Freshwater Resources in the Hoosier-Shawnee Ecological Assessment Area

Matt R. Whiles and James E. Garvey

ABSTRACT

The Hoosier-Shawnee Ecological Assessment Area contains 40 major watersheds with unique hydrological, ecological, and socioeconomic features. Depending on the watershed, major groundwater resources are a combination of sandstone, carbonate, and semiconsolidated or unconsolidated sand/gravel aquifers. Approximately 69,000 miles of streams flow through the assessment area, of which 60 percent are perennial and 14 percent are artificial or greatly altered (e.g., drainage ditches). Even though headwater streams represent the majority of stream miles and exert a strong influence on downstream processes, relatively little is known about their extent and condition within the region. Most stream riparian zones are either urban or agricultural; only 22 percent of watersheds in the assessment area contain streams with abundant forested riparian areas. More than 8,000 reservoirs have been constructed in the region; these provide important water supplies, recreational opportunities, and economic benefits, but they also potentially influence the ecological integrity of streams. Consistent with nationwide trends, wetland habitats are some of the most degraded and diminished freshwater resources in the region; only 2.8 percent woody and 0.3 percent herbaceous wetland vegetation remain in the assessment area. Water quality varies greatly across the region, with elevated nutrients and contaminants (e.g., heavy metals and organic compounds) exceeding U.S. Environmental Protection Agency (USEPA) regional standards in many of the systems. Most water in the region is used for power generation and public supply, with 16 times more surface water consumed annually than groundwater. Increased surface water and groundwater contamination and rising public and industrial demand may continue to compromise water quality and quantity within much of the assessment area. Predicted reductions in precipitation associated with global climate change may further compromise the limited water resources of the region.

About the Author:

Matt R. Whiles
Assistant Professor of Zoology, Department of Zoology, Southern Illinois University, Carbondale, IL 62901-6501.
Phone: 618-453-7639; e-mail: mwhiles@zoology.siu.edu

James E. Garvey
Assistant Professor of Zoology, SIUC Fisheries and Illinois Aquaculture Center, Southern Illinois University, Carbondale, IL 62901-6511.
e-mail: jgarvey@siu.edu

INTRODUCTION

The Shawnee and Hoosier National Forests contain a wide variety of freshwater resources that are vital to the ecological integrity and human population of the region. Freshwater resources in the region provide habitat for a great diversity of plants and animals, as well as recreational, industrial, and domestic goods and services for humans. Across the planet, freshwater resources are imperiled, with more than 50 percent of the world's freshwater runoff already used by humans (Gleick 2000, Jackson et al. 2001) and an even greater percentage adversely influenced by human activities in some manner (Naiman et al. 1995, Naiman and Turner 2000). Currently, the largest threat to freshwater systems in the United States, in terms of number of systems adversely affected, is non-point pollution associated with agriculture (USEPA 1994a). However, urbanization, industrial activities such as mining, exotic species, predicted climate change, and other factors linked to human activities also pose great threats (Cooper 1993; Cushing and Allan 2001; USEPA 1994a, 2001).

No region in the U.S., not even within the boundaries of our national parks and forests, is immune to the variety of problems facing freshwater ecosystems. Hydrological cycles at local or regional scales often are linked, meaning that water use practices and activities that influence water quality within one region may affect hydrological processes and water quality in others. There is also an increasing awareness that atmospheric deposition is a major pathway for the introduction of pollutants into freshwater habitats, even in seemingly pristine regions (Allan 1995, Winter et al. 1999). Projected increases in human population growth, and changes in the hydrological cycle that are linked to predicted climate change, suggest that per capita availability of freshwater will decline in the future (Jackson et al. 2001). This, coupled with water quality issues, demonstrates that prudent management and conservation of remaining freshwater systems are paramount. Conservation of freshwater resources requires an inventory of existing resources and current information about their condition. This inventory of the Hoosier-Shawnee Ecological Assessment Area will provide a benchmark for future assessments of trends in the quantity and quality of freshwater resources and patterns of water use.

Streams, lakes, and wetlands are the lifeblood of a region because freshwater is a vital resource for all organisms, including humans. Additionally, freshwater resources influence local and regional climate, and they have an economic value associated with recreation, industry, and agriculture. Wise management and conservation of freshwater are imperative for maintaining or restoring the ecological and economic well-being of the Hoosier-Shawnee Ecological Assessment Area. This is a particularly challenging task, given the diversity of factors influencing water quantity and quality within the region, including local climate, geology, and human population density and activities.

The boundaries of the Shawnee National Forest include parts of 6 major drainages in Illinois: the upper Mississippi-Cape Girardeau, Big Muddy, Cache, Saline, lower Ohio, and lower Ohio Bay. The Hoosier National Forest boundaries include parts of lower Ohio-Little Pigeon, Blue Sinking, Patoka, and lower East Fork White. At least portions of 40 major watersheds constitute the Hoosier-Shawnee assessment area, and these range in size from 359 square miles (Cache River in Illinois) to 3,174 square miles (upper Green River in western Kentucky) (fig. 1, table 1). Most of these major watersheds include multiple ecological units and numerous subsections of these units. The majority of the watersheds in the study region drain portions of the Interior Low Plateau Shawnee Hills and Highland Rim

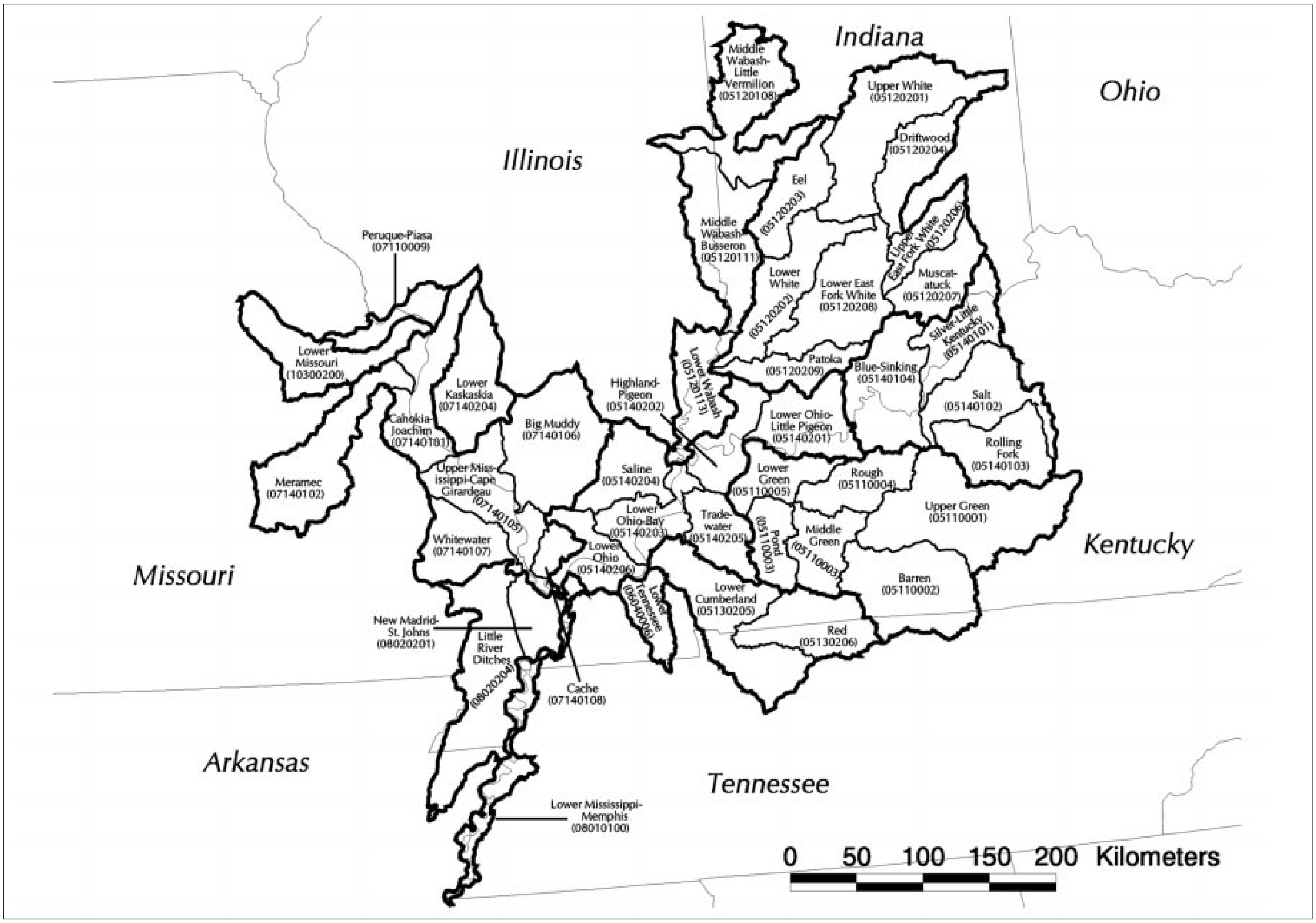


Figure 1. Watershed units of the Hoosier-Shawnee assessment area. Numbers are USGS cataloging hydrologic unit codes.

Sections (fig. 1, table 1). Most of these catchments integrate a variety of land cover types, including those with primarily urban, agricultural, and forested land characteristics.

We identified and quantified the major aquatic resources in the Hoosier-Swanee study region, including groundwater resources, lotic surface water habitats, and lentic surface waters and wetlands. We also examined indicators of the ecological integrity of surface water habitats and assessed recent patterns of water use within the region.

METHODS

Geographic and water use data within the watersheds of the Hoosier-Shawnee assessment area were obtained from a variety of sources, with an emphasis on the most recent and large-scale data sets described below. We approached this effort from the major watershed scale, where watersheds were U.S. Geological Survey (USGS) cataloging units, the finest scale hydrological unit in the USGS classification system (Seaber et al. 1987; fig. 1). Each of these 2,111 units nationwide is comprised of a combination of interconnected surface drainages with unique hydrologic features (Seaber et al. 1987). All 40 cataloging-unit watersheds on which we focused intersect at least a portion of the assessment area, and they represent the major units of analysis in this aquatic resource inventory.

Watershed Characteristics

Aquifers and their associated geologic composition within each watershed derive from the USGS Principal Aquifers of the 48 contiguous U.S. (Lloyd and Lyke 1995). Stream and river data derive from the USEPA's most recent River Reach File (RF3), a hydrographic database of the surface waters of the continental United

Table 1. USGS hydrological units (watersheds) within each ecological unit and subsection of the Hoosier-Shawnee Ecological Assessment Area.

Watershed	Watershed area (mi^2)	Ecological unit	Subsection	Proportion of watershed in subsection
Barren	2,244	Interior Low Plateau—Shawnee Hills Section	Southern Dripping Springs	0.054
			Outer Western Coal Fields	0.008
Big Muddy	2,369	Interior Low Plateau—Shawnee Hills Section	Greater Shawnee Hills	0.089
			Lesser Shawnee Hills	0.008
		Ozark Highlands	Mississippi River Alluvial Plain	0.022
			Illinois Ozarks	0.004
Blue Sinking	1,898	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.484
		Interior Low Plateau—Shawnee Hills Section	Northern Dripping Springs	0.178
			Crawford Upland	0.176
			Crawford Escarpment	0.097
Cache	359	Interior Low Plateau—Shawnee Hills Section	Lesser Shawnee Hills	0.302
		Ozark Highlands	Illinois Ozarks	0.215
		Upper Gulf Coastal Plain	Ohio and Cache River Alluvial Plain	0.175
			Cretaceous Hills	0.168
Cahokia-Joachim	1,660	Ozark Highlands	Mississippi River Alluvial Plain	0.221
			Illinois Ozarks	0.154
Driftwood	1,179	Interior Low Plateau—Highland Rim Section	Brown County Hills	0.035
Eel	1,211	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.048
			Brown County Hills	< 0.001
		Interior Low Plateau—Shawnee Hills Section	Crawford Upland	0.074
			Crawford Escarpment	0.070
Highland-Pigeon	1,005	Interior Low Plateau—Shawnee Hills Section	Lower Ohio-Cache-Wabash Alluvial Plains	0.373
			Interior Western Coal Fields	0.300
			Outer Western Coal Fields	0.284
Little River Ditches	2,646	Ozark Highlands	Illinois Ozarks	0.014
Lower Cumberland	2,311	Interior Low Plateau—Shawnee Hills Section	Southern Dripping Springs	0.087
			Marion Hills	0.032
		Upper Gulf Coastal Plain	Ohio and Cache River Alluvial Plain	0.019
Lower East Fork White	2,055	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.260
			Brown County Hills	0.239
		Interior Low Plateau—Shawnee Hills Section	Crawford Upland	0.234
			Crawford Escarpment	0.132
			Outer Western Coal Fields	0.033
Lower Green	918	Interior Low Plateau—Shawnee Hills Section	Interior Western Coal Fields	0.392
			Outer Western Coal Fields	0.384
			Lower Ohio-Cache-Wabash Alluvial Plains	0.218
			Northern Dripping Springs	0.003
Lower Kaskaskia	1,617	Ozark Highlands	Illinois Ozarks	0.054
			Mississippi River Alluvial Plain	0.001
Lower Missouri	1,610	Ozark Highlands	Mississippi River Alluvial Plain	0.013
Lower Ohio	936	Interior Low Plateau—Shawnee Hills Section	Lesser Shawnee Hills	0.196
			Greater Shawnee Hills	0.057
		Upper Gulf Coastal Plain	Ohio and Cache River Alluvial Plain	0.263
			Cretaceous Hills	0.204

(table continued on next page)

(table 1 continued)

Watershed	Watershed area (mi^2)	Ecological unit	Subsection	Proportion of watershed in subsection
Lower Ohio Bay	1,090	Interior Low Plateau—Shawnee Hills Section	Lesser Shawnee Hills	0.352
			Marion Hills	0.191
			Greater Shawnee Hills	0.148
			Lower Ohio-Cache-Wabash Alluvial Plains	0.120
			Interior Western Coal Fields	0.058
			Outer Western Coal Fields	0.007
		Upper Gulf Coastal Plain	Ohio and Cache River Alluvial Plain	0.080
			Cretaceous Hills	0.047
Lower Ohio-Little Pigeon	1,395	Interior Low Plateau—Shawnee Hills Section	Outer Western Coal Fields	0.390
			Lower Ohio-Cache-Wabash Alluvial Plains	0.277
			Crawford Upland	0.256
			Northern Dripping Springs	0.080
Lower Tennessee	691	Upper Gulf Coastal Plain	Ohio and Cache River Alluvial Plain	0.115
Lower Wabash	1,315	Interior Low Plateau—Shawnee Hills Section	Outer Western Coal Fields	0.125
			Lower Ohio-Cache-Wabash Alluvial Plains	0.031
Lower White	1,646	Interior Low Plateau—Highland Rim Section	Brown County Hills	0.092
			Mitchell Karst Plain	0.065
		Interior Low Plateau—Shawnee Hills Section	Crawford Upland	0.151
			Crawford Escarpment	0.082
			Outer Western Coal Fields	0.013
Meramec	2,143	Ozark Highlands	Mississippi River Alluvial Plain	<0.001
Middle Green	1,018	Interior Low Plateau—Shawnee Hills Section	Outer Western Coal Fields	0.741
			Southern Dripping Springs	0.209
			Interior Western Coal Fields	0.009
Middle Wabash-Little Vermilion	2,267	Interior Low Plateau—Shawnee Hills Section	Crawford Upland	0.003
Muscatatuck	1,145	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.013
New Madrid-St. Johns	707	Ozark Highlands	Illinois Ozarks	0.010
Patoka	868	Interior Low Plateau—Shawnee Hills Section	Crawford Upland	0.395
			Outer Western Coal Fields	0.303
			Crawford Escarpment	0.028
Peruque-Piasa	636	Ozark Highlands	Mississippi River Alluvial Plain	0.019
			Illinois Ozarks	0.004
Pond	785	Interior Low Plateau—Shawnee Hills Section	Outer Western Coal Fields	0.449
			Interior Western Coal Fields	0.286
			Southern Dripping Springs	0.271
Red	1,482	Interior Low Plateau—Shawnee Hills Section	Southern Dripping Springs	0.038
Rolling Fork	1,439	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.074
Rough	1,095	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.040
		Interior Low Plateau—Shawnee Hills Section	Northern Dripping Springs	0.483
			Outer Western Coal Fields	0.450
			Interior Western Coal Fields	0.026
Saline	1,182	Interior Low Plateau—Shawnee Hills Section	Greater Shawnee Hills	0.243
			Lower Ohio-Cache-Wabash Alluvial Plains	0.010
			Lesser Shawnee Hills	0.006
Salt	1,475	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.021
Silver-Little Kentucky	1,253	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.010

(table continued on next page)

(table 1 continued)

Watershed	Watershed area (mi^2)	Ecological unit	Subsection	Proportion of watershed in subsection
Tradewater	949	Interior Low Plateau—Shawnee Hills Section	Outer Western Coal Fields	0.402
			Interior Western Coal Fields	0.328
			Southern Dripping Springs	0.120
			Marion Hills	0.112
			Lesser Shawnee Hills	0.038
Upper East Fork White	806	Interior Low Plateau—Highland Rim Section	Brown County Hills	0.036
Upper Green	3,171	Interior Low Plateau—Highland Rim Section	Mitchell Karst Plain	0.160
		Interior Low Plateau—Shawnee Hills Section	Northern Dripping Springs	0.153
			Southern Dripping Springs	0.072
			Outer Western Coal Fields	0.034
Upper Mississippi-Cape Girardeau	1,687	Interior Low Plateau—Shawnee Hills Section	Greater Shawnee Hills	0.014
		Ozark Highlands	Mississippi River Alluvial Plain	0.215
			Illinois Ozarks	0.006
Upper White	2,722	Interior Low Plateau—Highland Rim Section	Brown County Hills	0.095
			Mitchell Karst Plain	0.008
Whitewater	1,213	Ozark Highlands	Mississippi River Alluvial Plain	0.028

States and Hawaii (USEPA 1994b). Data provided by the River Reach File are limited to the resolution (1:100,000) of the digital maps from which the data set derives (Horn et al. 1994). Classifications of streams as natural or unnatural derive from the Multi-Resolution Land Consortium's National Land Cover Database (NLCD). Major drainages within each watershed were identified as the stream or river with the greatest mean annual discharge ($ft^3.s^{-1}$) within the USGS gauging station database (USGS 2001). Riparian vegetation cover percentages derive from 1-km grid cells adjacent to streams in the USGS 1:2,000,000 digital line graph coverage (1990 USGS-EROS). Surface area and numerical data on reservoirs and wetlands derive from the NLCD and the 1992 U.S. Army Corps of Engineers National Inventory of Dams database (Army Corps of Engineers 1992).

Watershed Condition and Water Use

Our assessment of watershed condition includes the USEPA's Index of Watershed Indicators (IWI; USEPA 1999) that incorporates current watershed condition with vulnerability to future perturbations (table 2). The IWI characterization is based on a scoring procedure accounting for several indicator values including waters that meet designated uses, fish consumption advisories, source water condition, contaminated sediments, water quality, wetland loss, species at risk, pollutant loads over permit levels, urban/agricultural runoff, population change, hydrologic modification, and atmospheric nitrogen deposition (table 2). We determined the proportion of reservoirs and streams within each watershed that failed to meet water quality standards under Section 303D of the Clean Water Act in 1998 (State-USEPA Partnership Program 1998). We also quantified various patterns of water use within each watershed using 1990 and 1995 data sets from the USGS Water Information Coordination Program (see Solley et al. 1998). Data were compiled and are presented in table 2 to reflect current resource conditions and quantities. When possible, we also identified trends of water quality and use.

OVERVIEW OF FRESHWATER RESOURCES

Groundwater Resources

Aquifers are continuous groundwater systems that contain water in sufficient quantity for domestic, commercial, industrial, or agricultural uses, and they represent important long-term storage of water in given regions. In most cases, aquifers and other groundwater resources interact with surface waters, and each can have an important influence on the other. Hence, the pollution or depletion of one can adversely affect the other. Aquifers and other groundwaters are primarily used by humans for irrigation, industrial activities, and domestic water supplies, and there is global concern over the long-term implications of groundwater overuse and pollution (Jackson et al. 2001). For example, many aquifers in the Western United States are being depleted more rapidly than they are being recharged.

The source of groundwater in the Hoosier-Shawnee assessment area is precipitation. Average annual precipitation in the region ranges from approximately 36 inches in the northern part of the study area in Illinois to 48 inches in the eastern part of the region in Kentucky. Approximately 50 to 75 percent of this precipitation is returned to the atmosphere via evaporation and transpiration, and much of the remainder represents stream discharge (Lloyd and Lyke 1995). Groundwater recharge is a factor of both precipitation and surface layer permeability, and most recharge goes to shallow groundwater pools. Annual groundwater recharge in the Hoosier-Shawnee study region is estimated at 1 inch/year in relatively drier regions of Illinois and eastern Missouri, but recharge rates increase in the eastern part of the study area to near 3 to 5 inches/year (Lloyd and Lyke 1995). Much of the deepest groundwater (generally >500 feet depth) in the region is classified as saltwater, defined as water with >1,000 mg/L dissolved solids (Lloyd and Lyke 1995).

Table 2. Interpretation of Index of Watershed Indicators (IWI; USEPA 1999), an index that incorporates current watershed condition with vulnerability to future perturbations.

IWI Score	Water quality	Vulnerability
1	Better	Low
2	Better	High
3	Less serious	Low
4	Less serious	High
5	More serious	Low
6	More serious	High
7	Insufficient data	Insufficient data

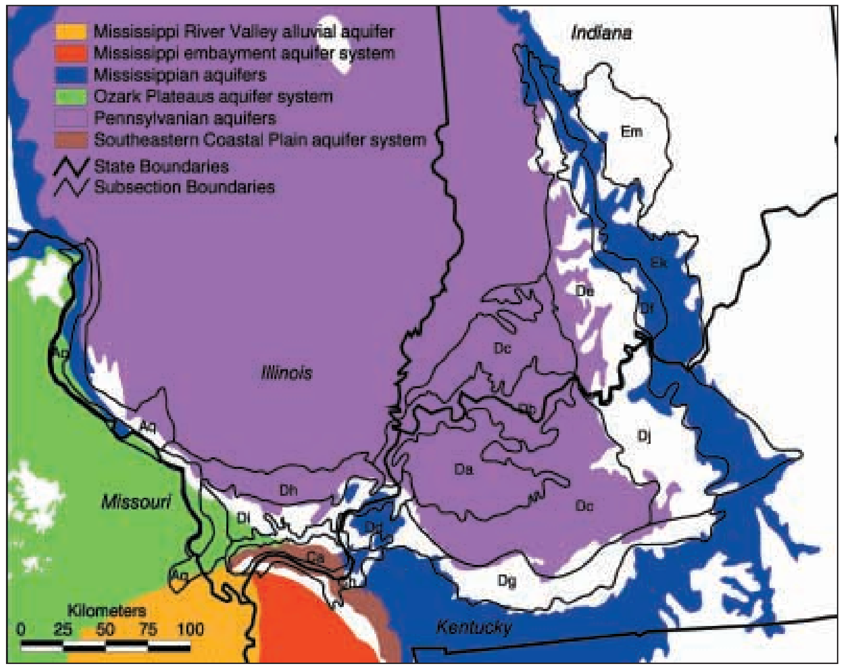


Figure 2. Aquifers of the Hoosier-Shawnee assessment area. Letter codes refer to ecoregion subsections in the assessment area (Keys et al. 1995, Ponder 2004).

Most aquifers in the Hoosier-Shawnee study region are associated with sedimentary rock, primarily sandstone (Pennsylvanian systems) and carbonate-rock (Ozark Plateaus aquifer system) or a combination of the two (Mississippian aquifers) (figs. 2, 3). However, the Mississippi River valley alluvial system, which includes parts of the Cache, Little River Ditches, lower Ohio, New Madrid-St. Johns, upper Mississippi, and Whitewater drainages consists of unconsolidated sand and gravel; and the Mississippi Embayment system (parts of the lower Ohio and lower Tennessee drainages) and the Southeastern Coastal Plain system (Cache, lower Ohio, lower Ohio Bay, and lower Tennessee drainages) consist of semiconsolidated sand and gravel (table 3). Combined, these systems represent 19 percent of aquifers in the region that are composed of semiconsolidated or unconsolidated materials (fig. 3). In general, the sand and gravel aquifers in the region are relatively shallow and are associated with the alluvial deposits of the large rivers in the region.

The majority of the major drainage basins in the study area include two to three principal aquifer types, although some drainages are geologically more diverse and include more (fig. 2, table 3). For example, the lower Ohio drainage includes six aquifer types (Mississippi Embayment, Mississippi River valley alluvial, Mississippian, Ozark Plateaus, Pennsylvanian, and Southeastern Coastal Plain), and a substantial portion of its area (about 224 square miles) has no associated aquifer. In contrast, some smaller drainages in more homogenous areas of the study region, such as the Red, Pond, and Saline, include only one aquifer type and have extensive areas with no associated aquifers.

Sandstone aquifers are characterized by having relatively low rates of water movement. However, both carbonate-rock aquifers and those associated with semiconsolidated or unconsolidated materials can have relatively high recharge rates and hydraulic conductivity,

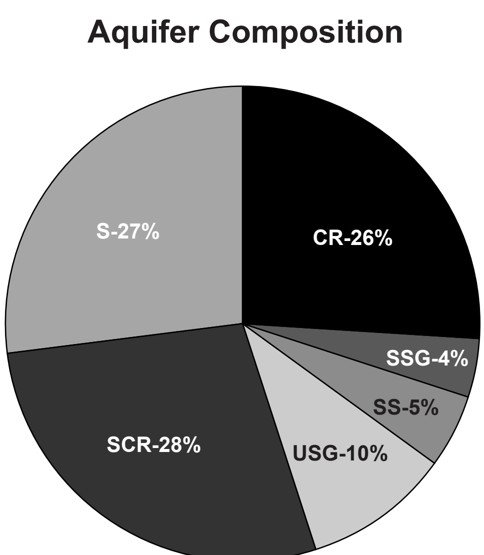


Figure 3. Percent area of watersheds within the Hoosier-Shawnee assessment area with aquifers comprised of carbonate-rock, sandstone, sandstone and carbonate-rock, unconsolidated sand and gravel, semiconsolidated sand, and semiconsolidated sand and gravel.

indicating that water can move relatively rapidly into and within these types of aquifers. In addition, a large portion of the Hoosier-Shawnee study region, such as the Shawnee Hills and Salem Plateau regions of southern Illinois and the Blue Sinking drainage of south-central Indiana and northwest Kentucky, is karst, with significant networks of caves and associated subterranean aquatic systems (Weibel et al. 1997). Groundwaters in karst regions are particularly vulnerable to pollution from surface activities (e.g., agricultural activities and septic waste) because nutrients, agrochemicals, and other pollutants can move into these systems via percolation of water through thin and porous substrates, sinkholes, and sinking streams (Panno et al. 1996, Taylor and Webb 2000). Further, water movements in karst terrain can be very unpredictable, and groundwater contamination problems that might be localized in some regions can become regional problems in karst areas (Winter et al. 1999). Taylor and Webb (1998) noted that it is common for landowners in the region to use sinkholes as waste dumping sites, exacerbating problems of groundwater pollution. A recent investigation in a cave in St. Clair County, Illinois, demonstrated the linkage between surface activities and groundwater in karst regions by showing major changes in turbidity and assorted water chemistry parameters in a cave stream during a storm on the surface (Taylor and Webb 2000).

Given the geology of many of the aquifers and other groundwater resources of the Hoosier-Shawnee assessment area, protection of groundwater resources is an important issue for this region. In particular, careful monitoring of land use practices, including farming practices and maintenance of private septic systems will be required to maintain the quality of groundwater resources. Further, much of the groundwater of the region is interconnected, such that careless or destructive practices in even a small area can negatively influence other parts of the region.

Table 3. Major aquifer types and associated geologic composition within each USGS hydrological unit (watershed) of the Hoosier-Shawnee Ecological Assessment Area (see Lloyd and Lyke 1995).

Watershed	Aquifer type	Rock type	Area (mi^2)
Barren	Mississippian	sandstone-carbonate-rock	1,106
	None	NA	1,027
	Pennsylvanian	sandstone	11
	Silurian-Devonian	carbonate-rock	81
Big Muddy	None	NA	36
	Ozark Plateaus	carbonate-rock	5
	Pennsylvanian	sandstone	2,345
Blue Sinking	Mississippian	sandstone-carbonate-rock	1,161
	None	NA	726
	Pennsylvanian	sandstone	6
Cache	Mississippi River Valley Alluvial	unconsolidated sand and gravel	38
	None	NA	53
	Ozark Plateaus	carbonate-rock	224
	Southeastern Coastal Plain	semiconsolidated sand and gravel	41
Cahokia-Joachim	Mississippian	sandstone-carbonate-rock	246
	None	NA	102
	Ozark Plateaus	carbonate-rock	861
	Pennsylvanian	sandstone	441
Driftwood	None	NA	207
	Silurian-Devonian	carbonate-rock	947
Eel	Mississippian	sandstone-carbonate-rock	313
	None	NA	438
	Pennsylvanian	sandstone	444
Highland-Pigeon	Pennsylvanian	sandstone	997
Little River Ditches	Mississippi River Valley Alluvial	unconsolidated sand and gravel	2,378
	Ozark Plateaus	carbonate-rock	261
Lower Cumberland	Mississippian	sandstone-carbonate-rock	1,856
	None	NA	478
Lower East Fork White	Mississippian	sandstone-carbonate-rock	633
	None	NA	996
	Pennsylvanian	sandstone	396
Lower Green	None	NA	8
	Pennsylvanian	sandstone	915
Lower Kaskaskia	Mississippian	sandstone-carbonate-rock	39
	None	NA	180
	Pennsylvanian	sandstone	1,386
Lower Missouri	Ozark Plateaus	carbonate-rock	946
Lower Ohio	Mississippi Embayment	semiconsolidated sand	113
	Mississippi River Valley Alluvial	unconsolidated sand and gravel	56
	Mississippian	sandstone-carbonate-rock	12
	None	NA	362
	Ozark Plateaus	carbonate-rock	18
	Pennsylvanian	sandstone	101
	Southeastern Coastal Plain	semiconsolidated sand and gravel	276
Lower Ohio Bay	Mississippian	sandstone-carbonate-rock	247
	None	NA	469
	Pennsylvanian	sandstone	374
	Southeastern Coastal Plain	semiconsolidated sand and gravel	5
Lower Ohio-Little Pigeon	None	NA	269
	Pennsylvanian	sandstone	1,134
Lower Tennessee	Mississippi Embayment	semiconsolidated sand	255
	Mississippian	sandstone-carbonate-rock	44
	None	NA	200
	Southeastern Coastal Plain	semiconsolidated sand and gravel	188
Lower Wabash	Pennsylvanian	sandstone	1,321
Lower White	Mississippian	sandstone-carbonate-rock	169
	None	NA	429
	Pennsylvanian	sandstone	1,077

(table continued on next page)

(table 3 continued)

Watershed	Aquifer type	Rock type	Area (mi²)
Meramec	None	NA	26
	Ozark Plateaus	carbonate-rock	2,125
Middle Green	None	NA	336
	Pennsylvanian	sandstone	681
Middle Wabash-Little Vermilion	Mississippian	sandstone-carbonate-rock	68
	None	NA	1,114
	Pennsylvanian	sandstone	1,047
	Silurian-Devonian	carbonate-rock	58
Muscatatuck	Mississippian	sandstone-carbonate-rock	2
	None	NA	560
	Silurian-Devonian	carbonate-rock	582
New Madrid-St. Johns	Mississippi River Valley Alluvial	unconsolidated sand and gravel	723
Patoka	Mississippian	sandstone-carbonate-rock	1
	None	NA	189
	Pennsylvanian	sandstone	669
Peruque-Piasa	Mississippian	sandstone-carbonate-rock	331
	Ozark Plateaus	carbonate-rock	2
	Pennsylvanian	sandstone	214
	None	NA	111
	Silurian-Devonian	carbonate-rock	4
Pond	None	NA	209
	Pennsylvanian	sandstone	594
Red	Mississippian	sandstone-carbonate-rock	1,330
	None	NA	121
Rolling Fork	Mississippian	sandstone-carbonate-rock	39
	None	NA	1,294
	Silurian-Devonian	carbonate-rock	124
Rough	Mississippian	sandstone-carbonate-rock	44
	None	NA	626
	Pennsylvanian	sandstone	422
Saline	None	NA	12
	Pennsylvanian	sandstone	1,168
Salt	Mississippian	sandstone-carbonate-rock	38
	None	NA	1,170
	Ordivician	carbonate-rock	118
	Silurian-Devonian	carbonate-rock	152
Silver-Little Kentucky	Mississippian	sandstone-carbonate-rock	7
	None	NA	914
	Silurian-Devonian	carbonate-rock	369
Tradewater	Mississippian	sandstone-carbonate-rock	7
	None	NA	192
	Pennsylvanian	sandstone	748
Upper East Fork White	None	NA	327
	Silurian-Devonian	carbonate-rock	484
Upper Green	Mississippian	sandstone-carbonate-rock	1,185
	Pennsylvanian	sandstone	213
	Silurian-Devonian	carbonate-rock	1,770
Upper Mississippi	Mississippi River Valley Alluvial	unconsolidated sand and gravel	91
	Mississippian	sandstone-carbonate-rock	26
	None	NA	193
	Ozark Plateaus	carbonate-rock	1,157
	Pennsylvanian	sandstone	205
Upper White	Mississippian	sandstone-carbonate-rock	19
	None	NA	1,119
	Silurian-Devonian	carbonate-rock	1,616
Whitewater	Mississippi River Valley Alluvial	unconsolidated sand and gravel	3
	Ozark Plateaus	carbonate-rock	1,215

Streams and Rivers

The assessment area includes a great diversity of streams, ranging from ephemeral headwaters, to perennial spring seeps, to large, navigable rivers (fig. 4, table 4). These systems, along with their associated reservoirs, account for the vast majority of surface water and are thus a crucial component of the freshwater resources of the area. Because of their longitudinal, unidirectional, and dynamic nature, streams integrate and reflect the landscapes that they drain (Hynes 1970, Vannote et al. 1980) and are thus vulnerable to all disturbances in their drainage areas. Streams are often a strong bellwether of watershed health, and several indices have been developed to characterize stream condition (e.g., Qualitative Habitat Evaluation Index, Yoder and Rankin 1999).

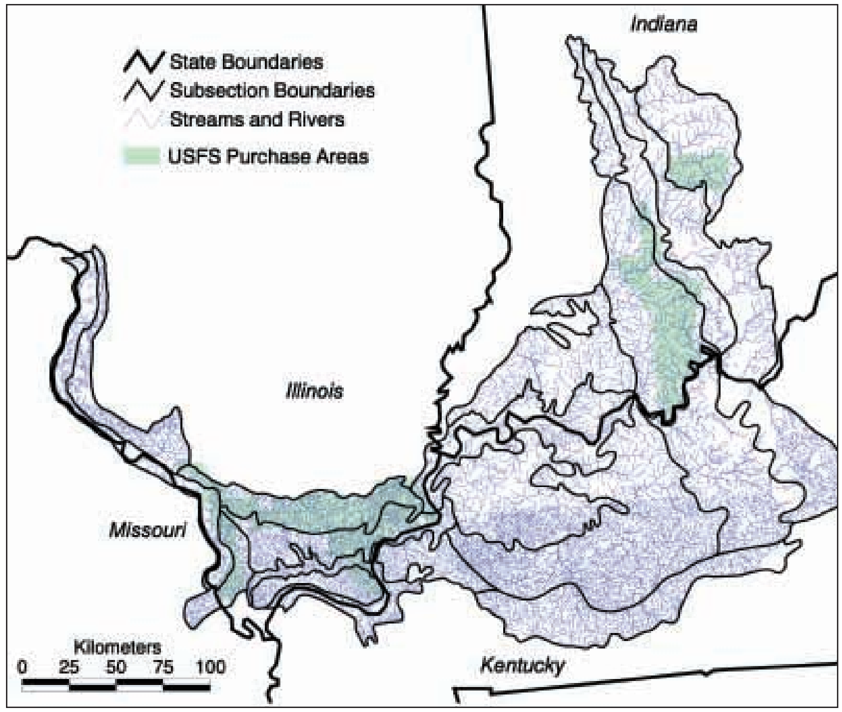


Figure 4. Streams of the Hoosier-Shawnee assessment area.

Because small streams, particularly ephemeral and intermittent headwaters, are inevitably underrepresented in data sets derived from maps, data reported in this section do not reflect total streams in the region. Rather, the trends we present are biased to larger streams that appear in the USEPA River Reach File and are included in regional assessments and data sets. Nonetheless, small headwater streams represent the majority of stream reaches in the U.S. (Cushing and Allan 2001, Leopold et al. 1964) and are of great ecological significance (e.g., Cummins 1977, Vannote et al. 1980, Wallace et al. 1992). Further, it has recently been demonstrated that the influence of headwater streams on important processes such as nutrient cycling transcends their relatively small size, and they can potentially influence even large-scale processes such as hypoxia in the Gulf of Mexico (Peterson et al. 2001). Headwater streams also represent some of the most threatened lotic ecosystems because they are often highly modified by human activities such as agriculture and urbanization, sometimes to the point where they are no longer recognizable as streams.

Major watersheds of the assessment area include anywhere from 5 (Cache basin) to 26 (Big Muddy basin) major streams in the basin, and this is proportional to the size of the watersheds (table 4, fig. 4). Likewise, total length of streams ranges from 582 miles (Cache) to 4,716 miles (Little River Ditches), reflecting the sizes of areas drained by watersheds. However, the proportion of stream miles that are perennial varies greatly across the region, as a function of climate, geology, and topography. For the whole region, there are a total of 69,000 miles of streams, and 41,096 miles, or 60 percent of these, are perennial. The proportion of perennial streams in each drainage is highly variable, ranging from only 29 percent in the lower Missouri drainage to 97 percent in the upper East Fork of the White River basin (table 4). As illustrated by these two basins, there is a trend of increasing proportion of perennial miles of streams moving from west to east across the study region, and this is largely related to differences in precipitation.

Along with natural stream channels, there are also a number of unnatural streams in the region. These include drainage ditches that are constructed in agricultural areas and artificial channels constructed to connect bodies of water. In many cases, these unnatural streams

Table 4. Surface water characteristics for each hydrologic unit (watershed) of the Hoosier-Shawnee Ecological Assessment Area.

Watershed	Number of streams	Total river mi	Perennial river mi	Proportion perennial river mi	Proportion natural streams	Major drainage	Mean annual discharge ($ft^3.s^{-1}$)
Barren	16	2,299	1,741	0.76	0.96	Barren River	2,586
Big Muddy	26	3,349	1,059	0.32	0.94	Big Muddy River	710
Blue Sinking	14	1,125	972	0.86	0.90	Blue River	327
Cache	5	581	272	0.47	0.81	Cache River	300
Cahokia-Joachim	12	2,321	730	0.31	0.92	Mississippi River	190,723
Driftwood	9	782	718	0.92	0.91	Big Blue River	473
Eel	7	834	749	0.90	0.88	Eel River	896
Highland-Pigeon	13	674	509	0.75	0.80	Ohio River	132,549
Little River Ditches	9	4,713	1,756	0.37	0.28	Little River	2,892
Lower Cumberland	24	2,739	1,979	0.72	0.88	Cumberland River	24,494
Lower East Fork White	16	1,403	1236	0.88	0.87	East Fork White River	4,900
Lower Green	7	771	718	0.93	0.83	Green River	11,229
Lower Kaskaskia	9	2,511	926	0.37	0.96	Kaskaskia River	3,761
Lower Missouri	18	2,425	693	0.29	0.93	Missouri River	80,985
Lower Ohio	15	1,245	540	0.43	0.84	Ohio River	277,541
Lower Ohio Bay	18	4,458	2,817	0.63	0.90	Ohio River	1,891,012
Lower Ohio-Little Pigeon	17	1,085	962	0.89	0.83	Ohio River	128,839
Lower Tennessee	8	1,201	778	0.65	0.96	Tennessee River	NA
Lower Wabash	15	1,042	730	0.70	0.76	Wabash River	28,264
Lower White	18	1,221	1,079	0.88	0.72	White River	4,900
Meramec	16	3,663	970	0.26	0.98	Meramec River	3,279
Middle Green	15	1,537	1,089	0.71	0.91	Green River	8,502
Middle Wabash-Little Vermilion	12	2,492	1,373	0.55	0.90	Wabash River	6,672
Muscatatuck	14	953	856	0.90	0.91	Muscatatuck River	226
New Madrid-St. Johns	10	957	366	0.38	0.23	Ohio River	NA
Patoka	7	672	497	0.74	0.89	Patoka River	1,044
Peruque-Piasa	7	834	316	0.38	0.88	Mississippi River	109,182
Pond	10	1,225	760	0.62	0.88	Pond River	274
Red	16	919	724	0.79	0.98	Red River	1,354
Rolling Fork	16	2,014	1,696	0.84	0.99	Rolling Fork	1,818
Rough	10	1,016	838	0.83	0.92	Rough River	1,085
Saline	18	1,731	602	0.35	0.94	South Fork Saline River	164
Salt	16	1,507	1,271	0.84	0.95	Salt River	1,589
Silver-Little Kentucky	9	961	844	0.88	0.90	Ohio River	116,408
Tradewater	13	1,533	1,231	0.80	0.90	Tradewater River	333
Upper East Fork White	6	631	610	0.97	0.85	East Fork White River	2,537
Upper Green	20	3,612	2,496	0.69	0.95	Green River	2,741
Upper Mississippi-Cape Girardeau	20	2,131	1,085	0.51	0.87	Mississippi River	207,882
Upper White	15	1,774	1,591	0.90	0.87	White River	2,533
Whitewater	13	2,001	894	0.45	0.96	Mississippi River	NA

are located where natural stream channels occurred historically, but channelized ditches have replaced the natural features. On average, 14 percent of streams in the study region are artificial or highly modified, and this ranges from only 28 percent natural streams in the heavily agricultural region of the Little River Ditches drainage in the "bootheel" of Missouri to 99 percent natural streams in the Rolling Fork basin of western Kentucky. In general, the proportion of unnatural streams is highest in low, flat areas near major rivers where a high proportion of the land is cultivated (table 4). There is little information about the ecological integrity of these unnatural streams in the study region, but evidence from other regions suggests they are highly degraded systems (e.g., Cooper 1993, Whiles et al. 2000).

Discharge data reflect water export from the major stream in each drainage basin, and these values are highly variable across the region. Numerous basins are drained by relatively small rivers (e.g., Saline, Muscatatuck, Cache), whereas others include major rivers such as the Ohio and Mississippi that have substantial discharge (e.g., Cahokia-Joachim, upper Mississippi-Cape Girardeau, lower Ohio Bay). However, it is important to note that basins bisected by large rivers like the Mississippi and Ohio are not exporting all discharge reported. Rather, these values reflect export by the entire landscape drained by these large rivers, and the contribution from areas within the Hoosier-Shawnee study region represent only a fraction of total discharge. Average total discharge for the entire study area (including large rivers that flow through the region) is 87,937 $ft^3.s^{-1}$.

Riparian land use has been shown to be one of the most important determinants of water quality and biotic integrity. Riparian vegetation can influence the movement of water, sediments, and nutrients into streams and also influences instream physical habitat and temperature (Naiman 1997). Riparian vegetation also influences the trophic status of streams by influencing light penetration that fuels instream primary production and by providing energy inputs such as leaf litter (Vannote et al. 1980). Historically, riparian vegetation in this region was primarily forest, but human activities have greatly altered this pattern (fig. 5). Of the 40 major drainages in the assessment area, only 22 percent—including the Blue Sinking and upper Green watersheds—have greater than 75 percent forested riparian vegetation, and 63 percent have between 25 and 75 percent forested riparian zones. Conversely, 75 percent—including the Little River Ditches and Lower Wabash catchments—have >50 percent agricultural and urban riparian zones, and only 15 percent have less than 20 percent agricultural and urban riparian zones.

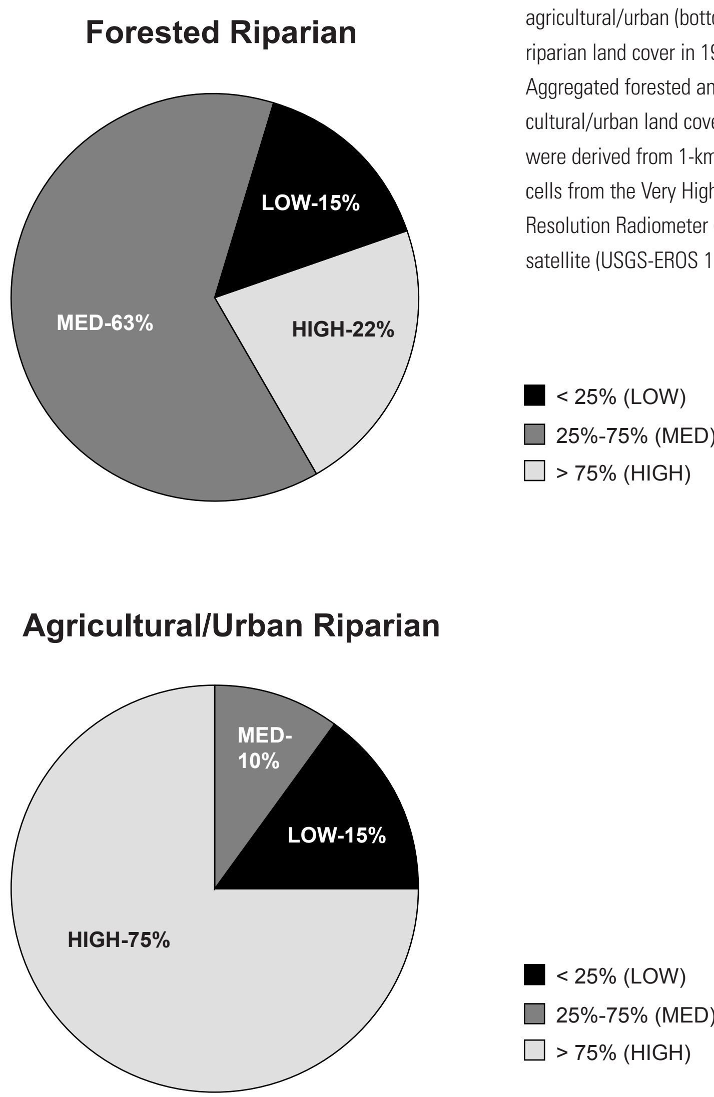


Figure 5. Percentage of watersheds (N=40) within the Hoosier-Shawnee assessment area that contained low, moderate, or high forested (top) or agricultural/urban (bottom) riparian land cover in 1990. Aggregated forested and agricultural/urban land cover data, were derived from 1-km grid cells from the Very High Resolution Radiometer (AVHRR) satellite (USGS-EROS 1990).

Aside from occasional studies on individual stream reaches, there is little quantitative information on instream habitats across the assessment area. In one of the few comprehensive studies in the region, Hite et al. (1990) surveyed 14 streams in the Shawnee National Forest during 1986-1987 and found that conditions varied greatly in the region, but that the streams they examined generally had good physical habitat, water quality, and biological integrity. In particular, they noted that streams such as Big, Lusk, and Big Grand Pierre Creeks (lower Ohio-Bay drainage) and upper Clear and upper Miller Creeks (upper Mississippi-Cape Girardeau), which drain forested uplands, were exceptional in quality. In contrast, streams that drained agricultural areas, such as Bay and Cedar Creeks (lower Ohio-Bay drainage) and lower Clear Creek (upper Mississippi-Cape Girardeau), were relatively degraded. Hite et al. (1990) noted that riparian land use was a major determinant of stream quality in the region and cited loss of riparian vegetation, sediment and nutrient inputs from crop fields, and unregulated ATV traffic as threats to stream habitat quality and biological integrity in the region. Similarly, Muir et al. (1995) found better stream conditions in relatively undisturbed uplands of the Cache River basin compared to lower stream reaches draining agricultural areas.

Stream biodiversity, ecosystem function, and overall health are generally maximized when habitat heterogeneity is high (Allan 1995). Habitat heterogeneity in streams is largely a function of substrates (e.g., a mix of substrate particle sizes with some stable substrate types present) and channel morphology and current dynamics (e.g., sinuosity and regular riffle-pool sequences) (Allan 1995). Although high habitat heterogeneity is evident in some stream reaches in the study area, particularly in headwaters and mid-reaches, land use patterns in much of the region and the large number of systems impacted by sediments result in poor physical habitat quality in many stream reaches (Hite et al. 1990, Muir et al. 1995).

A large portion of streams in the assessment area drain agricultural landscapes and have been channelized to maximize drainage of the land. Channelization of streams degrades instream and riparian habitat, including reaches upstream of the channelized segments. Subtle changes in elevation at the upstream end of channelized reaches causes formation of migrating head cuts that result in downcutting and widening of upstream reaches, and thus increases bank erosion and sedimentation. Channelized stream reaches also have reduced capacity to dissipate stream energy, further enhancing erosion and sedimentation.

Streams draining agricultural regions of the assessment area are also vulnerable to sediment inputs from exposed soils in croplands. As an example, Big Creek in Union County, Illinois (Cache drainage) has high quality instream habitat and harbors a high diversity of aquatic species in upper reaches where it is protected by extensive riparian forest. However, stream habitat and the inhabitant community degrade rapidly downstream as it approaches the Cache River where it flows through extensive cropland, including channelized reaches with minimal riparian forest cover. As a result, this stream is a current focus of restoration activities by the Illinois Department of Natural Resources and Illinois Environmental Protection Agency (Guetersloh 2001).

In addition to water quality, instream physical habitat is also important to the integrity of stream ecosystems. Although water quality and instream habitat quality are often related, improvements in water quality without consideration of instream habitat quality may not produce benefits in terms of biodiversity and stream ecosystem function.

Lakes and Reservoirs

Aside from oxbows associated with larger rivers, and a few sinkhole ponds located in southern Indiana and eastern Missouri, there are no natural lakes in the Hoosier-Shawnee study area. Nonetheless, human activities (i.e., dam construction) have resulted in an abundance of lentic habitats that are used for flood control, recreation, and water supplies (table 5). The Shawnee National Forest alone contains more than 200 small (<5 acre) ponds that were constructed to serve as watering stations for wildlife and provide habitat for birds, fish, aquatic invertebrates, and breeding amphibians. It has also been suggested that these forest ponds are important feeding and watering areas for resident bats, including the federally endangered Indiana bat (*Myotis sodalis*).

The reservoirs within the Hoosier-Shawnee Ecological Assessment Area are primarily warmwater systems with relatively high primary productivity (primarily eutrophic; Bremigan and Stein 1999, DiCenzo et al. 1996), and the general trend is for decreasing fertility from west to east within the study area. High primary productivity has been linked with high standing biomass of fish (Ney 1996). However, detrimental or undesirable species often become disproportionately represented in fish assemblages under these conditions (Stein et al. 1995). Hence, the high productivity in many of the reservoirs within the assessment area may have negative impacts on the recreational quality of the fish resource. Similarly, high productivity can create water quality problems associated with unchecked algal growth and reductions in oxygen concentrations.

Productivity, water clarity, and fish production within reservoirs are strongly influenced by land use practices within their drainage areas. Reservoirs within the study area have drainage areas that are on average 2,178 times larger than their surface area, although roughly half only drain areas 27 times or less of the reservoir surface area (table 6). Management of reservoirs in the study area will require an understanding of the linkages between human activities (e.g., land use) in the drainage area and water quality. Because these systems are strongly linked to the watershed, agricultural practices, urban runoff,

Table 5. Number of lakes and total lake surface area within each hydrologic unit (watershed) in the Hoosier-Shawnee assessment area.

Watershed	Number of lakes	Total lake area (acres)
Barren	127	16,173
Big Muddy	742	42,236
Blue Sinking	102	1,333
Cache	33	2,060
Cahokia-Joachim	210	4,011
Driftwood	150	2,551
Eel	383	7,905
Highland-Pigeon	194	4,598
Little River Ditches	186	4,606
Lower Cumberland	357	68,209
Lower East Fork White	242	16,845
Lower Green	70	789
Lower Kaskaskia	385	6,174
Lower Missouri	214	3,883
Lower Ohio	219	3,467
Lower Ohio Bay	202	2,302
Lower Ohio-Little Pigeon	248	4,125
Lower Tennessee	66	856
Lower Wabash	151	4,937
Lower White	229	2,966
Meramec	190	2,676
Middle Green	147	2,900
Middle Wabash - Little Vermilion	155	4,279
Muscatatuck	161	3,346
New Madrid- St. Johns	79	1,177
Patoka	240	11,706
Peruque-Piasa	159	2,867
Pond	153	2,275
Red	111	745
Rolling Fork	99	1,251
Rough	107	7,222
Saline	372	6,453
Salt	229	3,414
Silver-Little Kentucky	174	2,110
Tradewater	119	3,136
Upper East Fork White	101	1,591
Upper Green	149	38,917
Upper Mississippi	277	4,931
Upper White	439	11,569
Whitewater	97	1,459

Table 6. Mean (±1SD) and median surface area of lakes and their drainages in the ecological units of the Hoosier-Shawnee assessment area.

Statistic	Surface area (acres)	Drainage area (mi^2)	Drainage area (acres): surface area (acres)
Mean	364	1,232	2,178
Standard Deviation	2,197	12,561	6,574
Median	16	1	27

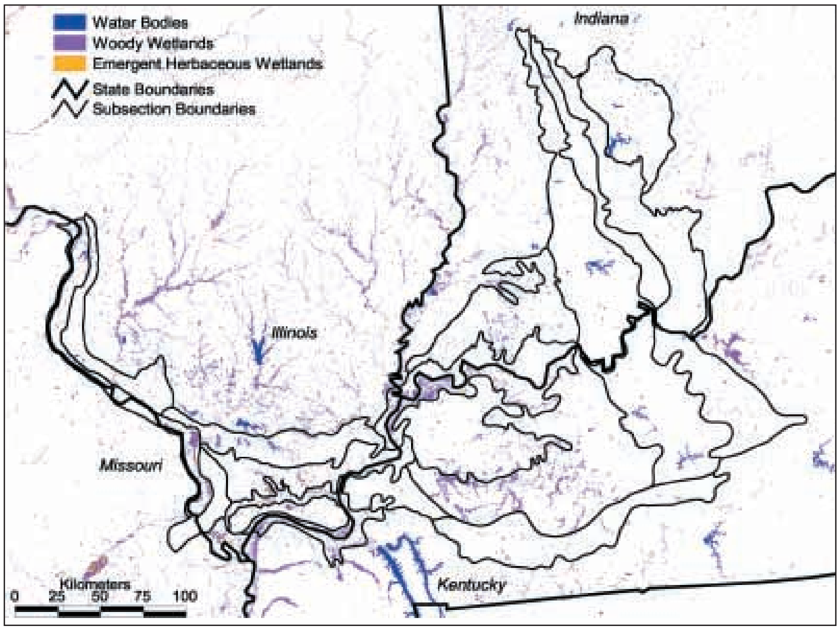


Figure 6. Lakes, reservoirs, and wetlands in the Hoosier-Shawnee assessment area.

and wastewater discharge can greatly affect system productivity with detrimental effects to fish assemblages and water quality. Thus, as with other freshwater resources, an awareness of land use patterns is necessary for proper management of lentic resources in the region.

There are a total of 8,068 lakes and reservoirs in the Hoosier-Shawnee study area, totaling 314,048 acres of surface area (table 5, fig. 6). The lower Cumberland, Big Muddy, and upper Green stand out as having much greater total surface areas of reservoirs than the other catchments in the study area. Both the lower Cumberland and upper Green watersheds contain reservoirs with large surface areas (e.g., ranging from 143,137 to 170,924 acres) and high storage capacities including Kentucky Lake, Lake Barkley, and Nolin Lake. The reservoirs within the Big Muddy watershed are only moderately sized (e.g., Cedar and Crab Orchard Lakes at 1,704 and 6,916 acres, respectively), but their high abundance (N=742) generates a high total surface area. Mean surface area of lakes and reservoirs in the assessment area is 364 acres. However, half of the reservoirs are less than 16 acres in surface area (table 6, fig. 6).

Although they can provide numerous benefits, reservoirs can also have negative ecological impacts. In particular, impounding streams changes both the physical (e.g., flow, depth, temperature, sediments) and biological aspects of lotic systems, and can result in isolation of stream reaches. The decline and/or loss of numerous aquatic species is linked to impoundments (Ricciardi and Rasmussen 1999, Richter et al. 1997, Vaughn and Taylor 1999), and Schrank et al. (2001) recently demonstrated that even very small impoundments (e.g., cattle ponds <2 acres) on streams in the Midwest were linked to the absence of a now federally endangered fish species, the Topeka shiner (Notropis topeka). Further, reservoirs can exacerbate regional water quantity problems by enhancing evaporation (Wetzel 2001). Given the number of impoundments that already exist on streams of the assessment area, there have undoubtedly been negative ecological impacts.

For existing impoundments, dam breaching or removal may be an option for reversing deleterious environmental effects. This strategy has been effectively implemented in many states to improve fish passage and to improve instream water quality (Bednarek 2001, Smith et al. 2000). When dams deteriorate, removal may be a particularly viable option if the positive environmental benefits outweigh the high costs of repairs. Water resource managers must carefully consider the consequences of removal projects because community support has not been historically strong, given the loss of impounded waters for recreation (Born et al. 1998). Any planned removal projects in the Hoosier-Shawnee Ecological Assessment Area would likely have socioeconomic and environmental consequences (Bednarek 2001, Born et al. 1998).

Wetlands and Springs

Wetlands are generally defined as areas where the water table is at or near the land surface, soils are hydric, and dominant plants are hydrophytes. Wetlands may be difficult to define, but they are almost universally regarded as ecosystems that are vital to regional biodiversity and water quality. In Illinois, it is estimated that >40 species of threatened or endangered birds and ~30 threatened or endangered fish species use wetland habitats (CTAP 1994). Further, a large number of amphibian species, a group that is currently of great interest due to massive declines and extinctions across the globe, are associated with wetlands (Stebbins and Cohen 1995). Wetlands also provide important recreational opportunities in the form of waterfowl hunting and fishing. Wetlands are important in hydrological processes and help control flooding during wet periods and maintain base flows during dry periods (Mitsch and Gosselink 1993). Wetlands mediate the impacts of excess nutrients and may facilitate the uptake of pollutants, and it is usually more economically feasible to preserve wetlands than to build water treatment plants (Chichilnisky and Heal 1998). Although the importance of wetlands is now widely accepted, they are one of the most beleaguered ecosystems in North America, and the current extent of wetland habitats across the country is only a fraction (<50 percent) of historical conditions (Vileisis 1997).

Wetland area, and the proportion of catchments classified as wetland, varies considerably across the Hoosier-Shawnee study area (table 7, fig. 6). However, no single catchment in the region has >7 percent woody and >3 percent herbaceous wetland areas. Woody wetlands are characterized by areas where forest or shrubland vegetation accounts for >25 percent of the vegetation cover and the soil is periodically saturated with or covered by water (e.g., swamps). Herbaceous wetlands, the less common of the two, are areas in which perennial herbaceous vegetation accounts for >75 percent of the cover, with the same hydric soil characteristics as the former (e.g., marshes). Wetlands in the study region are fed by precipitation, surface runoff, groundwater, or various combinations of each.

Table 7. Total area (square miles) and proportion of watershed area of woody and herbaceous vegetation wetlands within each USGS hydrological unit (watershed) of the Hoosier-Shawnee assessment area.

	Area (mi^2)		Proportion of watershed area	
Watershed	**Woody**	**Herbaceous**	**Woody**	**Herbaceous**
Barren	23	1.6	0.0103	0.0007
Big Muddy	142	15.0	0.0596	0.0063
Blue Sinking	6	0.3	0.0033	0.0002
Cache	20	7.6	0.0571	0.0212
Cahokia-Joachim	40	5.6	0.0240	0.0034
Driftwood	9	0.4	0.0076	0.0003
Eel	4	0.4	0.0032	0.0003
Highland-Pigeon	56	4.3	0.0564	0.0043
Little River Ditches	58	4.3	0.0221	0.0016
Lower Cumberland	21	2.0	0.0090	0.0009
Lower East Fork White	5	1.1	0.0023	0.0005
Lower Green	35	1.9	0.0374	0.0021
Lower Kaskaskia	80	4.9	0.0501	0.0031
Lower Missouri	32	4.0	0.0198	0.0025
Lower Ohio	56	9.7	0.0602	0.0105
Lower Ohio Bay	48	7.9	0.0442	0.0073
Lower Ohio-Little Pigeon	21	1.6	0.0146	0.0012
Lower Tennessee	43	0.4	0.0612	0.0005
Lower Wabash	67	8.3	0.0507	0.0063
Lower White	14	0.6	0.0084	0.0004
Meramec	12	2.6	0.0055	0.0012
Middle Green	42	1.9	0.0411	0.0018
Middle Wabash-Little Vermilion	60	5.0	0.0264	0.0022
Muscatatuck	22	0.4	0.0195	0.0003
New Madrid- St. Johns	27	3.7	0.0369	0.0051
Patoka	14	1.8	0.0162	0.0021
Peruque-Piasa	24	4.5	0.0369	0.0067
Pond	52	3.6	0.0654	0.0045
Red	38	3.4	0.0272	0.0024
Rolling Fork	27	0.7	0.0185	0.0005
Rough	19	0.3	0.0177	0.0003
Saline	50	6.1	0.0424	0.0052
Salt	23	1.1	0.0154	0.0007
Silver-Little Kentucky	15	1.1	0.0117	0.0009
Tradewater	57	1.3	0.0613	0.0014
Upper East Fork White	7	0.1	0.0085	0.0001
Upper Green	28	0.6	0.0090	0.0002
Upper Mississippi	56	10.8	0.0337	0.0065
Upper White	19	1.4	0.0069	0.0005
Whitewater	9	1.2	0.0077	0.0010

Predictably, most wetlands in the assessment area are located in low, floodplain areas associated with the larger river systems (fig. 6). However, even these areas have only a fraction of their original wetlands remaining, due mostly to agricultural activities that required draining most of the original wetlands. This pattern is of particular concern, as it has been demonstrated that floodplain wetlands are an important component of large river function and productivity (e.g., Junk et al. 1989). The consequences of floodplain wetland loss to large river health in the region are still not fully understood, and this issue certainly deserves more attention.

Currently, the average proportion of woody and herbaceous wetlands in the entire study region is only 2.8 percent and 0.3 percent, respectively, and Illinois ranks as one of the top 10 states in the U.S. in terms of wetland loss (>70 percent loss for the state). There are also indications that many remaining wetland systems in the region are polluted. Historically, wetlands have been used extensively as dumping areas, and thus many may be polluted with a variety of contaminants. For example, a large portion of the >3,000 sites that have been used for waste disposal in Illinois are located in wetlands, and 8 percent of the wetlands in the state are located within 1 mile of a landfill or open dump (CTAP 1994). Clearly, wetlands are limited and imperiled in the study region and could be primary targets for conservation and restoration activities on this basis.

A variety of spring habitats are found throughout the assessment area, but their occurrence is poorly documented and there is little information on the hydrology and biology of these important freshwater habitats in this region. Typically, springs occur where the water table meets the land surface, and they range greatly in size, from small seeps to large features with substantial discharge that contribute greatly to surface waters. The LaRue-Pine Hills Ecological Area in Union County, Illinois (Upper Mississippi Cape Girardeau watershed), is an example of a region within the study area that is rich in wetland and spring habitats. Spring habitats contribute greatly to the high biodiversity of the area, supporting a great diversity of aquatic species, including the spring cavefish (*Forbesicthys agassizi*) and cave salamander (*Eurycea lucifuga*) that are associated with the numerous spring seeps found on the property.

Because both wetlands and springs are closely linked to groundwater dynamics, monitering of groundwater quality and withdrawals is important for their conservation. Even small reductions in groundwater resources can have large impacts on the hydrology of wetland and spring habitats (Carter 1996, Hunt et al. 1999), and groundwater contamination, particularly in karst regions, will also negatively impact wetlands and springs.

WATER QUALITY PATTERNS

Watershed integrity, as characterized by the USEPA's Index of Watershed Indicators (IWI), in 1999 varied greatly among the watersheds within the Hoosier-Shawnee study area (table 8). These scores are a composite of several factors that influence water quality and vulnerability within each watershed, and lower scores reflect better overall conditions (see Approach section, table 2).

Eight of the forty watersheds were assigned a score of 1, indicating these were areas of high integrity and low vulnerability to perturbations (table 8). These catchments typically contained only a few systems that did not meet water quality standards (table 8). Conversely, 14 watersheds had IWI scores of 5-6, suggesting that water quality was relatively poor in these areas (table 8). An average of 21 lakes and streams failed to meet water quality standards within these watersheds. Drainages that were assigned the highest score of 6 contained lakes and streams with high nutrients, contaminants, and pathogens (table 8). Overall, nutrients and contaminants account for >50 percent of water quality problems within the Hoosier-Shawnee Ecological Assessment Area

Table 8. USEPA's index of watershed integrity (IWI) and number of 303d listed streams and lakes (1998) within each hydrologic unit (watershed) of the Hoosier-Shawnee assessment area. Systems with nutrient contamination commonly have high biological oxygen demand and low dissolved oxygen. Common contaminants within streams and lakes are heavy metals (e.g., mercury, lead), PCBs, and pesticides. Habitat alterations include flow changes and channel modification.

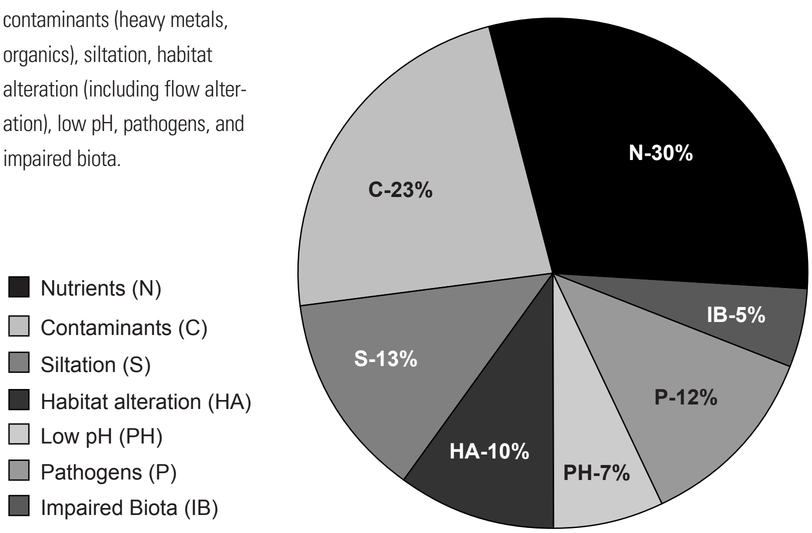
			Proportion of systems						
Watershed	IWI	No. of systems	Nutrients	Contaminants	Siltation	Habitat alteration	Low pH	Pathogens	Impaired biota
Barren	2	8	0.50	0.25	0.00	0.13	0.00	0.13	0.00
Big Muddy	5	78	0.49	0.15	0.27	0.01	0.08	0.00	0.00
Blue Sinking	4	4	0.00	0.50	0.00	0.00	0.00	0.50	0.00
Cache	5	16	0.50	0.00	0.19	0.31	0.00	0.00	0.00
Cahokia-Joachim	5	25	0.36	0.20	0.24	0.16	0.00	0.04	0.00
Driftwood	NA	6	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Eel	3	12	0.00	0.25	0.00	0.00	0.00	0.42	0.33
Highland-Pigeon	6	4	0.25	0.50	0.00	0.00	0.00	0.25	0.00
Little River Ditches	1	3	0.00	0.33	0.67	0.00	0.00	0.00	0.00
Lower Cumberland	1	6	0.50	0.00	0.33	0.00	0.00	0.17	0.00
Lower East Fork White	4	12	0.00	0.58	0.00	0.00	0.00	0.08	0.33
Lower Green	3	8	0.13	0.00	0.25	0.63	0.00	0.00	0.00
Lower Kaskaskia	5	18	0.78	0.06	0.11	0.00	0.06	0.00	0.00
Lower Missouri	3	2	0.00	0.50	0.00	0.50	0.00	0.00	0.00
Lower Ohio	5	20	0.40	0.15	0.10	0.20	0.10	0.05	0.00
Lower Ohio Bay	3	22	0.36	0.05	0.18	0.36	0.00	0.05	0.00
Lower Ohio-Little Pigeon	3	5	0.20	0.60	0.00	0.00	0.00	0.20	0.00
Lower Tennessee	1	3	0.33	0.00	0.33	0.00	0.00	0.33	0.00
Lower Wabash	5	8	0.38	0.13	0.38	0.00	0.00	0.13	0.00
Lower White	4	18	0.00	0.22	0.00	0.00	0.00	0.33	0.44
Meramec	1	2	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Middle Green	3	11	0.36	0.09	0.09	0.09	0.18	0.18	0.00
Middle Wabash-Little Vermilion	5	12	0.08	0.50	0.08	0.00	0.00	0.00	0.33
Muscatatuck	3	1	0.00	1.00	0.00	0.00	0.00	0.00	0.00
New Madrid-St. Johns	5	1	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Patoka	1	3	0.00	0.67	0.00	0.00	0.00	0.00	0.33
Peruque-Piasa	4	6	0.00	0.33	0.17	0.50	0.00	0.00	0.00
Pond	3	10	0.00	0.20	0.00	0.10	0.60	0.10	0.00
Red	1	13	0.31	0.08	0.46	0.08	0.00	0.08	0.00
Rolling Fork	4	7	0.29	0.00	0.00	0.00	0.43	0.29	0.00
Rough	1	4	0.75	0.00	0.00	0.25	0.00	0.00	0.00
Saline	5	45	0.29	0.27	0.09	0.16	0.20	0.00	0.00
Salt	6	19	0.32	0.26	0.00	0.05	0.00	0.37	0.00
Silver-Little Kentucky	6	17	0.29	0.47	0.00	0.06	0.00	0.18	0.00
Tradewater	3	7	0.29	0.14	0.14	0.00	0.29	0.14	0.00
Upper East Fork White	5	3	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Upper Green	3	10	0.30	0.30	0.00	0.10	0.00	0.30	0.00
Upper Mississippi	5	16	0.63	0.06	0.06	0.25	0.00	0.00	0.00
Upper White	6	37	0.03	0.32	0.00	0.00	0.05	0.46	0.14
Whitewater	1	0	NA	NA	NA	NA	NA	NA	NA

(fig. 7). Siltation, habitat alterations, and pathogens were responsible for an additional 35 percent of water quality problems (fig. 7). Impaired biota and low pH were relatively rare occurrences in the listed systems.

This analysis suggests that nutrient loading, presumably from agricultural activities and wastewater discharges, plus contaminants from industry and sediments from agriculture are the primary factors negatively affecting water quality within much of this region. Agricultural conservation programs (e.g., implementing best management practices such as conservation tillage and vegetated riparian buffers), municipal nutrient abatement, and regulation/monitoring of industrial practices appear to be necessary to prevent further degradation of water quality and to allow current systems to meet federally mandated water quality standards. Unfortunately, many of these problems, particularly nutrient additions from agricultural activities, are non-point source, and these are often more difficult to assess and remediate than point-source issues. In general, non-point pollution issues are best dealt with at the watershed scale and may require relatively long periods of time before improvements to aquatic habitats are evident.

To address management and remediation of non-point threats to water quality and stream integrity at the watershed scale, the Illinois Department of Natural Resources, along with other private, State, and Federal entities, implemented the Pilot Watersheds Program in 1998, with one pair of watersheds (Big Creek and Cypress Creek in the Cache drainage) located in the Hoosier-Shawnee region. This program is designed to monitor changes in hydrology, water quality, instream habitat, and biological integrity in paired watersheds through time as best management practices such as vegetated riparian buffers, conservation tillage agriculture, and instream habitat restorations are implemented.

Figure 7. Percentage of USEPA 303d-listed streams and lakes (N= 344) within the ecological units of the Hoosier-Shawnee assessment area in 1998 that have been categorized as failing to meet water quality standards relative to nutrients (including high BOD), contaminants (heavy metals, organics), siltation, habitat alteration (including flow alteration), low pH, pathogens, and impaired biota.



WATER USE TRENDS

Patterns of water use in the assessment area provide insight into potential sources of water loss and contamination. Trends between 1990 and 1995 provide some sense of past and future changes through time. During 1990 and 1995, the number of wastewater facilities varied among watersheds, largely as a function of resident population density and industrial activity (table 9). The total number of wastewater facilities increased only by 2 percent between 1990 and 1995. If nutrient and contaminant loading from these facilities is roughly proportional to their abundance, we may predict that wastewater point sources of these pollutants are not increasing appreciably.

Average per capita offstream water use within the study region was 3,055 and 3,075 gallons.d^{-1} in 1990 and 1995, respectively (table 10), which is higher than the national average of 2,000 gallons.d^{-1} (Dodds 2002). Offstream use is water diverted or withdrawn from a surface or groundwater source and conveyed to a place of use (Solley et al. 1998). Per capita offstream use for the States of Illinois, Indiana, Kentucky, and Missouri was 1,680, 1,570, 1,150, and 1,320 gallons.d^{-1} during this time (Solley et al. 1998). Thus, average water use per person is generally higher in the assessment area than in the states in which it resides. It is important to note that per capita use varied widely among watersheds within the region; per capita use was less than 376 gallons.d^{-1} in half of the watersheds (table 10). Nationally, per capita water use has declined since the early 1980s due to increased efficiency of use, particularly with agriculture (Dodds 2002, Solley et al. 1998). In comparison, change in per capita use varied widely between 1990 and 1995 within each watershed of the assessment area (table 10).

Total groundwater and surface water use within the entire Hoosier-Shawnee Ecological Assessment Area increased by about 11 percent from 1990 through 1995 (table 11). Surface water use was approximately 16 times greater than groundwater use during both years, primarily due to thermoelectric power generation (fig. 8). Total water use varied greatly among watersheds. Power plants and other factors such as irrigation influenced this variability among catchments. Below, we explore factors influencing differences in total water use.

Water use for irrigation and livestock was particularly important in the Little River Ditches, lower White, and New Madrid-St. Johns watersheds (table 12). Total water use for agriculture increased by an average of 50 percent between 1990 and 1995 but was relatively minor compared to various other water uses (fig. 8). Total domestic water use was relatively low during both years (fig. 8) and changed only 4 percent between years (table 12). Highest domestic use (i.e., for residential use) occurred in upper White, the watershed with the highest human population density. Mining was a relatively minor consumer of total water within the entire region (fig. 8), but use increased by more than 100 percent between 1990 and 1995 (table 12). Watersheds with high water consumption by mining activities typically overlapped subsections such as the Interior and Outer Western Coal Fields of the Shawnee Hills Section. As is typical nationally (Solley et al. 1998), power generation consumed the most water in the region during both years (fig. 8), but total consumption increased by only an average of 5 percent during 1990 through 1995 (table 12). Power generation varied greatly among watersheds, likely due to the availability of cooling sources such as large

Table 9. Number of wastewater facilities during 1990 and 1995 within each hydrologic unit (watershed) of the Hoosier-Shawnee assessment area.

	Number of facilities	
Watershed	**1990**	**1995**
Barren	45	41
Big Muddy	103	79
Blue Sinking	38	37
Cache	8	7
Cahokia-Joachim	190	167
Driftwood	45	45
Eel	28	24
Highland-Pigeon	34	34
Little River Ditches	83	59
Lower Cumberland	36	74
Lower East Fork White	39	29
Lower Green	61	61
Lower Kaskaskia	49	39
Lower Missouri	139	150
Lower Ohio	46	39
Lower Ohio Bay	21	23
Lower Ohio-Little Pigeon	14	49
Lower Tennessee	55	54
Lower Wabash	20	20
Lower White	29	29
Meramec	133	141
Middle Green	25	25
Middle Wabash-Little Vermilion	40	45
Muscatatuck	26	19
New Madrid-St. Johns	15	15
Patoka	10	10
Peruque-Piasa	41	42
Pond	22	22
Red	18	9
Rolling Fork	29	29
Rough	31	31
Saline	14	13
Salt	96	96
Silver-Little Kentucky	177	176
Tradewater	23	23
Upper East Fork White	26	25
Upper Green	63	63
Upper Mississippi	49	42
Upper White	98	107
Whitewater	48	38

rivers or reservoirs. Public supply (i.e., public source for public and residential use) was another major consumer of water in the entire assessment region during 1990 and 1995 (fig. 8), increasing by 13 percent during this period (table 12). As with domestic use, differences in public use among watersheds varied positively with population density (table 12). Commercial water use changed little (<1 percent) during the 5 years, with high consumption in the Cahokia-Joachim, lower Ohio-Little Pigeon, Salt, and upper White watersheds (table 12). Commercial consumption ranked second to thermoelectric power generation in total consumption (fig. 8).

Table 10. Per capita (gallons/day) offstream water use during 1990 and 1995 in each hydrological unit (watershed) of the Hoosier-Shawnee assessment area.

Watershed	1990	1995
Barren	145	199
Big Muddy	361	280
Blue Sinking	227	341
Cache	66	131
Cahokia-Joachim	1,167	1,386
Driftwood	144	167
Eel	142	190
Highland-Pigeon	310	350
Little River Ditches	1,353	2,099
Lower Cumberland	15,608	20,913
Lower East Fork White	285	303
Lower Green	3,059	3,093
Lower Kaskaskia	3,258	3,655
Lower Missouri	2,878	2,513
Lower Ohio	19,819	21,399
Lower Ohio Bay	169	304
Lower Ohio-Little Pigeon	10,853	11,048
Lower Tennessee	460	749
Lower Wabash	731	1,042
Lower White	3,289	3,283
Meramec	220	203
Middle Green	9,196	9,173
Middle Wabash-Little Vermilion	2,732	2,722
Muscatatuck	135	150
New Madrid-St. Johns	30,184	22,666
Patoka	361	255
Peruque-Piasa	3236	2,855
Pond	2,119	2,198
Red	120	177
Rolling Fork	220	199
Rough	237	119
Saline	1,298	224
Salt	292	292
Silver-Little Kentucky	4,581	4,763
Tradewater	243	210
Upper East Fork White	270	347
Upper Green	201	176
Upper Mississippi	1,545	1,981
Upper White	390	444
Whitewater	283	397

The surface waters of the assessment region are important for recreational use. In the U.S. in 1991, $15.1 billion was spent on freshwater angling, and 63 percent of non-consumptive outdoor recreation visits in the U.S. included lakeside or streamside destinations (U.S. Department of Interior 1993). In 1996, Illinois waters received about 20 million angling days, and anglers averaged 15 trips.year^{-1} (U.S. Fish and Wildlife Service 1996a). Over $1.6 billion were spent on angling during 1996 in Illinois (U.S. Fish and Wildlife Service 1996a). In Indiana, water use for angling is less than that in Illinois; anglers performing 16.5 million angling days, for an average of about 19 days per angler and $800 million (U.S. Fish and Wildlife Service 1996b). Fishing statistics in Kentucky are similar to those in Indiana, with 15 average days per angler, 10.6 million angling days, and $718 million in revenue (U.S. Fish and Wildlife Service 1996c). These statewide values demonstrate the clear importance of recreational use to the local economy as well as aquatic resources within the Hoosier-Shawnee region. To illustrate, the value of the fishery at Lake Monroe, Indiana, was estimated at $2.16 million during April through October 1991 (Andrews 1992). These statewide statistics suggest that the greatest use of surface waters for fishing should be in the Illinois portion of the study region, but that angling and other nonconsumptive uses are quite important throughout the study region. It also is important to note that some commercial fishing occurs in several rivers within the assessment area, including the Wabash, Ohio, and Cumberland.

Table 11. Total groundwater and surface water use (million gallons/day) during 1990 and 1995 within each hydrologic unit (watershed) of the Hoosier-Shawnee assessment area.

	Groundwater		Surface water		Totals	
Watershed	**1990**	**1995**	**1990**	**1995**	**1990**	**1995**
Barren	3	3	22	26	25	29
Big Muddy	30	9	1	44	31	54
Blue Sinking	18	19	8	20	26	39
Cache	1	2	0	0	1	2
Cahokia-Joachim	62	77	1,368	1,467	1,430	1,544
Driftwood	21	25	3	5	24	30
Eel	7	9	3	2	10	12
Highland-Pigeon	7	7	70	78	77	85
Little River Ditches	166	277	0	3	166	280
Lower Cumberland	2	4	1,666	2,228	1,669	2,231
Lower East Fork White	5	6	27	28	33	34
Lower Green	16	19	251	250	266	270
Lower Kaskaskia	7	9	0	1,180	7	1,189
Lower Missouri	18	14	1,151	1,007	1,170	1,021
Lower Ohio	13	14	1,480	1,598	1,493	1,612
Lower Ohio Bay	3	5	2	4	5	9
Lower Ohio-Little Pigeon	44	44	1,122	1,143	1,166	1,187
Lower Tennessee	8	11	19	33	27	44
Lower Wabash	12	19	30	39	41	58
Lower White	13	16	541	539	554	554
Meramec	15	16	52	44	67	60
Middle Green	1	1	396	396	397	397
Middle Wabash-Little Vermilion	59	65	469	461	527	526
Muscatatuck	2	2	8	8	9	10
New Madrid-St. Johns	23	43	1,057	767	1,080	811
Patoka	3	2	13	9	16	12
Peruque-Piasa	32	29	657	579	689	608
Pond	2	2	108	110	110	112
Red	9	2	8	19	17	21
Rolling Fork	6	2	16	17	21	19
Rough	9	2	5	6	14	8
Saline	11	12	77	3	87	15
Salt	17	15	120	123	137	138
Silver-Little Kentucky	38	39	2,310	2,402	2,348	2,441
Tradewater	3	4	11	9	15	14
Upper East Fork White	14	18	6	8	21	26
Upper Green	12	4	22	24	34	28
Upper Mississippi-Cape Girardeau	9	12	149	187	158	199
Upper White	108	115	425	493	533	608
Whitewater	7	12	3	2	11	15

Table 12. Combined groundwater and surface water (million gallons/day) used for commercial activities, domestic supply, mining, public supply, thermoelectric power generation, and agriculture during 1990 and 1995 within each hydrologic unit (watershed) of the Hoosier-Shawnee assessment area. Agriculture includes water used for irrigation and livestock.

	Agriculture			Domestic			Mining			Thermoelectric			Public Supply			Commercial		
Watershed	**90**	**95**	**Chng**	**90**	**95**	**Chng**	**90**	**95**	**Chng**	**90**	**95**	**Chng**	**90**	**95**	**Chng**	**90**	**95**	**Chng**
Barren	4	9	1.53	2	1	-0.61	0	0	NA	0	0	0.20	18	22	NA	0	1	s2.07
Big Muddy	3	2	-0.18	2	3	0.52	2	14	4.81	0	0	-0.05	25	23	NA	35	10	-0.73
Blue Sinking	2	2	0.14	2	2	-0.10	1	1	-0.35	0	0	0.06	8	8	NA	13	26	0.94
Cache	0	1	0.51	0	1	0.90	0	0	NA	0	0	-0.08	1	0	NA	0	0	-0.68
Cahokia-Joachim	2	2	0.09	4	11	1.80	1	0	-1.00	1,111	1,142	0.69	249	421	0.03	41	96	1.35
Driftwood	2	2	0.35	6	5	-0.01	1	1	0.54	0	0	0.08	12	13	NA	4	8	0.89
Eel	1	1	-0.06	2	2	0.09	1	1	-0.22	0	0	0.29	4	6	NA	1	2	0.49
Highland-Pigeon	1	1	0.46	3	2	-0.43	12	19	0.51	14	14	-0.01	37	37	-0.01	10	14	0.31
Little River Ditches	150	264	0.77	1	5	3.30	0	0	NA	4	0	0.18	16	19	-1.00	16	2	-0.89
Lower Cumberland	1	5	3.00	1	0	-0.70	0	0	6.50	1,649	2,196	0.33	17	23	0.33	0	11	157.00
Lower East Fork White	2	2	0.03	2	2	-0.07	4	0	-0.99	0	0	0.18	19	23	NA	5	7	0.24
Lower Green	1	1	0.36	1	0	-0.90	1	0	-0.68	245	245	0.15	12	14	0.00	6	9	0.68
Lower Kaskaskia	3	2	-0.37	3	5	0.50	0	2	4.29	1,048	1,174	0.03	5	5	0.12	0	0	1.00
Lower Missouri	2	3	0.53	2	2	-0.01	0	0	NA	1,069	958	-0.36	89	57	-0.10	7	1	-0.89
Lower Ohio	2	3	0.82	1	2	1.42	0	0	NA	1,449	1,565	0.03	9	10	0.08	32	32	0.00
Lower Ohio Bay	2	3	0.60	0	1	1.15	1	3	4.31	0	0	0.02	2	2	NA	0	0	1.00
Lower Ohio-Little Pigeon	1	2	0.26	2	1	-0.39	1	3	1.00	709	731	0.10	11	12	0.03	442	438	-0.01
Lower Tennessee	1	2	2.50	0	0	-0.17	0	0	NA	0	0	0.12	6	7	NA	20	35	0.78
Lower Wabash	3	4	0.21	1	1	0.02	3	3	0.06	29	40	1.39	4	9	0.37	0	0	4.50
Lower White	16	16	0.01	3	2	-0.21	2	7	3.34	523	517	0.09	8	9	-0.01	2	2	-0.29
Meramec	1	2	0.53	2	3	0.43	2	17	8.45	0	0	-0.25	50	38	NA	12	2	-0.85
Middle Green	1	1	0.36	1	0	-0.78	2	1	-0.47	389	389	0.06	4	4	0.00	0	1	4.27
Middle Wabash-Little Vermilion	2	2	0.17	4	4	-0.02	1	1	1.63	467	458	-0.03	20	20	-0.02	34	41	0.21
Muscatatuck	1	1	0.05	1	1	-0.08	2	3	0.06	0	0	0.11	4	4	NA	1	1	0.21
New Madrid-St. Johns	16	37	1.33	2	1	-0.74	0	0	NA	1,058	769	0.08	4	4	-0.27	0	0	-0.76
Patoka	2	2	0.02	1	1	-0.27	7	2	-0.72	0	0	0.04	7	7	NA	0	0	1.60
Peruque-Piasa	1	1	0.46	2	6	2.39	0	0	-1.00	643	565	0.05	24	25	-0.12	19	11	-0.43
Pond	1	1	0.32	1	0	-0.79	1	2	1.43	98	98	0.08	6	6	0.00	1	5	2.56
Red	2	6	2.14	4	0	-0.95	0	0	NA	0	0	0.30	11	15	NA	0	4	15.30
Rolling Fork	3	4	0.32	2	1	-0.70	0	0	NA	0	0	0.12	9	10	NA	7	4	-0.42
Rough	1	1	0.51	1	0	-0.74	1	0	-0.53	0	0	0.17	5	6	NA	6	0	-1.00
Saline	4	4	-0.12	1	1	-0.14	9	6	-0.35	70	0	0.24	3	4	-1.00	0	0	1.00
Salt	3	5	0.45	4	2	-0.33	0	0	NA	0	0	0.14	75	85	NA	55	45	-0.18
Silver-Little Kentucky	1	1	0.10	2	2	0.03	1	13	14.27	2,208	2,282	0.10	85	93	0.03	51	50	-0.03
Tradewater	1	1	0.42	1	0	-0.71	3	4	0.62	0	0	0.06	8	8	NA	2	0	-0.92
Upper East Fork White	3	3	0.02	2	2	-0.15	2	2	-0.08	0	0	0.39	12	17	NA	2	3	0.82
Upper Green	5	7	0.30	3	1	-0.60	0	0	NA	0	0	0.02	19	20	NA	6	1	-0.91
Upper Mississippi-Cape Girardeau	3	6	0.76	1	2	0.20	0	0	-0.44	143	180	0.29	8	11	0.26	1	1	-0.20
Upper White	3	3	0.09	23	22	-0.08	34	49	0.45	245	292	0.12	172	192	0.19	56	49	-0.11
Whitewater	4	10	1.42	1	1	-0.29	0	0	NA	0	0	-0.36	5	3	NA	0	0	-0.46

A recent General Circulation Model coupled with a BIOME-BGC ecosystem model predicted that evapotranspiration rates within the assessment region will change relatively little within the next 100 years, although annual precipitation will decline by about 10 percent (Jackson et al. 2001). The model assumed that atmospheric carbon dioxide would increase by 0.5 percent per year, with leaf area of terrestrial vegetation changing as a function of carbon dioxide, climate, water, and nitrogen availability. If this decline in precipitation occurs, the quantity of both surface water and groundwater will decline as a function of decreased recharge rates and increased atmospheric loss. Further, reduced flows in streams often translate into reduced water quality, particularly in regions with moderate to high population density where an appreciable component of baseflow is effluent from wastewater treatment plants. Within the region, the impact of these changes on lentic and lotic aquatic ecosystems and the regional economy is unknown, but is most likely to be adverse.

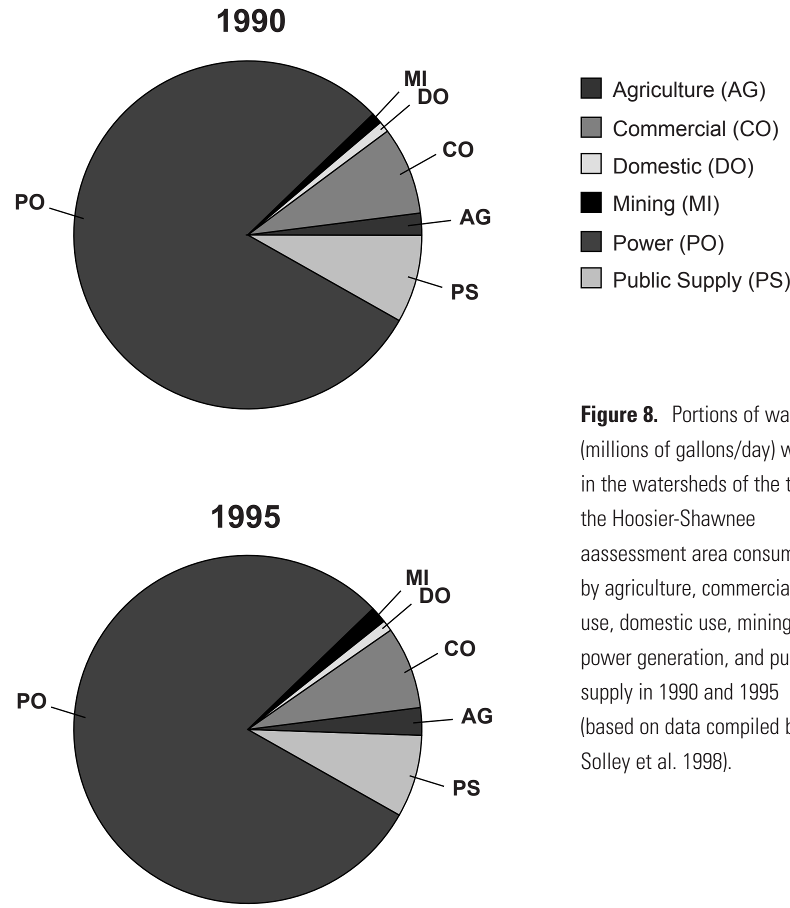


Figure 8. Portions of water (millions of gallons/day) within the watersheds of the the the Hoosier-Shawnee aassessment area consumed by agriculture, commercial use, domestic use, mining, power generation, and public supply in 1990 and 1995 (based on data compiled by Solley et al. 1998).

SUMMARY

Freshwater resources throughout the world are imperiled. Water resources within the Hoosier-Shawnee Ecological Assessment Area are no exception, and this necessitates that current resources and their condition be inventoried and carefully monitored to forge prudent decisions in the future. The 40 watersheds that intersect the region have a diverse array of surface water and groundwater characteristics. The regional aquifers are comprised of several geologic types, and karst areas within the region are potentially problematic because they allow for rapid movement of pollutants into and through groundwater resources. This situation mandates close scrutiny of land use and waste disposal practices, and an understanding of the interrelationships between groundwater and surface water habitats.

The region contains many streams and rivers, including segments of several large systems such as the Ohio and Mississippi Rivers. Little is known about the small headwater streams within this region, although these systems are often gravely affected by land use practices such as rowcrop agriculture, and their importance on a larger scale is just now becoming clear. Assessing the current condition of these headwater systems and understanding how they respond to land use change is necessary for gauging watershed condition. Stream riparian zones have been dramatically transformed in most of the region's watersheds, with a high proportion of streams bounded by relatively little forested vegetation. Because riparian vegetation is closely linked to freshwater resource quality, further losses of these areas will lead to increased water quality problems in both streams and reservoirs. Conversely, riparian restoration practices could result in significant improvements to freshwater resource quality in the region. It is also important that the role of instream habitat quality in promoting stream diversity and ecosystem function be understood, and that future monitoring and management efforts account for this vital component of stream health.

Lentic systems are abundant in the assessment area, although the vast majority have been constructed by humans. Like other freshwater habitats, these systems integrate land use practices, and productivity and sedimentation are often high across the region because of agricultural activities, with concomitant reductions in recreationally important fish and water quality. Improved land use practices such as increasing forested riparian zones of headwaters or installing upstream sediment catch basins may improve conditions in these systems.

Wetland habitats are scarce and fragmented in all watersheds of the assessment region, with less herbaceous than woody wetlands remaining. Remaining wetland areas are critical for maintaining watershed integrity because of ecosystem subsidies they provide. Additionally, wetland restoration activities in the region could produce large, tangible benefits to water quality, flood control, regional biodiversity, and waterfowl hunting.

Watershed integrity, as defined by USEPA, varies greatly among the watersheds within the assessment area. Of the 40 watersheds, 35 percent are in poor condition and 20 percent are in good condition. Watersheds receiving poor scores tended to have a high proportion of streams and reservoirs with high nutrient loads and contaminants (e.g., heavy metals and pesticides).

Average per capita water use within the region is relatively high by State and national standards, although estimates vary widely among watersheds. Most water use is devoted to thermoelectric power generation, with public supply being a distant but still substantive second. Agricultural use is relatively low in most areas, except for a few watersheds in the western region of the assessment area. Surface water use was 16 times greater than that of groundwater, with total use increasing by 11 percent during a recent 5-year period. In addition to serving consumptive needs, surface waters within the assessment area provide economically important recreational resources for fishing and other outdoor activities.

Future challenges for water resource management in the Hoosier-Shawnee Ecological Assessment Area are complex. Important issues include preventing any further degradation of water quality, reversing existing water and habitat quality problems, and preventing depletion of existing freshwater resources by the human population. Factors underlying these problems are similar to those in the rest of the country, primarily non-point source issues affecting water and habitat quality and population growth fueling water use. Fortunately, the human population of the Hoosier-Shawnee region is expected to grow at a lower rate than that of many other regions of the country. However, current global circulation models predict that annual precipitation will decline during the next century, and this could further tax the quantity and quality of freshwater resources, regardless of human population dynamics. A high priority for future research and management is investigations of linkages between land use practices and freshwater resource quality, with a particular focus on small, headwater streams in the region, a component of watershed management that has often been neglected. In particular, there is a need to quantitatively assess the effects of best management practices in agricultural landscapes on both groundwater and surface water habitats.

LITERATURE CITED

Allan, J.D. 1995.
Stream ecology. Dordrecht, The Netherlands: Kluwer Academic Press. 388 p.

Andrews, S.J. 1992.
Fishing pressure and fish harvest at Lake Monroe, 1991. Fish Manage. Rep. Indianapolis, IN: Indiana Department of Natural Resources, Division of Fish and Wildlife. Fisheries section. 15 p.

Bednarek, A.T. 2001.
Undamming rivers: a review of the ecological impacts of dam removal. Environmental Management. 27: 803-814.

Born, S.M.; Genskow, K.D.; Filbert, T.L.; et al. 1998.
Socioeconomic and institutional dimensions of dam removals: the Wisconsin experience. Environmental Management. 22: 359-370.

Bremigan, M.T.; Stein, R.A. 1999.
Larval gizzard shad success, juvenile effects, and reservoir productivity: toward a framework for multi-system management. Transactions of the American Fisheries Society. 128: 1106-1124.

Carter, Virginia. 1996.
Wetland hydrology, water quality, and associated functions, In: National water summary–wetland resources. U.S. Geological Survey Water-Supply Paper 2425. Washington, DC: U.S. Geological Survey: 35-48.

Chichilnisky, G.; Heal, G. 1998.
Economic returns from the biosphere. Nature. 391: 629-630.

Cooper, C.M. 1993.
Biological effects of agriculturally derived surface water pollutants on aquatic systems - a review. Journal of Environmental Quality. 22: 402-408.

CTAP. 1994.
The changing Illinois environment: critical trends. Springfield, IL: Illinois Critical Trends Assessment Project, Illinois Department of Energy and Natural Resource. 100 p.

Cummins, K.W. 1977.
From headwater streams to rivers. The American Biology Teacher: 305-312.

Cushing, C.E.; Allan, J.D. 2001.
Streams, their ecology and life. New York, NY: Academic Press. 366 p.

DiCenzo, V.J.; Maceina, M.J.; Stimpert, M.J. 1996.
Relations between reservoir trophic status and gizzard shad population characteristics in Alabama reservoirs. North American Journal of Fisheries Management. 16: 888-895.

Dodds, W.K. 2002.
Freshwater ecology: concepts and environmental applications. New York, NY: Academic Press. 569 p.

Dodds, W.K.; Evans-White, M.A.; Gerlanc, N.M.; et al. 2000.
Quantification of the Nitrogen cycle in a prairie stream. Ecosystems. 3: 574-589.

Gleick, P. 2000.
The world's water: The Biennial Report on Freshwater Resources. Washington, DC: Island Press. 310 p.

Guetersloh, M. 2001.
Big Creek watershed restoration plan. Report to the Cache River Watershed Resource Planning Committee. Springfield, IL: Pilot Watersheds Program, Illinois Department of Natural Resources. 52 p.

Hite, R.L.; Bickers, C.A.; King, M.M. 1990.
An intensive survey of Shawnee National Forest region streams of southern Illinois 1986-1987. Springfield, IL: Illinois Environmental Protection Agency, Division of Water Pollution Control, Planning Section.

Horn, C.R.; Hanson, S.A.; McKay, L.D. 1994.
History of the U.S. EPA's river reach file: a national hydrographic database available for ARC/INFO applications. Washington, DC: U.S. Environmental Protection Agency.

Hunt, R.J.; Walker, J.F.; Krabbenhoft, D.P. 1999.
Characterizing hydrology and the importance of groundwater discharge in natural and constructed wetlands. Wetlands. 19: 458-472.

Hynes, H.B.N. 1970.
The ecology of running waters. University of Toronto Press. 555 p.

Jackson, R.B.; Carpenter, S.R.; Dahm, C.N.; et al. 2001.
Water in a changing world. Ecological Applications. 11: 1027-1045.

Junk, W.J.; Bayley, P.B.; Sparks, R.E. 1989.
The flood pulse concept in river-floodplain systems. In: Dodge, D.P., ed. Proceedings of the International large river symposium. Canadian Special Publications of Fisheries and Aquatic Sciences. 106: 110-127.

Keys, J., Jr.; Carpenter, C.; Hooks, S.; et al. 1995.
Ecological units of the eastern United States – first approximation (map and booklet of map unit tables). Atlanta, GA: U.S. Department of Agriculture, Forest Service. 83 p.

Leopold, L.B.; Wolman, M.G.; Miller, J.P. 1964.
Fluvial processes in geomorphology. San Francisco, CA: Freeman. 522 p.

Lloyd, O.B., Jr.; Lyke, W.L. 1995.
Ground water atlas of the United States: Illinois, Indiana, Kentucky, Ohio, Tennessee. HA 730-K. Washington, DC: U.S. Geological Survey. 30 p.

Mitsch, W.J.; Gosselink, J.G. 1993.
Wetlands. 2nd ed. New York, NY: John Wiley and Sons.

Muir, D.B.; Hite, R.L.; King, M.M.; Mattson, M.R. 1995.
An intensive survey of the Cache River Basin, summer 1992. IEPA/WPC/95-013. Springfield, IL: Illinois Environmental Protection Agency, Bureau of Water, Planning Section. 126 p.

Naiman, R.J. 1997.
The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics. 28: 621-658.

Naiman, R.J.; Magnuson, J.J.; McKnight, D.M.; Stanford, J.A. 1995.
The freshwater imperative: a research agenda. Washington, DC: Island Press. 165 p.

Naiman, R.J.; Turner, M.G. 2000.
A future perspective on North America's freshwater ecosystems. Ecological Applications. 10(4): 958-970.

Ney, J.J. 1996.
Oligotrophication and its discontents: effects of reduced nutrient loading on reservoir fisheries. In: Miranda, L.E.; DeVries, D.R., eds. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium. 16: 285-295.

Panno, S.V.; Krapac, I.G.; Weibel, C.P.; Bade, J.D. 1996.
Groundwater contamination in karst terrain of southwestern Illinois. Environ. Ser. Rep. 151. Champaign, IL: Illinois State Geological. 43 p.

Peterson, B.J.; Wollheim, W.M.; Mulholland, P.J.; et al. 2001.
Control of nitrogen export from watersheds by headwater streams. Science. 292: 86-90.

Ponder, F., Jr. 2004.
Ecological regions and soil conditions in The Hoosier-Shawnee Ecological Assessment Area. In: Thompson, F.R., III, ed. The Hoosier-Shawnee Ecological Assessment. Gen. Tech. Rep. NC-244. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 9-22.

Ricciardi, A.; Rasmussen, J.B. 1999.
Extinction rates of North American freshwater fauna. Conservation Biology. 13: 1220-1222.

Richter, B.D.; Braun, D.P.; Mendelson, M.A.; Master, L.L. 1997.
Threats to imperiled freshwater fauna. Conservation Biology. 11: 1081-1093.

Schrank, S.J.; Guy, C.S.; Whiles, M.R.; Brock, B.L. 2001.
Influence of instream and landscape-level factors on the distribution of Topeka shiners Notropis topeka in Kansas streams. Copeia. 2001: 413-421.

Seaber, P.R.; Kapinos, F.P.; Knapp, G.L. 1987.
U.S. Geological Survey Water Supply Paper 2294. Washington, DC: U.S.Geological Survey Information Services. 63 p.

Smith, L.W.; Dittmer, E.; Prevost, M.; Burt, D.R. 2000.
Breaching of a small irrigation dam in Oregon: a case history. North American Journal of Fisheries Management. 20: 205-219.

Solley, W.B.; Pierce, R.P.; Perlman, H.A. 1998.
Estimated use of water in the United States in 1995. U.S. Geological Survey Circular 1200. Washington, DC: U.S.Geological Survey Information Services. 71 p.

State-USEPA Partnership. 1998.
Total maximum daily load program: national section 303(d) list fact sheet. Washington, DC: U.S. Environmental Protection Agency. [Available online: http://oaspub.epa.gov/waters/national_rept.control]

Stebbins, R.C.; Cohen, N.W. 1995.
A natural history of amphibians. Princeton, NJ: Princeton University Press. 332 p.

Stein, R.A.; DeVries, D.R.; Dettmers, J.M. 1995.
Food web regulation by a planktivore: exploring the generality of the trophic cascade hypothesis. Canadian Journal of Fisheries and Aquatic Sciences. 52: 2518-2526.

Taylor, S.J.; Webb, D.W. 2000.
Human impacts on groundwater quality and subterranean aquatic biota in southwestern Illinois. Champaign, IL: Illinois Natural History Survey Reports. 361: 2-3.

Taylor, S.J.; Webb, D.W. 1998.
The fragile fauna of Illinois caves. The Illinois Steward. 7(2): 2-6.

U.S. Army Corps of Engineers. 1992.
National inventory of dams. Washington, DC: U.S. Army Corps of Engineers. [Available only on CD-ROM.]

U.S. Department of the Interior, Fish and Wildlife Service: U.S. Department of Commerce. 1993.
1991 33 National Survey of Hunting, Fishing, and Wildlife-Associated Recreation. Washington, DC.

USEPA. 2001.
National water quality inventory: 1998 report to Congress. Washington, DC: U.S. Enviornmental Protection Agency, Office of Water. [Avaiable online: http://www.epa.gov/305b/98report]

USEPA. 1999.
Overall watershed characterization: September 1999 IWI release. Washington, DC: U.S. Environmental Protection Agency, Office of Water. [Avaiable online: http://www.epa.gov/iwi/1999sept]

USEPA. 1994a.
The quality of our nation's water: 1992. EPA 841-s-94-002. Washington, DC: U.S. Environmental Protection Agency, Office of Water. 43 p.

USEPA. 1994b.
The US EPA Reach File Version 3.0 Alpha Release. Washington, DC: U.S. Environmental Protection Agency, Office of Water. [Avaiable online: http://www.epa.gov/owowwtr1/monitoring/rf]

USFWS. 1996a.
1996 survey of fishing, hunting, and wildlife-associated recreation for Illinois. FHW/96-IL. Washington, DC: U.S. Fish and Wildlife Service. 87 p.

USFWS. 1996b.
1996 survey of fishing, hunting, and wildlife-associated recreation for Indiana. FHW/96-IN. Washington, DC: U.S. Fish and Wildlife Service. 87 p.

USFWS. 1996c.
1996 survey of fishing, hunting, and wildlife-associated recreation for Kentucky. FHW/96-KY. Washington, DC: U.S. Fish and Wildlife Service. 87 p.

USGS, Earth Resources Observation Systems. 1990.
Advanced very high resolution radiometer satellite data, 1990. Sioux Fall, SD: U.S. Geological Survey, EROS Data Center. n.p. [Electronic database]

USGS. 2001.
Surface water for the nation. Washington, DC: U.S. Geological Survey. [Available online: http://waterdata.usgs.gov/usa/nwis/sw]

Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. 1980.
The river continuum concept. Canadian Journal of Fisheries and Aquatic Science. 37: 130-137.

Vaughn, C.C.; Taylor, C.M. 1999.
Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology. 13: 912-920.

Vileisis, A. 1997.
Discovering the unknown landscape: a history of America's wetlands. Washington, DC: Island Press. 445 p.

Wallace, J.B.; Webster, J.R.; Lowe, R.L. 1992.
High-gradient streams of the Appalachians. In: Hackney, C.T.; et al., eds. Biodiversity of southeastern United States aquatic communities. New York, NY: John Wiley and Sons, Inc.

Weibel, C. Pius; Panno, S.V. 1997.
Karst terrains and carbonate bedrock in Illinois. Illinois Map 8. Champaign, IL: Illinois State Geological Survey.

Wetzel, R.G. 2001.
Limnology, lake and river ecosystems. 3rd ed. New York, NY: Academic Press.

Whiles, M.R.; Brock, B.L.; Franzen, A.C.; Dinsmore, S.C., II. 2000.
Stream invertebrate communities, water quality, and land-use patterns in an agricultural drainage basin of northeastern Nebraska, USA. Environmental Management. 26: 563-576.

Winter, T.C.; Harvey, J.W.; Franke, O.L.; Alley, W.M. 1999.
Ground water and surface water, a single resource. Circular 1139. Denver, CO: U.S. Geological Survey. 79 p.

Yoder, C.O.; Rankin, E.T. 1999.
Biological criteria for water resource management: measures of environmental performance and ecosystem condition. Washington, DC: National Academy Press: 227-259.