds (Demissie et al., 2008).

The most dramatic adjustments in engineered rivers are often a result of slope changes caused by channel shortening (Brookes, 1988). Detouring 368 square miles of drainage, the Post Creek Cutoff significantly altered the hydraulics and hydrology of the watershed (Demissie et al., 2008). By shortening the path of flow from the upper Cache River to the Ohio River, the slope of the river channel was increased (Figure 3.4). The average slope of the upper Cache River from Route 146 bridge (352.1 feet msl) to the confluence of the Ohio River (288.8 feet msl) was most recently calculated as 2.35 feet per mile (Demissie et al., 1990). The original slope from the Route 146 bridge to the confluence of the Ohio River (based on additional 35-40 miles) can be estimated to be approximately 1 foot per mile. To reestablish hydraulic equilibrium with the Ohio River, the upper Cache River has dissipated energy through several physical adjustments. The increased gradient enabled transport of more sediment than which is supplied at the upstream end of the river. The additional sediment that can be transported is acquired from the channel bed and banks, causing headcutting upstream of the Post Creek Cutoff. As this entrenchment continues, the stream bed downcuts, and the hydraulic gradient between the ponds, wetlands, and stream increases. This increase in hydraulic gradient results in increased seepage and drainage from the ponds and wetlands towards the stream channel and changes the hydrologic balance required to maintain the ponds and wetlands in their natural states (Demissie and Xia, 1991).

Channel entrenchment also has a cascading effect on tributaries. As the main channel of a watershed incises its tributaries will tend to incise at the same rate (Heine and Lant, 2009). At some points in the channel, entrenchment has even reached bedrock, resulting in increased bank erosion, gully formations, and lateral progression of the river and its unstable, nearly vertical banks threaten to drain Heron Pond and other wetlands. In 1996, the US Geological Survey reported that at one point the Cache River comes within 35 feet of Heron Pond (Holmes, 1996). In 1990, the Illinois State Water Survey released an in depth report on the hydrology, hydraulics, and sediment transport in the Cache River, which included channel geometry comparisons (Demissie et al., 1990). They reported that the Post Creek Cutoff was roughly two times wider, and at least twice as deep as its design specifications (Figure 3.5). Lateral gullies, ranging from 30 to 40 feet deep, formed along the cutoff, eroding valuable farmland and access roads.

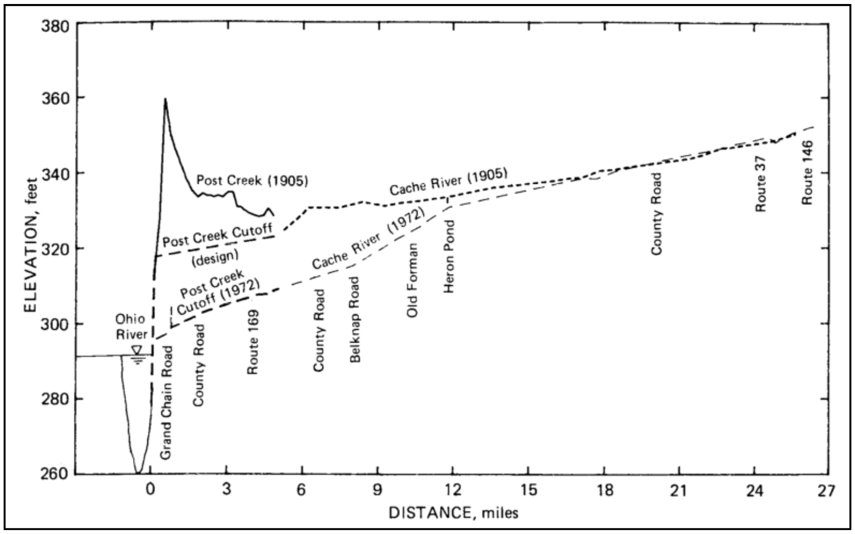

Figure 3.4. The bed profiles of the Post Creek Cutoff and upper Cache River segments show significant change from 1905 to 1972 (Demissie et al., 1990).

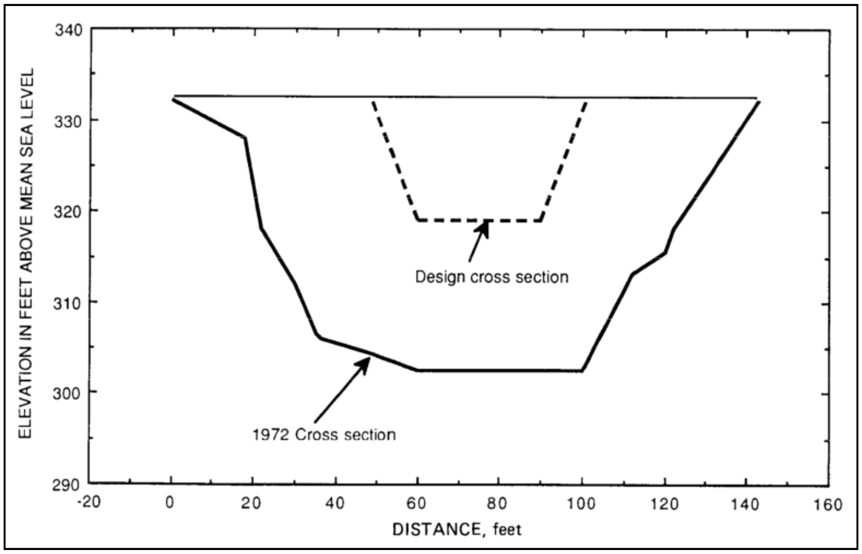

Figure 3.5. Erosion has increased the cross-sectional area of the channel as seen in the comparison between the original Post Creek Cutoff channel design and a cross section measured in 1972 (Demissie et al., 1990).

In the lower Cache River, surface water drainage is a major issue due to the flat terrain. Due to its disconnection from the upper Cache River, the lower Cache River only receives discharge from its upstream tributaries. The main tributaries include Big, Cypress, and Mill Creeks and Ketchell and

Limekiln Sloughs. Compared to the lower Cache River these tributaries have high gradients, much greater than that of the upper Cache River (Figure 3.6).

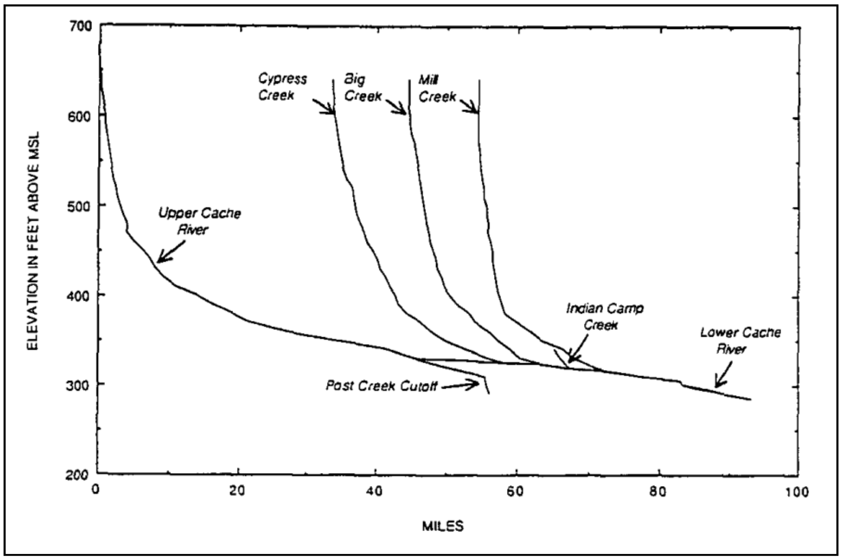

Figure 3.6. Profiles of major tributaries in the Cache River Basin show higher gradients than the lower Cache River channel (Demissie et al., 1990).

When these tributaries discharge into the lower Cache River, they create backwater conditions in the valley that reach upstream into the tributaries as well. Backed-up water is particularly problematic during major storm events where floodwaters enter the lower Cache River rapidly, but discharges into the Mississippi and Ohio Rivers very slowly. These differences in discharge over time between the lower Cache River and its tributaries can be seen in Figure 3.7 (Demissie et al., 1990; Bhowmik et al., 1997)

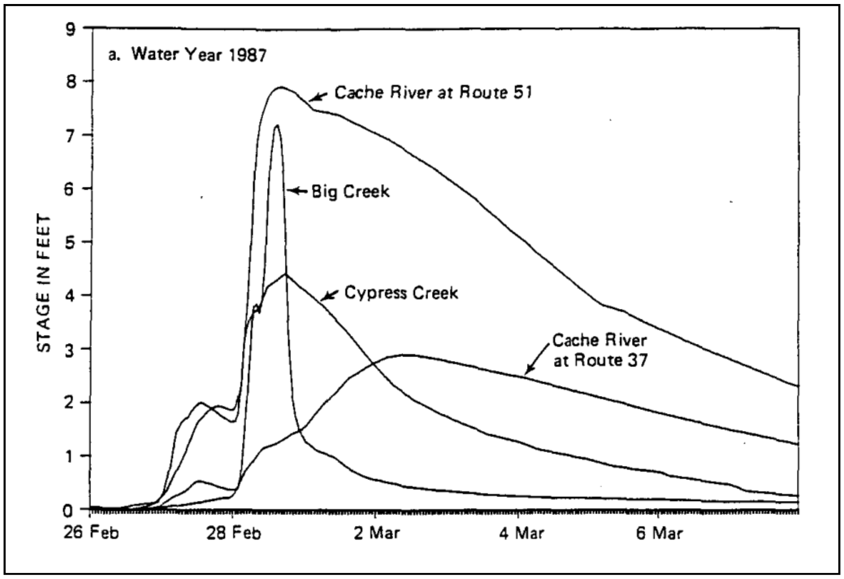

Figure 3.7. Stage hydrographs for the lower Cache River and its tributary streams show the flashiness of tributaries such as Big Creek in comparison to the mainstem lower Cache River (Bhowmik et al., 1997).

Drainage in the lower Cache River is further complicated in an area of Buttonland Swamp where the river can flow east or west. East of the Cypress Creek confluence, the lower Cache River has a downward slope to the east toward Karnak/Cache River Levee. The direction of flow in the area is dependent on the amount of water in Buttonland Swamp, downstream water levels, and which tributary is contributing the most water (Demissie et al., 1990). During low or moderate flow conditions, flow will move in both directions, but during flood conditions most of the water will flow towards the west. The location where the flow is divided is dynamic, varying for each flood event (Bhowmik et al., 1997). Figure 3.8 depicts the channel bed and surface water profile of this area during low and moderate flow conditions.

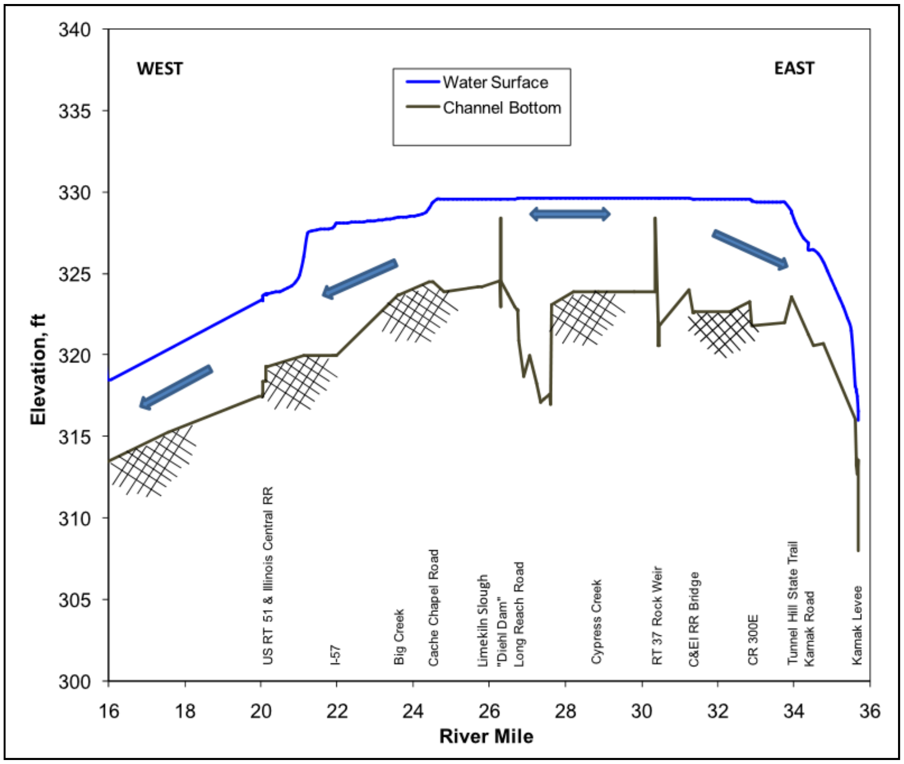

Figure 3.8. The channel bed profile of lower Cache River currently allows water to flow in both directions, depending on water elevation conditions (Demissie et al., 2008).

The uplands of the lower Cache River include highly channelized agricultural drainage networks. The removal of natural vegetative cover and tile drainage cause water to runoff from the uplands rapidly (Figure 3.7). Due to the high runoff rate and drainage channels, soil is eroded from land and channel banks and quickly transported into the river and wetlands. Since the lower Cache River lies in such a flat area and lacks its pre-engineering discharge characteristics, sediment deposited from the uplands into the river and wetlands is not flushed as fast as it is received. The continual accumulation of sediment alters the hydraulics and hydrology of wetlands and causes flooding in tributary streams (Allgire and Cahill, 2001). While erosion and sedimentation are natural geomorphic processes necessary for forming stable landscapes, under current conditions in the lower Cache Watershed these processes are degrading the ecological condition of the system.

Sedimentation is most troublesome in the area previously described near Buttonland Swamp where flow can move east or west. The swamp is a complex system of interconnecting channels and natural levees which stay flooded all year, but the water level varies with the season and rainfall. Water in the upper part of Buttonland Swamp is largely supplied by Cypress Creek, while the lower part is partially supplied by Big Creek. The upper parts of each tributary are bedrock controlled and have natural meanders, while the lower reaches are alluvial and heavily channelized. These channelized reaches show signs of active degradation and instability, resulting in transportation of large sediment loads. Much of this sediment, 69-84%, accumulates in Buttonland Swamp (Demissie et al., 1992). A small in-channel weir located downstream of Buttonland Swamp may play a role in sedimentation of the swamp. Sediment within the swamp is deposited along the natural levees and on the higher areas covered with Buttonbush. Due to low water dams on both edges of the swamp, it acts as a shallow water lake rather than a floodplain. As the ancillary channels fill with sediment, a delta will form at the confluence of the lower Cache with Cypress Creek and the vegetation will start to get choked off as the shallow lake fills (Bennett et al., 2001).

Using a radiometric analysis involving ^{137}Cs tracer, the sedimentation rate was found to range from a low of 0.2 cm per year in the forested floodplain near Highway Route 37 to a high range of greater than 2 cm per year in the edge of the river channel in the Long Reach area (Allgire and Cahill, 2001). In comparison to a sedimentation survey from 1988, the sedimentation rates have changed little over time, especially in Eagle Pond and Section 8 Nature Preserve (Demissie et al., 1992).

Habitat Loss

The primary drivers of worldwide environmental change and biodiversity loss are habitat loss, alteration, and fragmentation of natural habitat (Hooper and Vitousek, 1997; Wolters et al., 2000). Some regions experience disproportionate impacts of land use change on biodiversity due to high species endemism (Chapman et al., 2009). In the United States, only about 20% of historical amounts of bottomland forest remain and this loss is nearly five times greater than for any other major hardwood forest type (Abernethy and Turner, 1987). Within the Cache River Watershed, 97,000 ha of bottomland forests were converted to cropland (Kruse and Groninger, 2003), although many fields have now been restored or abandoned.

In bottomland forest ecosystems, hydrologic processes are responsible for modifying and perpetuating the habitat within the system (Pashley and Barrow, 1993), creating and maintaining habitat complexity, and promoting high levels of biodiversity (Kozlowski, 2002) through the interplay of topography and hydrology. Intact bottomland forest ecosystems are important habitats for many species of birds (Wakeley et al., 2007) and are especially valuable because they support a high diversity and density of breeding Neotropical migratory birds (Sallabanks et al., 2000; Wakeley et al., 2007).

Channelization in the Cache River Watershed has led to incision and the subsequent destruction and degradation of stream corridor habitats (Shields et al., 1998; Hupp et al., 2009; Shields et al., 2010), with the formations of lateral gullies that connect the main channel of streams to adjacent (off-channel) wetlands, altering the hydrology of the wetlands (Shields et al., 1998; Shields et al., 2010). This process degrades off-channel wetlands and threatens the integrity of bottomland ecosystems and the quality of bottomland forests as breeding habitat for Neotropical migratory birds (Pashley and Barrow, 1993; Sallabanks et al., 2000). Lateral gullies are currently draining more than 20 off-channel wetlands (forested wetlands adjacent to the main river channel) (Hoover, 2009) in the Cache River Valley, potentially exposing birds breeding in these habitats to nest predators like raccoons (*Procyon lotor innaeus*) (Hoover, 2006), and altering the plant community in ways that reduce bird diversity (Wakeley et al., 2007).

The spatial pattern of development at landscape scales may have important, but varying ecological impacts. For example, dispersed development may consume more land and lead to more widespread ecological degradation (Xie et al., 2005), but clustered developments may be dominated by greater proportions of non-native vegetation (Lenth et al., 2006). The spatial pattern of development can also affect hydrology, nutrient cycling and microclimate, and thus the provision of ecosystem services that benefit society (Solecki and Oliveri, 2004).

One of the most notable changes is the loss of the river-floodplain connection to the river which facilitated a large part of the wetland ecosystem's natural processes. River-floodplain connectivity are important components of riverine system's function and health (Junk et al., 1989; Poff et al., 1997) and play an important role in the movement and lifecycles of fish and invertebrates (Lytle and Poff, 2004; Vannote et al., 1980; Stanford and Ward, 1993).

The altered hydrology and loss of the natural flood pulse has also changed the vegetation structure in many of the swamps of the Cache River system. Many species of wetland vegetation, such as cypress and tupelo trees, have evolved life histories around the natural inundation of flood waters followed by periods of low water (Middleton 2000), which is restricted when waterways are severed from their floodplains. Cypress and water tupelo seeds are unable to germinate directly in water and require dry periods for successful regeneration (Anderson and White, 1969). Retention structures are present that control water levels and may hinder the regeneration of these and other woody species (Middleton, 2006). Temperature and water availability may be the most critical environmental factors in maintaining conducive conditions for these trees’ production; climate change, coupled with altered hydrological systems, will likely further alter their range (Middleton and McKee, 2005; Middleton and McKee, 2004). Plant diversity and species richness have declined in Buttonland Swamp (Middleton, 2000), a likely result of the changed hydrology in the system and the aforementioned water control structures.

Logging in the Cache River has also impacted the system. Although significant portions of land have been protected and reforested, the effects of logging are still evident through observations in changes of vegetation structure. Cut-over stands of forested swamp in Heron Pond contain more shrubs, tupelo, floating logs, and open canopy than undisturbed stands (Anderson and White, 1969). Land use changes that alter the hydrology of a system may also alter the vegetation structure and potentially impact the success of restoration practices, the regeneration of native vegetation (Kruse and Groninger, 2003), and animal species composition, movement, and herbivory (Ruzicka et al., 2010).

Riparian Buffers

Riparian forests connect upland forests to aquatic ecosystems along an ecotonal gradient. As a result, riparian forests are characterized by high species diversity and productivity (Naiman et al., 1993; Naiman and Decamps, 1997). Land use changes have the potential to impact terrestrial and aquatic communities in addition to water quality within the gradient. Therefore, an area is often retained adjacent to water bodies to reduce land use impacts (Darveau et al., 1995; Machtans et al., 1996; Blinn and Kilgore, 2001). These areas are known as “riparian management zones” (RMZs), or riparian buffers, and have received considerable attention for mitigating disturbance, including agricultural runoff. Reductions in sediment loads and their associated nutrients in surface runoff is a fairly universal effect of riparian forests because of the physical nature of the processes involved. Many studies present evidence that riparian zones reduce nitrogen, phosphorus, and sediment loads to adjacent streams (McColl, 1978; Karr and Schlosser, 1978; Schlosser and Karr, 1980; Schlosser and Karr, 1981b; Schlosser and Karr, 1981a). In the southwestern region of eastern deciduous forest where the Cache River basin is located, riparian buffers may be critical for nutrient attenuation in upland riparian sites, where there may be less potential for denitrification relative to lowland areas with shallow water tables and greater tendency to flood (Blattel et al., 2009).

Most riparian research focuses on the effects of harvested versus unharvested riparian management zones (RMZs) (Hanowski et al., 2000; Hanowski et al., 2002; Hanowski et al., 2003; Hanowski et al., 2007; Chizinski et al., 2011) or the widths of RMZs on birds or reductions in nutrient loading (Lee et al., 2004; Shirley and Smith, 2005; De Steven and Lowrance, 2011). In one of the few replicated experimental studies that examined varying levels of residual basal area, more edge and early successional species and individuals colonized harvested RMZs after harvest. By contrast, the number of mature forest birds declined in harvested RMZs, but remained high in unharvested RMZs. Thus, retaining higher residual basal area in harvested RMZs decreased the impact on the avian community (Hanowski et al., 2005).

Vegetation type also plays a factor in riparian buffers. Native forest and grass riparian buffers are common best management practices for controlling nonpoint source pollution in agricultural watersheds (De Steven and Lowrance, 2011). Dense stands of invasive trees along river margins change habitat structure, fire regimes, hydrology, and water quality, which in turn changes light regime, temperature, oxygen levels, leaf litter input, nutrient cycling, pH, turbidity, soil chemistry, erosion processes and sedimentation (Rutt et al., 1989; Fischer et al., 2003; Kollmann and Fischer, 2003). Invasive trees often have dense canopies that shade out habitats and prevent growth of indigenous understory plants such as sedges, reeds and grasses, altering availability and quality of marginal habitats (Kinvig and Samways, 2000; Samways and Steytler, 1996; Samways et al., 2011) and soil (Fischer et al., 2010). Loss of marginal vegetation impacts benthic macroinvertebrate larvae which use the vegetation for nursery or feeding habitats or for shelter, and adult macroinvertebrates. Macroinvertebrates use vegetation for perching or oviposition sites. Invasive riparian vegetation therefore affects both riparian and aquatic habitats and the removal of vegetation improves the situation (Samways et al., 2011).

Cane

The southern Illinois landscape offers an opportunity to examine a riparian zone species, giant cane [*Arundinaria gigantea* (Walt.) Chapm.]. Cane is a native bamboo species that has a relatively dense rooting network, functioning as a riparian zone plant (Brantley and Platt, 2001) to consider in restoration. Cane was a dominant component of riparian vegetation in the lower Midwestern and southeastern United States, including southern Illinois (Platt and Brantley, 1997; Brantley and Platt, 2001; Platt et al., 2009). Giant cane is a viable candidate to include in multispecies riparian buffers designs, as it promotes infiltration of surface runoff and deposition of sediment and associated nutrients through its high density culms and extensive shallow rooting network (Schoonover et al., 2005; Schoonover et al., 2006). Also, giant cane can provide significant wildlife habitat benefits, especially in the fragmented Midwestern United States landscape (Blattel et al., 2009). It provides cover for wildlife throughout the year as an evergreen species (Platt et al., 2001). The dense, aboveground culms provide sanctuary to many species of insects, birds, reptiles and mammals (Rose, 1981; Platt et al., 2001). Some species such as the threatened Swainson's Warbler (*Limnothylpis swainsonii*) inhabit giant cane stands exclusively (Eddleman et al., 1980; Hoover et al., 2000). In addition, giant cane performed as well as, or better than, forest vegetation in terms of maintaining low ground water nitrogen levels (Schoonover et al., 2010). Thus, giant cane should be considered in multi-species restoration strategies aimed at reducing nutrient inputs into surface and ground water systems.

Water Quality

Water quality is a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. To determine water quality, scientists first measure and analyze characteristics of the water such as temperature, dissolved mineral content, dissolved oxygen, turbidity, conductivity, and levels of nutrients, pesticides, and heavy metals (Cao and Hawkins, 2011; Ghumman, 2011). Selected characteristics are then compared to numeric standards and guidelines to decide if the water is suitable for a particular use. The U.S. Environmental Protection Agency (USEPA) and the states are responsible for establishing water quality standards to protect human health and natural ecosystems (Cordy, 2001).

Natural water quality varies from place to place, and with season, climate, and types of soil and rocks strata. When water from precipitation moves over land and through the ground, the water may dissolve minerals in rocks and soil, percolate through organic material such as roots and leaves, and react with algae, bacteria, and other microscopic organisms (Martinez and Shu-Nyamboli, 2011; Rinaldo et al., 2011). Water may also carry plant debris, sand, silt, and clay to rivers and streams making the water appear “muddy” or turbid. When water evaporates from lakes and streams, dissolved minerals are more concentrated in the remaining water (Cordy, 2001; Rinaldo et al., 2011). Each of these natural processes changes the water quality and subsequently, how the water can be used.

Urban and industrial development, farming, mining, combustion of fossil fuels, stream-channel alteration, animal-feeding operations, and other human activities can also impact the quality of natural waters (Vitousek et al., 1997). For example, the nitrogen and phosphorus fertilizers applied to crops and lawns can be dissolved easily in rainwater or snowmelt runoff (Cordy, 2001; Vitousek et al., 1997). Excess nutrients carried to streams and lakes encourage abundant growth of algae, which leads to low oxygen in the water and the possibility of fish kills (Cordy, 2001; Martinez and Shu-Nyamboli, 2011; Blattel et al., 2009; Vitousek et al., 1997).

Chemicals such as pharmaceutical drugs, dry-cleaning solvents, and gasoline have been found in streams and ground water. After decades of use, pesticides are now widespread in streams and ground water, and can exceed the existing standards and guidelines established to protect human health (Meador and Goldstein, 2003; Montreuil et al., 2010). Some pesticides have not been used for 20 to 30 years, but they are still detected in fish and streambed sediment at levels that pose a potential risk to human health, aquatic life, and fish-eating wildlife (Velisek et al., 2011). In addition, mixtures of chemicals typically are found in water, but health-based standards and guidelines have not been established for chemical mixtures and their interactions (Cordy, 2001).

Through the Illinois Environmental Protection Agency's (IEPA) Ambient Water Quality Monitoring Network, water quality parameters are collected every six weeks at two fixed sampling locations within the watershed. Water quality is also measured throughout the watershed though the Illinois' Intensive Basin Surveys which occurs on a five-year revolving cycle. Every two years, IEPA reports water quality impairments to USEPA. Between 2002 and 2006, the upper Cache River had numerous sites with impairments, with the most common types of impairment related to high amounts of total ammonia, nutrients (phosphorus), habitat alterations, or low dissolved oxygen (Figure 9). During the same years in the lower Cache River, primary impairments were siltation, habitat alterations and low dissolved oxygen (Figure 10) (United States Environmental Protection Agency, 2011).

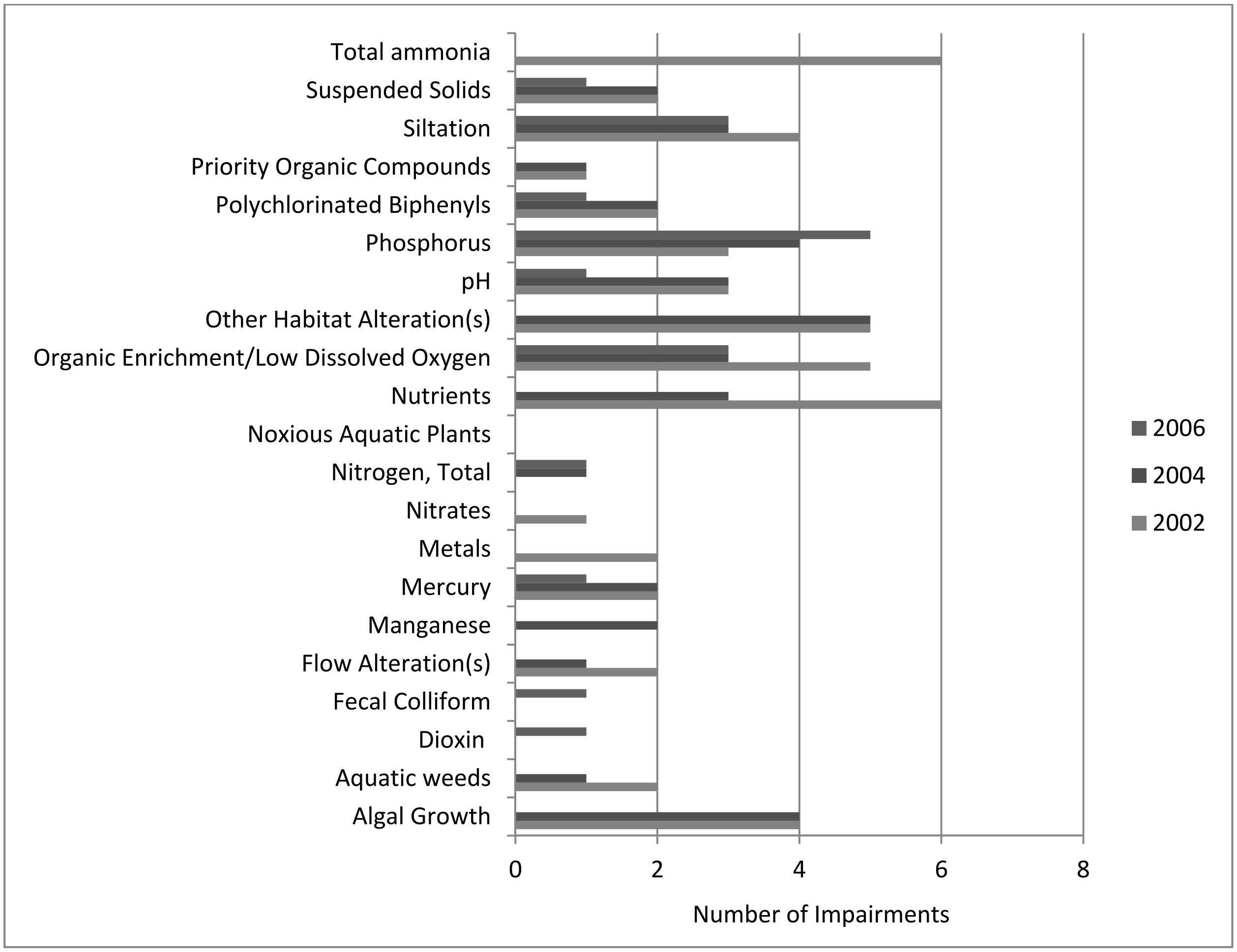

Figure 3.9. In the upper Cache River, nutrients, low dissolved oxygen, habitat alterations and phosphorus were the leading water quality impairments between 2002 and 2006 (U.S. EPA, 2011).

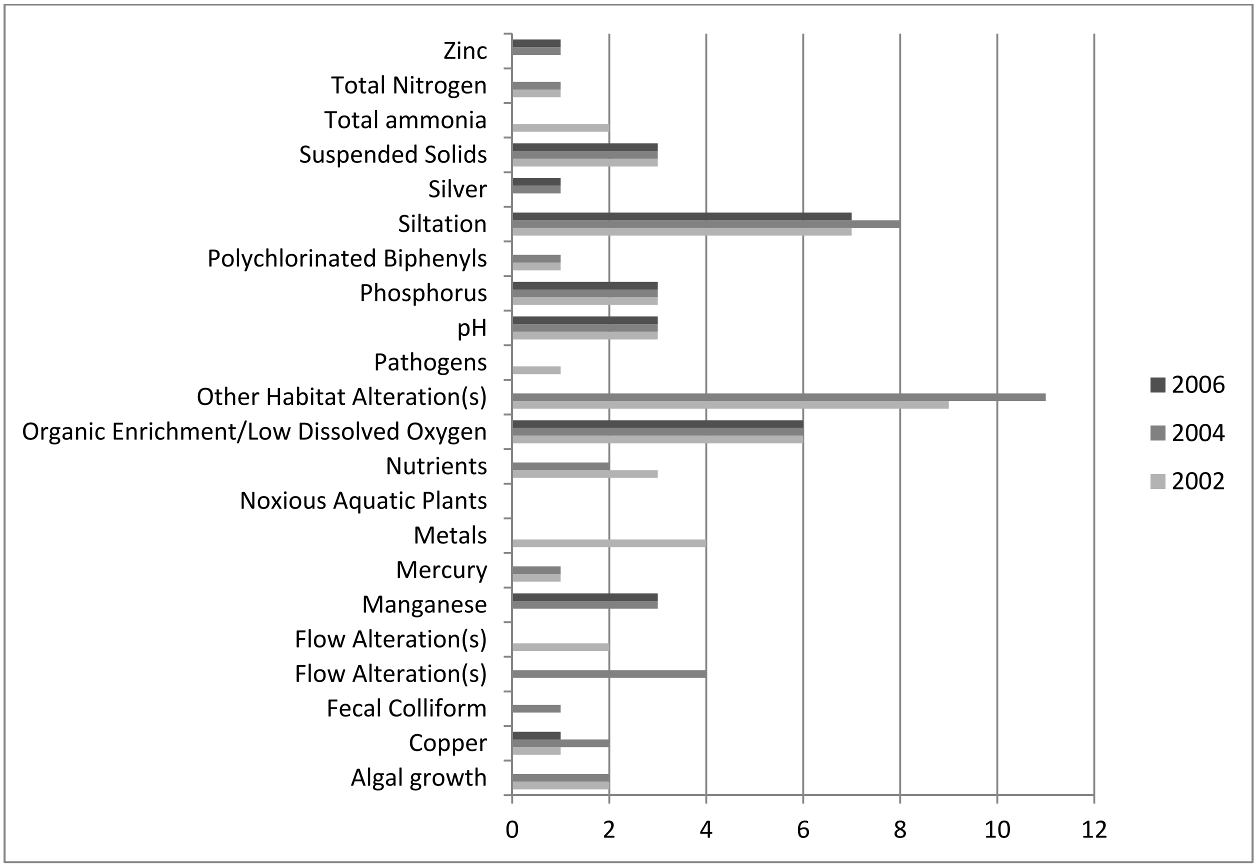

Figure 3.10. In the lower Cache River, habitat alterations, siltation and low dissolved oxygen were the major water quality impairments between 2002 and 2006 (U.S. EPA, 2011).

In stream production

Macroinvertebrate community structure can be strongly influenced by land use (Sponseller et al., 2001) and terrestrial vegetation within the floodplain provides bank stabilization, nutrient retention, flood control, wildlife habitat, and in-stream organic matter resources that are vital for ecological processes. Allochthonous material, organic matter inputs from the floodplain, provides food resources and habitat for aquatic life, and plays an important role in shaping stream channel morphology (Zimmerman et al., 1967; Bilby, 1981) such as pools and depositional areas (Keller and Swanson, 1979). These depositional areas shift and facilitate the transport of materials downstream and cause local flooding by holding back water and utilizing the floodplain, which may also result in less severe flood pulses downstream (Keller and Swanson, 1979).

Many critical processes such as trophic structure (Wallace et al., 1997), primary production, and decomposition rates (Middleton, 1994) can also be significantly influenced by riparian inputs. Therefore, the loss of or change in canopy cover may have multiple impacts to a stream system including shifting light availability and quantity, types of nutrients entering a system (Denicola et al., 1992; Sweeney, 1993; Dodds et al., 1996; Kiffney et al., 2003) and the processing rates and colonization of leaf material by invertebrates (Whiles and Wallace, 1997).

Biota

Aquatic Macroinvertebrates

The in-stream habitat loss that has occurred as a result of the land use changes in the basin has impacted the invertebrate community structure and function of the river. Differences in invertebrate community structure between the upper and lower Cache River has been noted in recent studies which examined an increase in emerging insect diversity at weir sites along the upper Cache river compared to non-weir sites in the lower Cache (Heinrich, 2011). These differences in emerging insects have been seen to impact higher trophic levels.

Since the early 1980s, when the first survey of freshwater mussels occurred, 27 species of mussels have been collected in the Cache River Watershed (Appendix A) (Phillippi et al., 1986; Shasteen, 2011). Surveyed mussels include riverine mussels which are generally most successful in habitats with sand and gravel substrates, such as mapleleaf (*Quadrula quadrula*) and threehorn wartyback (*Obliquaria reflexa*). Also included are mussels that often inhabit headwater, slough and pond habitats such as flat floater (*Anodonta suborbiculata*), white heelsplitter (*Lasmigona complanata*), paper pondshell (*Anodonta* *imbecilis*), giant floater (*Anodonta grandis*), and pondmussel (*Ligumia subrostrata*) (Burr et al., 2004). Species occurring in lentic habitats with mud or silt substrates are often limited to shallow habitats due to their poor tolerance of hypoxia (McMahon and Bogan, 1991). Other species, including threeridge (*Amblema plicata*) and fragile papershell (*Leptodea fragilis*), have been reported as being adaptable to water depth variability and can tolerate impoundments (Cummings and Mayer, 1992).

Habitat destruction, channelization, sedimentation, pollution, commercial exploitation, and invasive species, have been identified as contributing causes of mussel extinction and species distribution loss (Bogan, 1993). One invasive mussel, asiatic clam (*Corbicula fluminea*), has been recorded at various sites in the watershed. This species is smaller than most native species, has a short lifespan, grows rapidly, matures earlier, and reproduces multiple times a year (McMahon and Bogan, 1991). It has been suggested that successful asiatic clam invasion decreases with increasing biomass of adult native mussels (Strayer, 1999; Vaughn and Spooner, 2006).

Fishes

In terms of the fish communities within the Cache River, the combination of differing habitats, including cypress and tupelo swamps, upland streams and lowland rivers has resulted in unique and diverse assemblages. In fact, the 85 native fish species found in the watershed represent 42% of all native fish found in Illinois and 21% of all native fish in the Mississippi River basin (Burr and Mayden, 1992; Burr, 1992). Five major guilds of fish assemblages have been classified in the watershed: the upland guild, composed of sediment intolerant species which require rocky substrates for spawning; the bottomland guild, composed of obligate swamp species; the midreach guild, includes species inhabiting upland and bottomland habitats as well as transition areas and is made up of species tolerant of homogenous, channelized habitats; the lower reach guild, composed of riverine fishes which are highly mobile and adaptable; and the ubiquitous guild, made up of wide-ranging habitat generalists (Table 3.1) (Bennett et al., 2001).

Table 3.1. Five major fish assemblage guilds have been described for the Cache River Watershed (Bennett et al., 2001).

Major Guilds	Characteristics
Upland	- Composed of riffle-dwelling species, which require either rocky substrates for spawning, or continuously flowing water for egg development, are mostly benthic invertivores and intolerant of sedimentation - Characteristic species include Central Stoneroller (*Campostoma anomalum*), Creek Chub (*Semotilus atromaculatus*), Creek Chubsucker (*Erimyzon oblongus*), Spring Cavefish (*Forbesichthys agassizi*), Fringed Darter (*Etheostoma crossopterum*), Fantail Darter (*Etheostoma flabellare*), Stripetail Darter (*Etheostoma kennicotti*), and Banded Sculpin (*Cottus carolinae*)
Bottomland	- Composed of persistent and obligate swamp species which depend upon floodplains for reproduction, vegetated peripheries for juvenile and adult life history stages and channels for migration - Characteristic species include Pugnose Minnow (*Opsopoeodus emiliae*), Cypress Minnow (*Hvbognathus hayi*), Brown Bullhead (*Ameiurus nebulosus*), Grass Pickerel (*Esox americanus*), Central Mudminnow (*Umbra limi*), Banded Pygmy Sunfish (*Elassoma zonatum*), Flier (*Centrarchus macropterus*), Bantam Sunfish (*Lepomis symmetricus*), and Slough Darter (*Etheostoma gracile*)
Midreach	- Species are habitat generalists, often found in highly modified (dredged, channelized) stream reaches with homogenous habitats, little pool/riffle development, uniform depths and substrates, and bordered by steep, eroding banks - Characteristics species include Ribbon Shiner (*Lythrurus fumeus*), Redfin Shiner (*Lythrurus umbratilis*), Bluntnose Minnow (*Pimephales notatus*), White Sucker (*Catostomus commersoni*), Golden Redhorse (*Moxostoma erythrurum*), Freckled Madtom (*Noturus noctumus*), Grass Pickerel (*Esox americanus*), Spotted Bass (*Micropterus punculatus*), and Blackside Darter (*Percina maculata*)
Lower	- Species are highly mobile, lack dependence on aquatic vegetation, and are adapted to the changing environmental conditions typical of large, lowland streams - Characteristic species include Goldeye (*Hiodon alosoides*), Mississippi Silvery Minnow (*Hybognathus nuchalis*), Bullhead Minnow (*Pimephales vigilax*), White Bass (*Morone chrysops*), Mud Darter (*Etheostoma asprigene*), River Darter (*Percina shumardi*), Sauger (*Stizostedion canadense*), and Freshwater Drum (*Aplodinotus grunniens*)
Ubiquitous	- Species which are found in varied and wide-ranging habitats - Characteristic species include gars (Lepisosteidae), large suckers (Catostomidae), Bluegill (*Lepomis macrochirus*) and Longear Sunfish (*Lepomis megalotis*)

Since 1992, IDNR has performed basin-wide fisheries surveys on a five-year revolving cycle. Analysis of these data include the calculation of site-level index of biotic integrity (IBI) scores, which have ranged from 0 (very low) to 55 (moderate) over the past 19 years (Table 3.2) (Muir et al., 1995; Shasteen et al., 2002; Muir, 2011). Over that 19 year time span, average IBI scores for sites in the upper Cache River mainstem and tributaries and lower Cache River tributaries indicate moderately low biotic integrity while the average IBI score for sites in the lower Cache River mainstem suggests low biotic integrity. Generally, moderately low to low biotic integrity classes are described as having fewer native species present, particularly intolerant, benthic invertivore, and mineral-substrate spawning species. An independent assessment of select tributaries showed that although the average IBI score of all sites was classified as low, a longitudinal gradient was apparent in some tributaries where upstream sites were of higher biotic integrity than downstream sites (Bennett et al., 2001).

Table 3.2. Ranges and descriptions of IDNR's fisheries biotic integrity classes suggest the Cache River to have low to moderately low biotic integrity (Mick, 2011).

IBI Score Range	Biotic Integrity Class	Description
56-60	Moderately High	Values of fish metrics are very similar to values expected in Illinois streams where levels of human impact appear to be least in the state.
46-55	Moderate	Number of native fish species is reduced primarily due to loss of intolerant species. Reduced abundance of mineral-substrate spawners indicates disruption of reproductive function structure.
31-45	Moderately Low	Number of native fish is reduced further primarily due to further loss of intolerant species, but also due to loss of sucker species and benthic-invertivore species. Reduced abundance of specialist benthic invertivores and increased abundance of generalist feeders indicates imbalance in trophic functional structure.

16-30	Low	Number of native species is reduced further due to near-complete loss of intolerant species and further pronounced loss of sucker species and benthic-invertivore species. Disruption of fish-community structure is evidenced as indiscriminate loss of species across major families (minnows, suckers, sunfish). Further reductions in abundances of specialist benthic invertivores and mineral-substrate spawners indicate disruption of trophic and reproduction functional structure.
0-15	Very Low	Number of native species is reduced further due to pronounced, indiscriminate loss of species across major families (minnows, suckers and sunfish) with a concurrent increase in the proportion of tolerant species. Intolerant species are absent; benthic invertivore species are nearly absent. Pronounced reductions in abundances of specialist benthic invertivores and mineral-substrate spawners indicate further disruption of trophic and reproductive functional structure.

Land use activities within a watershed can have long-term impacts on fish assemblage structure (Poff et al., 1997; Wang et al., 1997; Allan, 2004). Habitat loss and alterations within the Cache River impact individual species and are major drivers of reduced biotic integrity. For example, sedimentation, channelization and removal of riparian vegetation have been suggested to be the major drivers of reduced populations of the rare fringed darter (*Etheostoma crossopterum*) (Poly and Wilson, 1998). Sedimentation may be the major cause of the extirpation of the state-endangered pallid shiner (*Notropis amnis*), although there is a limited understanding of this species' life-history and habitat characteristics (Pflieger, 1997; Bennett et al., 2001). Drainage of wetlands has reduced habitats important for spawning and nursery of species including the state-endangered cypress minnow (*Hybognathus hayi*) and state-threatened bantam sunfish (*Lepomis symmetricus*) (Burr et al., 1996; Bennett et al., 2001; Smith, 2002; Illinois Endangered Species Protection Board, 2011).

Recently, numerous fish kills in the lower Cache River have suggested chronic low dissolved oxygen levels to be a significant ecological impairment (Shults, 2011). Preliminary dissolved oxygen data from

2010-2011 from sites in the upper Cache River ranged between 5-9 mg/l year round with little diurnal change. Nevertheless, dissolved oxygen in lower Cache River sites averaged around 1 mg/l most of the year, with the exception of summer when dissolved oxygen ranges from 20 mg/l during the daytime to 0 mg/l at night (Rantala et al., 2010; Rantala, 2011). Although many of the obligate swamp species in the lower Cache River can survive occasional low oxygen levels, continuous low levels have been found to have detrimental impacts on fish species richness, abundance and body size (Killgore and Hoover, 2001). Chronically low dissolved oxygen concentrations generally only support fish with behavioral and structural adaptations to hypoxia, such as gars (*Lepisosteus sp.*), bowfin (*Amia calva*), and warmouth (*Lepomis gulosis*) (Killgore and Hoover, 2001).

Amphibians and Reptiles

Approximately 75 species of reptiles and amphibians inhabit the Cache River watershed (Appendix A) (Mankowski, 1997) and numerous species utilize the wetlands in the basin for breeding grounds and overwintering (Cagle, 1942). Additionally, the unique and fragile habitats in the spring and cave systems of the basin are also home to highly specialized amphibians such as the cave salamander (*Eurycea lucifuga*) (Mankowski, 1997).

As with other organisms, the flood pulse, or series of high water events, plays a role in the distribution and behavior of amphibians and reptiles. Research suggests that the lack of diverse habitats such as fishless pools and regularly inundated riparian habitat inhibit the broad distribution of species within the area (Burbrink et al., 1998). Some species in the Cache River basin, such as the rat snake (*Elaphe obsoleta*), may demonstrate habitat specialization within the species, with some individuals utilizing the floodplain exclusively, even during periods of high water (Carfagno and Weatherhead, 2009). Additional research indicates that rat snake avian nest predation during flood events may lessen due to an increase in predation of small mammals seeking refuge in trees (Carfagno and Weatherhead, 2009).

Birds

There are over 120 species of native breeding birds that have been reported in the Cache River basin (Mankowski, 1997). The terrestrial environment, specifically tree species composition is a critical component to certain avian populations within the Cache River basin (Gabbe et al., 2002). Additionally, the importance of the link between the terrestrial and aquatic landscapes is well demonstrated by the avian community where water depth can be a determining factor in nest predation, parasitism, feeding behavior and fledgling success (Hoover et al., 2000; Hoover, 2006; Carfagno and Weatherhead, 2009; Hoover, 2009).

Hydrologic changes in a system also influence behavior and species composition. Research on the Blue-winged Teal (*Anas discors*) demonstrates that hydrological change influences shifts in diet. Prior to hydrologic change the diet of breeding blue-winged teal was high in snails from seasonal wetlands, but shifted to midge larvae on semi-permanent lakes (Swanson and Meyer, 1977). Additional research has shown that densities of waterbirds, such as dabbling ducks and wading birds, such as shorebirds and ibis, increase in shallow wetlands (Colwell and Taft, 2000).

Mammals

Approximately 50 species of mammals utilize the unique habitats within the basin, 9 of which are listed as State or Federally Endangered or Illinois Threatened. Most research that has been performed on the mammals of the Cache River basin has focused on a select species, but lends valuable insight to species dispersal (Mankowski, 1997; Nielson and Woolf, 2002) and the complexity and value of the system (Hofmann et al., 1990; Barbour et al., 2001). The size, location, and preservation of the wetland and forested ecosystems in the basin are integral to the mammalian communities present. The marsh rice rat (*Orzomys palustris*), utilizes permanent or ephemeral wetlands and emergent vegetation for habitat

(Hofmann et al., 1990) and the swamp rabbit (*Sylvilagus aquaticus*) utilizes forested bottomland swamps (Barbour et al., 2001). Habitat loss and alteration, specifically the draining of off-channel wetlands, poses significant threats to the existence of these two mammal species in the Cache River Basin.

Invasive species

As previously mentioned, literature indicates, changes in land use often result in changes in plant and animal species composition in both aquatic and terrestrial ecosystems. Disturbances often facilitate the transportation or colonization of species within an ecosystem (Junk et al., 1989; Kruse and Groninger, 2003; Lytle and Poff, 2004). This is true for both native and non-native species and the ecological landscape of the Cache River Basin is changing due to the influx of non-native species. Non-native plant species are often invasive and their presence can cause significant harm to native ecosystems through increased demands for ground and surface water, increased risks of soil erosion and by changing soil chemistry; all of which can be economically costly to industries such as forestry, agriculture and fisheries (Henry and Davey, 2010). Over 600 non-native plant species have been reported in southern Illinois alone (Gibson et al., 2006). Numerous non-native animal species also exist in the basin and can be equally damaging to native ecosystems.

Strong correlations exist between habitat loss and abundance of invasive species, both of which are major influences on declining biodiversity (Didham et al., 2007). Invasive fish species in the watershed have so far been limited to carp species, including common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*). According to IDNR data, common carp are well established in the watershed while the three other invasive species have only been found occasionally and in low numbers. These species have potential ecological impacts on trophic structure, habitat selection, and reproductive success of native fishes, but little research has been conducted in the Cache River on this topic.

Restoration Efforts

Ecosystem restoration has received increased funding in recent years, spurring on-the-ground restoration projects nation-wide (Palmer et al., 2005a). At the same time, the study of restoration science is relatively new and pre- and post-restoration monitoring is limited, creating a gap in knowledge on the effectiveness of various restoration projects (Bernhardt et al., 2005). Awareness of the declining ecological integrity throughout the Cache River Watershed has attracted restoration interest from state and federal agencies, environmental non-profit organizations and local citizens. A number of restoration projects have been implemented in the watershed, with additional restoration projects in planning and design stages (Guetersloh, 2002; Demissie et al., 2008; Demissie et al., 2010). Understanding the effectiveness and impact of restoration projects in the Cache River Basin can help guide management towards restoring the natural form and function of the watershed and improving water quality and habitat.

One such restoration project is the construction of 25 rock riffle weirs along a segment of the upper Cache River by the Illinois State Water Survey (Figure 3.11). These structures are generally formed by constructing a series of riffles from natural materials. The riffle design has an upstream slope of 4:1 that impounds water upstream of the riffle (Figure 3.11). The v-shaped crest of weir directs stream flow toward the center of the riffle. Stream energy is then dissipated through turbulence as the water flows over the rough substrate of the downstream tail of the riffle (slope of 20:1) (Walther, 2007). The weirs were installed between 2001-2004 and were designed to reduce channel incision, improve in-stream habitat, and to protect riparian wetlands by providing stable substrate and turbulent flows similar to those of natural riffles while impounding water into upstream pools (Beardsley, 2010). At that same time, ten gully plugs were installed with earthen fill, geotextile fabric and rock rip rap through the USDA NRCS Wildlife Habitat Incentive Program to repair gullies as large as 14 meters wide and 6 meters deep and which threatened to drain bottomland wetlands (Hoover, 2009). The geomorphic changes in this river segment have not been re-evaluated; however, the biological responses suggest the riffles and gully plugs to be important in recreating high quality habitat. When compared to snags and scoured clay streambeds, the riffle weirs supported higher Ephemeroptera, Plecoptera and Trichoptera (EPT) biomass and total biomass (Walther and Whiles, 2008). Additionally, distinct macroinvertebrate assemblage types were found for rock weirs, snags, and clay streambed. The weirs harbored high densities of large-bodied insects and created feeding "hot spots" for insectivorous birds and likely other riparian insectivores such as bats and amphibians (Heinrich, 2011). The wetlands with gully plugs retained more flooded area and greater depths during bird breeding season when compared to nearby wetlands lacking gully plugs, leading to higher density and nesting success of prothonotary warblers (*Protonotaria citrea*) (Hoover, 2009).

A second restoration project took place in Big Creek, a tributary of the lower Cache River, between 2002 and 2008. Due to its sediment contribution to the lower Cache River and Buttonland Swamp, Big Creek was selected as a pilot watershed by the Illinois Pilot Watershed Program in 2000. This interagency program has encouraged cooperation between private landowners, state, and federal agencies and provided special funding for restoration projects, research and monitoring (Guetersloh, 2002). Restoration goals for Big Creek included reducing peak flows, restoring channel bottom elevations, reconnecting the stream and its floodplains, restoring riparian vegetation, promoting the conversion of highly erodible land from farmland to natural land cover, educating landowners of environmental costs of land use activities and documenting restoration changes (Guetersloh, 2002).

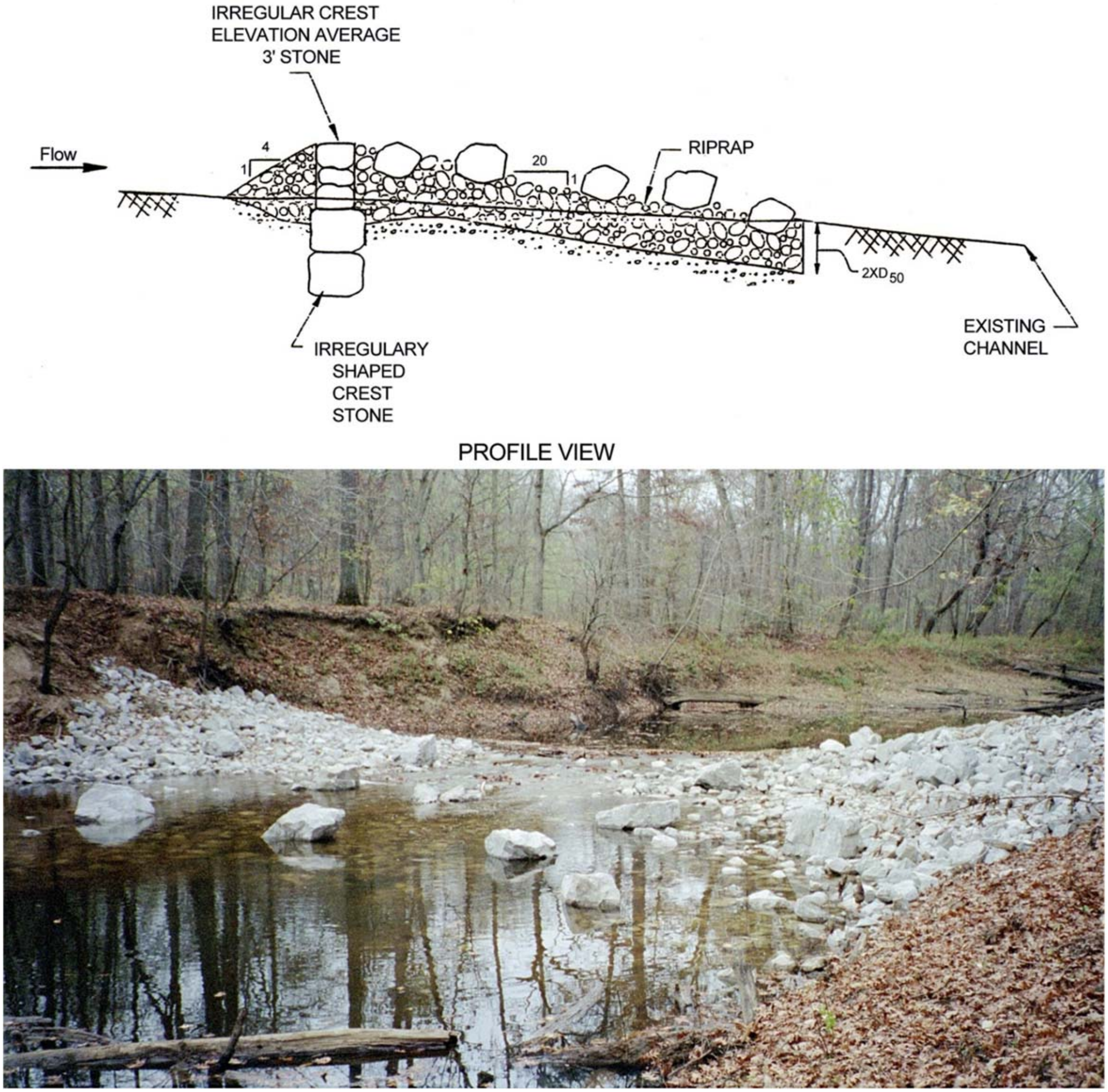

Figure 3.11. The engineering design of the riffle weirs creates s pool upstream of the weir and a tail of shallow rock material to dissipate stream energy.

On-the-ground restoration projects in Big Creek included the construction of 69 water retention structures on private properties, creating an additional 474 acre feet of water storage (Union County Soil and Water Conservation District, 2006; Union County Soil and Water Conservation District, 2008).

The water retention structures were designed to reduce excessive runoff and subsequently reduce erosion and transport of sediment. Although no formal analysis has been conducted on hydrologic changes related to the installation of the retention structures, they have been credited with protecting the town of Dongola from flooding following a 13 inch rain event in 2008 (Union County Soil and Water Conservation District, 2008). Thirteen riffle weirs were also constructed and designed to stabilize four large head-cuts that were moving upstream (Keefer, 2011). Geomorphology changes have not been assessed since the installation of the weirs.

As previously mentioned, properties acquired by state and federal agencies have generally been taken out of agricultural production and have been converted into bottomland forests and wetlands (Kruse and Groninger, 2003). Thus far, restoration of these properties has had positive effects on native fauna. In sites that have been reforested, nest predation of Acadian flycatchers (*Empidonax virescens*) declined from 59% in 1993 to 39% in 2010 and cowbird (*Molothrus ater*) parasitism has decreased from 40% to 13% (Hoover, 2010). Also, cowbird parasitism on Prothonatary Warblers decreased with increased forest cover (Hoover and Hauber, 2007). Twenty-two species of amphibians and reptiles colonized a 1,123 acre former vegetable farm within one year of its conversion into constructed wetlands (Grassy Slough Preserve) (Palis, 2007).

A major component of watershed-scale restoration is the restoration of natural hydrology throughout the system. The restoration of surface hydrology is necessary to restore bottomland wetland functions important for nutrient and sediment removal (Hunter et al., 2008). Efforts are underway to design a structural partial reconnection of the upper and lower sections of the river (Demissie et al., 2008; Demissie et al., 2010). Nevertheless, these efforts are not without local concern over potential flooding, drainage needs, and lack of management transparency and community involvement (Davenport et al., 2010).

Conclusion

Policy and land use decisions regarding watershed management in the Cache River Basin involve ecological restoration and preservation activities, flood damage mitigation, water quality monitoring, and maintenance of drainage channels for agriculture production and irrigation. Hydrological alterations as well as land uses and activities have impaired ecological functioning of the Cache River system. As discussed, land acquisition by public agencies and the enrollment of private land in the USDA conservation programs were policy and management choices intended to counteract environmental degradation. Another potential future management decision of note is the proposed partial reconnection of the upper and lower Cache River near the town of Karnak. A reconnection would be intended to create increased flow in the primarily stagnant lower segment of the river subsequently increasing oxygenation and ultimately, the ecological health of the river.

Watershed management decision-making operates within the context of economic and political systems and is critical to consider in a predominantly privately-owned and largely agricultural basins such as the Cache River Watershed (Beaulieu, 1998). These management choices are driven by socioeconomic and political influences including: national policy and the global agricultural economy, landowners' decisions on land use, spatial patterns of land uses at a watershed scale, and sedimentation rates (Lant et al., 2001). For example, while CRP and WRP enrollment are designed to offset the opportunity costs to private landowners of the provision of ecosystem services and benefits to ecological systems. These farm land programs have had some success enhancing environmental quality (U.S. Natural Resources Conservation Service, 2011) and there is evidence to suggest that land conservation programs can contribute to rising crop prices which, in turn, raise the opportunity costs of land retirement (Secchi et al., 2008). Consequently, policies which concurrently target land for retirement in the Cache River basin and elsewhere with the highest potential ecological benefit and lowest opportunity cost of preservation are more efficient than programs that allow indiscriminate enrollment (Yang et al., 2005; Secchi and Babcock, 2007; Secchi et al., 2008). Just as in other systems and on larger scales, integration of research on policy and economically-driven land use and natural system functioning is necessary to guide decision-makers' land use strategies including discerning optimal areas to target restoration activities within the Cache River Watershed.

Broadly, stakeholders directly and indirectly convey their prioritization of development, recreation, and the provision of ecosystem services by their activities within their watersheds. Policy can incentivize or disincentivize human activities that have effects on natural systems. In order for stakeholders to assign value and prioritize ecosystem services produced by local natural resources, effective management must include awareness of the environmental impacts of management choices to system functioning. Scientifically-informed policy-making and management decisions that account for the diverse interests of stakeholders are therefore critical to successful river and wetland restoration (Palmer et al., 2005a; Palmer, 2009; Ryder et al., 2010).

The ecological integrity of the Cache River watershed is impaired. However, since the 1980s, the conversion of land back into natural land covers and in-stream restoration efforts have helped set a trajectory towards improving ecological health. Restoration has the potential to improve ecosystem functioning and therefore add value to local communities by providing goods and services such as hunting, fishing, birdwatching, filtering water, cycling nutrients, and storing flood waters. Nevertheless, the magnitude of alteration in the watershed is so great that restoration will require long-term, watershed-scale planning. Restoration planning and projects are costly, and follow-up research to evaluate the effectiveness of projects often fails to be included in final budgets. Due to high costs, geomorphologic assessment of the installation of riffle weirs in the upper Cache River has been stalled (Beardsley, 2010).

Although a wealth of information about the current state of the watershed is building, there remain large gaps in knowledge. As mentioned earlier, giant cane was once abundant in the watershed and looks to be a promising species for riparian restoration. Many cane brakes were cut down as land was converted into agricultural fields or pasture for grazing or lost by logging. The first step in understanding the role of cane in riparian systems is determining where current cane stands persist. Additionally, agency-collected water quality, fish and macroinvertebrate data sets have been able to provide snapshots of information on in-stream health. However, long-term trends of these data sets may provide more insight as to how land use changes and restoration projects are impacting the system.

This chapter reviewed historical information and past studies conducted within the Cache River Watershed as well as relevant, associated literature. Through reviewing literature on past land use choices in the basin and the subsequent effects on natural systems operating in the watershed, opportunities for future research can be noted. Evaluating indicators of in-stream health in the Cache River to assess the current status of ecological integrity in the system, monitoring the effects of selected past restoration efforts, and exploring the potential applications of new restoration activities have been identified as several of these areas. An expanded knowledge base surrounding the natural functioning in the system is crucial to understanding the ecological impacts of human activity and can therefore, guide stakeholders' future decision-making. Understanding these gaps in knowledge will provide information to help restore and manage the system. The goal of subsequent chapters is to begin filling these research gaps.

Chapter 4: A Geomorphic Evaluation of Newbury Weirs

Introduction

The alterations to the Cache River and its tributaries have resulted in major changes in channel structure. A combination of channel straightening, ditching and tiling of agricultural fields, and the construction of the Post Creek Cut-off have increased bed slope and stream power. The increased stream power has steadily incised the stream bed and eroded the banks of the Cache River. These watershed alterations have also led to lateral gullying near Heron Pond, a state protected cypress and tupelo swamp complex. The deepening and lateral movement of the Cache River channel gradually encroached upon Heron Pond threatening to permanently drain the swamp.

As a result, the Cache River Watershed Resource Plan of 1995 recommended the installation of grade control structures to stabilize Heron Pond by raising the bed elevation and reducing erosion and channel scouring (Cache River Watershed Resource Planning Committee, 1995). The grade control structures chosen were Newbury weirs (Newbury and Gaboury, 1993), also commonly referred to as riffle weirs (Figure 1). Riffle weir construction was initiated by the Cache River Wetlands Joint Venture Partnership, funded through the Illinois Department of Natural Resources (DNR), and constructed in the upper Cache River by the Illinois State Water Survey (SWS), with six built in 2001, seven in 2003 and 12 in 2004 (Beardsley, 2010). The riffle design has an upstream slope of 4:1 that impounds water upstream of the riffle (Figure 4.1). The v-shaped crest of weir directs stream flow toward the center of the riffle. Stream energy is then dissipated through turbulence as the water flows over the rough substrate of the downstream tail of the riffle (slope of 20:1) (Walther, 2007). Additionally, ten gully plugs were constructed with earthen fill, geotextile fabric and rock rip rap by the USDA-NRCS Wildlife Habitat Incentive Program to repair gullies as large as 14 meters wide and 6 meters (Hoover, 2009). A reach of gabion baskets were also installed along a stretch of the upper Cache River near the state-protected Heron Pond. The objective of this study is to document changes in channel geomorphology before and after the installation of restoration structures.

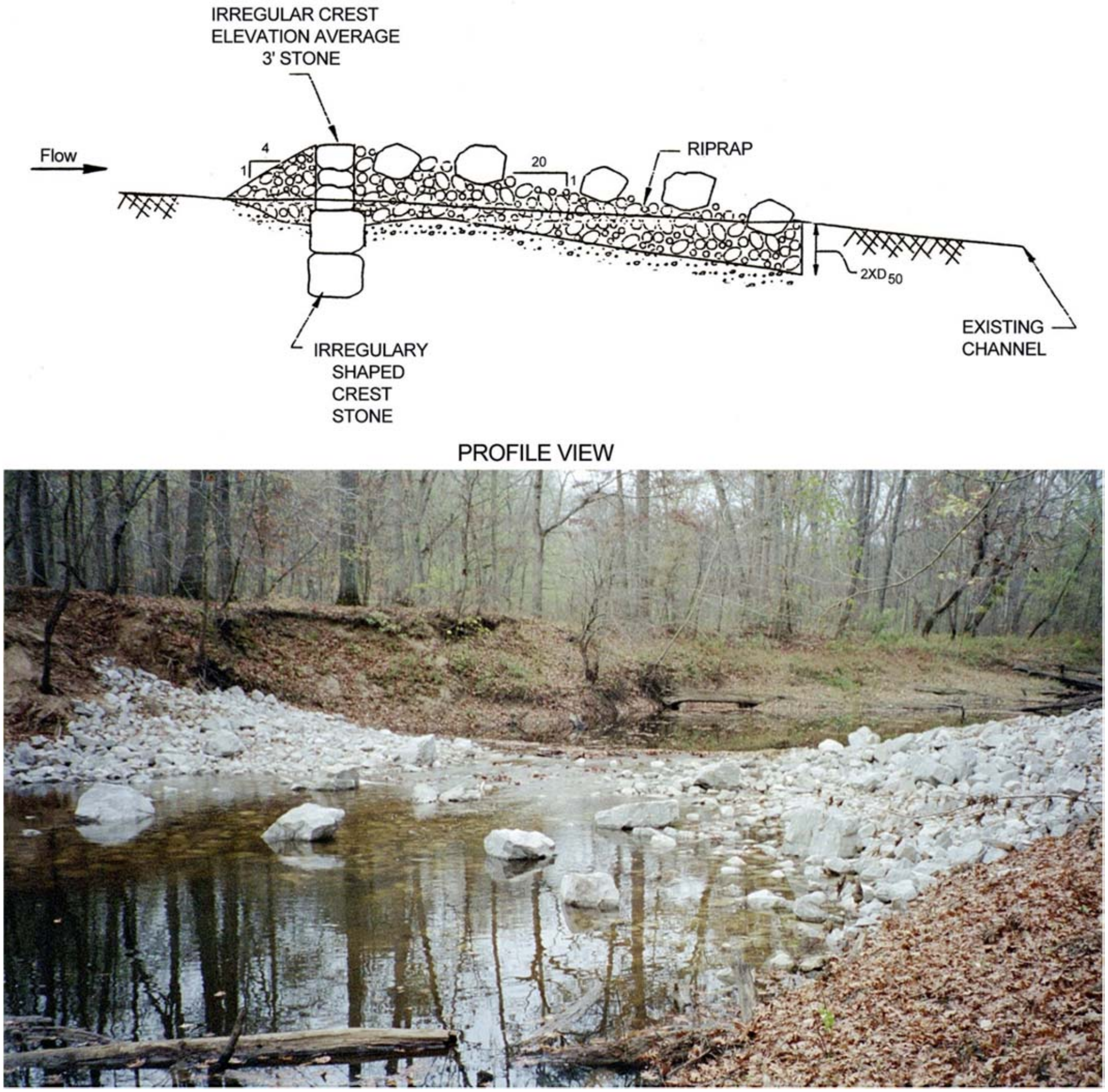

Figure 4.1. The engineering design schematic of a typical riffle weirs and a picture shortly after installation of a weir. Figure and photograph courtesy of John Beardsley of the Illinois State Water Survey.

Since weir installation, research has primarily focused of the impacts to the biological communities. Biological responses suggest the riffle weirs and gully plugs to maintain and improve habitat. When compared to snags and scoured clay streambeds, the riffle weirs were found to support higher Ephemeroptera, Plecoptera and Trichoptera (EPT) biomass in addition to higher total insect biomass (Walther and Whiles, 2008). Additionally, distinct macroinvertebrate assemblages types were found for rock weirs, snags, and clay streambed. The weirs also appear to be beneficial by harboring high densities of large-bodied insects and creating feeding "hot spots" for insectivorous birds and likely other riparian insectivores such as bats and amphibians (Heinrich, 2011). The wetlands with gully plugs retained more flooded area and greater depths during bird breeding season when compared to nearby wetlands lacking gully plugs, leading to higher density and nesting success of prothonotary warblers (*Protonotaria citrea*) (Hoover, 2009). Similar weirs in other lotic systems have been found to improve habitat for fish communities (Schwartz and Herricks, 2007; Dodd and Wahl, 2007; Shields et al., 1998).

While the biological responses point towards a successful restoration project, improving in-stream habitat was not the primary purpose of weir installation. In order to assess whether the weirs are serving their primary purpose of slowing channel incision, research is needed on pre- and post-restoration geomorphic patterns. The objective of this study is to compare longitudinal and cross-sectional profiles over the past twenty years and document potential impacts of weirs on channel structure.

Study Area

The study was conducted within the Illinois Department of Natural Resources (IDNR) State Natural Area, which includes the Heron Pond – Wildcat Bluff Nature Preserve. A survey was conducted on a five mile length of the Cache River with additional cross sections along the section of the river adjoining Heron

Pond. The five-mile longitudinal profile portion of the survey was conducted from the Belknap road bridge to the confluence of the Cache River and Dutchman Creek. The confluence is approximately 1000 feet west of Heron Pond. Three of the five cross sections surveyed are within the section of the river adjoining Heron Pond. The remaining two cross sections are located along the longitudinal profile; one being approximately 1200 feet southwest of the Cache-Dutchman confluence, while the other was located near the Chicago Burlington Quincy Railroad Bridge, approximately 1.25 river miles downstream of the confluence (Figure 4.2).

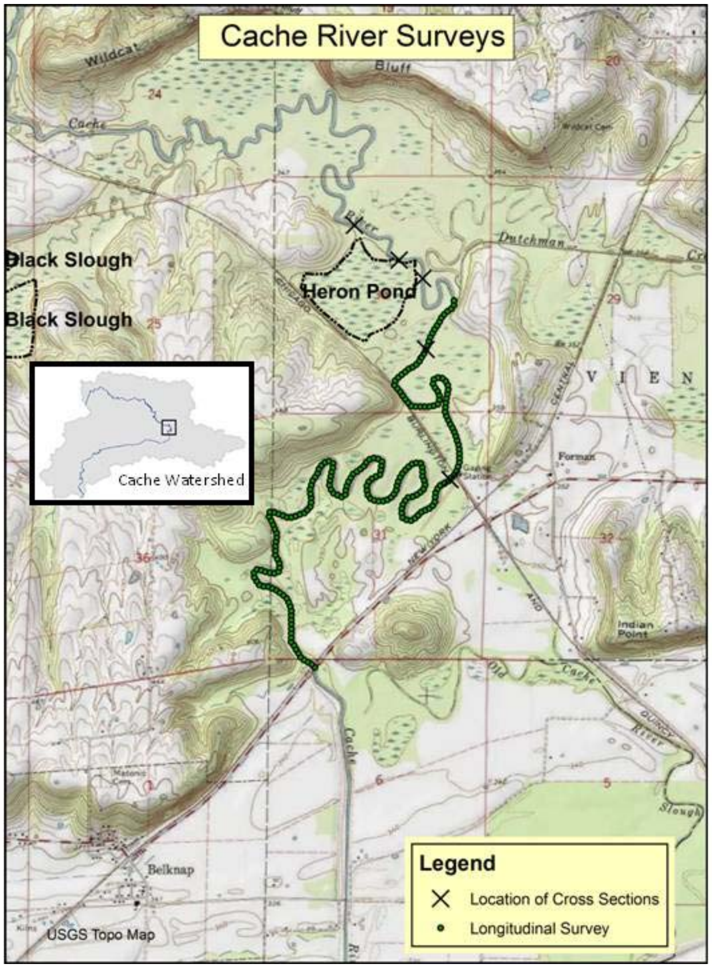

Figure 4.2. Within the Cache River Watershed, the study area focused on a five mile stretch of river between the Belknap Road bridge and the Heron Pond State Nature Preserve.

Methods

Data Collection

Pre-restoration surveys were conducted by state and federal agencies for use in this project. In 1991, a longitudinal survey (Figure 4.2) was completed from the Belknap Road bridge to the Heron Pond trail bridge (J.H. Bass & Associates, 1991). Surveyed cross sections were collected from previous surveys conducted by United States Geologic Survey (USGS) and Illinois State Water Survey (ISWS) (Beardsley, 2010; Holmes, 1996) Five cross sections from these previous surveys were selected for re-survey. These five cross sections were surveyed in 1996, 1998, 1999, 2001 and 2003 and have not been re-surveyed since restoration structures were completed in 2004.

To assess the geomorphic changes, a new survey was conducted throughout September and October 2011. The longitudinal and cross sectional surveys were surveyed close to original survey locations using a TopCon GTS 320 total station and a Tripod Data System's Survey Pro data collector. Survey data was post-processed using Tripod Data System's Survey Link and Foresight DXM software programs. Control points were taken with Trimble GeoHX 3.5G Edition handheld GPS units at the beginning and end points of the survey. The Trimble GeoHX incorporates technology which reduces shadowing and multipathing of GPS satellite signals increasing the accuracy of the unity. As well, the collection was conducted in areas of reduced tree canopy and during leaf-off conditions. Further improvement in accuracy was obtained through utilizing Trimble GPS Pathfinder Office software and post processed using differential correction. Ten National Oceanic and Atmospheric Agency (NOAA) Continuously Operating Reference Stations (CORS) were used in the process. This allowed for <4 inch vertical accuracy for the three control points. The GeoHX utilizes GRS80 vertical datum to calculate mean sea level elevation. Although the previous surveys used different datums, error was still within acceptable limits. The Bass longitudinal survey used the NGVD'29 datum and the previous cross section surveys were calculated using the NAVD'88 datum. Based on the literature the NGVD'29 datum has <10 cm of error vs the NAVD'88 datum and the NAVD'88 datum has <4cm error vs the GRS80 datum for the study area (Zilkoski et al., 1992; Milbert and Smith, 2012).

It should be noted that due to lack of benchmarks, the 2011 cross-sections were not at the exact locations of the previous cross-sections. Cross-sections three and four were approximately 1-3 feet from original surveys, and cross-section one was 2-5 feet from original survey. Cross section five was approximately 50 feet from the original survey and therefore may not be useable in the analysis.

Data analysis

Longitudinal profiles were tested for differences in slope and y-intercepts using a one-way analysis of covariance (ANCOVA), with distance as the independent variable and elevation as the dependent variable. It was hypothesized that slope would not change, however a significant difference in the y-intercept could be used to calculate a rate of channel erosion. Pre- and post-riffle weir cross-sectional profiles were compared to determine changes in mean bed elevation, channel width, mean depth, thalweg and cross sectional area of all cross sections except cross section 5 which was too deep to survey for most years. Channel width was measured from the top of the left bank to the top of the right bank. Mean bed elevation was the average of all channel bed elevations. Mean channel depth was calculated by subtracting mean bed elevation from top of bank width. The thalweg for each profile is the deepest channel bed elevation.

Results

The results of the ANCOVA indicate that the slopes of the longitudinal profile regression lines are not significantly different ($F_{1,424}$=1.06, P=0.3031). The y-intercepts of the regression lines are significantly

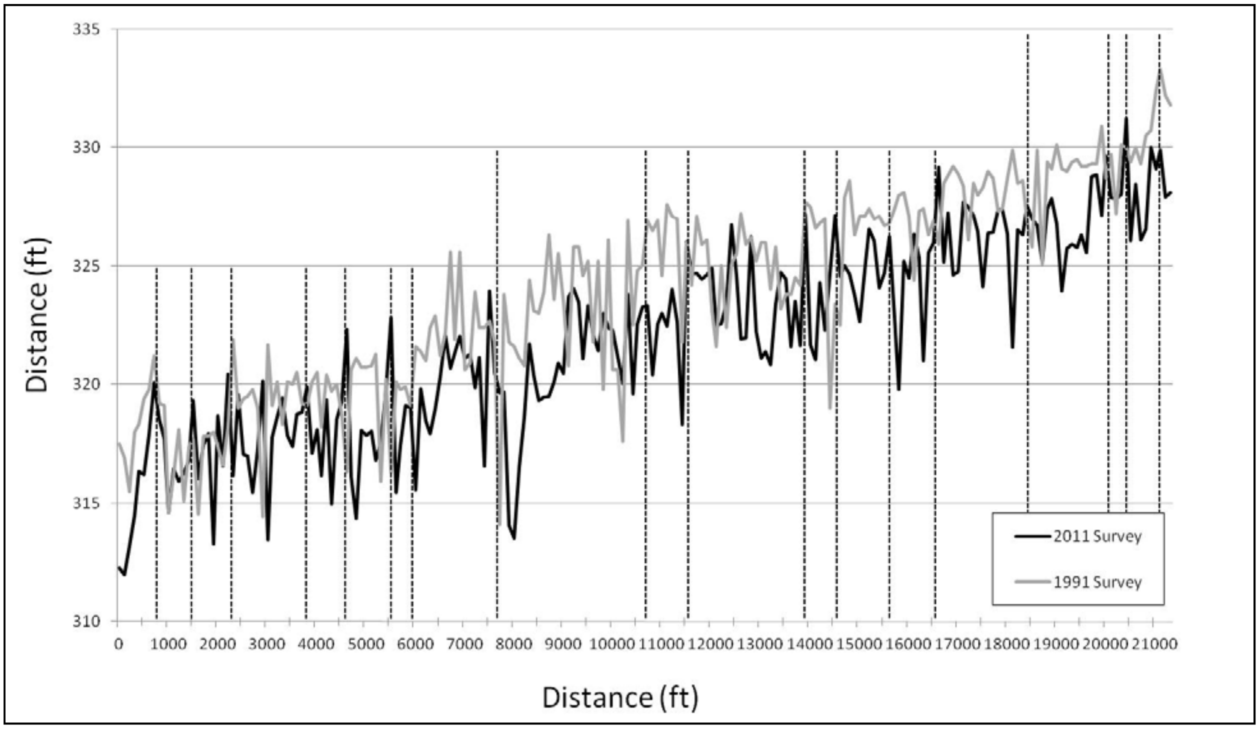

Figure 4.3. The longitudinal profiles from the 1991 Bass survey and the 2011 re-survey with approximate location of weirs noted.

different ($F_{1,425}$=110.55, P<0.0001), indicating that the mean elevation of the longitudinal profile from 1991 was approximately 2 feet greater than the mean elevation of the longitudinal profile from 2011 (Figure 4.3). The rate of erosion, calculated as change in y-intercept over 19 years, was 0.10 feet/year. Peaks in the longitudinal profile often correspond with weir locations and were commonly followed by signs of bed scour.

Cross sectional measurements varied widely throughout the five mile stretch of river. For example, top of channel widths ranged from 63.60 ft to 136.05 ft and cross sectional area ranged from 601.79 ft^2 to 2379.29 ft^2 (Table 4.1). Between the years 1996 to 1998, there was a general trend of increasing channel width, depth, and cross sectional area across all cross sections. For all other between year comparisons, there were no clear trends across all cross sections. Instead, cross section measurements show signs of varying levels of degradation and aggradation, with no consistent trend in a single direction.

The 2011 survey measurements indicate consistent change in the channel structure since 2001 and 2003. The width at top of bank for all cross-sections is the widest in the 2011 survey, with the largest change being seen for cross-section two. Again we note that cross section five was re-surveyed 50 ft from the original and therefore cannot be accurately assessed. Thalweg measurements from the 2011 survey show cross sections one, two and three to be the deepest it had been ever surveyed (Figures 4.4-4.6), while cross-section four was the shallowest it had ever been surveyed (Figure 4.7). The cross sectional area of cross section one increased 249 ft^2 between 2003 and 2011, suggested significant erosion. Cross sectional areas of cross sections two and three also increased 39 ft^2 and 68 ft^2, respectively. Although cross section four had widened approximately 4 feet since last measured, the cross sectional area decreased approximately 28 ft^2, primarily due to increased channel bottom elevation.

Table 4.1. Measurements of five cross sections over the past 15 years.

	1996	1998	1999	2001	2003	2011
Cross section 1						
Width (top of bank)	67.29	68.77	67.75	67.38	67.08	78.70
Mean Depth	10.869	11.479	10.841	11.206	11.352	11.86
Mean bed elevation	334.287	333.784	334.325	333.978	333.837	333.987
Thalweg	333.294	333.021	333.219	332.747	333.32	330.31
Area	619.324	652.075	631.110	638.774	614.589	863.797
Cross section 2						
Width (top of bank)	63.6	66.73	66.95	64.48	-	84.658
Mean Depth	10.618	11.185	10.861	10.589	-	10.709
Mean bed elevation	334.447	334.061	334.165	334.516	-	332.145
Thalweg	333.945	333.715	333.753	334.058	-	330.282
Area	611.646	602.861	610.062	601.799	-	640.713
Cross section 3						
Width (top of bank)	74.27	80	83.64	77.73	79.45	85.956
Mean Depth	10.578	11.512	11.183	11.3	11.812	11.072
Mean bed elevation	333.695	333.442	333.854	333.586	333.299	332.909
Thalweg	333.178	331.813	332.682	333.101	332.945	331.025
Area	807.473	856.538	826.643	850.559	830.038	898.299
Cross section 4						
Width (top of bank)	73.48	75.56	74.66	74.03	-	77.95
Mean Depth	13.978	15.054	15.058	13.482	-	12.533
Mean bed elevation	330.389	329.341	329.183	330.481	-	330.670
Thalweg	328.893	328.479	328.052	327.901	-	329.366
Area	883.459	906.593	934.599	924.382	-	896.519
Cross section 5						
Width (top of bank)	117.24	122.52	122.59	123.05	-	136.05
Mean Depth	-	-	-	22.956	-	-
Mean bed elevation	-	-	-	320.992	-	-
Thalweg	-	-	-	316.02	-	-
Area	-	-	-	2379.289	-	-

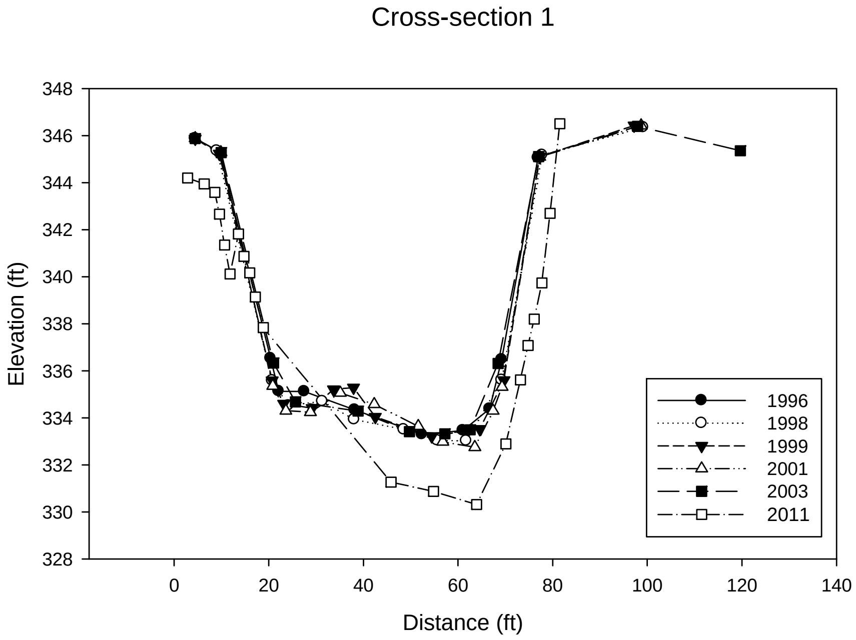

Figure 4.4. Overlay of cross sectional profiles from various years of the cross section furthest upstream.

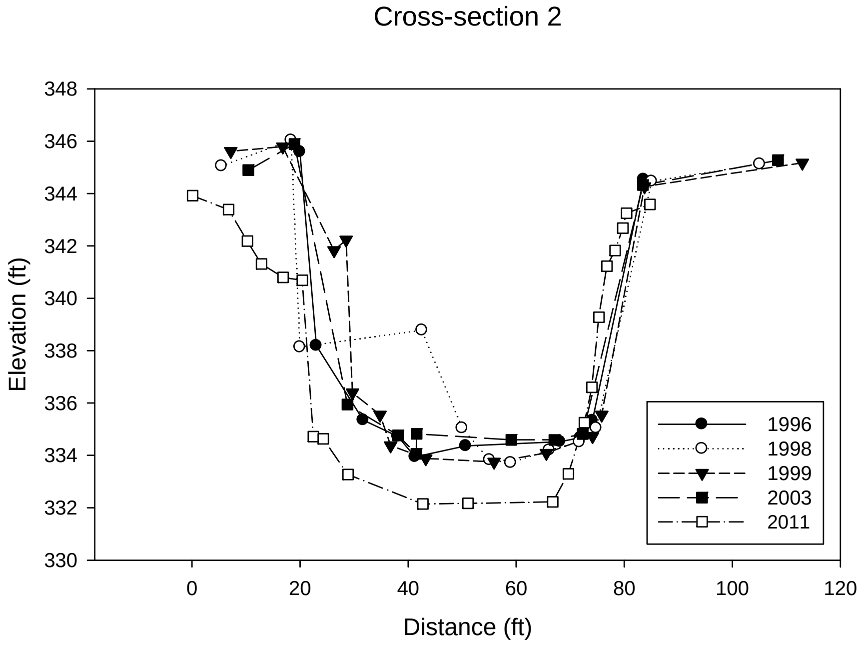

Figure 4.5. Overlay of cross sectional profiles from various years of the second furthest upstream cross section. Note: the 1998 cross section had a fair amount of rip-rap along the left side of the channel.

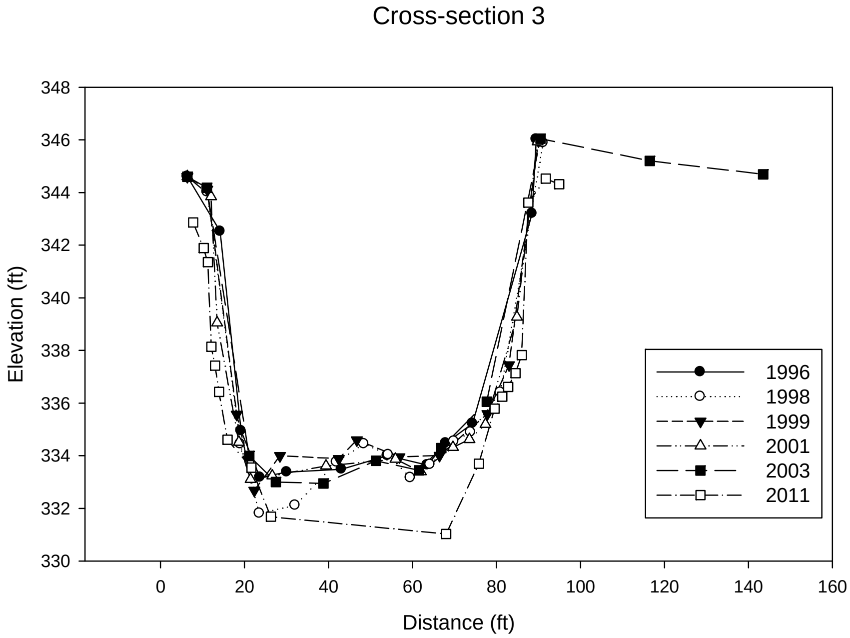

Figure 4.6. Overlay of cross sectional profiles from various years of the third most upstream cross section.

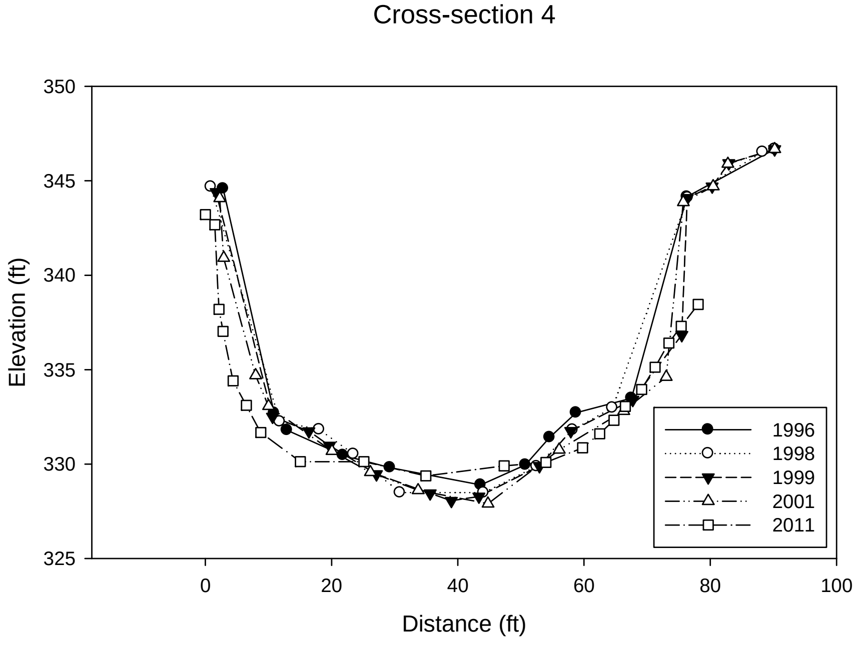

Figure 4.7. Overlay of cross sectional profiles from various years of the second most downstream cross section.

Discussion

A previous investigation of incision of the upper Cache River revealed that between the construction of the Post Creek Cutoff in 1915 and a Soil Conservation Survey study from 1972, incision had doubled channel depth and tripled channel width from the original channel design size (Demissie et al., 1990). Another survey compared channel geometry at the old Forman gage station, revealing channel widening of 10 feet between 1958 and 1995 (Holmes, 1996). This 2011 survey suggests further degradation of the Cache River channel. Riffle weirs are generally designed to increase bed elevation and dissipate flow energy, therefore slowing the headward migration of incision. While the longitudinal profile shows a two foot drop in channel elevation between 1991 and 2011, it does not provide information on the relative impact of weirs on channel incision. It should also be noted that a record flood occurred in May of 2011 and may have resulted in an increased amount of bank and bed scour.

It could be expected that cross-sections which are of similar location in relationship to installed weirs would have similar changes in morphology. Cross-sections three and four are both 100 feet downstream from a weir, so should have similar changes in morphology. However, they actually have different changes with the exception of top of bank width, which in both cases has widened. However the thalweg measurements are different, where the measurement for 2011 cross section three is the deepest of all the surveys and cross-section four is the shallowest of all the surveys. This indicates a lack of correlation between channel morphology change and the different weirs.

Research in a channelized stream in Mississippi found grade control structures to be ineffective in reducing erosion and incision because they were installed long after initial headcutting (Simon and Darby, 2002). The authors suggest that the grade control structures may have disrupted the channel's evolution of attaining a dynamic equilibrium. A similar trend seems to be occurring in the Cache River, where channelization began as early as 1915. In fact, the intent of weir construction was to stop the dynamic equilibrium from draining Heron Pond and other near-channel wetlands. It could be argued that as the river adjusts and continues toward a dynamic equilibrium, erosion and incision will continue to be major problems. In the Cache River Watershed, incision results from an excess of stream power, or flow energy, relative to the amount of sediment supplied to the stream (Darby and Simon, 1999). The root causes of increased stream power include the construction of the Post Creek Cutoff, agricultural tiling and numerous channelization activities. Without addressing the root causes of increased stream power, restoration activities will only be short-term solutions, putting into question the protection of Heron Pond. Regardless, discussions of long-term restoration strategies should include channel evolution and impacts of structures on these processes.

Other ramifications which could result from continued erosion of the Cache River, but were not investigated in this study are the continued headcutting upstream as well as headcutting up tributaries and formation of ever growing gullies. A recent study has shown a correlation between the amount of channel incision between a stream and its tributaries (Heine and Lant, 2009). Therefore tributaries of the Cache River are at as great a risk of erosion as the Cache itself. There is also another aspect of the erosion which is unique to the Cache River situation. Currently a study is being planned in conjunction with the JVP to determine erosional effects of the reversed flow from the Lower Cache River back through the now open Post Creek Cutoff Levee into the Post Creek Cutoff channel. Therefore not only is headcutting moving upstream into the upper Cache River, but it may also be moving downstream into the Lower Cache River as well. This could create a permanent reverse flow in the Lower Cache River. This continued erosion can lead to loss of soils and land to both public and private owners including valuable agricultural land.

This project provides preliminary information not only for the management of Cache River Watershed, but also in understanding the effectiveness of weirs as restoration strategies. Additional surveys with a more intensive focus on cross sections are needed to document geomorphic changes further. There are numerous opportunities in the Cache River Watershed to further understanding of restoration impacts on geomorphology. Various models can be developed and used to understand sediment transport, erosion forces and hydrology under different levels of discharge. Long-term dynamic models could help in determining better ways of protecting Heron Pond on a more permanent basis. Models can be extremely useful in assessing alternative management choices. For example models may indicate that the only way to stop erosion of the Cache River would be to reduce the overall stream power, which would mean finding a way to reduce runoff across the entire upper Cache Watershed. This would be similar to the catchment project implemented in the Big Creek watershed to reduce peak flows (Guetersloh, 2002).

To better understand local impacts of weirs on geomorphology, numerous cross sections across a large sample of weirs could help determine general patterns. As stated, the results of this study indicate inconsistent channel morphology change under similar conditions. Another factor is the distance between weirs which is not consistent throughout the longitudinal profile. This could also create different morphology changes which should be studied. Therefore, future investigations should include not only the effectiveness of weirs in general, but the effectiveness of how weirs were implemented in this particular case.

Although other studies indicate some biological improvements, this study indicates that the Cache River weirs may not be as effective as expected in reducing the erosion process for the upper Cache River. More detailed and continued research should be conducted to provide the information needed to better determine the effectiveness of the weirs.

Chapter 5: Long-term Water Quality Trends

Introduction

Water quality is a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. To determine water quality, scientists first measure and analyze characteristics of the water such as temperature, dissolved mineral content, dissolved oxygen, turbidity, conductivity, and levels of nutrients, pesticides, and heavy metals (Cao and Hawkins, 2011; Ghumman, 2011). Selected characteristics are then compared to numeric standards and guidelines to decide if the water is suitable for a particular use. The U.S. Environmental Protection Agency (USEPA) and state-level water quality agencies are responsible for establishing the standards for constituents in water which pose a risk to human health, while other standards protect aquatic life, including fish, and fish-eating wildlife such as birds (Cordy, 2001).

Through the Illinois Environmental Protection Agency's (IEPA) Ambient Water Quality Monitoring Network, water quality parameters are collected every six weeks at two fixed sampling locations within the watershed. Water quality is also measured throughout the watershed though the Illinois' Intensive Basin Surveys which occurs on a five-year revolving cycle. Every two years, IEPA reports water quality impairments to USEPA.

Methods

Through the IEPA Ambient Water Quality Monitoring Network, water quality parameters are collected every six weeks at two fixed sampling locations within the watershed. Stream water samples were collected at five sites in the Cache River Watershed (Figure 5.1, Table 5.1) in accordance with quality assurance procedures outlined in the Illinois Bureau of Water quality assurance and field sampling procedures manual (Shasteen et al., 2002) periodically over the last 55 years by the Illinois Environmental Protection Agency (IEPA) (Illinois Environmental Protection Agency, 1987; Illinois Environmental Protection Agency, 1994).

Water quality data was obtained through US Environmental Protection Agency's online Legacy STORET database (United States Environmental Protection Agency, 2011). *In situ* measurements of water temperature, ph, DO, and conductivity were made with a Hydrolab multi-parameter digital meter. All other parameters were sampled using hand held or weighted bottle holders to collect depth-integrated samples representative of the water column, and kept at 4°C until received by the IEPA Champaign Laboratory, City of Carbondale Water, or Waste Water Central Laboratory. Water chemistry samples for oxygen consuming material, nutrients, metals, solids and other constituents were conducted by IEPA, whereas bacterial analyses were conducted by the other laboratories (Table 5.2) (Illinois Environmental Protection Agency, 1987; Illinois Environmental Protection Agency, 1994).

For this analysis, sixty-eight water quality parameters were measured, though not all parameters were collected every sampling period or every site, for a total of over 35,000 sampling records. Samples were analyzed over time and site location, and USEPA stream quality standards for aquatic life were used for comparison when available. When comparisons were not available, general use water quality standards based on Section 302 (subpart B) of Title 35: Subtitle C: Chapter I, Illinois were used (Table 5.3).

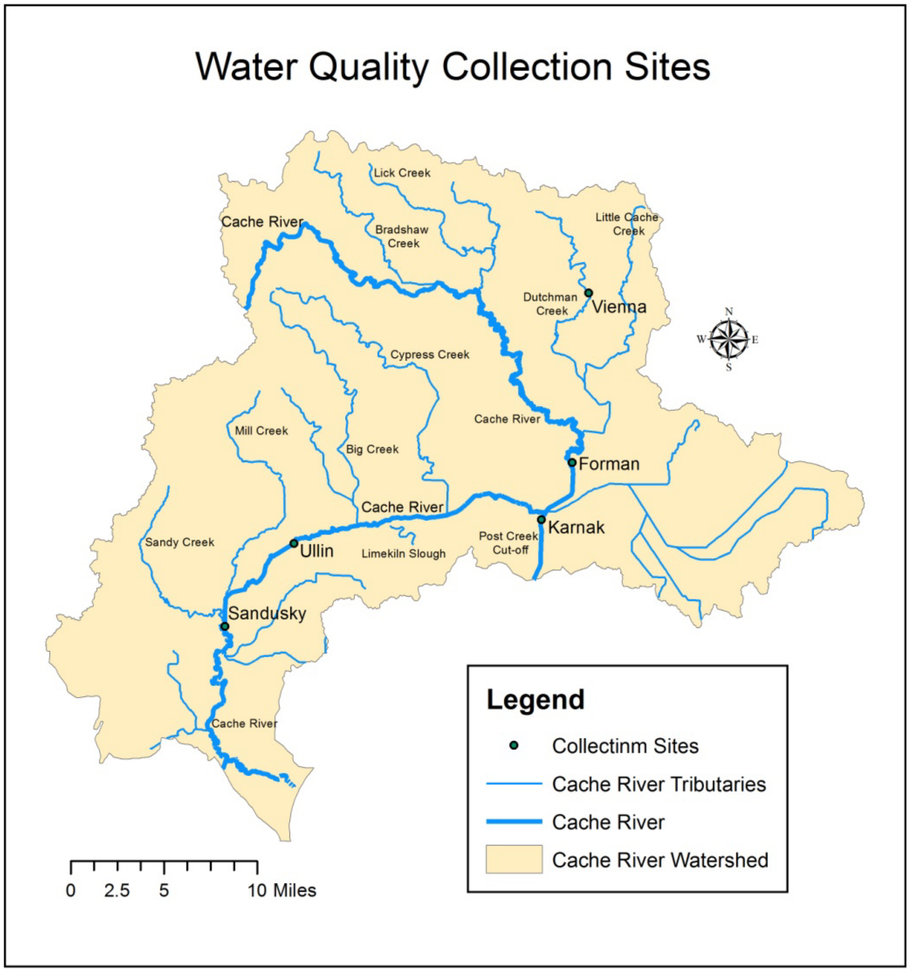

Figure 5.1 Samples were taken by the IEPA at five sites on the main stem of the Cache River.

Table 5.1. Analysis includes all samples at five sites in the Cache River Watershed over a period of 55 years (United States Environmental Protection Agency, 2011).

Years Sampled	Site Name	Location	County	Latitude	Longitude
1978-1998	Sandusky	Cache River at Sandusky	Alexander	37.203333	-89.258056
1972-1992	Karnak	Cache River at route 168, 1 mile E Karnak	Pulaski	37.291667	-88.952778
1956-1998	Forman	Cache River at Forman	Johnson	37.336389	-88.923889
1972-1977	Vienna	Dutchman Creek, 3 miles NNW Vienna	Johnson	37.468333	-88.911389
1972-1992	Ullin	Cache River at route 51, .5 mile S Ullin	Pulaski	37.256944	-89.183889

Table 5.2. Sampling preservatives, bottles, and methods varied by parameter (Illinois Environmental Protection Agency, 1994).

Parameter	Sample Container	Field Preservative	Method of Analysis in US EPA guideline handbook
Fecal Coliform Bacteria	120 mL Plastic	.15 mL 10% thiosulfate at 4°C	SM9222D
Total Nitrate/Nitrite	500 mL PE	10 mL 20% H_2SO_4 at 4°C	USEPA 353.2
Ammonia	1000 mL HDPE	10 mL 20% H_2SO_4 at 4°C	USEPA 350.1
Total and Dissolved Phosphorous	1000 mL HDPE	10 mL 20% H_2SO_4 at 4°C	USEPA 365.1
Total and Dissolved ICP (Pb, Cu, Fe, Mn, Cd, Cr, Mg, Zn, K, Ba, Be, Co, Ni, Sr, Ca, Na, Al, B, Ag, V, Se	250 mL PE	Cooled at 4°C	USEPA 200.7, 200.8
Sulfate	500 mL PE	Cooled at 4°C	USEPA 375.2/9036
Cyanide	250 mL PE	5 mL 5N NaOH	USEPA 335.4/9014
Chloride	500 mL PE	Cooled at 4°C	USEPA 325.2/9251
Alkalinity	500 mL PE	Cooled at 4°C	SM 2320B
Mercury	500 mL glass	Cooled at 4°C	USEPA 1631
Hardness	500 mL PE	Cooled at 4°C	USEPA 200.7
Arsenic	250 mL PE	20 mL 50% HNO_3 at 4°C	USEPA 200.8
Fluoride	500 mL PE	Cooled at 4°C	USGS 1-4327-85

Note: Dissolved metals and phosphorous are filtered through a 0.45 µm nitrocellulose membrane filter.

Table 5.3. U.S. Environmental Protection Agency stream quality standards for aquatic life were used for comparison when available. If they were not, general use water quality standards based on Section 302 (subpart B) of Title 35: Subtitle C: Chapter I, Illinois were used.

Parameter	**Standard Amount**
Alkalinity, total (mg/L as $CaCO_3$)	10 mg/L
Aluminum, dissolved (ug/L as Al)	750, 87 ug/L
Ammonia, unionized (Calculated from temperature, pH, and NH_4) (mg/L)	A criterion of 2.9 or 5.0 mg N/L (at pH 8 and 25 C) depending on whether freshwater mussels are present or absent
Barium, dissolved (ug/L as Ba)	2-5 mg/L
Beryllium, dissolved (ug/L as Be)	4 ug/L
Boron, dissolved (ug/L as B)	750 ug/L
Cadmium, dissolved (ug/L as Cd)	dependent on hardness; 9-93 ug/L
Calcium, total (mg/L as Ca)	500 mg/L
Chloride, total in water (mg/L)	4 mg/L
Chromium, dissolved (ug/L as Cr)	0.1 mg/L - 100ug
Cobalt, dissolved (ug/L as Co)	1 mg/L
Copper, dissolved (ug/L as Cu)	requires 10 criterion
Cyanide, total (mg/L as Cn)	0.2 mg/L
Fecal coliform, membrane filter M-FC broth, 44.5 C	126/100mL
Fluoride, dissolved (mg/L as F)	1.4 mg/L
Hardness, total (mg/L as $CaCO_3$)	1 mg/L
Iron, dissolved (ug/L as Fe)	1 mg/L
Lead, dissolved (ug/L as Pb)	0.065 mg/l
Manganese, dissolved (ug/L as Mn)	0.5 mg/L
Mercury, total (ug/L as Hg)	0.012 ug/L
Nickel, dissolved (ug/L as Ni)	4.77 ug/L
Nitrate nitrogen, dissolved (mg/L as NO_3)	0.06 mg/L
Nitrite plus nitrate, total (mg/L as N)	0.69 mg/L
Oxygen, dissolved, by probe (mg/L)	3-5.5 mg/L
pH (standard units)	6.5-9
Phosphorous, dissolved (mg/L as P)	0.0001 mg/L
Phosphorous, total (mg/L as P)	36.56 ug/L
Silver, dissolved (ug/L as Ag)	5 ug/L
Sulfate, total (mg/L as SO_4)	250 mg/L
Turbidity, Hach Turbidimeter	5.7 NTU
Zinc, dissolved (ug/L as Zn)	dependent on hardness 180-570 ug/L

Results

All sites were considered within normal limits for beryllium, boron, cadmium, chromium, cobalt, fluoride, lead, sulfate, and zinc. Nevertheless, there were still some patterns over time for many of the parameters at many sites. Patterns of water hardness, iron, magnesium, calcium levels have been inconsistent since the 1950s. Strontium and sodium quantities have had periodic peaks since the 1980s, when these parameters were added to the sampling routine, though the samples were always below standards of water quality. Beryllium and nickel have had a few sharp spikes above standards since the mid 1980s. Chromium and boron levels have been stable since the 1950s, and cadmium, cobalt, and copper have been stable since the 1980s, when sampling for these parameters began. Silica levels were consistently below standards in 1950s and 1960s, but have not been measured since. Fluoride levels had several spikes in that same time period, but have not been measured since 1961.

All of the sites were recorded as ranging from severely acidic to severely basic over the years. The sites at Sandusky and Forman seemed to range seasonally, but have been consistent overall (Figure 5.2). All of the sites exceeded the USEPA recommendations for hardness.

Karnak exceeded safe levels of cyanide in 1976, while Sandusky and Forman exceeded it several times in the 1990s. Sandusky, Forman, Karnak, Ullin, and Vienna exceeded EPA standards for manganese on several occasions. Nickel has been consistently higher than the standards since the 1980s, when the IEPA switched their analysis procedures.

Sandusky, Forman, Cobden, Karnak, and Vienna all have exceeded the newly determined standards for USEPA Ecoregion 9 for both acute and chronic USEPA nitrate-nitrogen standards since the 1970s (Figure 5.2). Sandusky reached 100 times over the limit. Phosphorous has been exceeded nearly every sample at every site. Aluminum, ammonia, barium, nitrate/nitrite, phosphorous, and potassium all seem to spike in the fall (Figures 5.3 and 5.4).

Turbidity is consistently highest at Forman, though all sites have exceeded standards at one time or another. Every site exceeded fecal coliform standard, though the Sandusky and Forman sites exceeded most consistently and with highest numbers.

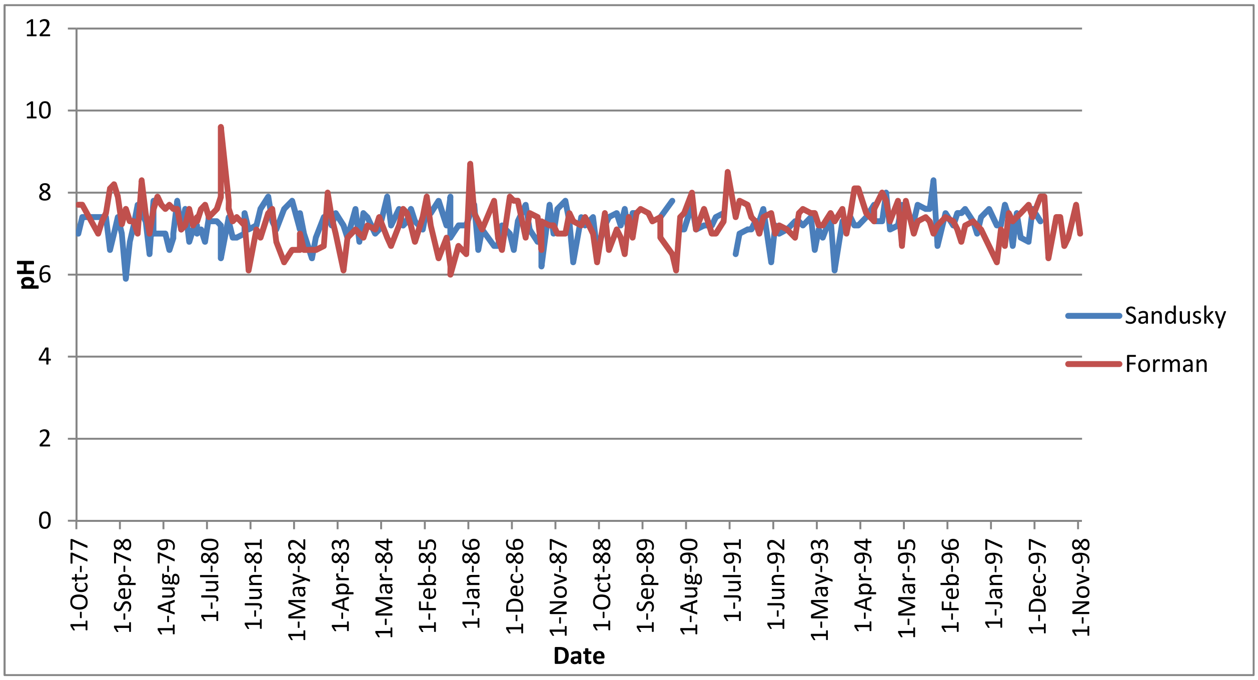

Figure 5.2. The pH at the Forman site has been fairly consistent over the years (United States Environmental Protection Agency, 2011).

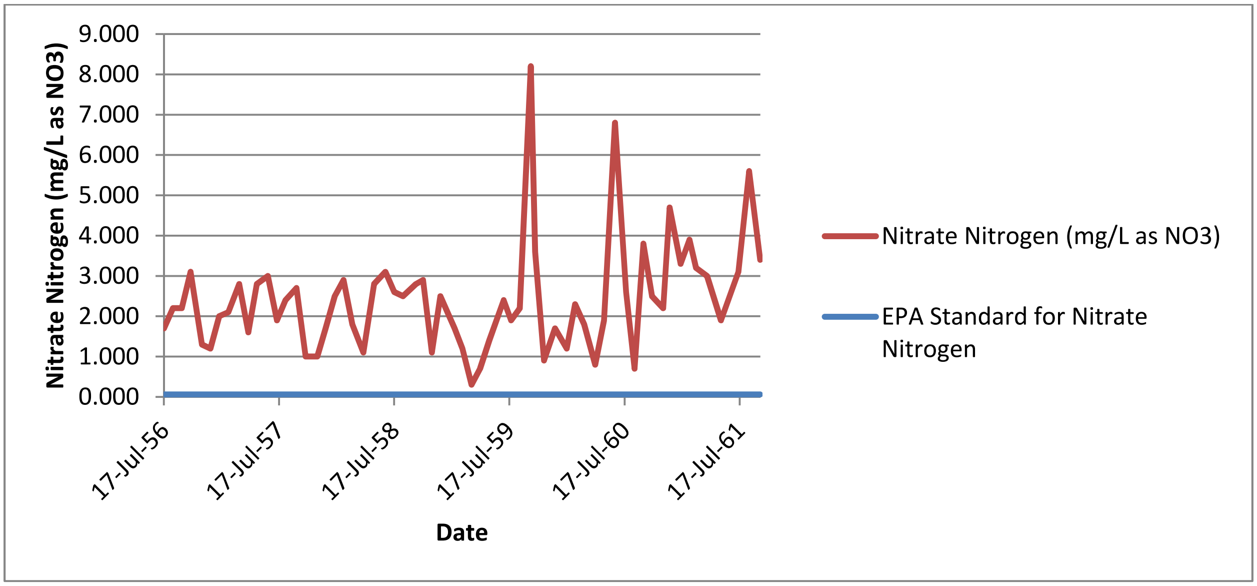

Figure 5.3. Nitrate nitrogen always exceeded EPA standards at Forman (United States Environmental Protection Agency, 2011).

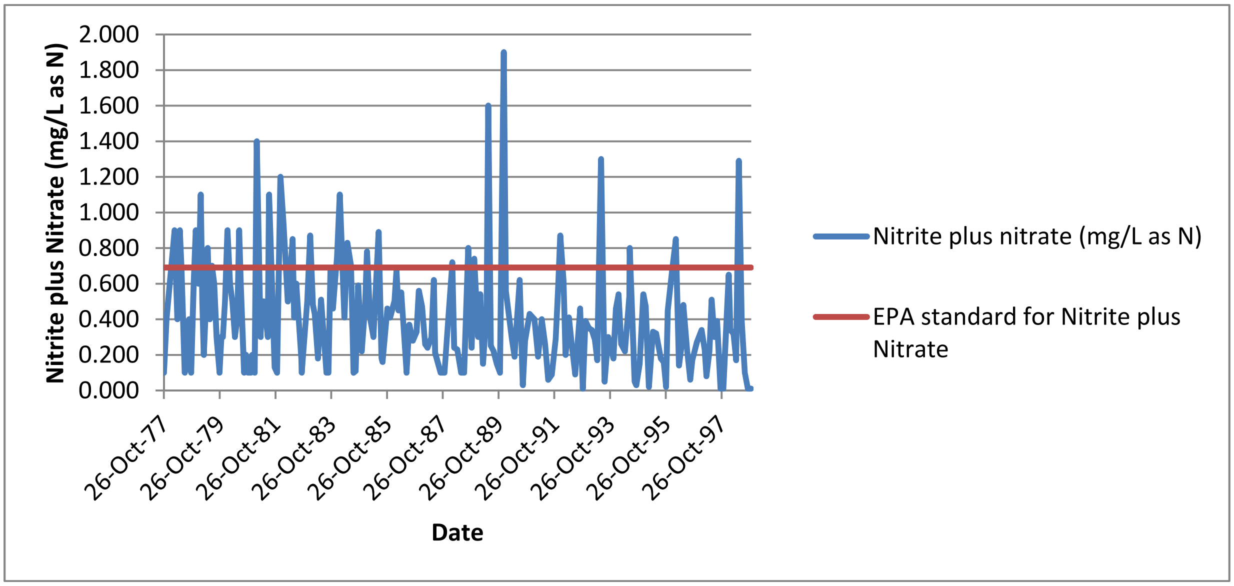

Figure 5.4. Nitrite plus nitrate exceeded EPA standards in the fall, after fall application of nitrogen fertilizer (United States Environmental Protection Agency, 2011).

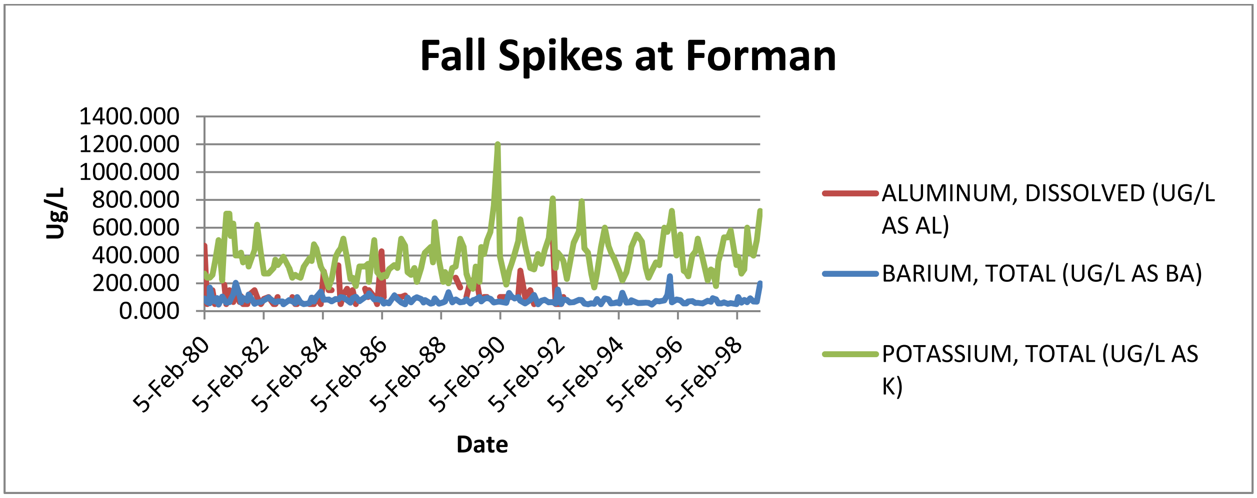

Figure 5.5. There were seasonal spikes for aluminum, barium, and potassium at the multiple sites (United States Environmental Protection Agency, 2011).

Discussion

Karnak exceeded safe levels of cyanide in 1976, while Sandusky and Forman exceeded it several times in the 1990s. Cyanide is highly toxic and affects the thyroid and nervous system. Biomass burning is a major source of free cyanide (HCN and CN^{-}), as well as natural decomposition of some plants, and production by some microorganisms (Smith et al., 2011). Available cyanide concentrations in small streams may approach levels of concern soon after fire, but increases are likely to be of short duration (Barber et al., 2003; Crouch et al., 2006). There are no standard methods for the removal of cyanide from drinking water (Smith et al., 2011).

Sandusky, Forman, Karnak, Ullin, and Vienna exceed USEPA standards for manganese. Manganese causes primarily aesthetic issues with taste and the staining of plumbing fixtures (Smith et al., 2011). Soils and rock are natural sources of manganese, where it exists as both soluble and insoluble compounds in divalent, tetravalent and heptavalent states (Townsend and Douglas, 2004; Townsend et al., 2004). The method of manganese removal consists of converting soluble forms of manganese to insoluble precipitates and then filtering the water (Illinois Environmental Protection Agency, 1987; Illinois Environmental Protection Agency, 1994).

All sites were considered within normal limits for beryllium, boron, cadmium, chromium, cobalt, fluoride, lead, sulfate, and zinc(Gust and Fleeger, 2005; Ozverdl and Erdem, 2010; Momani, 2006). Nevertheless, there were still some patterns over time for many of the parameters at many sites. Hardness, iron, magnesium, calcium levels have been inconsistent since the 1950s, though no pattern was apparent (Schoonover et al., 2005; Cordy, 2001; Momani, 2006{Martinez, 2011 #15)}. All of these parameters are likely to spike naturally, depending on weather patterns and the substrate in the stream (Cordy, 2001; Momani, 2006; Moscoso Perez et al., 2010).

Strontium and sodium quantities have periodically increase suddenly since the 1980s (first sampling). The most significant strontium mineral is celestite (strontium sulphate; SrSO4), followed by strontianite (strontium carbonate; SrCO3), which are both naturally occurring (Shi et al., 2011; Harrison et al., 2011). Strontium is non-toxic and a daily intake of about 0.8-5 mg is harmless. Sodium compounds naturally end up in water and quantities are dependent on geological and weather conditions, but may also enter a stream system by wastewater contamination (Shi et al., 2011; Cordy, 2001).

Beryllium and nickel have had a few sharp spikes since the mid 1980s. Nickel may be found in slate, sandstone, clay minerals and basalt. The main nickel source is pentlandite. The element accumulates in sediments and is a part of various biological cycles and may end up in water from both point and non-point sources (Herlihy et al., 1991; Kaufmann et al., 1991). Beryllium is a hard, grayish element which occurs as a chemical component of certain rocks, coal and oil, soil, and volcanic dust (Doering and Akber, 2008). Two kinds of mineral rocks, bertrandite and beryl, are mined commercially for the recovery of beryllium. Both elements are directly emitted from various industries through discharge on surface waters. Nickel compounds are also applied in agricultural fields. Phosphate fertilizers contain traces of nickel. Nickel is often present in agricultural soils situated near fossil fuel industries. Organic matter often adsorbs nickel, causing coal and oil to contain traces of the element. Nickel compounds may be found in sludge, and slags and fly ashes from waste incinerators (Izumida et al., 2011; Norris et al., 2010). Better waste separation could be useful, because nickel is up to 60% recyclable (Norris et al., 2010).

In the 1980s, the IEPA lab switched from methods in digesting samples. Prior to that date, metals were digested when the analytical method was mainly atomic absorption (AA). Nitric acid was added to the sample to break down material and create a solution, without heating of the sample. Over time, AA has dropped off in use, and analytical procedures have moved more to graphite furnace AA and ICP-AES (inductively coupled plasma-atomic emission spectroscopy). These newer methods require acid plus heated techniques for the digest to put the metals into solution (Illinois Environmental Protection Agency, 1987; Illinois Environmental Protection Agency, 1994). These methods are thought to be comparable; (Moscoso Perez et al., 2010; Atz and Pozebon, 2009), however, nickel has been consistently higher than the USEPA standards since IEPA switched from cold digest. IEPA is looking into possible reasons for the variation.

Chromium and boron levels have been consistent since the 1950s. Chromium does not occur freely in nature. The main chromium mineral is chromite. The element and its compounds can be discharged in surface water through various industries (Kottelat et al., 2010; Soucek et al., 2011; Bai et al., 2010). The most abundant minerals containing boron are kernite, borax, ulexite and colemanite. Boron can also be found in slate and in loam rich rock formations. Air-tight soil contains boron concentrations of between 5 and 80 ppm (Atz and Pozebon, 2009). The degree of binding to clay minerals is mainly pH-dependent. Boron is released from rocks and soils through weathering, and subsequently ends up in water (Bai et al., 2010). Small amounts of boron (25ppm) are required for invertebrates, but higher amounts

(>100ppm) are toxic to vertebrates like fish (Soucek et al., 2011). Levels of boron in the Cache River never exceeded 50 ppm.

Sandusky, Forman, Cobden, Karnak, and Vienna all have exceeded both acute and chronic EPA standards for ammonia since the 1970s. Sandusky reached 100 times over the limit. Nitrogen levels have exceeded the newly determined standards for USEPA Ecoregion 9 for all the sites. Phosphorous has exceeded accepted levels in nearly every sample at every site. Nitrogen enters the environment mainly through agricultural processes. The main source of nitrogen compounds in water is fertilizers that mainly contain nitrate, but also ammonia, ammonium, urea and amines (Vitousek et al., 1997). The most widely applied nitrogen fertilizers are probably $NaNO_3$ (sodium nitrate) and NH_4NO_3 (ammonium nitrate)(Raty et al., 2010). After fertilization, crops take up a relatively small part of added nitrogen compounds (25-30%). The residue ends up in groundwater and surface water via soils, because nitrates are water soluble. Organic fertilizers mainly contain nitrogen as proteins, urea or amines, which have different mechanisms of absorption. Finally, various pesticides added to farmland contain nitrogen (Vitousek et al., 1997; Vidon et al., 2010). This fertilizer application period may also contribute to the fall peaks of aluminum, barium, nitrate/nitrite, phosphorous, and potassium.

Nitrogen compounds are applied in several different industries. Most nitrogen is applied to synthesize ammonia by the Haber-Bosch process (Vitousek et al., 1997). Thereby other nitrogen compounds, such as nitrous oxide applied in anaesthetics can be produced. Nitric acid, urea, hydrazine and amines are other products from nitrogen industries. Nitrogen compounds are by-products of coloring and synthetic agent production (Vitousek et al., 1997).

Turbidity is consistently highest at Forman, though all sites have exceeded standards at one time or another. Human activities that disturb land, such as tilling farmlands, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff (Quigg et al., 2010). Areas prone to high bank erosion rates contribute large amounts of turbidity, as well. Certain industries such as quarrying, mining and coal recovery can generate very high levels of turbidity from colloidal rock particles (Hu et al., 2011).

In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths, which can inhibit growth of submerged aquatic plants and consequently affect species which are dependent on them, such as fish and shellfish. High turbidity levels can also affect the ability of fish gills to absorb dissolved oxygen (Hu et al., 2011; Quigg et al., 2010).

Every site exceeded fecal coliform levels, though the Sandusky and Forman sites exceeded most consistently and with highest numbers. Total coliform bacteria are a collection of relatively harmless microorganisms which live in large numbers in the intestines of animals. Coliform bacteria aid in the digestion of food. A specific subgroup of this collection is the fecal coliform bacteria, and the most common member is *Escherichia coli*. These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and are associated only with the fecal material of warm-blooded animals (Cordy, 2001).

The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of man or other animals (Tyagi et al., 2011). At the time of contamination, the source water may have harbored pathogens or disease producing bacteria or viruses which can also exist in fecal material. Some waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis, and hepatitis A (Tyagi et al., 2011; Viau et al., 2011). The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. Fecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste (Tyagi et al., 2011; Viau et al., 2011; Cordy, 2001).

A number of water quality parameters consistently exceed federal water quality standards. In addition, the majority of the impairments are directly related to land use. These water quality standards were put into place to protect water for designated uses such as drinking, recreation, agricultural irrigation, or protection and maintenance of aquatic life. Illinois EPA reports all impaired waters of the state to the USEPA every two years under the 303(d) list. Under the Clean Water Act, states are required to establish a prioritized schedule for waters on the 303(d) list and develop Total Maximum Daily Loads (TMDL) for the identified waters based on severity of the pollution and the sensitivity of the uses to be made of the waters. The Cache River has multiple river segments that are listed on the 303(d) list of impaired waters for Illinois; however, none of these impairments were included on the 2010-2012 TMDL priority list, which can be found at http://www.epa.state.il.us/water/tmdl/303d-list.html.

Chapter 6: A Spatial Analysis of Giant Cane

Introduction

The southern Illinois landscape offers an opportunity to examine a riparian zone species, giant cane [*Arundinaria gigantea* (Walt.) Chapm.]. Cane is a native bamboo species with a relatively dense rooting network which can withstand water flow in riparian zones (Brantley and Platt, 2001) and so is useful to consider in restoration. Cane was a dominant component of lower Midwestern and southeastern United States' riparian areas, including southern Illinois (Platt and Brantley, 1997; Brantley and Platt, 2001; Platt et al., 2009). Giant cane is a good candidate to include in multispecies riparian buffers designs, as it promotes infiltration of surface runoff and deposition of sediment and associated nutrients through its high density culms and extensive shallow rooting network (Schoonover et al., 2005; Schoonover et al., 2006). Also, giant cane can provide significant wildlife habitat benefits, especially in the fragmented midwestern United States landscape (Blattel et al., 2009). In addition, giant cane performed as well as, or better than, forest vegetation in terms of maintaining low ground water nitrogen levels (Schoonover et al., 2010). To determine if giant cane should be considered for use in multi-species restoration strategies for nutrient removal in surface or groundwater systems, one must determine if the location is within the distribution of the species.

Methods

Infrared aerial photography of the Cypress Creek Refuge and Cache River were taken in March 2009 by the United States Fish and Wildlife Service. Known canebrake sites were plotted using ArcGIS v9.3 to confirm the suspected locations of canebrakes based on photographic interpretation (Environmental Systems Research Institute, 2011). Similar looking plots were manually marked as canebrakes on the maps. Canebrakes were confirmed with groundtruthing and preliminary measurements of canebrake size were taken to confirm the accuracy of delineating using ArcGIS. Elevation of station sites was pulled out from US Geological Survey's ASTER Global Digital Elevation Model (ASTGTM). The spatial analyst slope tool in ArcMap 9.3 was used to calculate the slope, aspect, and elevation of each pixel in the ASTGTM raster (Environmental Systems Research Institute, 2011). In addition, proximity to water and roads were determined of the canebrakes and SAS statistical software (SAS Institute Inc., 2007) used to determine correlations.

Results

Fifty percent of canebrakes were on land with less than one percent slope. Almost 20% of canebrakes were on land with a one to two percent slope, but above two percent, there was no significant difference among the slopes (Figure 6.1). The fewest canebrakes were located on Southwest and Western facing slopes, though there was no significant difference among the remaining aspect directions (Figure 6.2). The highest number of canebrakes was found between 100 and 105 meters above mean sea level (msl) (Figure 6.3). Seventy-six percent of the canebrakes grew between 95 and 110 m msl. Cane was found only within 90 and 150 m msl. About half of the canebrakes were found within 40 meters of a stream, and the majority of those were within 20 m (Figure 6.4). Further than 60 m, the probability of finding cane was equal.

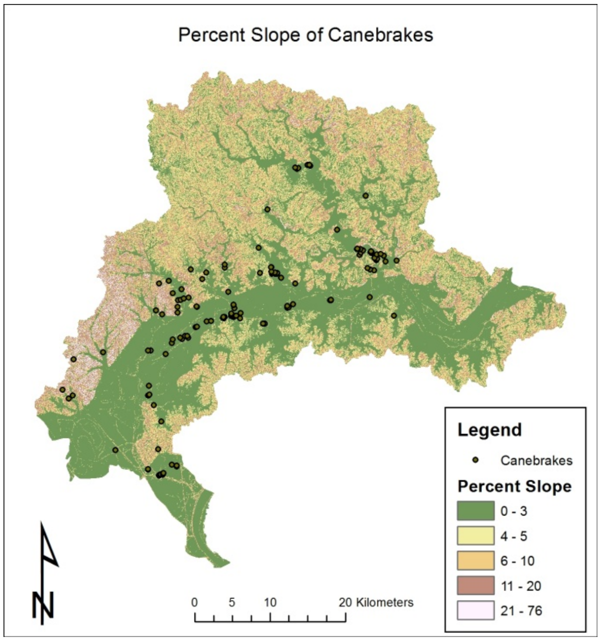

Figure 6.1. The majority of the canebrakes, marked in red dots, are located in low slope areas, marked by the reddish colors.

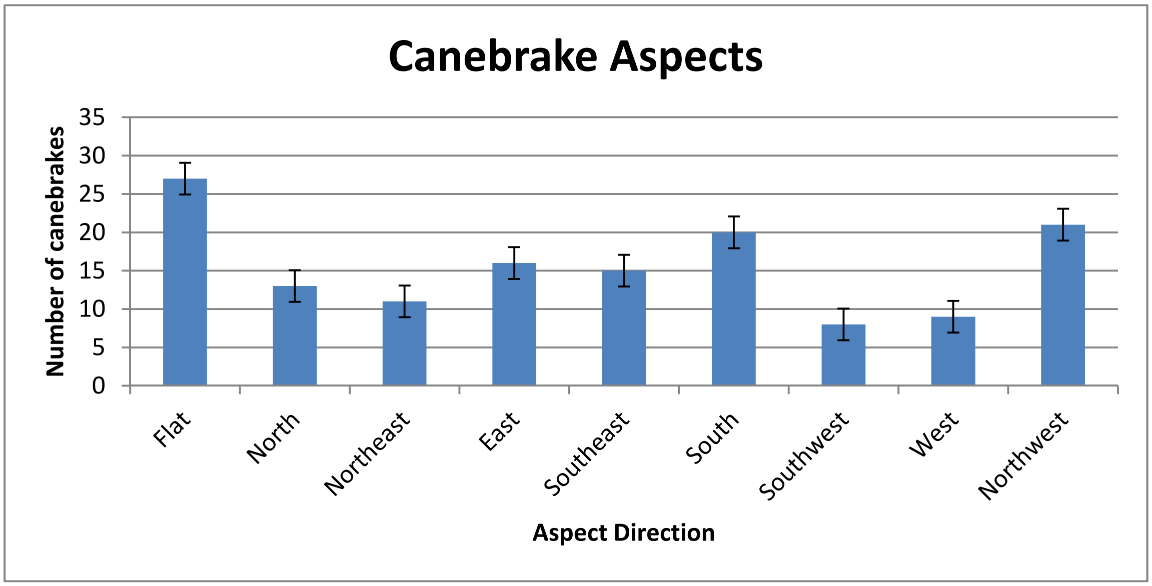

Figure 6.2. Canebrakes were found facing all directions, though many were on flat ground in a survey of Southern Illinois.

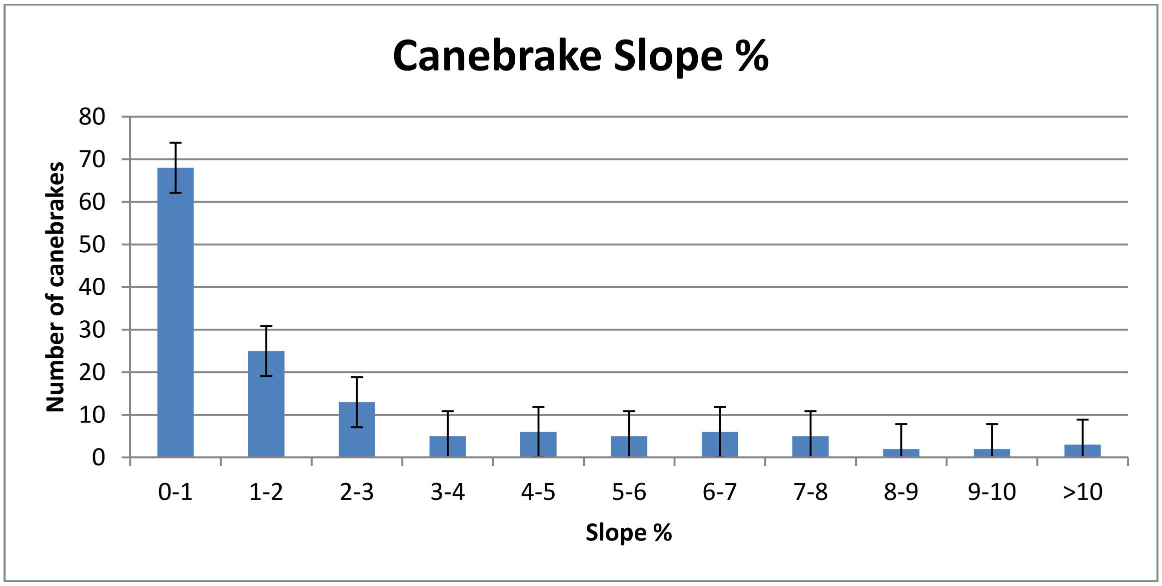

Figure 6.3. Most canebrakes were found on land with slopes less than two percent in a survey of Southern Illinois.

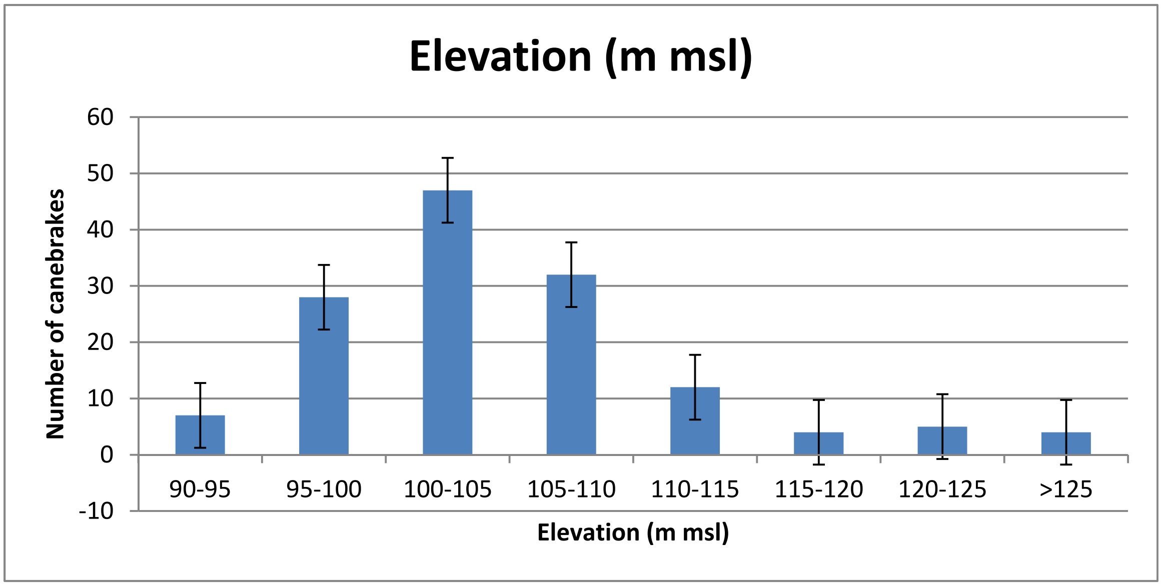

Figure 6.4. The frequency of canebrakes peaked between 100 and 105 meters above mean sea level in a survey of Southern Illinois.

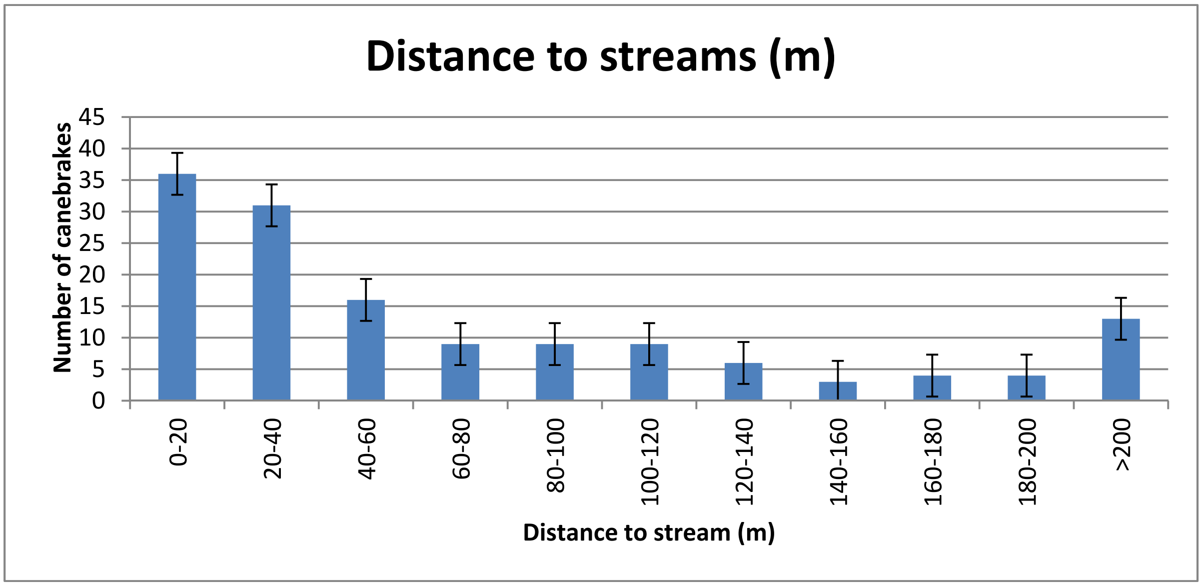

Figure 6.5. More canebrakes were found closer to the streams in a survey of Southern Illinois.

Discussion

About half of the canebrakes were found within 40 meters of a stream, and the majority of those were within 20 m and on a 1% slope or less. These parameters describe an ideal situation for riparian buffers, which have received considerable attention for mitigating disturbance, including agricultural runoff. Reductions in sediment loads and associated nutrients in surface runoff is a fairly universal effect of riparian forests due to the physical nature of the processes involved. Many studies present evidence that riparian zones reduce nitrogen, phosphorus, and sediment loads to within 40 meters of streams (McColl, 1978; Karr and Schlosser, 1978; Schlosser and Karr, 1980; Schlosser and Karr, 1981a; Schlosser and Karr, 1981b).

In the southwestern region of eastern deciduous forest where the Cache River basin is located, riparian buffers may be critical for nutrient attenuation in upland riparian sites, where there may be less potential for denitrification relative to lowland areas with shallow water tables and greater tendency to flood (Blattel et al., 2009) and based on the current location of successful canebrakes, giant cane seems to be an excellent candidate for building riparian buffers. Giant cane is a native bamboo species which has a relatively dense rooting network, making it an ideal riparian zone plant (Brantley and Platt, 2001) to consider in restoration. Historically, cane was a dominant component of lower Midwestern and southeastern United States' riparian areas, including southern Illinois (Brantley and Platt, 2001; Platt and Brantley, 1997; Platt et al., 2009) and promotes infiltration of surface runoff and deposition of sediment and associated nutrients through its high density culms and extensive shallow rooting network (Schoonover et al., 2006; Schoonover et al., 2005). In addition, giant cane can provide significant wildlife habitat benefits in the fragmented Midwestern United States landscape (Blattel et al., 2009). Canebrakes provide cover for wildlife throughout the year as an evergreen species (Platt et al., 2001), while the dense culms provide sanctuary to many species of insects, birds, reptiles and mammals (Rose, 1981; Platt et al., 2001). Some species such as the threatened Swainson's Warbler (*Limnothylpis swainsonii*) inhabit giant cane stands exclusively (Eddleman et al., 1980; Hoover et al., 2000), leading canebrakes to be listed as a conservation target by the Joint Venture Partnership in the Cache River Watershed (Bouteille-Fidler, 2012).

Chapter 7: Macroinvertebrate Community Assessments

Introduction

Benthic macroinvertebrates are highly sensitive to land use changes (Kiffney et al., 2004), sedimentation (Murphy et al., 1981), and instream alterations (Richards et al., 1996). Additionally, due to the range of life cycle lengths, variable sensitivities to pollution, and preferences for specific types of habitats, they can be an important tool for evaluating the ecological health of a system (Silva et al., 2005). Macroinvertebrate community assessments are also extremely useful tools in evaluating ecological responses to in-stream restoration practices (Friberg et al., 1998; Walther, 2007).

Both qualitative and quantitative assessments are common when evaluating the ecological health of an aquatic system. However, quantitative macroinvertebrate sampling techniques, while costly and require significant laboratory time for identification, are often preferred over qualitative. Numerous types of equipment used for quantitative sampling including stove-pipe corers, coarse-mesh kick nets and dip nets and Surber samplers. Studies have compared sampling technique efficacy (Storey et al., 1991; Silva et al., 2005) and methods chosen often depend on sampling regime (rapid bioassessment or long-term sampling), habitat type (large river, tributary, headwater stream, etc.) and the availability of financial resources since trained staff to carry out assessments, identify specimens and perform analyses are often costly.

Data is often analyzed using numerous biotic indices; most commonly EPT (Ephemeroptera, Plecoptera and Trichoptera), the Shannon-Weiner Index, and the Hilsenhoff index. EPT family taxa are utilized in biotic assessments to evaluate species diversity and habitat disturbance. The Shannon-Wiener Index, useful for comparing habitats, examines species richness and the eveness of their abundance. Shannon-Wiener Index scores range from 1.5 (low species richness and eveness) to scores of 3.5 (high species richness and eveness). The Hilsenhoff index is perhaps the most informative and useful index for understanding the streams within the Cache River basin. It provides a numerical level for tolerance (ranging from 0 for low tolerance to 10 for high tolerance) to organic pollution for each taxonomic group in a sample.

Macroinvertebrate Sampling

Aquatic macroinvertebrate data were obtained for the Cache River basin from IEPA staff (Joseph, 2011). The data were originally collected from IEPA in 1984, 1987, 1992, 1999, 2001, and 2004. All samples were collected between May and October of each year. A total of 101 samples were collected at 49 sites. However, not all sites (Figure 3) were surveyed each year. Prior to 2001, methods included sampling using forceps, hand-held sieve (standard 30-mesh) and/or D-net at all habitats and substrata (Illinois Environmental Protection Agency, 1987; Shasteen et al., 2002). Since 2001, sites have been sampled using a 20-jab semi-quantitative technique, with allocation of jabs based on mean stream width and proportion of habitat types (Barbour et al., 1999). Samples were preserved in ethanol in the field. In the laboratory, a 300-organism subsample was identified by IEPA biologists (Illinois Environmental Protection Agency, 2007).

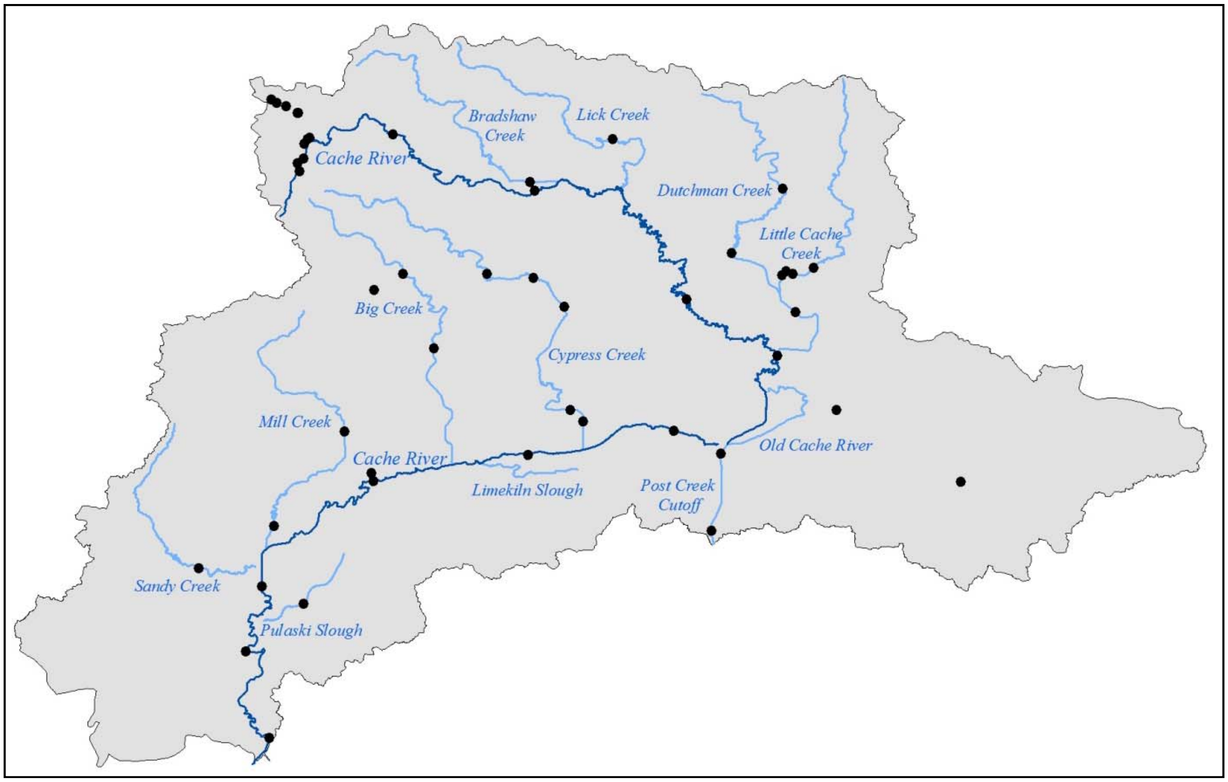

Figure 7.1. IEPA sites for sampling macroinvertebrates between 1984 and 2004.

Data Analysis

Macroinvertebrate community structure and function were examined to determine water quality. The total number of organisms; diversity of EPT taxa; and the tolerance of the invertebrate community were assessed. Diversity of EPT taxa and community quality were measured using the Shannon and the EPT indices (Ludwig and Reynolds, 1988) and the Hilsenhoff index was used to determine water quality and the degree of organic pollution (Hilsenhoff, 1987). Tolerance values for the Hilsenhoff index were obtained from Illinois EPA (IEPA, 1987).

Habitat associations with macroinvertebrate indices were tested using multiple regression. However, due to high collinearity among habitat variables, a principle component analysis (PCA) was used to reduce collinearity. Multiple regression models were then tested on data from 1992, 1999 and 2004 using principal components as independent variables in SAS version 9.2 (SAS Institute Inc., 2007). Multiple regression results were illustrated using Sigmaplot version 10.0

Results

Summary data for species richness, EPT taxa richness, Shannon Diversity Index, and the Hilsenhoff index are included in the Appendices (Appendices I-V) for the years where data are available with the exception of 2001 from which only one sample was present and the information was therefore excluded from this assessment.

Very few sites were sampled on multiple years, with the exception of a few in the upper Cache River - mainstem, Pulaski Slough, and Cypress Creek. Of sites that were sampled multiple years, only two in Pulaski Slough, two in the main stem of the upper Cache River, one in Cypress Creek, one in Big Creek and one in Lick Creek were sampled for 3 years.

The range for species richness scores was 1 - 56 across all samples. The highest mean score of 39.33 for species richness was found in sites for the upper Cache - mainstem in 2004 (Appendix V). However, this score came from only 3 samples taken from that portion of the river system. The range of scores for species richness in 2004 for sites in the upper Cache River - mainstem was 34-39 (Appendix V).

The range for Shannon Diversity scores was 0.33 - 2.85 across all samples. The highest mean score of 2.85 for Shannon Diversity was found in the upper Cache River - mainstem in 2004. The range of scores for Shannon Diversity in 2004 was 2.52 -3.28 for upper Cache River - mainstem (Appendix V).

The range for EPT scores was 0 - 16 across all samples. The highest mean score of 7.63 for EPT taxa was found in upper Cache River - mainstem in 1999. The range was 7.0 - 15.0 for upper Cache River - mainstem for 1999 (Appendix IV).

The lower the Hilsenhoff Index score, the higher the water quality. None of the sites samples achieved an excellent score (0.0 - 3.75) with the Hilsenhoff Index. The range for Hilsenhoff scores was 4.11 - 20.81 with 25% falling into the "good - some organic pollution" (4.26 -5.00) range, 33% "fair - fairly significant organic pollution," 14% "fairly poor - significant organic pollution," 9% "poor - very significant organic pollution," and 19% "very poor - severe organic pollution" (Hilsenhoff, 1987).

During 1992, 1999, and 2004 a general trend of low EPT and Shannon Diversity scores was observed at sites that were characterized as having a high percentage of silt (> 60%). Conversely, sites that were characterized as having a very low percentage of silt (< 20%) demonstrated higher EPT and Shannon Diversity scores.

In 2004, the highest ungrouped scores of 56 for species richness and 16 for EPT taxa were found at Mill Creek, a tributary of the lower Cache River. The highest ungrouped score of 3.33 for Shannon Diversity was found in 2004 at Sandy Creek, a tributary of the lower Cache River. The lowest (best) score for the Hilsenhoff Index 4.11 was found in the upper Cache River - mainstem (Figure 7.1).

When examined spatially, the mainstem of the upper and lower portions of the Cache River and its tributaries vary dramatically over time. However, no real pattern is seen in this variation. The upper portions of the tributaries of Big Creek and Mill Creek in the lower Cache River, tend to have the higher species richness and Shannon index scores and lower Hilsenhoff scores (Figure 7.2).

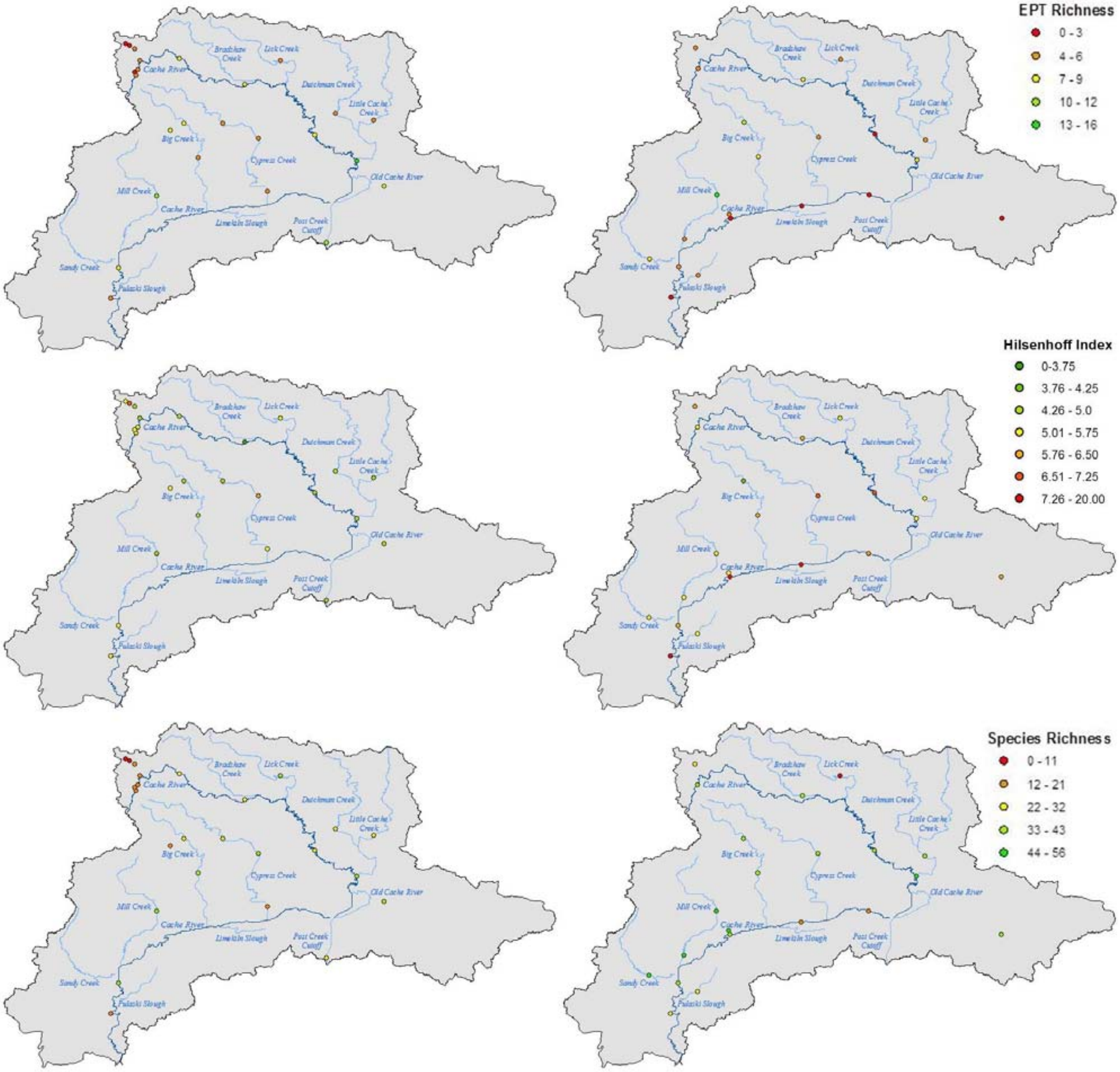

Figure 7.2. EPT Richness, Hilsenhoff Index and Species Richness scores for 1999 and 2004.

Principal components analysis reduced the correlated habitat variables to four principal components, together explaining 86.46% of total variance (Table 7.1). Principal component 1 explained nearly 38% of variation and was negatively associated with percent silt. Principal component 2 explained 23% of total variation and was positively associated with percent claypan. Principal components 3 and 4 explain 13% and 11% of variation, respectively. Principal component 3 was positively associated with percent sand while principal component 4 was negatively associated with percent gravel and percent cobble.

Table 7.1. Principal components analysis results of habitat variables from macroinvertebrate sampling locations in the Cache River Watershed.

	PC 1	**PC 2**	**PC 3**	**PC 4**
Eigenvalues	0.3756	0.2344	0.1376	0.1170
Eigenvectors				
Silt	- 0.89	0.27	- 0.10	- 0.04
Sand	- 0.02	- 0.21	0.86	0.28
Gravel	0.23	- 0.12	0.10	- 0.49
Cobble	0.13	- 0.07	0.08	- 0.36
Boulder	0.05	- 0.02	0.01	- 0.09
Bedrock	0.05	- 0.07	- 0.03	- 0.26
Claypan	0.37	0.78	- 0.07	0.34
Log	0.04	- 0.06	0.04	0.03
Other	0.03	- 0.50	0.48	0.60

Multiple regression analyses of macroinvertebrate indices and principal components indicate negative associations between principal component 1 and species richness ($p = 0.03$, Figure 7.3a), EPT ($p < 0.0001$, Figure 7.3b), and Shannon Index ($p = 0.05$, Figure 7.3d). These results suggest that silt negatively influences species richness and EPT and Shannon diversity indices. Additionally, there was a positive association between EPT score and principal component 4 ($p = 0.0018$, Figure 7.3d), suggesting gravel and cobble are important substrates for EPT taxa. No other principal components were found to significantly influence macroinvertebrate indices (Table 7.2). A summary of macroinvertebrate data and habitat substrate data for 1992, 1999, and 2004 can be viewed in Appendix VI.

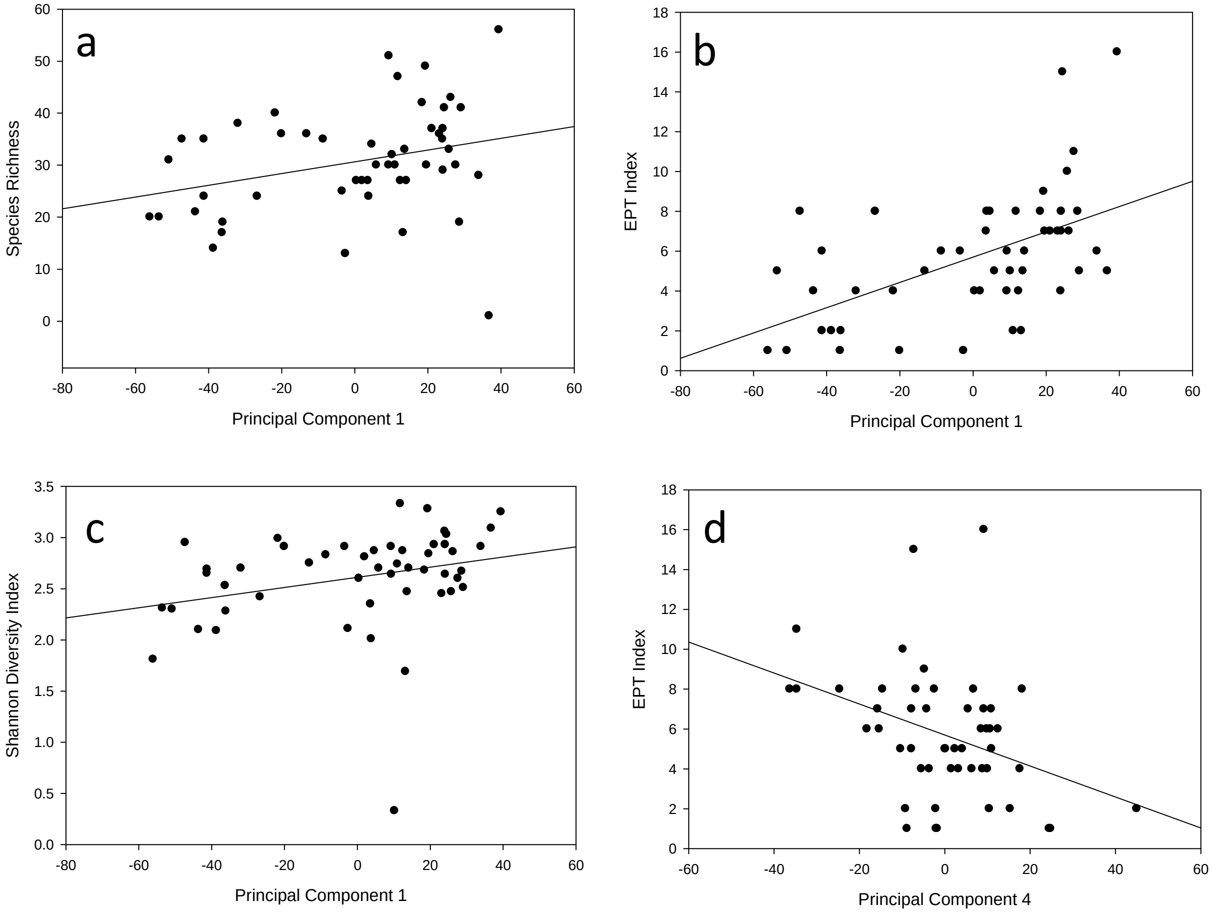

Figure 7.3 Regression plots of significant relationships found between macroinvertebrate indices and habitat-based principal components: a) species richness and principal component 1, b) EPT index values and principal component 1, c) Shannon diversity index values and principal component 1, and d) EPT index values and principal component 4.

Table 7.2. Multiple regression results of macroinvertebrate indices and habitat principal components from the Cache River Watershed.

	PC 1	PC 2	PC 3	PC 4
Richness				
Parameter estimate	0.11	0.06	- 0.17	- 0.07
t-value	2.22	0.93	- 2.00	- 0.77
p-value	0.03	0.36	0.05	0.45
95% CI	0.01, 0.22	- 0.07, 0.19	- 0.34, 0.00	- 0.25, 0.11
EPT				
Parameter estimate	0.06	0.01	- 0.02	- 0.08
t-value	4.85	0.80	- 0.84	- 3.32
p-value	<0.0001	0.42	0.40	0.002
95% CI	0.04, 6.41	- 0.20, 0.05	- 0.06, 0.03	- 0.12, - 0.03
Shannon Index				
Parameter estimate	0.005	0.0008	- 0.007	- 0.001
t-value	2.02	0.26	- 1.65	- 0.27
p-value	0.05	0.80	0.12	0.79
95% CI	0.00000547, 0.00707	- 0.00547, 0.00707	- 0.01489, 0.00148	- 0.01, 0.008
Hilsenhoff Index				
Parameter estimate	- 0.004	- 0.004	- 0.0003	0.002
t-value	- 0.46	- 0.35	0.02	0.13
p-value	0.64	0.73	0.98	0.89
95% CI	- 0.02, 0.01	- 0.03, 0.02	- 0.03, 0.03	- 0.03, 0.03

Discussion

Given that very few sites were sampled consecutively (every year sampling occurred), there are significant gaps in the data set. Additionally, our records indicate that habitat data was only collected at a portion of the macroinvertebrate sampling sites. Whether this information has been misplaced or was not collected is unknown. Nevertheless, this lack of corresponding habitat assessments for many of the sampling sites limits interpretation of the results.

Habitat characteristics vary greatly throughout the watershed, including among sampling locations within the same waterbody. The importance of habitat heterogeneity is emphasized by the differences in EPT and Shannon Diversity scores throughout the watershed. The observed trends in low EPT and Shannon Diversity scores at locations where there was a high percentage of silt in the substrate were located in the upper Cache River - mainstem and lower Cache River near the Mississippi River (Appendix VI). The relatively low Shannon Diversity, Species Richness, and EPT scores in the upper Cache River and its tributaries are possibly due to the high velocity and deeply incised streambed resulting from the alterations in the watershed (Demissie et al., 1990). These low scores may be a result of the scouring of the streambed which could remove structural habitat for invertebrates and/or cause them to seek refugia (Biesel et al., 2006). High velocity rates, such as those from seasonal floods have also shown to impact species composition (Dodds et al., 2004; Bertrand et al., 2009). Substrate may also be a key factor in determining macroinvertebrate community structure (Biesel et al., 2006). Numerous studies have linked substrate type, specifically habitat heterogeneity to macroinvertebrate community structure (Biesel et al., 2006; Minshall and Robinson, 1998). The low levels of silt and higher levels of habitat heterogeneity in the Cypress and Big Creek drainage areas are likely reasons for the low Hilsenhoff and high Species Diversity scores in this area. The higher scores in the upper Cache River - mainstem and the lower Cache River may also be attributed to the fact that the increased slope and water velocity due to the Post Creek Cut-off have eroded the channel-bed down to bedrock in some places or potentially exposed more suitable substrates for some species of benthic macroinvertebrates.

As previously mentioned, prior to 2001, methods included quantitative sampling using forceps, hand-held sieve (standard 30-mesh) and/or D-net at all habitats and substrates. In 2001, methods were changed and sites were sampled using a 20-jab-semi-quantitative technique. This change in methods may also have resulted in differences the in quality of the assessment and the quantity of organisms collected. However, due to the fact that there are very few data collected from multiple sites from multiple years it remains difficult determine the reasons for the differences.

The lack of consistent information available from the state funded basin surveys highlights the need for a more extensive, repetitive multi-year sampling regime for the Cache River and its tributaries. An increase in macroinvertebrate sampling locations and corresponding instream habitat assessments would aid in fully understanding the breadth and depth of the hydrologic, physical, and chemical changes occurring within the Cache.

There exists a strong relationship between land use and water quality. Consequently, it is likely that restoration and land protection performed in the lower Cache River Watershed such as the Big Creek project beginning in 2002 accounts for observed differences in the upper Cache River, lower Cache River and Post Creek Cut-off (Union County Soil and Water Conservation District, 2006; Union County Soil and Water Conservation District, 2008). While some studies have been performed evaluating the ecological benefits of restoration practices in the Cache River basin (Walther, 2007; Heinrich, 2011), further exploration of these issues could aid in a greater understanding of land use, water quality, and ecological linkages.

Chapter 8: Habitat Associations of Fish Assemblages[6]

Introduction

In order to successfully manage, conserve and restore native stream and riverine fishes, a thorough understanding of relationships between life history characteristics and species habitat requirements is essential (Fausch et al., 2002; Schlosser, 1991). A number of abiotic and biotic factors at multiple and interacting scales (Frissell et al., 1986) have been found to be associated with fish assemblage structure, including substrate, riparian and catchment land use, discharge, climate, geology, stream depth and woody debris (Stewart et al., 2001; Lammert and Allan, 1999; Allan et al., 1997; Talmage et al., 2002; Marsh-Matthews and Matthews, 2000; Quist et al., 2004; Fischer and Paukert, 2008). Due to the strong influence these factors have on fish communities, fish assemblages are often used as indicators of ecological integrity (Karr, 1981).

In the agricultural midwest, many streams have suffered significant alteration, largely due to agricultural land use decisions (Karr et al., 1985). Within the state of Illinois approximately 23% of streams have been channelized, most of which are first through fourth order streams (Mattingly et al., 1993). Land use decisions and channel alterations indirectly result in sedimentation, increased nutrient inputs, fragmentation from the floodplain, shifts in energy inputs, altered flows, increased water temperatures and overall habitat homogeneity (Allan, 2004). However, stream restoration projects in the U.S. have

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[6] This manuscript was accepted to the journal, Environmental Biology of Fishes, with co-author Greg Whitledge on January 17, 2013.

increased substantially since 1990 with the goal to improve the condition of a landscape to a desired endpoint (Bernhardt et al., 2005). In stream restoration, conditions prior to disturbance or of a nearby undisturbed stream are considered reference conditions and are commonly recommended to guide and assess restoration projects (Palmer et al., 2005b; White and Walker, 1997; Palmer et al., 1997; Lake et al., 2007). However, many systems lack reference conditions, and baseline assemblage-habitat relationships can provide valuable information on the influence of habitats on assemblage structure, and in turn, guide conservation activities.

The Cache River Watershed in southern Illinois has received much restoration attention. Its location at the junction of four physiographic provinces results in high levels of habitat heterogeneity and biodiversity (Mankowski, 1997). Once a region of dense bottomland forests and wetlands, centuries of timber harvest and agricultural activities have altered the landscape and hydrology of the watershed (Bhowmik et al., 1997). Seasonal flooding from the Ohio River led to the ditching of large sections of the river and its tributaries and drainage of thousands of acres of wetlands. Numerous alterations have impacted the hydrology of the river, including the construction of the Post-Creek Cutoff, a large ditch which drains the upper portion of the Cache River and its eastern tributaries into the Ohio River at a point further upstream than the natural outlet (Cache River Watershed Resource Planning Committee, 1995). This alteration has essentially split the river and watershed into two distinct sections for nearly a century. Efforts are currently underway to design a structural partial reconnection of the upper and lower sections of the river (Demissie et al., 2008; Demissie et al., 2010).

Today, the Cache River Watershed is predominantly rural, with 8% of land in a developed state, 37.2% as forest, 22.4% as cultivated crops (primarily corn and soybean) and 26.7% pasture/hay (United States Department of Agriculture, 2010). Eighty-five native fish species have been found within the watershed, representing 42% of all native fish found in Illinois and 21% of all native fish in the Mississippi River basin (Burr, 1992; Bennett et al., 2001). The Cache River Watershed contains a fragmented wetland ecosystem that includes bald cypress and water tupelo swamps and over 100 state threatened and endangered species. This list includes five fish species; the cypress minnow (*Hybognathus hayi*), pallid shiner (*Hybopsis amnis*), bigeye shiner (*Notropis boops*), redspotted sunfish (*Lepomis miniatus*), and bantam sunfish (*Lepomis symmetricus*) (Bennett et al., 2001). Although the watershed has extensive fish species records dating back to the late 1800's, there is a lack of understanding of how fish communities are structured along environmental gradients within the watershed (Phillippi et al., 1986; Bennett et al., 2001; Muir et al., 1995; Shasteen et al., 2002).

Our objective was to describe the current fish assemblages and to identify important environmental variables influencing fish assemblage structure throughout the Cache River Watershed. Specifically, we were interested in how habitat variables differed among locations within the watershed (i.e., mainstem versus tributaries, upper versus lower Cache River) and how those habitat variables related to fish assemblage structure. Our results contribute to both understanding aquatic community structure and management activities within the Cache River watershed.

Methods

Fish and Habitat Sampling

A total of 112 fish assemblage samples were collected at 51 stations by Illinois Department of Natural Resources (IDNR) during the years 1992, 1994, 1996, 1998, 1999, 2000, 2001, 2002, 2004, 2006, and 2009 (Figure 8.1). IDNR, in conjunction with Illinois Environmental Protection Agency (IEPA), conduct intensive basin surveys on a five-year rotating cycle, therefore sampling intensity and spatial coverage of stations sampled varied by year. Sampling occurred between May and August of each year. Habitat variability throughout the watershed required the use of multiple fish sampling gears, including boat electrofishing, seines, and electric seines. Due to the use of multiple gears, species were represented as presence or absence for all analyses. Species found in less than 5% of sample sites were removed for analysis.

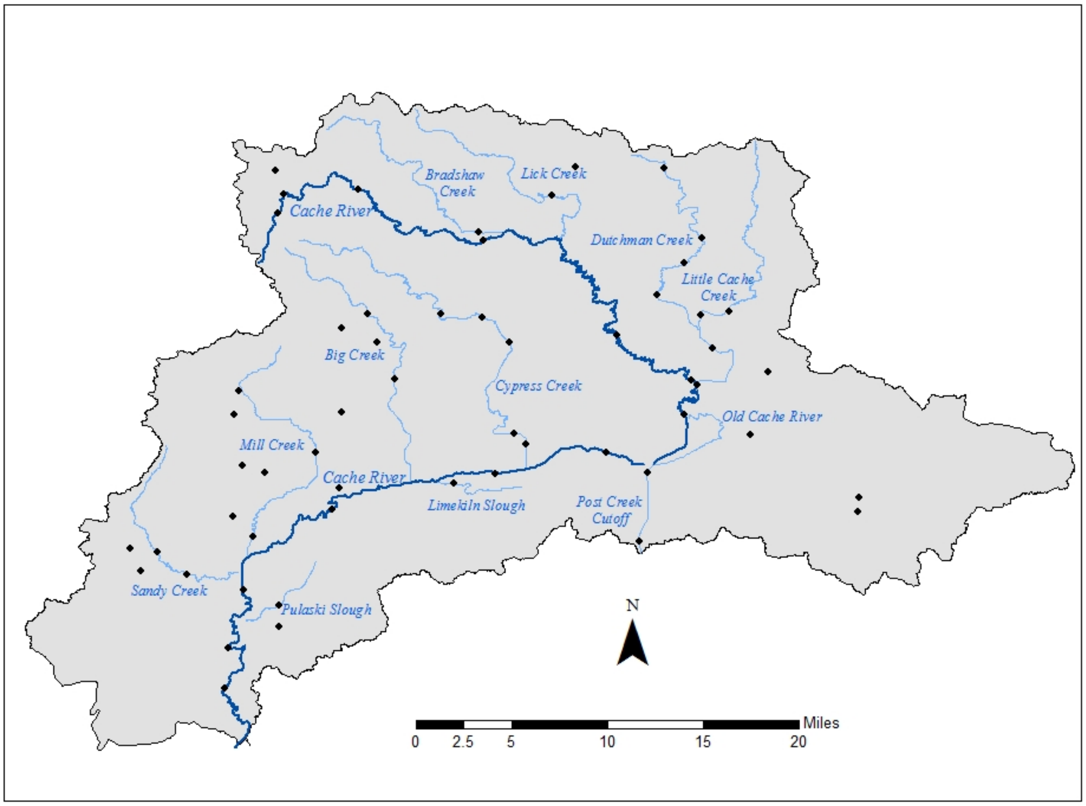

Figure 8.1. The Cache River Watershed is located in southern Illinois, near the confluence of the Ohio and Mississippi rivers. Sampling locations (black dots) included sites on tributaries and the mainstem Cache River.

For all samples collected during an intensive basin survey, habitat data was collected at each fish sampling site on the same day of sampling. An 11-transect approach was used and supplemented by measurement of stream discharge (Shasteen et al., 2002). Habitat variables collected and used for this analysis include substrate (i.e., percent silt, percent sand, percent gravel, etc.), discharge, mean velocity, mean wetted width, mean depth, and percent of channel shaded.

Additionally, elevation, slope, geology and land use were extracted from geographic information system (GIS) layers were used in analysis. Elevation of station sites was obtained from the U.S. Geological Survey's ASTER Global Digital Elevation Model (ASTGTM). The spatial analyst slope tool in ArcMap 9.3 was used to calculate the slope of each pixel in the ASTGTM raster (Environmental Systems Research Institute, 2011). Geology of each site was quantified as presence or absence of rock types, as recorded by USGS Mineral Resources' Illinois Geologic GIS layer. Land use percentages originated from the NASS/USDA Cropland Data Layer and were calculated for each sampling occurrence's respective watershed and year.

Data Analysis

A variety of multivariate statistical techniques were used to assess patterns in fish assemblage structure and relationships between fish assemblages and environmental characteristics in the watershed. Similarities in species composition among stations were evaluated using Jaccard's index of similarity (Guy and Brown, 2007). The matrix of similarity coefficients was then clustered using the unweighted pair-group with arithmetic averaging method (Guy and Brown, 2007) to produce a dendrogram depicting clusters of stations with similar fish assemblages. Cluster analysis has been useful in delineating organizations of fish assemblages (Grossman et al., 1998) and was used here to identify and describe fish assemblage types. Assemblage types were mapped using ArcMap 9.3 to view spatial patterns in assemblage structure (Environmental Systems Research Institute, 2011). Calculation of similarity indices and cluster analysis were conducted using SAS version 9.2 (SAS Institute Inc., 2007).

Relationships between fish assemblage structure and environmental variables were examined using canonical correspondence analysis (CCA) conducted in CANOCO software, Version 4.5 (TerBraak and Smilauer, 2002). All environmental variables were screened for high inflation factors (>20) and correlation coefficients (>|0.60|), which indicate high correlation among variables. All remaining variables were analyzed using the manual forward-selection procedure, which is a step-wise process of building a model for species data using Monte Carlo Permutation tests (TerBraak and Smilauer, 2002). Variables with $p<0.05$ were selected for the final model. The CCA plots species and samples in an ordination figure with environmental variables represented as vectors. Samples are plotted based on fish assemblage, where closely plotted samples are more similar. The direction and length of vectors represents the influence of environmental variables on the fish assemblage (Jongman et al., 1995).

Results

A total of 85 fish species were recorded in the watershed by IDNR between 1992 and 2009. The most ubiquitous species were longear sunfish (*Lepomis megalotis*), bluegill (*Lepomis macrochirus*) and green sunfish (*Lepomis cyanellus*), which were found in 88, 87 and 77 percent of all samples, respectively. The least common species, found in less than 2% of sites, included bighead carp (*Hypophthalmichthys nobilis*), banded pygmy sunfish (*Elassoma zonatum*), brindled madtom (*Noturis miuris*), channel shiner (*Notropis wickliffi*), goldeye (*Hiodon alosoides*), sand shiner (*Notropis stramineus*), slenderhead darter (*Percina phoxocephala*), slender madtom (*Noturus exilis*), and threadfin shad (*Dorosoma petenense*). Species richness ranged from 1 to 34 across samples. After removing species found in less than 5% of sites, a total of 54 species remained for analysis.

Fish Assemblage Structure

Jaccard's similarity index values ranged from 0 to 0.79. Using cluster analysis, we identified five major assemblage types (clusters 2, 3, 4, 5, and 7) and two additional groups (clusters 1 and 6) which had limited observations (Figure 8.2). Samples within major clusters had an average distance between other clusters of 0.75 or less. Almost all species were found in more than one cluster, with the exception of quillback (*Carpoides cyprinus*). Pirate perch (*Aphredoderus* sayanus) and warmouth (*Lepomis gulosus*) were present in all clusters (Table I). For the following cluster analysis results, species found at more than 75% of sites within a cluster are referred to as common species for that cluster.

The first major cluster, cluster 2, included five samples which had species richness ranging between 7 and 15. Common species found in this cluster included blackside darter (*Percina maculata*), blackspotted topmminow (*Fundulus olivaceus*), central stoneroller (*Campostoma anomalum)*, creek chub (*Semotilus atromaculatus)*, green sunfish, and pirate perch. Cluster 3, made up of 9 samples with species richness ranging between 15 and 20, most commonly included bluegill, bluntnose minnow (*Pimephales notatus*), channel catfish (*Ictalurus punctatus*), longear sunfish, and red shiner (*Cyprinella lutrensis*). Cluster 4 included 21 samples ranging in species richness from 8 to 28. Fish species common to this cluster included bluegill, blackspotted topminnow, longear sunfish, and green sunfish. Cluster 5 included 44 samples that ranged in species richness from 9 to 27. Fish species most common to the fifth cluster included longear sunfish, bluntnose minnow, redfin shiner (*Lythrurus umbratilis*), bluegill, central stoneroller, creek chub, blackspotted topminnow, and creek chubsucker (*Erimyzon oblongus*). Cluster 7 included 29 samples that ranged in species richness from 13 to 34. Most common species in the seventh cluster were gizzard shad (*Dorosoma cepedianum*), bluegill, common carp (*Cyprinus carpio*), longear sunfish, smallmouth buffalo (*Ictiobus bubalus*), black buffalo (*Ictiobus niger*), freshwater drum (*Aplodinotus grunniens*), warmouth, and bigmouth buffalo (*Ictiobus cyprinellus*).

Clusters were mapped to view spatial trends in the major assemblages (Figure 8.3). There was a high degree of spatial overlap between clusters 4 and 5. Both of these assemblages were found primarily in

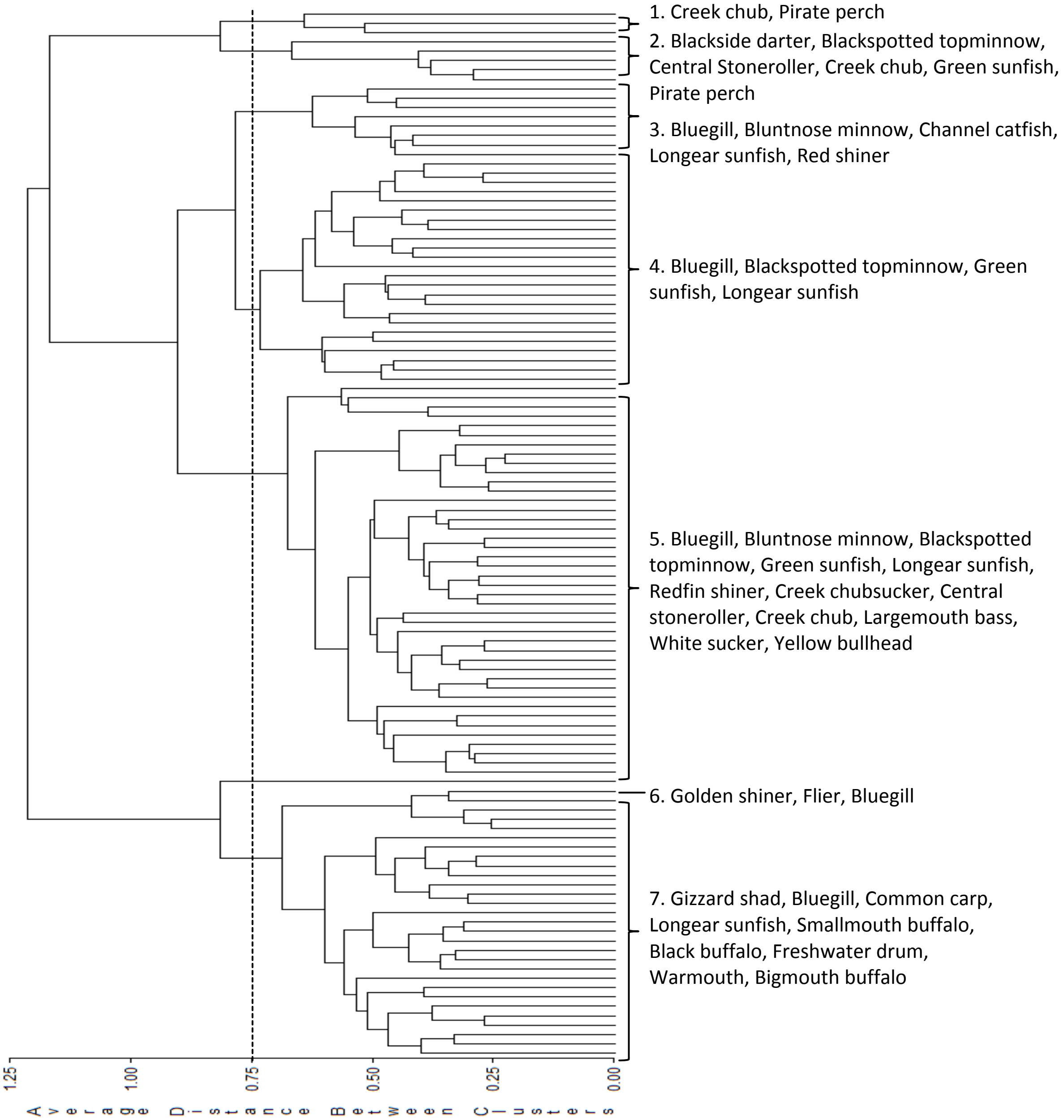

Figure 8.2. Dendrogram identifying major fish assemblage types and list of common species (species found at more than 75% of sites within a cluster) within each assemblage type found in the Cache River Watershed.

tributaries, with an additional few sites on the upper Cache River. The mainstem of the Cache River primarily consisted of an assemblage characterized by cluster 7. Samples with a cluster 2 assemblage were located only in Sandy Creek and Mill Creek, tributaries to the lower Cache River. Samples with an assemblage representative of cluster 3 were located only in the lower portion of the upper Cache River, including Post Creek Cutoff. The spatial segregation of these clusters suggests that each assemblage is associated with environmental variables characteristic of particular areas within the watershed.

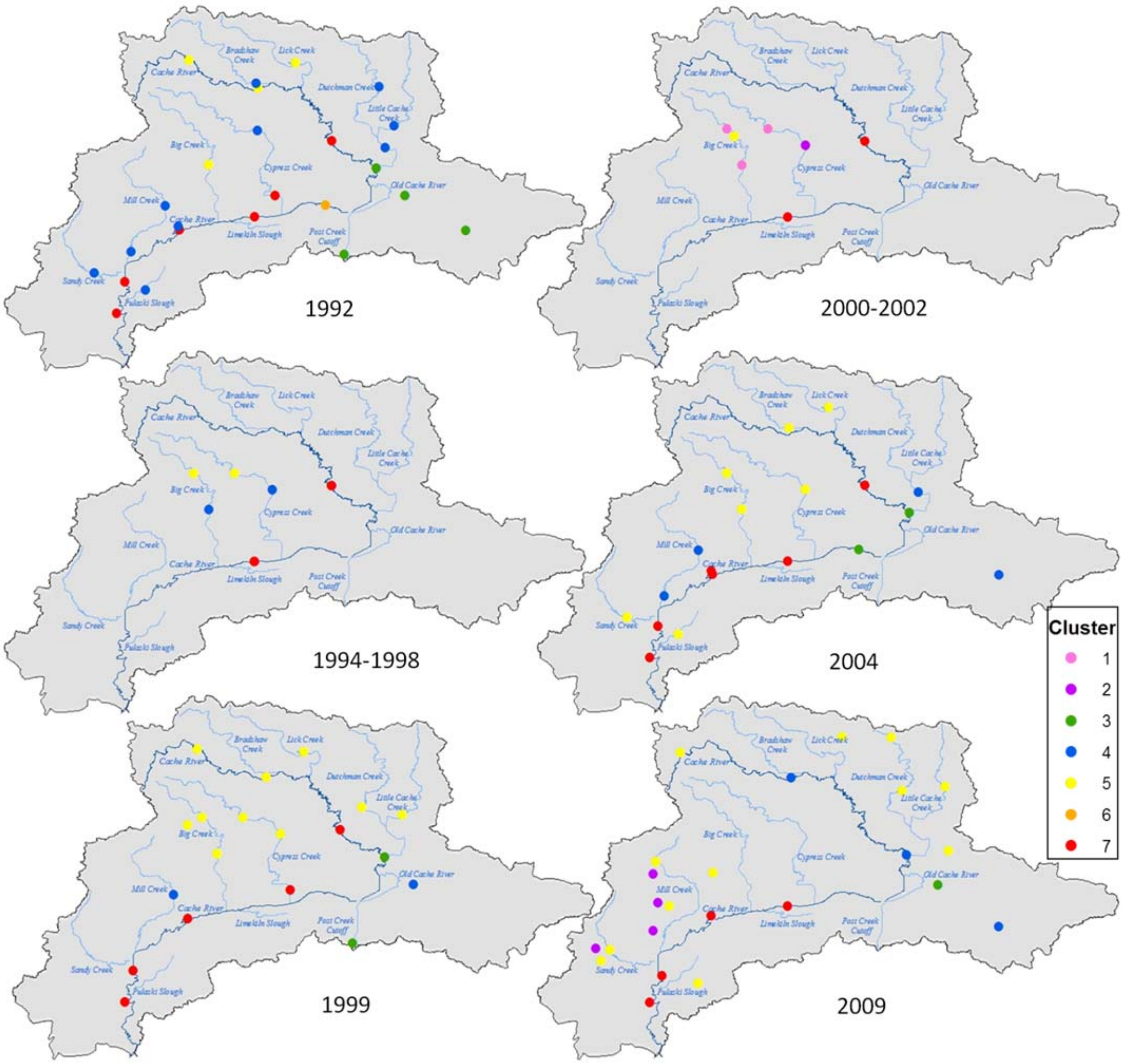

Figure 8.3. Sampling sites symbolized by major fish assemblage cluster for sampling IDNR sampling between 1992 and 2009.

Fish Assemblage and Habitat Associations

No habitat variables or GIS-extracted environmental characteristics were found to be strongly correlated ($r \geq |0.60|$ or inflation factor >20) with one another, and therefore none were initially removed from the CCA. The step-wise procedure identified 11 variables to include in the final model (Table 8.1). These variables included percent silt, percent gravel, percent cobble, stream width, discharge, percent row crops, percent pasture, percent woods, presence of siltstone, percent of channel shaded and drainage area.

The first canonical axis was positively correlated with drainage area (canonical coefficient, r*=0.68), stream width (r*=0.63), percent silt (r*=-0.64), discharge (r*=0.60) and percent row crops (r*=0.57) and negatively correlated with percent gravel (r*=-0.59), percent shade (r*=-0.49) and percent woods (r*=-0.43). These correlations suggest this axis represents a longitudinal gradient. The second canonical axis was strongly correlated with percent cobble (r*=0.56) and drainage area (r*=-0.48). The first axis explained 46.6% of the variance between fish assemblages and environmental variables while the second axis explained an additional 13.6% (Figure IVa).

Species commonly found at sites with gravel substrate and high amounts of forest and shade in the watershed included fringed darter (FRD), spottail darter (SPD), creek chub (CRC), central stoneroller (COS), white sucker (WHS), creek chubsucker (CCS), blackside darter (BSD), blackstripe topminnow (BLT) and yellow bullhead (YEB). Species found sites with increased discharge, wide stream channels, and high amounts of row crops in the watershed included river carpsucker (RVC), smallmouth buffalo (SAB), brook silverside (BRS), quillback (ULL), black buffalo (BKB), gizzard shad (GZS), shortnose gar (SHG), and bowfin (BOW). Numerous additional species were found at specific sites along the longitudinal continuum. Species found in sites with high percentages of cobble included dusky darter (DUD), freckled madtom (FRM), and silvery minnow (SVM). Ubiquitous species, such as longear sunfish (LOS) and bluegill (BLG) plotted near the center of the figure (Figure 8.4a).

Table 8.1. Mean and range of the environmental variables analyzed. Using a step-wise procedure, eleven environmental variables (shown in bold type) were found to be significantly related to fish assemblage structure and were included in the canonical correspondence analysis.

Environmental Variable	Mean (standard deviation)	Range	F Value (p) under full model
Substrate			
Percent Silt	**28.85 (24.96)**	**0-83.5**	**6.826 (0.002)**
Percent Sand	8.84 (16.14)	0-72.99	1.393 (0.056)
Percent Gravel	**18.88 (23.04)**	**0-96.7**	**3.405 (0.002)**
Percent Cobble	**5.59 (10.14)**	**0-56.2**	**2.370 (0.002)**
Percent Boulder	2.69 (5.90)	0-31.96	1.099 (0.328)
Percent Bedrock	1.57 (9.36)	0-81	0.620 (0.930)
Percent Claypan	15.89 (18.8)	0-69.7	1.426 (0.056)
Percent Logs	4.53 (6.00)	0-32.6	1.156 (0.234)
Hydraulic Features			
Width	**28.16 (21.18)**	**9.2-117.5**	**2.524 (0.002)**
Depth	1.68 (3.17)	0.29-22	1.015 (0.406)
Discharge	**6.45 (11.78)**	**0-62**	**1.645 (0.022)**
Land Use			
Percent Small Grains	2.56 (2.99)	0-9.7	0.880 (0.640)
Percent Rowcrops	**15.90 (11.07)**	**0.04-46.0**	**2.109 (0.002)**
Percent Pasture	**30.16 (12.73)**	**1.92-54.2**	**1.793 (0.052)**
Percent Forest	**38.41 (20.20)**	**9.19-91.9**	**2.226 (0.002)**
Percent Urban	2.17 (2.71)	0-10.8	1.143 (0.274)
Percent Water/Wetland	3.98 (4.59)	0.06-34.4	1.353 (0.098)
Geology			
Limestone	0.67 (0.47)	0-1	1.221 (0.144)
Sandstone	0.51 (0.50)	0-1	0.969 (0.532)
Siltstone	**0.15 (0.36)**	**0-1**	**2.927 (0.020)**
Shale	0.44 (0.50)	0-1	1.396 (0.072)
Chert	0.09 (0.29)	0-1	1.272 (0.128)
Other			
Elevation	106.42 (12.05)	88-158	0.933 (0.572)
Channel Slope	3.68 (3.26)	0-26.2	0.996 (0.444)
Percent Shaded	**35.59 (28.00)**	**0-94.5**	**1.395 (0.048)**
Drainage Area	**188.22 (251.17)**	**6.54-968.8**	**9.79 (0.002)**

Samples were symbolized by location (i.e., upper mainstem, lower mainstem, upper tributaries and lower tributaries, Post Creek Cutoff) to identify spatial trends in habitat variables and fish assemblages (Figure 8.4b). Although there was a high degree of overlap, some locations appeared to have distinct habitat features. For example, sites in Post Creek Cutoff were separated from other sites due to the strong association with cobble substrate. Samples in the mainstem of the lower Cache River also had little overlap with other sites and generally had a wider channel, increased discharge, silt substrate and a greater amount of row crops. Many sites in tributaries of the lower Cache River were associated with high percentages of gravel substrate, forest and shade. The greatest amount of overlap appeared among the mainstem of the upper Cache River and tributaries of both the upper and lower sections of the river.

Samples were also symbolized in biplots by cluster to verify classification of major assemblage types (Figure 8.4c). Clusters appeared to be delineated along a longitudinal gradient (axis 1). Sites from smaller streams with low discharge, gravel substrate and large amounts of forest commonly had fish assemblages described by clusters 2 and 5. As streams transition from a landscape of forest to row crops, substrate changes from gravel to silt and the stream increases in discharge and channel width. The fish assemblages also transitioned from cluster 5, to cluster 4, followed by cluster 3. Where the river had the greatest channel width and discharge, the assemblage was most similar to cluster 7. Sites represented by cluster 1 lacked habitat variables for CCA analysis.

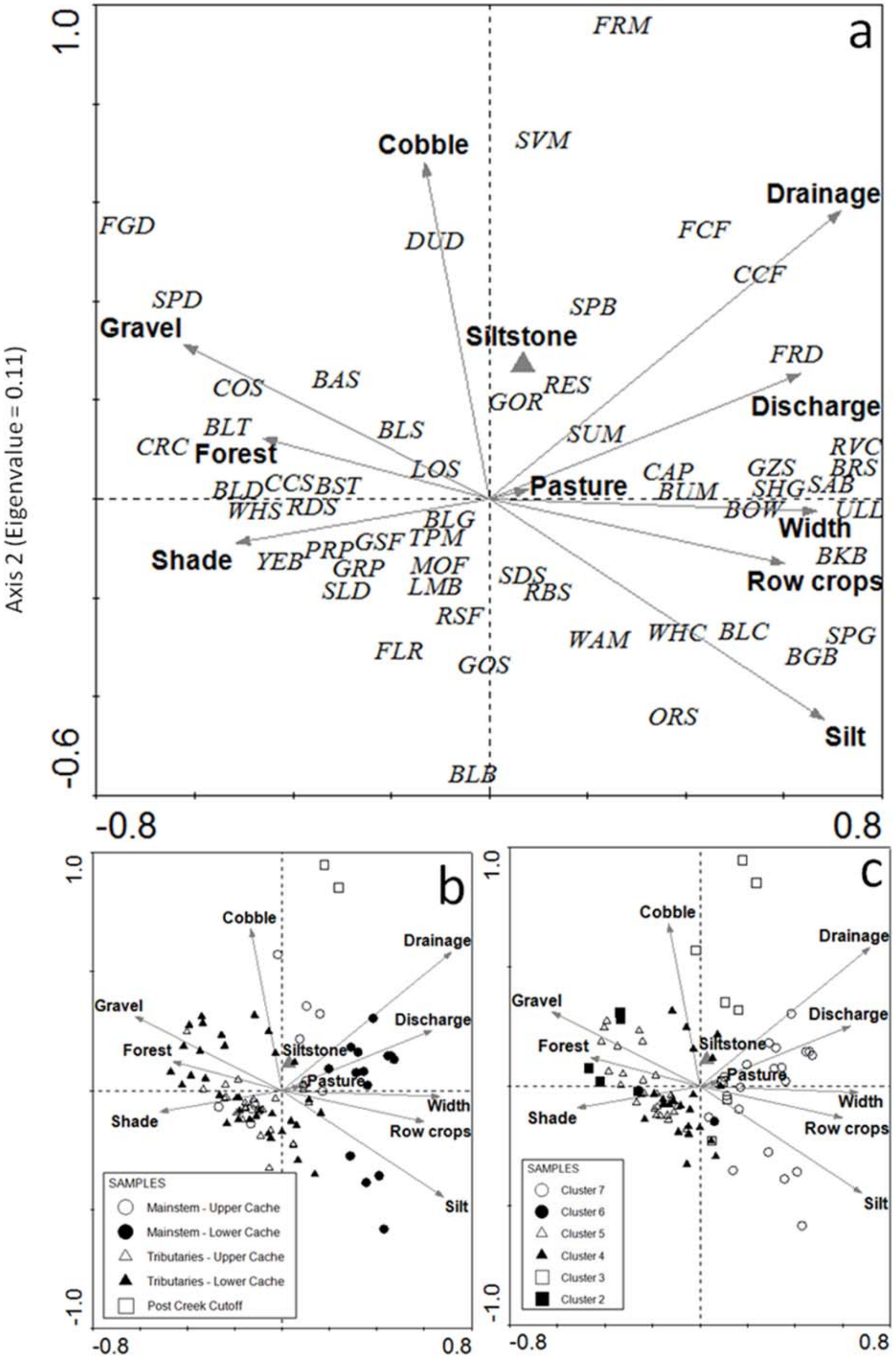

Figure 8.4. Canonical correspondence analysis plots showing relationships between habitat characteristics and fish species (a), sampling locations (b), and fish assemblage clusters (c) in the Cache River watershed. Species codes can be found in Appendix VI.

Discussion

Fish assemblages in the Cache River Watershed were structured along a longitudinal structure, consistent with previous research and general stream ecology theory (Vannote et al., 1980; Quist et al., 2004; Schlosser, 1982). Additionally, the influence of land use and substrate variables on fish community structure is consistent with prior studies in agricultural watersheds. Watersheds with intensive agriculture commonly have degraded water quality, poor habitat structure and relatively low biotic integrity (Omnerik et al., 1981; Roth et al., 1996; Allan et al., 1997) due to sedimentation, nutrient enrichment, hydrologic alteration, riparian vegetation clearing, and other disturbances associated with agricultural land use activities (Allan, 2004).

Habitat loss and land use activities within the Cache River are known to have impacted individual species and are likely major drivers of reduced biotic integrity. For example, sedimentation, channelization and removal of riparian vegetation have been suggested to be the major drivers of reduced populations of the rare fringed darter (*Etheostoma crossopterum*) (Poly and Wilson, 1998). Sedimentation may also be the major cause for the extirpation of the state-endangered pallid shiner (*Notropis amnis*), although there is a limited understanding of this species' life-history and habitat characteristics (Pflieger, 1997; Bennett et al., 2001). Drainage of wetlands has reduced habitats important for spawning and nursery of species including the state-endangered cypress minnow (*Hybognathus hayi*) and state-threatened bantam sunfish (*Lepomis symmetricus*) (Burr et al., 1996; Bennett et al., 2001; Smith, 2002; Illinois Endangered Species Protection Board, 2011).

Previous work from the mid-1990's in the Cache River Watershed described five distinct fish assemblage guilds for the middle portion of the Cache River and its tributaries (Bennett et al., 2001). These included an upland guild, a lower reach guild, a midreach guild, a bottomland guild and an ubiquitous guild (Table 8.2). When comparing these previously described guilds with our results, we find widespread overlap of the upland, midreach and ubiquitous guilds and an absence of the bottomland guild among the sites analyzed.

Spatial coexistence of the upland, midreach and ubiquitous guilds is to be expected in a natural continuum such as a river network. However, this overlap can be escalated through degradation of habitats and may result in biotic homogenization (McKinney and Lockwood, 1999; Rahel, 2002). As habitats are degraded, distribution and abundance of sensitive species commonly decline while generalist species benefit through range expansion. Although our analysis was limited to presence/absence data, those species considered to be generalists in terms of habitat selection (i.e., bluegill, longear sunfish) were found in the majority of sites whereas a total of 26 native species, many of which are considered specialists, were removed from analysis due to the rarity of their presence at the sampled sites. Species removed included fantail darter and stripetail darter, both considered to be characteristic of upland habitats. Additionally, bottomland species including banded pygmy sunfish, pugnose minnow and cypress minnow, and lower reach species including goldeye, mud darter and white bass were also removed due to rarity. These trends point towards habitat degradation, habitat homogeneity and restricted connectivity of habitats (Schlosser, 1991). Although some upland tributaries are considered less impacted, mobility can be hampered by unsuitable habitat found between suitable habitats (Poly, 2003). Research is needed to assess the effect of habitat fragmentation on the upland/tributary assemblage. Additionally, further habitat and population inventories, analysis of trophic structure, and linkages between habitats and life history requirements could be useful in elucidating the landscape scale influences on in-stream habitats in relation to individual species and fish assemblage structure.

Disappearance of the bottomland guild is likely to be at least partially due to heavy sedimentation and hydrologic alteration. Sedimentation rates from a 6-mile stretch of the lower Cache River were found to range from 0.2 cm/year in forested floodplain to >2 cm/year in the main river channel since 1963 (Allgire and Cahill, 2001). Sedimentation has been found to have varying effects on lotic fish communities, although fish species most sensitive to sedimentation tend to be herbivores, benthic insectivores or simple lithophilous spawners (Rabeni and Smale, 1995; Berkman and Rabeni, 1987). Although sedimentation rates have likely declined due to efforts to reduce erosion through the conversion to a more natural land cover (Kruse and Groninger, 2003) and construction of upland water retention structures (Guetersloh, 2002; Union County Soil and Water Conservation District, 2006), the lack of flow resulting from the fragmentation of the mainstem Cache River may continue to trap legacy sediment in bottomland habitats. The restoration of surface hydrology has been found to be necessary to restore bottomland wetland functions important for nutrient and sediment removal (Hunter et al., 2008) and is likely necessary to restore bottomland fish communities as well. Focused research in bottomland habitat is needed to more thoroughly understand the status of bottomland fish species and their habitat requirements.

Although the artificial Post Creek Cutoff is a well known source of hydrologic and geomorphic problems, it appears to have unique habitat in the Cache River watershed. The presence of bedrock and cobble is relatively rare in the basin and thus contains habitat that may be valuable for some species, including dusky darter, freckled madtom and silvery minnow. These species were found in 7%, 9% and 5% of total sites, respectively, suggesting limited habitat availability.

Awareness of the declining ecological integrity throughout the Cache River watershed has attracted restoration interest from state and federal agencies, environmental non-profit organizations and local citizens. A number of restoration projects have been implemented in the watershed, with additional restoration projects in planning and design stages (Guetersloh, 2002; Demissie et al., 2008; Demissie et al., 2010). Evaluation of the effectiveness and impact of restoration projects will be needed to assess projects and guide management. Additionally, further understanding of habitat associations, life history requirements and population dynamics of native fish assemblages can be used to identify, evaluate and prioritize restoration projects in relation to fish community structure.

Table 8.2. Five major fish assemblage guilds have previously been described for the middle portion of the Cache River and its tributaries in Southern Illinois (Bennett et al., 2001).

Major Guilds	**Characteristics**
Upland	- Composed of riffle-dwelling species, which require either rocky substrates for spawning, or continuously flowing water for egg development, are mostly benthic invertivores and intolerant of sedimentation - Characteristic species include Central Stoneroller (*Campostoma anomalum*), Creek Chub (*Semotilus atromaculatus*), Creek Chubsucker (*Erimyzon oblongus*), Spring Cavefish (*Forbesichthys agassizi*), Fringed Darter (*Etheostoma crossopterum*), Fantail Darter (*Etheostoma flabellare*), Stripetail Darter (*Etheostoma kennicotti*), and Banded Sculpin (*Cottus carolinae*)
Bottomland	- Composed of persistent and obligate swamp species which depend upon floodplains for reproduction, vegetated peripheries for juvenile and adult life history stages and channels for migration - Characteristic species include Pugnose Minnow (*Opsopoeodus emiliae*), Cypress Minnow (*Hvbognathus hayi*), Brown Bullhead (*Ameiurus nebulosus*), Grass Pickerel (*Esox americanus*), Central Mudminnow (*Umbra limi*), Banded Pygmy Sunfish (*Elassoma zonatum*), Flier (*Centrarchus macropterus*), Bantam Sunfish (*Lepomis symmetricus*), and Slough Darter (*Etheostoma gracile*)
Midreach	- Species are habitat generalists, often found in highly modified (dredged, channelized) stream reaches with homogenous habitats, little pool/riffle development, uniform depths and substrates, and bordered by steep, eroding banks - Characteristic species include Ribbon Shiner (*Lythrurus fumeus*), Redfin Shiner (*Lythrurus umbratilis*), Bluntnose Minnow (*Pimephales notatus*), White Sucker (*Catostomus commersoni*), Golden Redhorse (*Moxostoma erythrurum*), Freckled Madtom (*Noturus noctumus*), Grass Pickerel (*Esox americanus*), Spotted Bass (*Micropterus punculatus*), and Blackside Darter (*Percina maculata*)
Lower	- Species are highly mobile, lack dependence on aquatic vegetation, and are adapted to the changing environmental conditions typical of large, lowland streams - Characteristic species include Goldeye (*Hiodon alosoides*), Mississippi Silvery Minnow (*Hybognathus nuchalis*), Bullhead Minnow (*Pimephales vigilax*), White Bass

Lower (continued)	(*Morone chrysops*), Mud Darter (*Etheostoma asprigene*), River Darter (*Percina shumardi*), Sauger (*Stizostedion canadense*), and Freshwater Drum (*Aplodinotus grunniens*)
Ubiquitous	- Species which are found in varied and wide-ranging habitats - Characteristic species include gars (Lepisosteidae), large suckers (Catostomidae), Bluegill (*Lepomis macrochirus*), and Longear Sunfish (*Lepomis megalotis*)

Chapter 9: Synthesis of Basin Management Plan research

Rivers and streams are greatly influenced by the landscapes through which they flow (Hynes, 1975; Allan, 2004). Similar to other states in the Midwest and regions throughout the world, a large proportion of land in Illinois is in agricultural use. As a result, approximately 25% of river and stream miles within Illinois are maintained for agricultural drainage(Mattingly et al., 1993) (Prairie Rivers Network)through activities including channelization and removal of woody debris. While undisturbed landscapes generally support better water quality and higher levels of biotic integrity, even disturbed riparian vegetation can reduce the sediment and nutrient loads to waterways (Schlosser and Karr, 1981a; Lowrance et al., 1984). Water quality, an important component of biotic integrity can have important impacts on biotic communities, including macroinvertebrates and fish (Karr, 1991). Biotic indices indicate watershed health or condition (Silva et al., 2005) and can be used to help identify problem areas for possible water quality and habitat improvements. Therefore, regular comprehensive monitoring is critical to identify changes or impacts in the system.

In our efforts to document impacts of restoration structures on channel geomorphology, we identified changes in channel dimensions. Since 1991, the channel bed elevation of the surveyed stretch of the river has decreased by approximately 2 feet. Although the impact of restoration structures on the rate of bed erosion could not be quantified, there appears to be recent, noteworthy cross-sectional adjustments. It is possible that cross-sectional changes are a result of restoration structures, however the record flood of 2011 cannot be discounted as a major factor. Additional surveys are needed to quantify geomorphologic impacts of restoration structures more accurately and to determine if additional protection is needed to maintain wetlands.

Our research found a number of water quality parameters along the Cache River, which consistently exceeded federal water quality standards, including nitrogen, phosphorus and fecal coliform. When standards are exceeded or requirements are not met, the Clean Water Act requires states to develop Total Maximum Daily Loads (TMDLs) for waters identified as impaired on each state's 303(d) list. While the Cache River has multiple river segments that are listed on Illinois' impaired waters list, none of these impairments were included in the most recent TMDL priority list. Sufficient levels of environmental health are essential to provide ecosystem services to both human and natural systems. Clean Water Act standards are intended to ensure minimum water quality for designated uses including drinking, recreation, and agricultural irrigation as well as the protection and maintenance of aquatic life. Exceeded standards in the Cache River system reflect impaired conditions that jeopardize the suitability of water for these uses.

Management agencies often work to reduce water quality impairments by implementing a series of best management practices. As previously mentioned, cane can be a useful riparian management tool, optimally in a multi-species riparian buffer plan. Benefits of cane buffers include improving water quality and subsequently, macroinvertebrate and fish communities. The physical landscape trends observed in our research show that cane is commonly found in areas with low slopes, between 95-110 meters msl and within 40 meters of streams. This information, together with water quality data, should be utilized when designing riparian restoration plans. In the Cache River, water quality trends identified that all five mainstem sites examined exceeded standards for nitrogen, phosphorus and turbidity, suggesting a widespread need for tools such as riparian buffers in the watershed.

Habitat associations with biotic communities can be used to prioritize restoration projects based on habitat needs of focal species or communities. Although macroinvertebrate indices were highly variable throughout the watershed, they were strongly correlated with habitat metrics. Species richness, the Shannon diversity index and the EPT index were all negatively associated with percent silt, while EPT index was also positively associated with percent gravel and cobble. Generally, indices suggested higher quality habitats in tributaries as compared to mainstem sites. Fish assemblages were structured largely along a longitudinal gradient, with substrate, land use and local habitat features as important community assemblage drivers. The absence of a bottomland guild suggested either long-term impacts of sedimentation and limited flow or sampling bias against bottomland assemblages. Sites from Post Creek Cutoff appear to have unique cobble habitat that is associated with relatively rare species including dusky darter, freckled madtom, and silvery minnow.

Recommendations

Our analyses used available monitoring data from state agencies to assess the current condition of the watershed. While these datasets are useful for understanding aspects of watershed condition, they are often limiting because of the time in between data collections and the large number of factors influencing the data of interest. In order to understand how land use, water quality, and community assemblages interact and influence one another, directed questions need to be investigated through intensive data collection schemes which capture spatial and temporal variability. By identifying and prioritizing research and management needs, management agencies can collaborate with various research institutions to develop research projects further and identify effective management options.

Management actions are often stymied by resource limitations, inflexible programs, or stakeholder opposition. For example, the TMDL process can be lengthy if the affected stream or river is not on the short list of priority streams. However, the collaboration between management agencies and stakeholders to develop creative solutions that reduce water quality impairments, improve habitat quality and empower private landowners is becoming increasingly common. The positive aspect of such collaborations is evident in the Cache River Watershed through a number of different projects.

To implement management choices in any watershed, awareness of competing and complementary interests within the region is critical to garnering support and resources to make informed and effective watershed management decisions (Figure 1). To discern research needs and management recommendations from gaps noted in past literature and from the research produced in this report, the justification for these suggestions must be viewed in the context of the interests and motivations of various stakeholders. Goals of stakeholders in the basin which affect, and are affected by, watershed management activities include: ecological restoration; community engagement and cohesion; environmental education; economic development and stability; tourism and recreation; and flood damage mitigation.

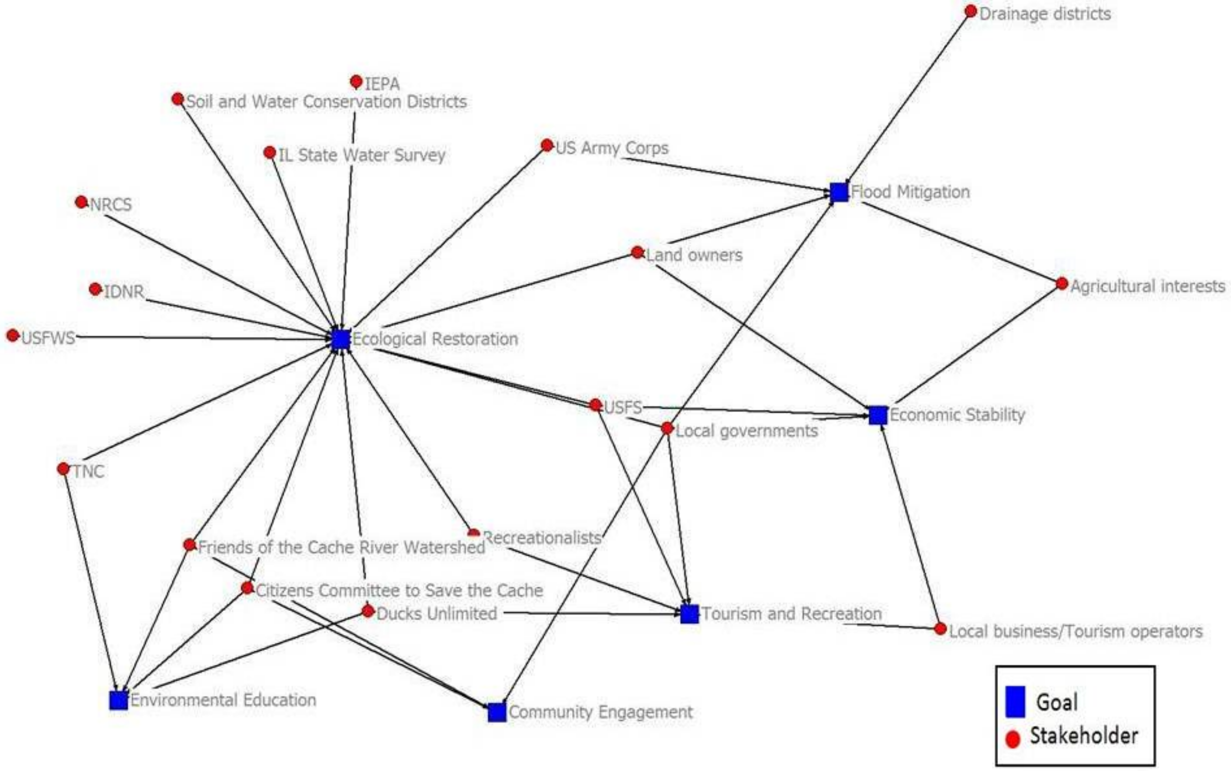

Figure 9.1. Cache River Watershed stakeholders are motivated by numerous goals and interests, complicating watershed management in the basin.

The research for this project was conducted primarily to inform management choices that promote ecological restoration of the natural systems in the Cache River Watershed. Scientific assessment of current conditions and ecosystem function can provide the baseline "state of the system" and allow for projections of expected consequences of alternative management choices. While understanding the interrelationships among components of the ecological system is critical to outlining watershed management options, it is imperative to have a more thorough grasp of relationships and feedback loops among components of society and markets affecting land use activities and the subsequent interactions between these activities and the natural world. For example, to advance ecological restoration in the watershed, it is necessary to study the impact of agricultural runoff on in-stream ecological health. However, to determine the cost-effective amount of pollution abatement and efficient policy and management interventions to undertake, the value of enhanced stream health to human communities must be balanced with the value of, among other things, the region's agricultural production and economic development. Scientifically-informed understanding of the natural system is imperative to accurately evaluate costs and benefits of management choices to advance stakeholder goals. However, the value of costs and benefits of management alternatives can only be defined and assessed by the stakeholders and decision-makers in the Cache River Watershed.

Research gaps

With an understanding of the myriad of interests at play, one can discern gaps in research that would inform watershed management options. However, balancing the value of promoting various goals over others is difficult due to the non-market nature of many ecosystem services provided by watersheds. In order to truly determine efficient management strategies accounting for the diversity of interests and goals at stake in any system, a comprehensive inventory of the ecosystem services provided by the watershed and a valuation study of stakeholders in management activities would be needed. Such in-depth ecosystem service valuation is generally unfeasible. However research needs to inform watershed management should be evaluated with awareness of the interests involved and the existence of potentially competing management objectives.

After evaluation of observed gaps in knowledge uncovered by the analyses included in this report and a comprehensive review of past literature and research pertaining to the Cache River Watershed; research needs to inform future management in the basin can be outlined:

Restoration generally:

- Comparative case studies of similar systems: As ecological restoration is determined to be a priority in the watershed, research needs that facilitate activities in order to enhance the ecological health of the system include the application of lessons learned from comparative case studies of similar, altered systems. Comprehensive planning for watershed-level restoration and attention to process and functioning over end-point goals (Wohl et al., 2005) and ecological theory (Lake et al., 2007)are critical to successful rehabilitation efforts. Determining viable evaluation criteria and processes for monitoring and evaluation through employing adaptive management strategies is concurrently important (O'Donnell and Galat, 2008). Evaluation of efforts and activities in other systems in which the ecological health of systems were enhanced and how improvement was evaluated would be useful to guide management in the Cache River Watershed.
- Land use and restoration: Land use change has been noted as a cause of ecological degradation (Evans et al., 2007) in the Cache River basin (Yadav and Malanson, 2008) as well as other watersheds (Molinero and Burke, 2009; Schoonover et al., 2006). Management effectiveness could be enhanced by the incorporation of lessons learned from past research on land use changes resulting in water quality improvements and reductions in sedimentation rates and would be particularly informative to decision-makers in the Cache River Watershed. Additionally, expansion of research evaluating the potential to increase cost-effective and ecologically-friendly tourism and recreation and to employ other conservation strategies in the basin should be undertaken. In particular, it is pertinent to assess the compatibility of ecological restoration-oriented goals and alternative management choices within the context of current and potential national and municipal land use policies.

Land use:

- Evaluation of land use conservation policies: The benefits of land use choices to alleviate the harmful effects of intensive production on ecological systems have been noted (Kovacic et al., 2000) and the effectiveness of land use policies in terms of both economic efficiency and environmental impacts evaluated (Brinson and Eckles, 2010; Cho et al., 2010; Davie and Lant, 1994). The impacts of the Conservation Reserve Program on the reduction of sedimentation in the Cache River basin has been assessed (Davie and Lant, 1994) and more extensive economic-ecological modeling in different policy scenarios has been conducted (Lant et al., 2005). Particularly due to the observed water quality impairments in the watershed, further research in this area is needed to link policy impacts and ecological outcomes in complex agricultural land use systems.
- Economic modeling predicting future conservation program enrollment and withdrawal in light of the latest farm bill and raising crop prices: The tendency for landowners to pull land out of retirement in response to rising crop prices has been observed in the Cache River Watershed (Lant et al., 2001) as well as other watersheds in the U.S. (Secchi and Babcock, 2007; Secchi et al., 2008). Particularly in light of the impending funding cuts to land use conservation programs in the next Farm Bill, it is realistic to anticipate reduced conservation retirement as funding dries up for conservation and agricultural production becomes more profitable. It will be imperative for watershed managers in the basin to be aware of changes in funding for these programs and the potential impact on land use choices.

Riparian issues:

- In order for cane to be utilized as a common component of planted riparian buffers, methods of propagation and management will need to be established. While there are many current experiments being run out of the Southern Illinois and Auburn Universities' forestry laboratories to address these needs, additional research is necessary.
- Once methods for cane propagation are established, environmental education programs promoting the use of cane in riparian buffers should be implemented. These programs should detail the costs, benefits, and proper installment procedures for cane riparian buffers.
- An inventory of current buffers and meanders where cane is suitable remains lacking and would be useful in identifying the proper location and need for future buffers.

Hydrology:

- As efforts continue to establish a partial reconnection between the upper and lower Cache River, hydrogeomorphic modeling of the partial reconnection would establish an understanding of the long-term impacts and maintenance required to sustain reconnection. A number of reports have been useful in understanding various restoration alternatives in relation to water surface elevation (Demissie et al., 2008; Demissie et al., 2010) and flood potential. However, it is not well understood how channel bed elevations would support downstream flow of water from the upper Cache River to the lower Cache River when the Post Creek Cutoff provides a steeper gradient. Hydrogeomorphic models could then aid in identifying the best sites for reconnection, designing a more efficient structure, developing a structural mechanism to support optimal seasonal flows into the lower Cache River, and generally providing an understanding of long-term resources needed for continued operation of the structure.

- High sediment loads from Cypress and Big creeks combined with limited downstream flow has resulted in high sedimentation rates (Demissie et al., 1992). In efforts to reduce sediment loads, nearly 70 retention ponds were constructed in the Big Creek watershed between 2002 and 2008. A before and after analysis of sediment load, sedimentation rates and peak flows from Big Creek (treatment) and Cypress Creek (control) would gain insight on the overall impact of retention ponds.

Ecology:

- Understanding community assemblage relationships with environmental gradients could be furthered by undertaking a community-trait assessment (Poff et al., 2006; Olden et al., 2006). This type of an assessment could identify which life-history, morphological, mobility and ecological traits of species within community assemblages are and are not supported by the current environment. Trait-based habitat assessments can give a mechanistic understanding of the ecological constraints of communities and can be useful in prioritizing instream habitat restoration projects, identifying a large suite of restoration needs, and recognizing if management activities have the potential to restore native communities.

Climate change:

- Incorporating changes in climate into decision-making within ecological-economic systems is crucial for regional stakeholders. Doing so allows for an understanding of potential implications and could increase the adaptation potential of the Cache River Watershed. Climate change is a critical threat to the structure and functioning of hydrologic systems (Gregory, 2006; Malmqvist and Rundle, 2002). Similarly, decision-makers need be aware of potential watershed management-relevant climate change impacts, such as altered flood pulses and natural disturbance patterns (Booij, 2005; Schreider et al., 2000) on human and natural communities and changes in weather patterns on agricultural production systems (Howden et al., 2007). Additional research could inform areas of concern including:

1. Impacts of current and future climatic changes on stream hydrology and flood risk in the basin,
2. Impacts of current and future climatic changes on both land and stream ecology - i.e. how species distributions are predicted to change and potential management strategies that might increase resilience of stream functions with particular attention to species at their northern range as the Cache River basin is the northernmost habitat for cypress tupelo (Middleton and McKee, 2005),
3. Impacts of current and future climatic changes on land use in the region and in particular, interactions among hydrological, ecological, agricultural, and economic systems.

Conclusion

The goal of this chapter was to evaluate research needs for the Cache River Watershed with a focus on improving ecological conditions with awareness of local economic and social needs. While ecological improvement is necessary for the continued and improved health of ecosystems within the Cache River Basin, how these improvements are conducted must be determined through a multidisciplinary approach. Therefore, research ideas for advancing the goal of ecological improvement in areas of water quality, hydrologic flows, and habitat provision are suggested. Additionally, research needs to inform the facilitation of economic development, flood risk mitigation, and other stakeholder objectives are noted. As discussed previously, land use decisions play a key role in the overall health of the watershed. Evaluation of current land uses including those that are primarily implemented to improve ecological health, such as CRP and WRP enrolled acreage and riparian zones of giant cane as well as those in productive uses affecting the watershed is critical.

At the same time, research and further management activities must take into account the many different climate change scenarios being predicted to ensure activities undertaken now will not have adverse effects in the future. Long term planning in the Cache River system in the early 1900s may have resulted in a very different and potentially, much healthier river system today. Research and restoration projects need to be conducted not only for short term improvements, but for long term goals as well.

Scientific research can help set priorities for stakeholders and managers. The condition of federal, state, and local economies will play a key role in determining how and to what extent stakeholders are able to implement projects aimed at improving ecological conditions of the watershed. Therefore, ecological impairments should be evaluated to determine which of these should take priority. Currently, the Cache River Joint Venture Partnership is attempting to determine the most efficient means of evaluating restoration projects by determining key indicators of ecological improvements. They are coordinating with scientists to help with this evaluation, making scientific research a key component of these decisions. Awareness of human valuation of ecosystem services and potentially competing goals among stakeholders is crucial. Multidisciplinary and cooperative approaches will help to ensure best management practices in the future. Whether it is economic, ecological, social, cultural or physical, scientific research should be a critical driver in all management decisions in the watershed.

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Appendix I. Summary of Cache River macroinvertebrate data for 1984

Site Code	Site Basin	Species Richness	EPT	Shannon Diversity (H')	Hilsenhoff Index
AD-AN-A1	Upper Cache River - mainstem	14	5	2.26	4.43
AD-AN-C1	Upper Cache River - mainstem	4	0	.63	9.91
AD-AN-C2	Upper Cache River - mainstem	8	0	.91	7.75
AD-AN-C3	Upper Cache River - mainstem	10	2	1.63	6.06
AD-AN-C4	Upper Cache River - mainstem	10	3	2.05	5.28

Appendix II. Summary of Cache River macroinvertebrate data for 1987

Site Code	Site Basin	Species Richness	EPT	Shannon Diversity (H')	Hilsenhoff Index
ADDB-VI-A1	Little Cache Creek	15	4	2.36	5.00
ADDB-VI-C1	Little Cache Creek	15	4	2.28	6.43
ADDB-VI-C2	Little Cache Creek	17	3	2.55	6.88
ADX-CB-A1	Cache Creek	7	1	1.44	5.17
ADX-CB-C1	Cache Creek	3	0	0.09	8.31
ADX-CB-C2	Cache Creek	8	0	1.13	8.57
ADX-CB-C3	Cache Creek	13	3	2.18	20.81

Appendix III. Summary of Cache River macroinvertebrate data for 1992

Site Code	Site Basin	Species Richness	EPT	Shannon Diversity (H')	Hilsenhoff Index
AD-01	Upper Cache River - mainstem	39	11	0.35	5.51
AD-04	Upper Cache River - mainstem	17	1	2.53	5.33
AD-05	Upper Cache River - mainstem	35	4	3.06	5.24
AD-06	Upper Cache River - mainstem	36	5	2.75	6.56
AD-08	Upper Cache River - mainstem	43	7	2.86	13.59
AD-10	Upper Cache River - mainstem	7	0	1.30	8.42
AD-11	Upper Cache River - mainstem	5	0	1.01	9.11
AD-AN-A1	Upper Cache River - mainstem	25	0	0.95	7.39
AD-AN-C1	Upper Cache River - mainstem	5	0	0.71	10.28
AD-AN-C3	Upper Cache River - mainstem	5	0	0.94	9.05
AD-AN-C5	Upper Cache River- mainstem	7	0	1.30	8.42
ADC-01	Main Ditch	25	6	2.91	5.74
ADCD-01	New Columbia Ditch	53	4	2.85	7.85

ADD-01	Dutchman Creek	27	4	2.81	5.45
ADD-02	Dutchman Creek	27	4	2.60	5.35
ADDB-01	Little Cache Creek	30	7	2.84	10.12
ADDB-02	Little Cache Creek	14	1	2.36	5.53
ADDB-VI-A1	Little Cache Creek	18	4	2.67	5.76
ADDB-VI-C1	Little Cache Creek	17	3	2.63	5.30
ADDB-VI-C2	Little Cache Creek	12	1	2.28	5.72
ADL-01	Lick Creek	27	4	2.87	5.05
ADP-01	Bradshaw Creek	30	5	2.70	5.62
ADX-01	Cache Creek	13	3	2.18	6.98
ADX-CB-A1	Cache Creek	11	2	2.00	5.34
ADX-CB-C1	Cache Creek	4	0	0.75	10.45
ADX-CB-C2	Cache Creek	9	0	1.52	8.90
ADX-CB-C3	Cache Creek	13	3	2.18	7.00
ADY-01	Old Cache River	13	1	2.11	5.43
IX-03	Cache River Miss. River	24	6	2.69	4.71
IX-04	Cache River Miss. River	30	2	2.74	5.25
IX-05	Cache River Miss. River	14	2	2.09	5.36
IX-06	Cache River Miss. River	20	6	2.00	4.23
IXCC-01	Pulaski Slough	19	2	2.28	5.23
IXD-01	Sandy Creek	41	9	3.20	5.84

IXF-01	Mill Creek	32	7	2.83	4.86
IXF-02	Mill Creek	28	8	2.83	4.64
IXI-01	Indian Camp Creek	32	8	2.96	4.92
IXJ-01	Big Creek	34	9	3.00	4.83
IXM-01	Cypress Creek	27	6	2.76	5.10
IXM-02	Cypress Creek	36	8	2.98	5.77

Appendix IV. Summary of Cache River macroinvertebrate data for 1999

Site Code	Site Basin	Species Richness	EPT	Shannon Diversity (H')	Hilsenhoff Index
AD-04	Upper Cache River - mainstem	27	7	2.35	4.52
AD-05	Upper Cache River - mainstem	24	8	2.01	4.11
AD-06	Upper Cache River - mainstem	24	8	2.42	4.70
AD-08	Upper Cache River - mainstem	41	15	3.03	4.64
AD-09	Upper Cache River - mainstem	30	11	2.60	4.82
AD-10	Upper Cache River - mainstem	32	9	2.71	4.81
AD-11	Upper Cache River - mainstem	31	7	2.66	4.76
AD-AN-A1	Upper Cache River - mainstem	16	6	2.51	5.32
AD-AN-C1	Upper Cache River - mainstem	14	3	2.39	5.59
AD-AN-C2	Upper Cache River - mainstem	19	5	2.33	5.29
AD-AN-C4	Upper Cache River - mainstem	20	5	2.38	4.92
ADC-01	Main Ditch	34	8	2.87	4.98
ADD-04	Dutchman Creek	28	6	2.91	4.78

ADDB-01	Little Cache Creek	27	6	2.70	5.00
ADL-01	Lick Creek	36	7	2.45	5.16
ADX-CB-C1	Cache Creek	11	2	1.97	5.56
ADX-CB-C2	Cache Creek	10	1	1.66	7.17
ADX-CB-C3	Cache Creek	13	4	2.35	4.90
IX-04	Cache River Miss. River	35	8	2.95	5.28
IX-06	Cache River Miss. River	20	5	2.31	5.63
IXF-02	Pulaski Slough	33	10	2.47	4.80
IXJ-01	Mill Creek	35	6	2.83	4.52
IXJ-02	Big Creek	29	8	2.64	4.36
IXJC-01	Big Creek	19	8	2.67	5.16
IXM-03	Cypress Creek	21	4	2.10	5.44
IXM-04	Cypress Creek	40	4	2.99	5.99
IXM-05	Cypress Creek	30	4	2.91	4.83

Appendix V. Summary table of Cache River macroinvertebrate data for 2004

Site Code	Site Basin	Species Richness	EPT	Shannon Diversity (H')	Hilsenhoff Index
AD-04	Upper Cache River - mainstem	35	3	2.52	7.10
AD-08	Upper Cache River - mainstem	49	9	3.28	5.71
AD-11	Upper Cache River - mainstem	34	5	2.76	5.72
ADCD-01	New Columbia Ditch	36	1	2.91	6.38
ADD-01	Dutchman Creek	41	5	2.51	5.61
ADL-01	Lick Creek	1	5	3.09	5.49
ADP-01	Bradshaw Creek	42	8	2.68	6.49
ADX-01	Cache Creek	26	4	2.25	6.24
ADY-01	Old Cache River	17	2	1.69	6.40
IX-03	Cache River - Miss. River	35	2	2.65	7.96
IX-04	Cache River - Miss. River	38	4	2.70	6.49
IX-05	Cache River - Miss. River	20	1	1.81	8.72
IX-06	Cache River - Miss. River	31	1	2.30	7.83
IXCC-01	Pulaski Slough	32	5	0.33	5.72
IXD-01	Sandy Creek	47	8	3.33	5.63

IXF-01	Mill Creek	51	6	2.64	5.21
IXF-02	Mill Creek	56	16	3.25	5.48
IXI-01	Indian Camp Creek	48	5	2.40	5.51
IXJ-01	Big Creek	37	7	2.93	6.41
IXJ-02	Big Creek	42	10	2.12	4.24
IXM-04	Cypress Creek	33	5	2.47	7.07

Appendix VI. Summary of Macroinvertebrate Data and Habitat Substrate Data for 1992, 1999, and 2004

Site	Year	Species Richness	EPT	Shannon	Hilsenhoff	% Silt	% Sand	% Gravel	% Cobble	% Boulder	% Bedrock	% Claypan	% Log	% Other
AD-04	1992	17	1	2.53	5.33	66.7	0	2.6	0	0	0	12.8	10.3	7.6
AD-05	1992	35	4	3.06	5.24	9.6	0	36.1	2.4	0	0	15.7	8.4	27.8
AD-06	1992	36	5	2.75	6.56	41.4	24.1	19.6	4.6	1.1	0	4.6	2.3	2.2
AD-08	1992	43	7	2.86	13.59	3.7	5.4	21.4	4.8	2.7	1.1	14.4	32.6	13.7
ADC-01	1992	25	6	2.91	5.74	24.6	51.9	5.2	1.3	0	0	1.3	1.3	14.3
ADD-01	1992	27	4	2.81	5.45	32.5	0	16.2	8.8	6.2	0	22.5	2.5	11.3
ADD-02	1992	27	4	2.6	5.35	22.7	14.4	2	1	1	0	4.1	19.6	35.1
ADDB-01	1992	30	7	2.84	10.12	6.9	15.5	28.4	8.6	6.9	0	0	12.9	20.7
ADL-01	1992	27	4	2.87	5.05	24.7	0	11.4	9.3	0	0	35.1	9.3	10.3
ADP-01	1992	30	5	2.7	5.62	30.4	0	21.7	0	0	0	27.8	4.3	15.7
ADY-01	1992	13	1	2.11	5.43	28.8	0	0	0	0	0	11.5	11.5	48.1
IX-03	1992	24	6	2.69	4.71	69.6	0	4.3	17.3	2.2	0	0	6.5	0
IX-04	1992	30	2	2.74	5.25	8.8	66.7	5.3	0	0	0	3.5	7	8.8
IX-05	1992	14	2	2.09	5.36	63.9	0	0	0	0	0	0	2.8	33.5
IXCC-01	1992	19	2	2.28	5.23	65.8	5.1	7.6	0	0	0	8.9	1.3	11.4
IXJ-01	1999	35	6	2.83	4.52	34.4	21.9	9.3	0	0	0	6.2	6.3	21.9
IXJ-02	1999	29	8	2.64	4.36	10.1	0	54.1	23	0.9	0	0.9	1.8	9.2
IXJC-01	1999	19	8	2.67	5.16	0	0	27.7	31.3	0	8.4	0	0	32.6
AD-04	1999	27	7	2.35	4.52	36.1	0	5.6	0	1.4	0	45.8	9.7	1.4
AD-05	1999	24	8	2.01	4.11	27.8	0	30.5	0	0	0	9.3	11.1	21.3
AD-06	1999	24	8	2.42	4.7	58.1	1.7	29.1	8.5	0	0	0	0	2.6
AD-08	1999	41	15	3.03	4.64	3.1	0.6	27.1	17	3.1	0.6	0.6	16.4	31.5
AD-09	1999	30	11	2.6	4.83	0.8	2.1	13.3	56.2	21.5	3.3	0	0.4	2.4
ADC-01	1999	34	8	2.87	4.98	16.1	58.4	2.5	0.6	0.6	0	5	1.3	15.5
ADD-04	1999	28	6	2.91	4.78	12.1	0.8	13	0	0	0	66.1	5.6	2.4
ADDB-01	1999	27	6	2.7	5	14.9	7.9	36	4.4	9.6	0	0.9	10.5	15.8
ADL-01	1999	36	7	2.45	5.16	11.6	4.6	39.5	4.7	1.2	0	16.3	12.8	9.3
IX-04	1999	35	8	2.95	5.28	72.3	20	0	0	0	0	0	4.6	3.1
IX-06	1999	20	5	2.31	5.63	82.2	2.2	2.2	0	0	0	4.5	6.7	2.2
IXF-02	1999	33	10	2.47	4.8	15.6	0	20	17.8	4.4	0	42.2	0	0
IXM-03	1999	21	4	2.1	5.44	70	0	0	0	0	0	2	2	26
IXM-04	1999	40	4	2.99	5.99	54.1	3.7	0	0	0	0	23.7	3.7	14.8
IXM-05	1999	30	4	2.91	4.83	21.2	18.2	6	0	0	4.5	24.3	12.1	13.7

IXJ-01	2004	37	7	2.93	6.41	15.5	11.9	10.8	3.6	1.2	0	39.3	7.1	10.8
IXJ-02	2004	42	102	4.24		5.4	2.7	55	33.6	0	0	0.7	0.7	2
AD-04	2004	35	3	2.52	7.1	44.4	0	0	1.4	4.2	0	44.4	4.2	1.4
AD-08	2004	49	9	3.28	5.71	12.2	3.3	21.6	9.4	8.8	1.1	15.5	9.4	18.8
ADCD-01	2004	36	1	2.91	6.38	43.5	0	0	0	0	0	0	0.9	55.7
ADD-01	2004	41	5	2.51	5.61	8.7	0	12.8	12.1	11.4	0	38.9	2.7	13.4
ADL-01	2004	1	5	3.09	5.49	8.1	1.2	18.6	0	0	0	60.5	1.2	10.5
ADP-01	2004	42	8	2.68	6.49	6.3	0	12.6	0	0	81	0	0	0
ADY-01	2004	17	2	1.69	6.4	7.5	0	0	0	0	0	0.9	4.7	86.9
IX-03	2004	35	2	2.65	7.96	71.5	0	9.8	2.1	0.7	0	6.3	2.8	6.9
IX-04	2004	38	4	2.7	6.49	57.1	34.8	0	0	0	0	6.2	0.6	1.2
IX-05	2004	20	1	1.81	8.72	83.5	0	0	0	0	0	1.7	1.7	13.1
IX-06	2004	31	1	2.3	7.83	79.3	7.6	3.5	1.4	0	0	4.1	4.1	0
IXCC-01	2004	32	5	0.33	5.72	31	3.4	17.2	1.7	0	0	44.8	0	1.7
IXD-01	2004	47	8	3.33	5.72	28.7	0	7.9	0	0	0	48.5	11.9	3
IXF-01	2004	51	6	2.64	5.21	18.4	32.5	13.6	0	0	0	14.9	3.5	16.7
IXF-02	2004	56	16	3.25	5.48	7.4	2.5	7.3	12.5	0.8	0	69.7	0.8	0
IXI-01	2004	37	7	2.93	6.41	20.7	0	0.8	7.4	5.8	0	65.3	0	0
IXM-04	2004	33	5	2.47	7.07	23.5	16.2	17.6	0	0	0	36.8	0	5.9

Appendix VII. Fish species codes.

BAS - Banded sculpin

BGB - Bigmouth buffalo

BKB - Black buffalo

BLB - Black bullhead

BLC - Black crappie

BLD - Blackside darter

BLG - Bluegill

BLS - Bluntnose minnow

BLT - Blackstripe topminnow

BOW - Bowfin

BRS - Brook silverside

BST - Blackspotted topminnow

BUD - Bluntnose darter

BUM - Bullhead minnow

CAP - Common carp

CCF - Channel catfish

CCS - Creek chubsucker

COS - Central stoneroller

CRC - Creek chub

DUD - Dusky darter

EMS - Emerald shiner

FCF - Flathead catfish

FGD - Fringed darter

FLR - Flier

FRD - Freshwater drum

FRM - Freckled madtom

GOR - Golden redhorse

GOS - Golden shiner

GRC - Grass carp

GRP - Grass pickerel

GSF - Green sunfish

GZS - Gizzard shad

LMB - Largemouth bass

LOS - Longear sunfish

MOF -Mosquitofish

ORD -Orangethroat darter

ORS - Orangespotted sunfish

PRP - Pirate perch

RBS - Ribbon shiner

RDS - Redfin shiner

RES - Red shiner

RSF - Redear sunfish

RVC - River carpsucker

SAB - Smallmouth bass

SDS - Spotted sucker

SFS - Spotfin shiner

SHG - Slenderhead darter

SHR - Shorthead redhorse

SLD - Slough darter

SPB - Spotted bass

SPD - Spottail darter

SPG - Spotted gar

STD - Stripetail darter

SUM - Suckermouth minnow

SVM - Silvery minnow

TPM - Tadpole madtom

ULL - Quillback

WAM - Warmouth

WHB - White bass

WHC - White crappie

WHS - White sucker

YEB - Yellow bullhead

Glossary

Allochthonous – not formed in the region where found; coming from without

Alluvium - a fine-grained fertile soil consisting of mud, silt, and sand deposited by flowing water on flood plains, in river beds, and in estuaries

Atomic adsorption spectroscopy– a spectroanalytical procedure for the qualitative and quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state

Barrens - level or slightly rolling land, usually with a sandy soil and few trees, and relatively infertile

Bottomland - low-lying alluvial land near a river

Coliform bacteria - of, relating to, or being gram-negative rod-shaped bacteria (as E. coli) normally present in the intestine

Common pool resources - non-excludablel and rivalrous human or natural goods that are costly to exclude potential beneficiaries from accessing

Cuesta - a long, low ridge with a relatively steep face or escarpment on one side and a long, gentle slope on the other

Culm - a stem or stalk, especially the jointed and usually hollow stem of grasses

Dendritic - of a branching form; arborescent

Glossary

Dynamic equilibrium - a state or situation which is not static, but rather reflects a balance between force and resistance

Ecosystem services - goods and services from which humans benefit supplied by the natural functioning and processes of the environment

Ecotonal gradient - transition between habitat types

Extirpated – local extinction

Flashy – quick to change, with regards to water levels

Flatwoods - a woodland in a low-lying region having little drainage

Glaciofluvial – streams and rivers associated with glacier movements

Guild - organisms that use a similar resource in a similar manner

Headcut – sudden change in elevation or knickpoint at the leading edge of a gully

Hydraulic gradient - a vector gradient between two or more hydraulic head measurements over the length of the flow path

Hydrologic balance - an accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified time period

Hypoxia - reduced dissolved oxygen content of a body of water detrimental to aerobic organisms

Incentive structure - formal or informal institutional arrangements that encourage certain activities, behaviors, and choices over others based on perceived or actual payoffs or penalties

Karst - an area of limestone terrain characterized by sinks, ravines, and underground streams.

Glossary

Knoll – a small, low natural hill

Landscape - 1. an extensive area of land regarded as being visually distinct;
2. the distinctive features of a given area of intellectual activity, regarded as an integrated whole

Lentic – standing or still water

Lithophilous – rock-loving

Loess - a sediment formed by the accumulation of wind-blown silt, typically in the 20–50 micrometer size range, twenty percent or less clay and the balance equal parts sand and silt that are loosely cemented by calcium carbonate

Lotic - moving water

Natural capital - stock of goods and services in the natural environment

Opportunity costs- cost of any choice relative to the next best alternative choice

Physiographic province - a geographic region with a specific geomorphology and often specific subsurface rock type or structural elements

Physiographic section – a subset within a physiographic province

Riparian – the interface between land and a river or stream

Slag – a partially vitreous by-product of smelting ore to separate the metal fraction from the unwanted fraction

Slough - an area of soft, muddy ground; swamp or swamp-like region

Glossary

Successional – The gradual and orderly process of ecosystem development brought about by changes in community composition and the production of a climax characteristic of a particular geographic region

Thalweg - the line defining the lowest points along the length of a river bed or valley

Wetted width - width of a channel based on water level

Acronyms

AA – Atomic adsorption spectroscopy

ASTGTM - ASTER Global Digital Elevation Model (from USGS)

CCA – Canonical correspondence analysis

CCNWR – Cypress Creek National Wildlife Refuge

CCSCR - Citizens Committee to Save the Cache River

CRP – Conservation Reserve Program

CWA – Clean Water Act

DU – Ducks Unlimited

EPT – Ephemeroptera, Plecoptera, and Trichoptera

IBI – Index of biotic integrity

ICP-AES - Inductively coupled plasma-atomic emission spectroscopy

IDNR – Illinois Department of Natural Resources

IEPA – Illinois Environmental Protection Agency

GIS – Geographic information system

JVP – Joint Venture Partnership

NLCD – National Land Cover Dataset

NRCS – Natural Resources Conservation Services

RMZ – Riparian management zones

SWCD – Soil and Water Conservation Districts

TMDL – Total Maximum Daily Load

TNC – The Nature Conservancy

US – United States

Acronyms

USDA – United States Department of Agriculture

USEPA – United States Environmental Protection Agency

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

WRP – Wetland Reserve Program

WS – Watershed, (the Cache River Watershed, unless otherwise noted)