United States
Department of
Agriculture

Forest Service

Southern
Research Station

General Technical
Report SRS-33

Ozark-Ouachita Highlands Assessment

Aquatic Conditions

REPORT
3
OF 5

Cover photo: Twin Falls, Richland Creek, Ozark Plateaus

Photo by A.C. Haralson, Arkansas Department of Parks and Recreation, Little Rock, AR.

Natural resource specialists and research scientists worked together to produce the five General Technical Reports that comprise the *Ozark-Ouachita Highlands Assessment*:

- Summary Report
- Air Quality
- Aquatic Conditions
- Social and Economic Conditions
- Terrestrial Vegetation and Wildlife

For information regarding how to obtain these Assessment documents, please contact: USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902 or telephone 501-321-5202.

To limit publication costs, few color maps and figures were used in the Assessment reports. For color versions of some of the Assessment figures and supplemental material, please see the Assessment's home page on the Internet at **<http://www.fs.fed.us/oonf/ooha/welcome.htm>**. The Assessment reports will be online for about 2 years after the date on this publication; then they will be archived.

Please note: When "authors" are agency or business names, most are abbreviated to save space in the citations of the body of the report. The "References" at the end of the report contain both the full name and abbreviations. Because abbreviations sometimes are not in the same alphabetical order as the references, for clarifications of abbreviations, consult the "Glossary of Abbreviations and Acronyms."

December 1999

Southern Research Station
P.O. Box 2680
Asheville, North Carolina 28802

Ozark-Ouachita Highlands Assessment:

Aquatic Conditions

Eastern Region
U. S. Department of Agriculture
Forest Service
Milwaukee, WI

North Central Research Station
U.S. Department of Agriculture
Forest Service
St. Paul, MN

Southern Region
U. S. Department of Agriculture
Forest Service
Atlanta, GA

Southern Research Station
U.S. Department of Agriculture
Forest Service
Asheville, NC

Contents

Preface

Change is evident across the Ozark and Ouachita Highlands. Whether paying attention to State and regional news, studying statistical patterns and trends, or driving through the Highlands, one cannot escape signs that growth may be putting strains on the area's natural resources and human communities. How people regard these changes varies widely, however, as does access to reliable information that might help them assess the significance of what is happening in the Highlands. The Assessment reports provide windows to a wealth of such information.

The *Aquatic Conditions* report is one of five that document the results of the Ozark-Ouachita Highlands Assessment. Federal and State natural resource agency employees and university and other cooperators worked together to produce the four technical reports that examine air quality; aquatic conditions; terrestrial vegetation and wildlife; and social and economic conditions. Dozens of experts in various fields provided technical reviews. Other citizens were involved in working meetings and supplied valuable ideas and information. The *Summary Report* provides an overview of the key findings presented in the four technical reports. Data sources, methods of analysis, findings, discussion of implications, and links to dozens of additional sources of information are discussed in more detail in the four technical reports.

The USDA Forest Service initiated the Assessment and worked with other agencies to develop a synthesis of the best information available on conditions and trends in the Ozark-Ouachita Highlands. Assessment reports emphasize those conditions and trends most likely to have some bearing on the future management of the region's three national forests—the Mark Twain, Ouachita, and Ozark-St. Francis. People who are interested in the future of the region's other public lands and waters, or of this remarkable region as a whole, should also find the reports valuable.

No specific statutory requirement led to the Assessment. However, data and findings assembled in the reports will provide some of the information relevant for an evaluation of possible changes in the land and resource management plans of the Highland's three national forests. The National Forest Management Act directs the Forest Service to revise such management plans every 10 to 15 years, which means that the national forests of Arkansas, Missouri, and Oklahoma should have revised plans in the year 2001. Due to restrictions in the appropriations bill that provides funding for the Forest Service, it is uncertain when these revisions can begin.

The charter for the Ozark-Ouachita Highlands Assessment established a team structure and listed tentative questions that the teams would address. Assembled in mid-1996, the Terrestrial, Aquatic and Atmospheric, and Human Dimensions (Social-Economic) Teams soon refined and condensed these questions and then gathered and evaluated vast quantities of information. They drafted their key findings in late 1997 and refined them several times through mid-1999. In addition to offering relevant data and key findings in the reports, the authors discuss some of the possible implications of their findings for future public land management in the Highlands and for related research. The Assessment reports, however, stop well short of making decisions concerning management of any lands in the Highlands or about future research. In no way do the reports represent "plans" or land management decisions. Instead, the findings and conclusions offered in the Assessment reports are intended to stimulate discussion and further study.

Contributors to This Report

Assessment Team Leader

William F. Pell, Ecologist, USDA Forest Service, Hot Springs, AR

Aquatic-Atmospheric Team Leader

J. Alan Clingenpeel, Forest Hydrologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR

Authors

Chapter 1: Introduction to the Aquatic Study Area

Physiography: Phillip D. Hays
Major River Basins: Richard W. Bell
Major Lakes: Richard W. Standage
Ground Water: Phillip D. Hays
Climate: Warren E. Heilman
Runoff: Richard W. Bell
Geology: Phillip D. Hays, David A. Freiwald
Soils: Len Weeks
Changing Land Conditions : Phillip D. Hays

Chapter 2: Status of Aquatic Resources

Surface Water Quality (Streams): Richard W. Bell
Surface Water Quality (Lakes): Richard W. Standage
Ground Water Quality: Phillip D. Hays, David A. Freiwald
Diversity of Fishes: Melvin L. Warren, Jr., Lisa Hlass
Diversity of Mussels: John L. Harris
Diversity of Crayfishes: Melvin L. Warren, Jr., Henry W. Robison, Karen Tinkle
Diversity of Aquatic Insects: Betty G. Crump, Melvin L. Warren, Jr.
Endangered, Threatened, and Other Aquatic Species of Special Concern: Melvin L. Warren, Jr., Karen Tinkle
Commercially and Recreationally Important Species: Richard W. Standage
Management Indicator Species: Richard W. Standage
Aquatic Habitats: Melvin L. Warren, Jr., J. Alan Clingenpeel
Riparian Areas: J. Alan Clingenpeel
Wetlands: Len Weeks

Chapter 3: The Clean Water Act and Aquatic Restoration Programs

Jack Hill

Chapter 4: Effects of Human Activities

Outstanding Resource Waters: J. Alan Clingenpeel
Impaired Waters: J. Alan Clingenpeel
EPA Index of Watershed Indicators: J. Alan Clingenpeel
CERCLA and Superfund Sites: Jack Hill
National Pollutant Discharge Elimination System (NPDES) Sites: Jack Hill
Municipal Water Supplies: Jack Hill
Toxic Releases: Jack Hill
Roads and Highways: Len Weeks
Agriculture and Silviculture: Len Weeks
Pesticides—Applications and Distributions: Richard W. Bell, Phillip D. Hays
Pesticides in Surface Water: Richard W. Bell
Pesticides in Ground Water: Phillip D. Hays
Animal Wastes: Richard W. Bell
Fertilizers: Richard W. Bell
Urbanization: J. Alan Clingenpeel
Mineral Extraction: John C. Nichols
Introduced Species: Richard W. Standage

Chapter 5: Water Supply and Use

Past and Present Supply and Use: Thomas C. Brown and Terry W. Holland
Future Patterns and Trends: Thomas C. Brown

Author Information

Richard W. Bell, Hydrologist, USDI Geological Survey, Water Resources Division, Little Rock, AR.
Thomas C. Brown, Economist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.
J. Alan Clingenpeel, Forest Hydrologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.
Betty G. Crump, Aquatic Ecologist, USDA Forest Service, Ouachita National Forest, Glenwood, AR.
David A. Freiwald, Supervisory Hydrologist, USDI Geological Survey, Water Resources Division, Little Rock, AR.
John L. Harris, Section Head-Special Studies, Arkansas Department of Highways and Transportation, Little Rock, AR, and Consulting Malacologist.
Phillip D. Hays, Hydrologist, USDI Geological Survey, Water Resources Division, Little Rock, AR.
Warren E. Heilman, Research Meteorologist, USDA Forest Service, North Central Research Station, East Lansing, MI.
Jack Hill, Forest Service–U.S. Environmental Protection Agency Liaison, USDA Forest Service, Dallas, TX.

Lisa Hlass, Biologist, USDA Forest Service, Ouachita National Forest, Mt. Ida, AR.
Terry W. Holland, Hydrologic Technician, USDI Geological Survey, Water Resources Division, Little Rock, AR.
John C. Nichols, Forest Minerals Geologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.
Henry W. Robison, Professor of Biology, Southern Arkansas University, Department of Biology, Magnolia, AR.
Richard W. Standage, Forest Fisheries and Aquatic Threatened and Endangered Species Biologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.
Karen Tinkle, Biologist, USDA Forest Service, Ozark National Forest, Mountain View, AR.
Melvin L. Warren, Jr., Research Fisheries Biologist, USDA Forest Service, Southern Research Station, Oxford, MS.
Len Weeks, Soil Scientist, USDA Forest Service, Ozark National Forest, Russellville, AR.

Other Contributors

James C. Adamski, Hydrologist, USDI Geological Survey, Little Rock, AR—data analysis.
Michael Armstrong, Assistant Fisheries Chief, Arkansas Game & Fish Commission, Little Rock, AR—background on commercial fish and mussel harvest in Arkansas and Sate fisheries management practices.
Steven W. Bearden, Cartographic Technician, USDI Geological Survey, Little Rock, AR—figures.
Chris Bennett, Geographic Information System (GIS) System Administrator, University of Arkansas, School of Forest Resources, Monticello, AR—GIS data bases.
Amy J. Benson, Fishery Biologist, USDI Geological Survey, Biological Resources Division, Gainesville, FL—nonindigenous aquatic vertebrate and nonvertebrate data for the Arkansas, Missouri, and Oklahoma species account reports.
Patti Bryant, Little Rock, AR—assistance with unionacean bivalve data base construction and analysis.
Al Buchanan, Fisheries Research Biologist, Missouri Department of Conservation, Jefferson City, MO—data interpretation and legal background on mussel harvests.
Tim Burnley, District Fisheries Biologist, Arkansas Game & Fish Commission, Brinkley, AR—recent commercial mussel harvest information and reports.
Dorothy Butler, Heritage Coordinator, Missouri Department of Conservation, Jefferson City, MO—heritage data information.
Ian Butler, Data Coordinator, Oklahoma Biological Survey, Norman, OK—heritage data information.
Steve Downing, Commercial Shell Buyer, Locust Grove, OK—background information on commercial harvest of mussels in Oklahoma.
Jeff Farwick, Regional Fisheries Biologist, Arkansas Game & Fish Commission, Brinkley, AR—commercial fish harvest and mussel harvest data and background information.
Larry Furniss, Forest Fisheries Biologist, USDA Forest Service, Mark Twain National Forest, Rolla, MO—assistance in gathering Missouri Department of Conservation publications for fish species legal status and stocking locations.
Anne Garner, Fisheries Secretary, Arkansas Game & Fish Commission, Hot Springs, AR—fish stocking records to fill data gaps.
Mike Gibson, Assistant Fisheries Chief, Hatcheries, Arkansas Game & Fish Commission, Little Rock, AR—fish stocking records of selected game fish species.
Jack Harper, Southeastern Region Fish Supervisor, Oklahoma Department of Wildlife Conservation, Caddo, OK—fish stocking records and management details for waters in southeastern Oklahoma.

Michael Hobbins, Civil Engineering student, Colorado State University, Fort Collins, CO—performing the model runs to estimate available water supply.

Colette Jacono, Botanist, USDI Geological Survey, Biological Resources Division, Gainesville, FL —nonindigenous aquatic plant data for Arkansas, Missouri, and Oklahoma species account reports.

Robert Limbird, Regional Fisheries Biologist, Arkansas Game & Fish Commission, Russellville, AR—commercial fish harvest data from Nimrod and Blue Mountain reservoirs and background information.

Charles M. Mather, Professor of Biology, University of Science and Arts of Oklahoma, Chickasha, OK—distributional data and unpublished reports regarding Oklahoma unionaceans.

Dave Mayers, District Fisheries Management Biologist, Missouri Department of Conservation, West Plains, MO—assistance with fish species legal status and fish stocking data.

Brian Obermeyer, Private Consultant, Stream and Prairie Research, Emporia, KS—distributional data and unpublished reports regarding Oklahoma unionaceans.

Mark Oliver, Regional Fisheries Biologist, Arkansas Game & Fish Commission, Mountain Home, AR—information on lake trout stocking and harvest in Greers Ferry Lake and other stocking practices in the Ozarks.

Cindy Osborne, Data Manager, Arkansas Natural Heritage Commission, Little Rock, AR—heritage data information.

Howard Perlman, Hydrologist, USDI Geological Survey, Atlanta, GA—assistance in accessing the water use data.

James C. Petersen, Hydrologist, USDI Geological Survey, Little Rock, AR—text and data review.

John W. Robinson, Fisheries Research Biologist, Missouri Department of Conservation, Jefferson City, MO—mussel and commercial fish species data and interpretation assistance.

Jim Smith, Northeast Region Fish Supervisor, Oklahoma Department of Wildlife Conservation, Porter, OK—fish stocking records and management details for waters in northeastern Oklahoma, assistance with fish species legal status, and background information on Oklahoma mussel harvest.

Wayne B. Solley, Chief of Water-Use Information Branch, USDI Geological Survey, Reston, VA—assistance in accessing the water use data.

Peter Trenchi, Natural Resource Research Specialist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR—GIS data management.

Caryn Vaughn, Coordinator and Aquatic Zoologist, Oklahoma Biological Survey, Norman, OK—distributional data and unpublished reports regarding Oklahoma unionaceans.

Jeremy S. Vestal, Hydrology Co-op, USDA Forest Service, Ouachita National Forest, Hot Springs, AR—final figure and glossary refinement.

Charles Wallace, Fisheries Division Administrative Assistant, Oklahoma Department of Wildlife Conservation, Oklahoma City, OK—provided commercial aquatic species harvest records and reports and interpreted this material.

Robert Weih, Associate Professor, University of Arkansas, School of Forest Resources, Monticello, AR—GIS data bases.

Stuart Wooldridge, Regional Fisheries Biologist, Arkansas Game & Fish Commission, Hot Springs, AR—background information on fisheries management in the Ouachitas.

Brenda Wulff, Clerk-Typist, Missouri Department of Conservation, Sweet Springs, MO—compiled requested fish stocking records.

Ozark-Ouachita Highlands Assessment Steering Team

G. Samuel Foster, Assistant Station Director of Research Programs–West, USDA Forest Service, Southern Research Station, Asheville, NC.

Randy Moore, Forest Supervisor, USDA Forest Service, Mark Twain National Forest, Rolla, MO.
Lynn C. Neff, Forest Supervisor, USDA Forest Service, Ozark-St. Francis National Forests, Russellville, AR.
Alan G. Newman, Forest Supervisor, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.

Editorial Team

Donna M. Paananen, Technical Writer-Editor, USDA Forest Service, North Central Research Station, East Lansing, MI.
Ariana Mikulski, Editorial Assistant, USDA Forest Service, North Central Research Station, East Lansing, MI.
Camilla M. Romund, Research Specialist, University of Arkansas, Fayetteville, AR.
Zachariah M. DeYoung, Editorial Assistant, USDA Forest Service, North Central Research Station, East Lansing, MI.
Bobbie L. Louthian, Writer-Editor, USDI Geological Survey, Little Rock, AR.
Louise A. Wilde, Production Editor, USDA Forest Service, Southern Research Station, Asheville, NC.

Acknowledgments

The Aquatic Team would like to thank members of the public who attended meetings and/or provided written or oral input during the Assessment process. The team also wishes to thank the aforementioned organizations and individuals who contributed information used to write this report.

In addition, the Aquatic Team appreciates the help of the many individuals who reviewed various sections of this general technical report. Their comments and suggestions contributed to the preparation of this final document; information about them follows.

Reviewers

Michael Armstrong, Assistant Fisheries Chief, Arkansas Game & Fish Commission, Little Rock, AR—"Commercially and Recreationally Important Species," and "Management Indicator Species" sections of Chapter 2 and "Introduced Species" section of Chapter 4.

Angela Braden, Geologist, Arkansas Geological Commission, Little Rock, AR—"Geology" section of Chapter 1.

Ken Brazil, Engineer Supervisor of Planning Section, Arkansas Soil and Water Commission, Little Rock, AR—Chapters 4 and 5.

Jim Brown, Geologist, Missouri Department of Natural Resources, Rolla, MO—"Geology" section of Chapter 1.

Sue A. Bruenderman, Fisheries Research Biologist, Missouri Department of Conservation, Columbia, MO—"Diversity of Mussels" section of Chapter 2.

Linda Chapman, Environmental Scientist, State Watershed Liaison, U.S. Environmental Protection Agency, Region 6, Dallas, TX—Chapter 4.

George E. Dissmeyer, Hydrologist, Eatonton, GA—Chapters 2 and 3.

Robert J. DiStefano, Fisheries Research Biologist, Missouri Department of Conservation, Columbia, MO—Chapter 2.

John Ford, Environmental Specialist, Missouri Department of Natural Resources, Jefferson City, MO—Chapter 4.

Larry Furniss, Forest Fisheries Biologist, USDA Forest Service, Mark Twain National Forest, Columbia, MO—"Commercially and Recreationally Important Species" and "Management Indicator Species" sections of Chapter 2 and "Introduced Species" section of Chapter 4.

John Giese, Environmental Preservation Division Chief, Arkansas Department of Pollution Control and Ecology, Little Rock, AR—Chapters 2 and 4.

George Harp, Professor of Environmental Biology, Arkansas State University, State University, AR—Chapter 2.

Larry Hedrick, Integrated Resources Team Leader, USDA Forest Service, Ouachita National Forest, Hot Springs, AR—original technical review of rough draft of "Commercially and Recreationally Important Species" and "Management Indicator Species" in Chapter 2 and "Introduced Species" in Chapter 4.

Jack Holcomb, Hydrologist, USDA Forest Service, Southern Region, Atlanta, GA—Chapter 3.

J. Michael Howard, Geological Supervisor, Arkansas Geological Commission, Little Rock, AR—"Geology" section of Chapter 1.

Bill Keith, Chief, Planning Section, Arkansas Department of Pollution Control and Ecology, Little Rock, AR—Chapters 1, 2, and 4.

Jim Leach, Assistant Director, Water Quality Program, Oklahoma Conservation Commission, Oklahoma City, OK—Chapters 2 and 4.

Bob Legler, Ozark Fisheries Region Supervisor, Missouri Department of Conservation, West Plains, MO—"Commercially and Recreationally Important Species" and "Management Indicator Species" sections of Chapter 2 and "Introduced Species" section of Chapter 4.

Dave Mayers, Fisheries Management Biologist, Missouri Department of Conservation, West Plains, MO—"Commercially and Recreationally Important Species" and "Management Indicator Species" sections of Chapter 2 and "Introduced Species" section of Chapter 4.

Steve McIntosh, Director, Water Resources Program, Missouri Department of Natural Resources, Jefferson City, MO—Chapter 5.

Mark Middendorf, Geologist, Missouri Department of Natural Resources, Rolla, MO—"Geology" section of Chapter 1.

Stephen R. Moulton, II, Biologist, Benthic Invertebrate Taxonomist, USDI Geological Survey, Water Resource Division, Aquatic Invertebrate Section, Arvada, CO—"Diversity of Aquatic Insects" section of Chapter 2.

James C. Petersen, Hydrologist, USDI Geological Survey, Little Rock, AR—Chapter 2.

Jimmie Pigg, Aquatic Biologist, Oklahoma Department of Environmental Quality, Oklahoma City, OK—"Diversity of Fishes" section of Chapter 2.

Barry C. Poulton, Research Ecologist, Aquatic Entomologist, USDI Geological Survey, Biological Resources Division, Columbia, MO—"Diversity of Aquatic Insects" section of Chapter 2.

W. L. Prior, Geologist, Arkansas Geological Commission, Little Rock, AR—"Geology" section of Chapter 1.

John W. Robinson, Fisheries Research Biologist, Missouri Department of Conservation, Columbia, MO—"Commercially and Recreationally Important Species" and "Management Indicator Species" sections of Chapter 2 and "Introduced Species" section of Chapter 4.

Henry W. Robison, Professor of Biology, Southern Arkansas University, Magnolia, AR—"Diversity of Fishes"; and "Endangered, Threatened, and Other Aquatic Species of Special Concern" sections of Chapter 2.

Ardel Rueff, Geologist, Missouri Department of Natural Resources, Rolla, MO—"Geology" section of Chapter 1.

Cheryl Seeger, Geologist, Missouri Department of Natural Resources, Rolla, MO—"Geology" section of Chapter 1.

Jim Smith, Northeast Regional Fish Supervisor, Oklahoma Department of Wildlife Conservation, Porter, OK—"Commercially and Recreationally Important Species" and "Management Indicator Species" sections of Chapter 2 and "Introduced Species" section of Chapter 4.

Derek Smithee, Chief, Water Quality Programs Division, Oklahoma Water Resources Board, Oklahoma City, OK—Chapters 4 and 5.

Charles E. Stone, Geological Supervisor, Arkansas Geological Commission, Little Rock, AR—"Geology" section of Chapter 1.

Neil Suneson, Geologist, Oklahoma Geological Survey, Norman, OK—"Geology" section of Chapter 1.

Don Turton, Associate Professor of Forest Hydrology, Oklahoma State University, Stillwater, OK—Chapters 1 and 2.

Jim Vandike, Hydrologist, Missouri Department of Natural Resources, Rolla, MO—"Geology" section of Chapter 1.

Caryn Vaughn, Coordinator and Aquatic Zoologist, Oklahoma Biological Survey, Norman, OK—"Diversity of Mussels" section of Chapter 2.

Dave Womack, Land Resource Specialist, Arkansas Soil and Water Commission, Little Rock, AR—Chapters 4 and 5.

Executive Summary

The Ozark-Ouachita Highlands Assessment was designed as an interagency effort led by the USDA Forest Service to collect and analyze ecological, social, and economic data concerning the Highlands of Arkansas, Missouri, and Oklahoma. The aquatic portion of this Assessment began in May of 1996 and was completed in December of 1998. The information compiled will facilitate an ecosystem approach to management of the natural resources on public lands within the Ozark Highlands, the Boston Mountains, the Arkansas Valley, and the Ouachita Mountains. The Aquatic Team studied conditions of the aquatic resources in these and surrounding areas.

The Aquatic Team, with input from scientists, forest planners, and concerned citizens, identified 33 questions that needed to be addressed in order to understand aquatic conditions and trends in the Ozark-Ouachita Highlands. Following is a summary of the team's findings.

Chapter 1: Introduction to the Aquatic Study Area

The introductory chapter describes the physiography, river basins, watersheds, major lakes, ground water, climate, geology, soils, and land uses of the aquatic study area and the slightly smaller Highlands Assessment area. The Aquatic Team used physiographic areas, river basins, and watersheds as the principal geographic units for displaying data throughout most of the report. An understanding of physiographic areas, river basins, watersheds, and the other background information in this chapter provides the reader with a context for the chapters that follow.

Chapter 2: Status of Aquatic Resources

Chapter 2 examines two broad categories of the aquatic ecosystem in the Highlands. "Water Quality" includes information about the chemical characteristics of streams, lakes, and ground water. "Aquatic Animals and their Habitats," the second major section, discusses the biological components of water, including the status of fish, mussels, crayfish, aquatic insects, and species of special concern; commercial and recreational roles of aquatic species; aquatic habitats; riparian areas; and wetlands.

Water Quality

Surface Water Quality (Streams). ***What are the status and apparent trends of the water quality of streams in the Highlands?***

- Median concentrations of nitrite plus nitrate, ammonia, total nitrogen, and total phosphorus collected at stream sites near sewage treatment plants in most physiographic areas were significantly higher than at any other type of site.
- Within the Boston Mountains, Springfield and Salem Plateaus, and Arkansas Valley, nitrite plus nitrate concentrations at stream sites increased significantly with more intensive uses of land (e.g., acres of "forest-pasture mix" had more of these concentrations than did "forest" acres).
- Where more intensive uses of land occurred in the Springfield and Salem Plateaus, Arkansas Valley, and Ouachita Mountains, ammonia concentrations in streams generally increased significantly. Within basins that have significant "agriculture" land use, total phosphorus concentrations were highest at stream sites in the Arkansas Valley where land was used for a mix of agriculture and forest activities.
- Concentrations of suspended solids were highest at stream sites in the Osage Plains (just outside the Highlands).
- From 1970 through 1990 at most stream sites in the Ozark Plateaus Province, concentrations of nitrogen and phosphorus forms and suspended solids did not change substantially; this was also true from 1975 through 1995 for streams in the Arkansas Valley and Ouachita Mountains.

Surface Water Quality (Lakes). ***What is the status of the surface water quality of lakes within the Assessment area?***

- Within the Assessment area in Arkansas, 35 percent of the 48 lakes were classified as mesotrophic, 63 percent as eutrophic, and 2 percent (1 lake) as hypereutrophic.
- Within the Assessment area in Missouri, 13 percent of the lakes were classified as oligotrophic, 32 percent as mesotrophic, and 55 percent as eutrophic.

- Of the 30 Oklahoma lakes within the Assessment area, 3 percent were classified as oligotrophic, 30 percent mesotrophic, 43 percent eutrophic, 17 percent hypereutrophic, and 7 percent (2 lakes) as silt dominated.

Ground Water Quality. *What are the status and apparent trends of the quality of ground water in the Highlands?*

- The Springfield Plateau aquifer, the Ozark aquifer, and aquifers of the Ouachita Province generally provide water of excellent quality, though substantial differences in basic water chemistry occur among these three settings.
- Ground water from springs differed substantially in quality from that from wells in the Ozark aquifer, the Springfield Plateau aquifer, and the aquifers of the Ouachita Province. Springs in the Springfield Plateau and Ozark aquifers are more susceptible to contamination from surface sources.
- Wide-ranging, inorganic concentrations observed in aquifers in the Ouachita Province are indicative of both the province's diverse geochemical environments and, for some water quality measures, the influential land uses that are present.
- Background concentrations of nutrients in the Springfield Plateau and Ozark aquifers are low; nutrient concentrations were below detection limits in many samples collected from sites in heavily forested areas.
- Nitrite plus nitrate was detected more often and in greater concentrations than any of the other nutrients. Concentrations were greater than background concentrations in many samples from the Springfield Plateau and Ozark aquifers and were positively correlated to the percent of agricultural land use around each site. Values ranged from less than 0.05 to 25 milligrams per liter (mg/L) as nitrogen, with a median of 1.6 mg/L in samples from the Springfield Plateau and Ozark aquifers.
- In the Springfield Plateau and Ozark aquifers, median nitrite plus nitrate concentrations generally were greater in samples from springs than in samples from wells.
- Concentrations of nitrite, ammonia, and ammonia plus organic nitrogen were affected by land use in the Springfield Plateau and Ozark aquifers.
- Background concentrations of nutrients in ground water of the Ouachita Province are low; nutrient concentrations were below detection limits in many ground water samples. Nitrite plus nitrate was detected in samples of ground water from sites in the Ouachita Province at concentrations ranging from below detection limits to 4.7 mg/L as nitrogen, with a median of 0.16 mg/L.
- The occurrence of nutrients in ground water in the Ouachita Province did not show a statistically significant correlation with the percentage of agricultural land use or urban land use around each site.

Aquatic Animals and their Habitats

Diversity of Fishes. *What are the status and distribution of fishes within the Assessment area?*

- Twenty-four fish families are represented by native species in the Assessment area, with five families containing about 78 percent of the fish fauna of the region; two families—the perches (Percidae) and minnows (Cyprinidae)—comprise more than half of the fish fauna.
- The fish faunas of the aquatic study area have been classified into four distinct geographical regions based on species composition as follows: the Ozark Fish Faunal Region, Southern Ozark and Ouachita Mountain Fish Faunal Region, Big River Fish Faunal Region, and Lowlands Fish Faunal Region—West Gulf Coastal Plain-Mississippi Delta (Mississippi Alluvial Basin).
- In the northeastern part of the Assessment area, native fish species richness is concentrated in the Upper St. Francis River, Upper Black River, and Upper White River drainages; in the west, it is concentrated in the drainages of the Neosho-Illinois Rivers and western portions of the Arkansas River.
- Native fish species density varies across the Assessment area with the highest densities of fish species associated with ecological-hydrologic units that are generally small and species rich or small and adjacent to species-rich units.
- Conservatively, at least 14 percent of the fish fauna is endemic to the Assessment area (restricted to a particular geographic area); endemic species are distributed among five fish families, with highest endemicity among darters and minnows. Endemic fishes are concentrated in 2 ecological sections: the Ozark Highlands (16 endemic fish species) and the Ouachita Mountains (7 endemic fish species).

Diversity of Mussels. ***What are the status and distribution of unionacean bivalves (mussels, clams, naiads, or unionids) within the Assessment area?***

- Seventy-three species of native freshwater mussels representing 37 genera occur within the Assessment area. Eleven species are endemic to the Assessment area, and there are two introduced species—the Asian clam and the zebra mussel.
- Twenty-four freshwater mussel species are widely distributed across the Assessment area; 16 species occurring within the Assessment area are restricted to streams draining the Ozark Highlands, and 8 species are restricted to streams draining the Ouachita Mountains.
- North American conservation status rankings for freshwater mussel species in the Assessment area reveal that 40 species are considered currently stable, 18 species are of special concern, 9 are ranked as threatened, and 6 are listed as endangered.
- Ecological-hydrologic units with relatively high species richness and density occur primarily in tier-like clusters in the northeastern, central, and southern portions of the Assessment area and appear to be associated with hydrologic units possessing both headwater and main stem habitats.
- The Aquatic Team calculated a relative importance index value to rank hydrologic units in terms of combined mussel species richness, species density, and habitat availability for rare species. The five highest ranking hydrologic units were the Spring and Strawberry Rivers (Upper Black River Basin), the Bourbeuse and Big Rivers (both in the Meramec River Basin), and the Upper Ouachita River (Ouachita-Saline River Basin).

Diversity of Crayfishes. ***What are the status and distribution of crayfishes within the Assessment area?***

- Crayfish species representing 6 genera and 1 family (Cambaridae) are present in the Ozark-Ouachita Highlands Assessment area, and the genera *Orconectes* (24 species), *Procambarus* (13 species), and *Cambarus* (9 species) comprise 84 percent of the crayfish fauna in the 50 hydrologic units.
- Crayfish species richness averaged 5.9 crayfish species per hydrologic unit with a range of from 2 to 14 species; however, most hydrologic units showed diverse crayfish faunas, with 29 of 50 units having crayfish richness values greater than 4 species.
- The southeastern Ouachita Mountains and an area trending southwest to northeast from the western Boston Mountains to the eastern Ozark Plateaus showed primary or secondary levels of crayfish richness (6 to 14 species).
- Crayfish density averaged 0.4 species per 100 square miles (mi^2) of a hydrologic unit and ranged from 0.1 to 0.9; 17 of 50 hydrologic units had densities equal to or exceeding 0.5 crayfish species per 100 mi^2.
- Concentrations of hydrologic units with primary levels of crayfish density occurred along the northeastern edge of the Assessment area (Middle White unit, Upper St. Francis unit, and most units in the Black River and Meramec drainages) and in the southern part of the Assessment area (most units in the Ouachita-Saline drainage and the Lower Little unit of the Kiamichi-Little drainage).
- The Ozark-Ouachita Highlands area supports at least 37 endemic crayfishes or 61 percent of the region's crayfish fauna; most of these endemic species are confined to the Ozark Plateaus and Boston Mountains (at least 22 endemic crayfishes), but endemicity is also relatively high in the Ouachita Mountains (at least 13 endemic crayfishes).

Diversity of Aquatic Insects. ***What are the status and distribution of aquatic insects within the Assessment area?***

- Streams and rivers of the Ozark-Ouachita Highlands harbor a richness of species representing about 15 percent and 17 percent of all stoneflies and caddisflies, respectively, known from North America. Eight families, including 23 stonefly genera and 82 species, and 17 families, including 57 genera caddisfly and 206 species, are known to occur in the Ozark-Ouachita Highlands Assessment area.
- The Ouachita Mountains support the greatest richness of stoneflies and caddisflies (195 species) in the Assessment area. Nineteen of the regionally endemic stonefly species occur in the Ouachita Mountains; six of these occur in no other subregion. Three of the 13

endemic caddisfly species (*Cheumatopsyche robisoni*, *Ochrotrichia robisoni*, and *Ochrotrichia weddleae*) found in the Ouachita Mountains are not known elsewhere.

Endangered, Threatened, and Other Aquatic Species of Special Concern. ***What are the status and distribution of endangered, threatened, and other aquatic species of special concern within the Assessment area?***

- A total of 125 aquatic taxa have 1 or more of the following designations: Federal status (14 species), globally imperiled through globally rare (78 taxa have G1, G2, or G3 ranks), and State critically imperiled (68 taxa have S1 ranks). Included are 7 insects; 37 mollusks, 35 of which are freshwater mussels; 23 crustaceans, 15 of which are crayfish; 55 fishes; and 3 herptiles (amphibians or reptiles).
- Of the 14 aquatic taxa with Federal status, 6 are mollusks, 2 are crustaceans, and 6 are fishes.
- In the Assessment area, about 32, 50, and 26 percent of fishes, mussels, and crayfishes, respectively, have Federal status, globally rare ranks, and/or S1 State ranks.
- Sixty percent of the hydrologic units recorded at least one species with a Federal status on Element Occurrence Records (EOR's); the pattern of distribution (i.e., 0 to 4 species per unit out of 14 possible species) suggests that the presence of such species differs dramatically across units.
- Hydrologic units with three or four species with Federal status were located in the southern Ouachita Mountains (Upper Little, Lower Little, and Upper Ouachita units), in the Neosho-Illinois drainage (Lake O' the Cherokees, Illinois, Elk, and Spring units), and in the Sac unit (Osage River drainage). Units with one to two species with Federal status were scattered widely across the Assessment area.
- Two concentrations of hydrologic units showed primary levels of endangered, threatened, and other species of special concern (10 to 30 species with Federal status, global ranks, or State ranks): (1) along the southern edge of the Assessment area in the Ouachita Mountains and (2) along the northeastern edge of the Assessment area in the Upper Black River and Upper St. Francis drainages. Secondary levels of endangered, threatened, and other species of special concern (seven to nine species per watershed) tended to be associated with hydrologic units adjacent to those with primary levels.

Commercially and Recreationally Important Species. ***What is the status of commercial and recreational aquatic species within the Assessment area?***

- Commercial fish harvesting within the Assessment area is limited to Arkansas waters. The only legal commercial fishing in Oklahoma occurs within the Eufaula Reservoir just west of the Assessment area, where one individual has a commercial license.
- Commercial fish harvests and the number of commercial fishers are somewhat stable.
- Mussel harvesting regulations in Arkansas govern whether an area is open, closed, or set aside as a refugium (protected area) within an open area.
- Oklahoma had only one licensed shell (mussel) buyer in 1997. The majority of the buying is of shells from backwater areas of lakes in northeast Oklahoma; the few species in this area with thick, large shells and little surface erosion are in demand commercially.
- Demand for shells is driven by the market for pearl blanks (a round piece of shell inserted in commercial pearl oysters to stimulate pearl formation). Actual harvest levels are lower than harvest limits because of the pearl industry's requirements for a specific color and size.
- Legally designated species of game and commercial fish vary by State, although sought-after species differ little among States. Designating a species as a game fish generally regulates its harvest more closely than harvests of other recreational species.
- Significant efforts have been made—mostly introductions of non-native fish species—to manage open-water habitats of large reservoirs within the Assessment area and to utilize adequately cool and cold water habitats within and downstream from these reservoirs.
- State and Federal fisheries-management agencies protect native stocks of smallmouth bass, walleye, and sauger by foregoing some stocking opportunities that might contaminate these native stocks genetically.

Where supplemental stocking is needed in habitats containing protected native species, hatcheries are using spawners of the same genetic stock as the protected native species found in the receiving water bodies.

Management Indicator Species. ***What management indicator species are located within the Assessment area, and what is their potential role for the aquatic resources?***

- Lists of fish, mussels, crayfish, and aquatic insects gathered during this Assessment include data about their special status as reported and ranked by Federal and State agencies, The Nature Conservancy, and the American Fisheries Society (AFS); such rankings can form the basis for the selection of management indicator species for forest plan revision.
- The American Fisheries Society identified 19 fish, 76 mussel, and 59 crayfish species that occur in the Highlands as endangered, threatened, of special concern, and currently stable.

Aquatic Habitats. ***What is the status of the aquatic habitats within the Assessment area?***

- Over half of the hydrologic units in the Assessment area have 10 or more stream types per hydrologic unit (average = 8.7 stream types per hydrologic unit; range of 5 to 15 per hydrologic unit), and no hydrologic unit has fewer than 5 stream types.
- Primary levels of stream type diversity (11 to 15 stream types per hydrologic unit) are located mostly in the southern half of the Assessment area; secondary levels (10 stream types per hydrologic unit) are located in hydrologic units along the periphery of the Assessment area.
- Native fish species richness is associated significantly and positively with the number of different stream types in hydrologic units.
- Numbers of endemic fish species and stream types are not associated among hydrologic units.
- Hydrologic units with primary and secondary levels of stream type diversity and native fish species richness may be considered of particular significance in maintaining present and future aquatic biodiversity within the Ozark-Ouachita Highlands.
- Available analyses indicate that strong associations exist between environmental variables (e.g., water quality, geology, substrate) and the distribution of fishes over much of the Assessment area, and any pervasive alteration of existing habitat conditions likely would affect the composition and distribution of the fish fauna.

Riparian Areas. ***What are the extent and vegetative composition of riparian areas within the Assessment area?***

- Of the almost 3 million acres of riparian areas identified within the Assessment area, approximately 57 percent are forested, 37 percent are agricultural, 2 percent are urban, and 4 percent are classified as "other."
- The Upper Saline watershed has the greatest percentage (87.4 percent) and the South Grand watershed has the lowest percentage (14.9 percent) of forested riparian cover in the study area.
- National forests generally have highly forested riparian areas (86 to 93 percent).

Wetlands. ***What are the extent and composition of wetlands within the Assessment area?***

- Since the 1780's, wetland losses in Assessment area States have ranged from 50 to greater than 75 percent (Dahl 1990).
- Most of the State Soil Geographic data base soil-map units that include hydric soils are found along the Grand, Sac, Black, White, Arkansas, Ouachita, and Little Rivers. These areas are potential wetlands because they have saturated soils, one of the essential components of the designation "wetlands."
- According to the State 305(b) inventory reports of water quality, most of the wetlands in Arkansas, Missouri, and Oklahoma have been converted to agricultural production during historic times.
- Camden and Taney Counties, MO, and Pulaski County, AR, had the most Clean Water Act 404 permits issued from 1988 through 1996. If the number of permits issued indicates activity in wetlands and other water bodies, the Osage, Upper White, and Arkansas River Basins had the most activity from 1988 through 1996.

Chapter 3: The Clean Water Act and Aquatic Restoration Programs

What laws, policies, and programs for the protection of water quality, streams, wetlands, and riparian areas are in place?

Federal and State laws and policies concerning aquatic resources provide a legal mandate to ensure that human activities are conducted with consideration for the protection, preservation, and restoration of our Nation's water resources.

Chapter 3 discusses and summarizes many of the laws and policies that are in effect and reviews the success of these regulations to date. Topics specifically addressed include: section 404 of the Clean Water Act (CWA); the National Pollutant Discharge Elimination System (NPDES); total maximum daily loads (TMDL's); and the control of nonpoint source pollution, which includes best management practices (BMP's).

In addition to laws, many federally funded programs exist to protect, restore, or improve aquatic resources. This chapter discusses and summarizes many of these programs in the context of the Assessment area.

- There have been significant changes in regulations that affect water resources, particularly regulations concerning nonpoint source problems such as sedimentation and nutrient loading.
- Nonpoint source pollution is one of the major water quality issues to contend with in the future.
- There are several U.S. Department of Agriculture (USDA) incentive programs that focus on the restoration of riparian areas and wetlands, including the Wetlands Reserve Program (WRP) and Environmental Quality Incentive Program (EQIP).

Chapter 4: Effects of Human Activities

State and Federal Classifications of Water Quality

Outstanding Resource Waters (ORW's). ***Which streams and rivers have been designated as Outstanding Resource Waters by pollution control agencies in Missouri, Oklahoma, and Arkansas?***

- There are 4,113 stream miles (mi) of extraordinary, ecologically sensitive, and legislatively designated waters within the Assessment area. A single body of water may fall within more than one of these categories.
- Of those miles, 17 percent occur on or adjacent to national forest lands.

Impaired Waters. ***Which waters have pollution control agencies in Missouri, Oklahoma, and Arkansas determined to be impaired or threatened, and what are the suspected sources of impairment?***

- The State 305(b) lists identify 5,588 mi of impaired streams within the Assessment area.
- The predominant sources of impairment of water quality (primary and secondary sources combined) within the Assessment area are agriculture (36.1 percent), unknown (10.9 percent), and mining (10.2 percent).
- Of the 5,588 mi of impaired streams, 133 are associated with national forest lands.
- Major sources of impairment for stream segments within national forest lands include agriculture, road construction, and silviculture.

EPA Index of Watershed Indicators (IWI). ***How does the condition of Assessment area watersheds compare with the rest of the United States?***

- Of the 50 watersheds within the Assessment area, 24 (48 percent) are designated as having "better water quality and low vulnerability to stressors" (pollutants that could further strain the aquatic resource). Nationwide, EPA gave this rating to only 9 percent of watersheds.

- Within the Assessment area, only the Spring watershed in the Neosho-Illinois River Basin has a rating of "more serious water quality problems and high vulnerability to stressors." The South Grand and Fourche La Fave watersheds are in the following class: "more serious water quality problems and low vulnerability to stressors."

Point Sources

CERCLA and Superfund Sites. ***What are the current status and potential effects of hazardous waste sites on aquatic resources within the Assessment area?***

- Within the Assessment area, there are 798 sites in CERCLIS.
- Of the 798 sites, 15 are Superfund sites on the National Priorities List (NPL).

National Pollutant Discharge Elimination System (NPDES) Sites. ***What are the current status and potential effects of permitted discharges on aquatic resources?***

- About 136 point sources currently discharge treated wastewater into surface waters of the Assessment area. Many of these sources with NPDES permits are considered major facilities based on the volume of discharge and pollutant loadings (concentrations of pollutants in discharged effluent).
- The majority of the permit sources with discharges greater than 1 million gallons per day (gal/d) are municipal treatment facilities.
- Approximately 200 sewage treatment plants that serve populations ranging from 1,000 to 132,000 discharge treated water into surface waters of the Ozark-Ouachita Highlands. Average facility flows range from 1,000 to 2 million gal/d. Larger municipal sewage treatment plants include those of Springfield, MO, and Little Rock, AR.
- Four industries constitute most of the point source dischargers: sewage treatment plants, pulp mills, lead and zinc ore operations, and electrical services.
- Of the four types of NPDES facilities that are ranked as major, the largest number are found in the Lower Neosho, Upper Black, and James River watersheds.
- Bull Shoals Lake watershed in the Upper White River Basin has the most NPDES sites in the Assessment area.

Municipal Water Supplies. ***How do municipal water facilities affect water quality within the Assessment area?***

- Municipal water supplies provide over 80 percent of the drinking water in the Assessment area.
- The largest drinking water supplies are located in the Meramec, Arkansas, Kiamichi, and Upper White River Basins, which serve about 1.6 million people.
- Smaller water supplies in the Assessment area are located in less populated watersheds such as the Upper Black and Upper St. Francis River Basins.

Toxic Releases. ***What are the current status and potential effects of toxic pollutants on aquatic resources in the Assessment area?***

- Densities of toxic release sites are highest in and near urban areas such as Little Rock, AR; Fort Smith, AR; Springfield, MO; St.Louis, MO; and areas that have large industries or concentrations of industries.
- The Spring (Neosho-Illinois River Basin), Lower Arkansas-Maumelle, James, and Illinois watersheds have the highest number and density of toxic release sites in the region.
- Discharge media for toxic releases include land, underground, air, water, and off-site transfer. Of these media, air releases account for 53 percent of all discharges.

Nonpoint Sources

Roads and Highways. ***What are the current status and potential effects of roads and highways on aquatic resources in the Highlands?***

- All watersheds in the Assessment area have road segments within 100 feet of streams.
- The Upper Black River, Bull Shoals Lake, Current River, Beaver Reservoir, and Illinois River watersheds have the most road miles within riparian areas in the Assessment area.

- Class 2 and 3 roads (State highways and county roads) have the highest number of miles within Highlands riparian areas.
- Class 3 roads (county and national forest roads) have the most miles within riparian areas in national forests.

Agriculture and Silviculture. ***What are the current status and estimated effects of potential erosion from agriculture and silviculture on aquatic resources within the Assessment area?***

- Total potential erosion declined in more than half of the watersheds in the Assessment area for the 3 years studied (1982, 1987, and 1992).
- The South Grand watershed had the highest average potential erosion rate in 1992.
- Most of the cropland potential erosion as a percent of total potential erosion came from watersheds along the eastern and western boundaries of the Assessment area for the 3 years studied.
- The Fourche La Fave, Ouachita Headwaters, and Upper Little River watersheds had the lowest average potential erosion rates for the 3 years studied.
- Forest potential erosion as a percent of total potential erosion was 3 percent or less for most of the Assessment area watersheds for the 3 years studied.
- In 1982, 1987, and 1992, watersheds with the highest forest potential erosion as a percent of total potential erosion were in the southern part of the Assessment area.
- The category with the highest potential erosion in most Assessment area watersheds for the 3 years studied was pasture lands.
- Most watersheds in the Assessment area had no appreciable potential erosion from rangelands.
- In more than half of the Assessment area watersheds potential erosion rates from “other” lands were 2 percent or less of total potential erosion.

Pesticides—Applications and Distributions. ***Which pesticides are most frequently applied in the Assessment area, and to what extent are they distributed?***

Ozark Plateaus

- Approximately 4.4 million pounds (lbs) of active ingredients per year from 130 pesticides were applied on 25 crop types within the Ozark Plateaus Province from 1987 through 1991.
- The herbicides 2,4-D, atrazine, propanil, metolachlor, alachlor, trifluralin, dicamba, and glyphosate were the eight pesticides used most extensively on or in the Ozark Plateaus.
- The most frequently applied pesticide was 2,4-D; an estimated 750,000 lbs/year of 2,4-D were applied in the Ozark Plateaus.

Arkansas Valley

- Approximately 771,000 lbs/year of active ingredients from 128 pesticides were applied on 25 crop types within the Arkansas Valley from 1987 to 1991.
- The seven pesticides used most extensively in the Arkansas Valley were the herbicides 2,4-D, propanil, trifluralin, atrazine, metolachlor, and dicamba and the fungicide sulfur.
- The most frequently applied pesticide was 2,4-D; an estimated 108,000 lbs/year of 2,4-D were applied in the Arkansas Valley.

Ouachita Mountains

- Approximately 356,000 lbs/year of active ingredients from 127 pesticides were applied on 22 crop types within the Ouachita Mountains from 1987 to 1991.
- The herbicides 2,4-D, dicamba, atrazine, metolachlor, trifluralin, and glyphosate and the fungicide, sulfur, were the seven pesticides used most extensively in the Ouachita Mountains.
- The most frequently applied pesticide in the Ouachita Mountains was 2,4-D, with an estimated application of 65,000 lbs/year.

Pesticides in Surface Water. *What are the current and potential effects of pesticides on surface water in the Highlands?*

Ozark Plateaus

- Pesticide data are available for 1,002 samples from 141 surface water sampling sites in the Ozark Plateaus.
- Many sites were sampled only once (42 sites) or twice (19 sites) during the 1970 through 1990 period of record.
- About 50 percent of the 1,002 samples were collected in the mid-1970's and early 1980's.
- Thirty-four of the 50 pesticides were below the detection limit for all the samples collected; 16 pesticides were detected in 132 samples collected from 43 sites.
- The pesticide detected most often was the insecticide toxaphene, detected in 17 of 866 samples from 5 of 112 sites. The concentration of toxaphene in samples with detections ranged from 0.1 to 6.0 mg/L.

Arkansas Valley

- Pesticide data are available for 53 samples from 14 sites in the Arkansas Valley.
- Many sites were sampled only once (four sites) or twice (seven sites) during the 1975 through 1995 period of record.
- About 65 percent of the 53 samples were collected in the early and mid-1980's.
- Three of the nine pesticides were below the detection limit for all the samples collected; six pesticides were detected in three samples collected from three sites.
- Five pesticides (DDE, DDT, aldrin, dieldrin, and lindane) were detected in 3 of 53 samples from 3 of 14 sites. The maximum concentration for these pesticides was 0.001 mg/L, except for DDT (0.002 mg/L).

Ouachita Mountains

- Pesticide data are available for 245 samples from 19 sites in the Ouachita Mountains.
- About 64 percent of the 245 samples were collected in the late 1970's and early 1980's.
- Sixteen of 23 pesticides were below the detection limit for all the samples collected; 7 pesticides were detected in 13 samples collected from 10 sites.
- The most commonly detected pesticide was methyl parathion, found in 10 of 234 samples at 10 of 20 sites, which had concentrations ranging from 0.001 to 0.002 mg/L.

Pesticides in Ground Water. *What are the current and potential effects of pesticides on ground water in the Highlands?*

Ozark Plateaus Province

- Pesticides were detected in 80 of 229 samples of ground water from 73 of 215 sites.
- Twenty pesticides were detected; a maximum of five pesticides was detected in any one sample.
- The most commonly detected pesticides are tebuthiuron, atrazine, prometon, desethylatrazine, and simazine. Maximum concentrations range from 0.003 to 1.0 mg/L.
- The occurrence and distribution of pesticides are related to land use. Samples with detectable pesticides come from sites having a higher percent of land used for agriculture than samples from sites with no pesticides detected.
- Pesticides are detected more often in samples from springs than in samples from wells.

Ouachita Province

- For the Ouachita Province, very little data are available from monitoring pesticides in ground water.
- Commonly applied pesticides in forest land—2,4-D, dichlorprop, hexazinone, and picloram—were not found at any of the eight Ouachita Mountains sites sampled in 1986.

Animal Wastes. *What are the current status and potential effects of animal confinement and waste on aquatic resources in the Assessment area?*

- An estimated 358,300 tons (7 tons/mi^2) of nitrogen and 123,400 tons (3 tons/mi^2) of phosphorus were available from animal wastes in the Ozark Plateaus in 1992.

- An estimated 82,312 tons (6 tons/mi^2) of nitrogen and 29,460 tons (2 tons/mi^2) of phosphorus were available from animal wastes in the Arkansas Valley in 1992.
- An estimated 57,555 tons (4 tons/mi^2) of nitrogen and 20,207 tons (2 tons/mi^2) of phosphorus were available from animal wastes in the Ouachita Mountains in 1992.

Fertilizers. *What are the current status and potential effects of fertilizer applications on aquatic resources within the Assessment area?*

Ozark Plateaus Province

- In 1985, nitrogen fertilizer application rates for the counties within the Ozark Plateaus part of the Assessment area ranged from an estimated 0 to 12 tons/mi^2.
- Phosphorus fertilizer application rates in 1985 for the counties within the Ozark Plateaus ranged from an estimated 0 to 5 tons/mi^2.

Arkansas Valley

- In 1985, nitrogen fertilizer application rates for the counties within the Arkansas Valley part of the Assessment area ranged from an estimated 0 to 12 tons/mi^2.
- Phosphorus fertilizer application rates in 1985 for the counties within the Arkansas Valley ranged from an estimated 0 to 1 ton/mi^2.

Ouachita Mountains

- In 1985, nitrogen fertilizer application rates for the counties within the Ouachita Mountains part of the Assessment area ranged from an estimated 0 to 3 tons/mi^2.
- Phosphorus fertilizer application rates in1985 for the counties within the Ouachita Mountains ranged from an estimated 0 to 0.5 ton/mi^2.

Urbanization. *What are the current status and potential effects of urbanization on aquatic resources within the Assessment area?*

- The 1990 population of the Assessment watersheds was 3,361,301.
- Between 1980 and 1990, an 8 percent population increase occurred within the Assessment watersheds.
- Twenty-four watersheds experienced population increases of 7 percent or more between 1980 and 1990.
- Between 1980 and 1990, the rate of urbanization was greater within the Assessment area than nationwide.
- Two Assessment area watersheds (the Upper Little River in southeastern Oklahoma and the Little Missouri in southern Arkansas) had a 7 percent decrease in population from 1980 to 1990.

Mineral Extraction. *What are the current status and potential effects of activities associated with the exploration and extraction of minerals on aquatic resources within the Assessment area?*

- In 1996, approximately 692 mining-related operations for hardrock and coal extraction occurred in the Assessment area.
- The primary mining activity in the Assessment area is surface mining of common variety minerals that generally go to the building and road construction industries.
- Several abandoned, historical mine sites continue to contribute to chemical and metal leachates and runoff, increasing acidity in some cases and affecting aquatic resources within the Assessment area.
- Effects on aquatic resources from present-day mining activities are primarily associated with increased sedimentation of streams caused by instream gravel and sand extraction.
- Approximately 595 mi of rivers, streams, and lakes are impaired as a result of mining activities within the Assessment area.

Introduced Species. *What effects are introduced aquatic species having on the Assessment area?*

- Introduced species such as zebra mussels, common carp, and a number of aquatic weeds have become pests.

- Arkansas, Missouri, and Oklahoma are making concerted efforts to retard the spread of zebra mussels both through general public education and the education of individual anglers and boaters.
- It is likely that zebra mussels eventually will show up in most lakes and reservoirs in the Assessment area as the result of a transient boating public. Zebra mussels are expected to ravage the native mussel fauna as well as disrupt the food chain of any water body they colonize.
- Nonindigenous species (non-native or transplanted species) require constant management attention to reduce the likelihood of introduced species, particularly exotics (non-natives), becoming established.

Chapter 5: Water Supply and Use

Past and Present Supply and Use. *What are the past and current water supplies and uses in the Assessment area?*

- Total withdrawals in the Assessment area in 1995 were 6,622 million gal/d. Of these withdrawals, 1,322 million gal/d (20 percent) were consumed and not returned to a stream.
- Twenty-two percent of the total 1995 withdrawals came from ground water pumping; the other 78 percent of withdrawals came from surface water.
- Hydropower plants used almost 103 billion gal/d of surface water to produce electricity.
- From 1985 to 1995, withdrawals increased in four categories of water use (domestic and public, commercial, thermoelectric, and irrigation) and decreased in three other categories (industrial, mining, and livestock).
- Increases in withdrawals, especially those at thermoelectric plants and for irrigation, far outpaced decreases, resulting in substantial net increases.
- In 1995, 64 percent of withdrawn water was for cooling at thermoelectric plants; another 20 percent was for crop irrigation.
- Annual precipitation in the Assessment area averages about 44 inches, of which roughly 70 percent evaporates. The rest is available as streamflow, to recharge ground water reservoirs, or for offstream use.
- Across the entire area in the average year, only 6.7 percent of the 53.7 billion gal/d of water yield is withdrawn for offstream use, and only 1.2 percent evaporates or returns to the stream.
- Withdrawals vary widely across watersheds and exceed 20 percent of available water in four watersheds. In three of these watersheds (South Grand, Illinois, and Dardanelle Reservoir), withdrawals for thermoelectric plants account for 83 to 97 percent of total withdrawals. In the other watershed (Lower Black), irrigation accounts for 97 percent of total withdrawals.

Future Patterns and Trends. *What future trends are likely for water use and supply?*

- Domestic and public withdrawals are projected to increase from 143 gal/day per person in 1995 to 156 in 2040. Total domestic and public withdrawals are thus projected to increase from 538 million gal/d in 1995 to 675 in 2040.
- Total industrial and commercial withdrawals are projected to drop from 339 million gal/d in 1995 to 214 in 2040
- Total annual energy production at thermoelectric plants in the Assessment area is projected to increase from 75 billion kilowatt hours (kWh) in 1995 to 107 billion kWh in 2040.
- Total withdrawals for thermoelectric plants are projected to drop from 4.2 billion gal/d in 1995 to 3.8 in 2040.
- Acres of crops irrigated are expected to increase from 798 thousand in 1995 to 1,226 thousand in 2040. Total irrigation withdrawals are projected to increase from 1.3 billion gal/d in 1995 to 2.0 billion gal/d in 2040.
- Total withdrawals are projected to increase until 2020 and remain rather stable after that, staying within 5 percent of 1995 withdrawals. Essentially the increases in withdrawals for domestic and public use and for irrigation are largely balanced by the decreases in withdrawals for industrial, commercial, and thermoelectric uses.

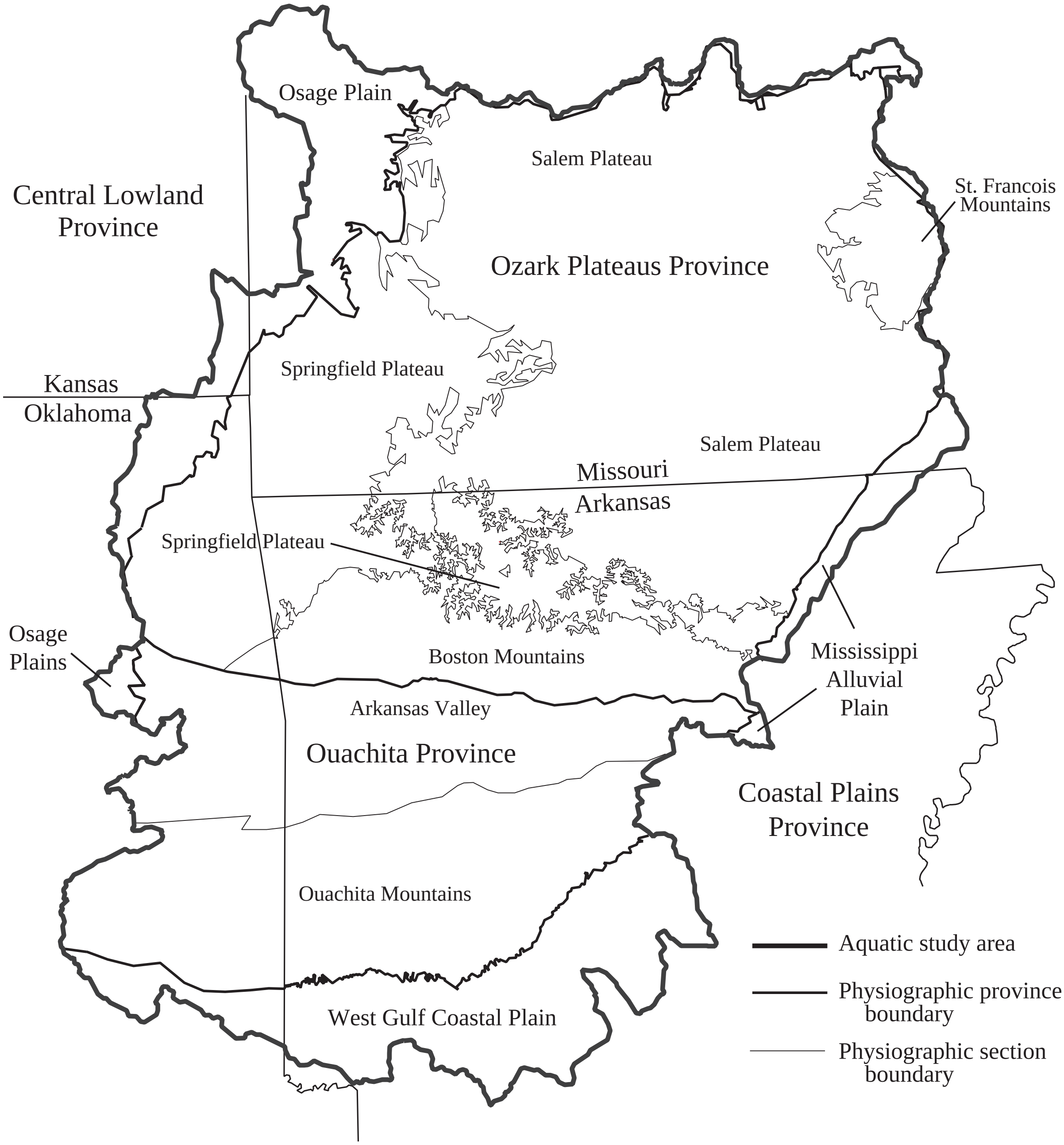


Figure 1.1—Physiographic subdivisions of the aquatic study area (adapted from Fenneman 1938).

Chapter 1: Introduction to the Aquatic Study Area

This introductory chapter of the *Ozark-Ouachita Highlands Assessment: Aquatic Conditions* describes the physiography, river basins, watersheds, major lakes, ground water, climate, geology, soils, and land uses of the aquatic study area and the slightly smaller Highlands Assessment area. The Aquatic Team used physiographic areas, river basins, and watersheds as the principal geographic units for displaying data throughout most of this report. (The exception is in the latter half of Chapter 2, where "ecological sections" are substituted for physiographic areas, as described in the text at that point.) An understanding of physiographic areas, river basins, watersheds, and the other background information in this chapter will provide the reader with a context for the chapters that follow.

Physiography

For the portions of this report that use physiographic areas as mapping or descriptive units, the Aquatic Team used Fenneman's (1938) definitions and terminology. A physiographic "province," for example, is a geographic area having particular geologic and landform characteristics. The study area for the aquatic portion of the Assessment included the Ozark Plateaus Province, the Ouachita Province, and small parts of the Coastal Plains and Central Lowland Provinces (fig. 1.1). (Portions of the Coastal Plains Province and the Central Lowland Province were included in the aquatic study area to encompass watersheds that lie partially within and partially outside the Highlands.) These four provinces include diverse topography, geomorphology, and soils that greatly influence the aquatic ecosystems of the Ozark-Ouachita Highlands.

Altitudes of land surfaces in the aquatic study area range from approximately 200 feet (ft) above mean sea level in the Coastal Plains Province to more than 2,300 ft in the Boston Mountains of the Ozark Plateaus Province and over 2,700 ft in the Arkansas Valley and the Fourche-Kiamichi Mountains of the Ouachita Province.

Ozark Plateaus Province

The Ozark Plateaus Province covers an area of 40,000 square miles (mi^2) and includes parts of four States. The physiography of this province is largely defined by its geology, which consists of a vast structural dome of igneous rocks (forming the St. Francois Mountains in southeastern Missouri). This dome is flanked by sedimentary rocks that gently dip away to form three distinct physiographic sections (Fenneman 1938): (1) the Salem Plateau (including the St. Francois Mountains), (2) the Springfield Plateau, and (3) the Boston Mountains (fig. 1.1). Topography ranges from "gently rolling hills" in the Springfield Plateau through "rugged landscapes with relief up to 500 ft" in the Salem Plateau to "extremely rugged with relief as much as 1,000 ft" in the Boston Mountains.

The southeastern boundary of the province is marked by contact between Paleozoic Era rocks of the Ozark Plateaus and younger, unconsolidated sediments of the Mississippi Alluvial Plain. The southern provincial boundary is defined by faults on the southern flank of the Boston Mountains. The western boundary is marked by contact between rocks of Mississippian and Pennsylvanian age. The northern and eastern boundaries of the province generally follow the Missouri and Mississippi Rivers, respectively.

The highest land surface altitude in the Ozark Plateaus, excluding the Boston Mountains (where altitudes exceed 2,300 ft), is 1,772 ft above sea level at Taum Sauk Mountain (part of the St. Francois Mountains). A ridge of locally high relief extends west-southwest from the St. Francois Mountains to the extreme southwestern corner of Missouri. Altitudes along this ridge range from the peak of Taum Sauk Mountain down to about 1,200 ft; altitudes generally decrease moving away from this ridge to the northwest (toward the Osage Plains) or south.

The varied (nearly flat to very rugged) provincial topography is marked by boundaries between plateau highs that form escarpments where deeply incised valleys separate narrow divides or "mountains." Here, the result is rugged topography with relatively high relief. Away from the escarpments, the topography is composed of nearly flat lands that rise to gently rolling hills with low relief. The exception is the Boston Mountains, which have pervasively rugged topography (Fenneman 1938).

Throughout much of the Ozark Plateaus, stream drainage patterns are radial. Drainage patterns can follow geologic features such as faults and joints in the rocks. Entrenched stream meanders, resulting from streams downcutting as the area was uplifted, are common in the larger stream valleys. In the more rugged parts of the Salem Plateau and Boston Mountains, drainage patterns are dendritic (branching).

The Ozark Plateaus Province contains numerous distinctive geomorphic (surface) features that are related to the geology and hydrology of the area. For example, local uplands can form two distinct landscape features—mounds and bald mountains. Mounds are erosional remnants of outliers of rocks of Mississippian or Pennsylvanian age overlying older sedimentary rocks. Bald mountains, commonly called "balds," are predominantly treeless hills present in south-central Missouri. Lines of trees on bald mountains can indicate water-bearing fractures in the underlying rock (Beveridge and Vineyard 1990).

Karst limestone features are common in the Ozark Plateaus. Dissolution of carbonate rocks along fractures and faults has produced cave systems, sinkholes, and natural tunnels in the area (Beveridge and Vineyard 1990). Missouri alone has at least 5,000 caves, and most of these are located in the Ozark Plateaus Province (MO DNR 1980).

Salem Plateau

The Salem Plateau covers a large part of the aquatic study area (approximately 27,200 mi^2) in Missouri and northern Arkansas (fig. 1.1). Underlain by rocks of Cambrian and Ordovician age, the Salem Plateau contains a central upland area. Topography in this upland—located west of the St. Francois Mountains—typically consists of gently rolling hills with local relief from 50 to 100 ft (Fenneman 1938). Away from the central upland area, numerous streams dissect the plateau, resulting in increased relief. South and east of the upland, topography is rugged, with local relief up to 500 ft. North of the central upland, topography is also rugged, but relief rarely exceeds 350 ft (Fenneman 1938).

Sinkholes and springs are abundant in the Salem Plateau. The upland area has an average of 1 to 10 sinkholes per 100 mi^2. A north-south trending band in south-central Missouri contains more than 10 sinkholes per 100 mi^2 (Harvey 1980). Springs generally have discharges exceeding 100 cubic feet per second (ft^3/s) (Imes and Smith 1990).

The St. Francois Mountains are formed from exposures of igneous rocks of Pre-Cambrian age associated with the structural dome of similar makeup in southeastern Missouri. The St. Francois Mountains are a series of resistant hills or knobs separated by valleys that are underlain by sedimentary rocks of Cambrian age. While the St. Francois Mountains cover about 1,350 mi^2, the area in which predominantly igneous rocks are exposed is less than 100 mi^2. Altitudes of land surfaces range from 1,000 to more than 1,700 ft above sea level. Topography is rugged, with local relief ranging from 500 to 800 ft (Fenneman 1938). The St. Francois Mountains are not a separate physiographic section as defined by Fenneman (1938) but will often be discussed separately in this report because of unique geological features that affect the hydrology of the area.

Springfield Plateau

The Springfield Plateau covers approximately 13,400 mi^2, including parts of west-central and southwestern Missouri, southeastern Kansas, northeastern Oklahoma, and northern Arkansas (fig. 1.1). Limestones and cherty limestones of Mississippian age underlie the plateau (Fenneman 1938).

Altitudes of land surfaces in the Springfield Plateau range from 1,000 to 1,700 ft, but local topographic relief, which decreases from east to west, rarely exceeds 200 to 300 ft. The topography is mostly gently rolling hills, except at the Eureka Springs Escarpment (which separates the Springfield and Salem Plateaus), where deeply incised stream valleys separate narrow divides (Fenneman 1938).

Sinkholes and springs are common in the Springfield Plateau, but generally are smaller and less abundant than in the Salem Plateau. The number of sinkholes in the Springfield Plateau averages less than 1 per 100 mi^2, except near the city of Springfield, MO, where there are more than 10 sinkholes per 100 mi^2 (Harvey 1980).

Boston Mountains

The Boston Mountains occupy approximately 2,400 mi^2 in a 200-mile-wide band extending through northern Arkansas and northeastern Oklahoma (fig. 1.1). Sandstones, shales, and limestones of late Mississippian to Pennsylvanian age underlie the Boston Mountains. Altitudes in the Boston Mountains range from land surfaces that are 1,200 to more than 2,300 ft above sea level. Topographic relief is as much as 1,000 ft in some places, and topography typically is rugged, with narrow divides separating steep-sided valleys (Fenneman 1938).

Ouachita Province

The Ouachita Province lies in west-central Arkansas and eastern Oklahoma. Its physiographic sections are defined by the contrasting nature of the geologic structure observed in each. The Arkansas Valley—the northern section of this province—consists of gently to moderately folded rocks exclusively of Pennsylvanian age. Further south, the Ouachita Mountains section consists of the remnants of heavily eroded roots of a mountainous belt. Similar in structure and topography to the Appalachians, the mountains are characterized by gently to intensely folded and faulted strata (layers of rock). The Ouachita Mountains have three distinct districts: the Fourche-Kiamichi Mountains, the Novaculite Uplift, and the Athens Piedmont Plateau (Fenneman 1938).

The northern and northwestern boundaries of the Ouachita Province form a common boundary with the Boston Mountains, as described above. The eastern boundary of this province is marked by contact between Paleozoic rocks with younger, unconsolidated sedimentary strata of the Mississippi Alluvial Plain, called the Fall Line. The southern boundary is defined by the contact of Paleozoic Era rocks with unconsolidated sedimentary strata of the Coastal Plains Province.

Altitudes of land surfaces in the Ouachita Province range from less than 300 ft to more than 2,750 ft above sea level. Topography ranges from “flat” in the Arkansas River floodplain through “rolling” in the Athens-Piedmont Plateau to “rugged” in the Ouachita Mountains interior. Drainage patterns are typically trellis type and are strongly influenced by geologic structure. Streams tend to follow lines of folding and faults.

Arkansas Valley

The Arkansas Valley is located along the Arkansas River between Muskogee, OK, and Little Rock, AR, and is distinguished from the Ouachita Mountains section by its structure. The valley has open, gentle folding resulting in isolated, synclinal mountains, while the Ouachita Mountains have intense geologic folding and faulting resulting in tightly spaced, east-west trending linear ridges. All consolidated rocks of the Arkansas Valley are of Pennsylvanian age and compose a sequence of predominantly clastic (fragmented) rocks of great thickness (more than 30,000 ft deep in some areas).

The synclinal mountains are an outstanding feature of the Arkansas Valley: these erosional remnants present the highest elevations of land in the Assessment area. They are isolated, steep-sided buttes, often with 2,000 ft or greater local relief. Sandstone layers in these synclinal troughs are nearly horizontal. During folding, the upper part of the less ductile or less malleable sandstone layers was less compressed and more gently fractured. The result was more resistant rock that contributed to the formation of the synclinal mountains.

A large area of the Arkansas Valley consists of rolling lowland that lies between mountain and ridge areas and is less than 600 ft in elevation. These areas give way to swampy alluvial plains near the Arkansas River. The Arkansas River primarily drains the valley. However, the Little Red River drains the northeastern corner of the Arkansas Valley, and several bayous that flow across the West Gulf Coastal Plain drain the southeastern edge.

Ouachita Mountains

The Ouachita Mountains section is a lens-shaped physiographic area stretching from Little Rock, AR, to Atoka, OK. It consists of tightly compressed, folded, and faulted strata with fault traces and fold axes generally trending east to west.

The Fourche-Kiamichi Mountains (no boundaries are shown on fig. 1.1 for this or the two other districts in the Ouachita Mountains) constitute about two-thirds of the Ouachita Mountains. This district consists of roughly equal segments of uneven valley floor and interceding rugged mountain ridges and relief. Mountain altitudes range from around 600 ft in the easternmost part of the district near Little Rock to more than 2,500 ft in the central area of the section. Valley floor altitudes range from approximately 400 ft or less in the eastern part to 1,100 ft above sea level in the central parts.

The Novaculite Uplift defines the core area of the Ouachita Province where uplift during the Ouachita orogeny (mountain building era) was greatest. Carboniferous and younger strata have eroded entirely away. The resulting exposed rocks are resistant to erosion and contribute to the district's distinctive hydrogeology (water and terrain interactions). Resistant sandstones form mountains of 600 to 2,000 ft in altitude separated by broad basins underlain by less resistant shales. Local relief typically ranges from 300 to 700 ft. The hot springs for which the Novaculite Uplift is famous are found on the plunging crestline of one of the district's many overturned anticlines.

The Athens Piedmont Plateau, located in the southernmost part of the Ouachita Mountains, is an erosional plateau with no mountains. Stratigraphy (the arrangement of layers) and structure in this district are similar to that observed in the district to the north. However, the plateau shows only minor topographic relief, with occasional east-west trending ridges and swells. Parallel sandstone ridges rise 150 to 250 ft above narrow, interceding valleys. Altitudes range from 1,100 ft at the western end of the piedmont to 400 ft above sea level in the southeast. The ranges generally slope to the south and east. The larger streams flow south across the district and generally have steep gradients (15 to 20 ft per mile); tributaries follow strike-trending valleys and intersect at right angles (Fenneman 1938).

Approximately two-thirds of the Ouachita Mountains section drains to the Red River Basin through the Ouachita River and its tributaries. The northern part of the section is in the Arkansas River Basin, drained primarily by the Fourche La Fave River and its tributaries.

Central Lowland and Coastal Plains Provinces

The Central Lowland Province occupies a large area in the Central United States extending from Texas to North Dakota and from Missouri to Colorado (Fenneman 1938). The Osage Plains portion of this province includes an area just west of the Assessment area that drains portions of the Ozarks.

The Coastal Plains Province extends along the Atlantic and Gulf Coasts from New England to Texas. It is a continuation of the Continental Shelf and has a very gentle slope. The Mississippi Alluvial Plain section of this province, which is an area of deltas and bottomlands of the Mississippi River and its tributaries, includes a small area in the eastern part of the aquatic study area. A small part of the West Gulf Coastal Plain section lies in the extreme southern part of the aquatic study area.

Osage Plains

The Osage Plains occupies approximately 6,700 mi^2 in the western and northwestern part of the aquatic study area (fig. 1.1). Soft shales with interbedded sandstones and limestones of late Mississippian to Pennsylvanian age underlie the Osage Plains. Altitudes of land surfaces in the study area portion of the Osage Plains range from 800 to 1,000 ft above sea level, and topography consists of gently rolling hills. In a few places, resistant beds of sandstones and limestones form rare, east-facing escarpments (Fenneman 1938).

Mississippi Alluvial Plain

The Mississippi Alluvial Plain section lies immediately east of the Assessment area (fig. 1.1). Unconsolidated sediments of Cretaceous through Quaternary age underlie the flat to gently rolling plain. The land surface of the Mississippi Alluvial Plain located in the aquatic study area averages less than 200 ft above sea level; the range of topographic relief seldom exceeds 30 ft.

Geologic structure and erosion have contributed to the formation of the plains. The boundary between the unconsolidated sedimentary strata of the Mississippi Alluvial Plain and sedimentary rocks of Paleozoic age is formed by normal faults. Faulting has resulted in subsidence of the older sedimentary rocks, allowing a thick sequence of unconsolidated sedimentary strata to be deposited on top. The Mississippi River and its tributaries have eroded the unconsolidated sedimentary strata in places, forming occasional bluffs and ridges in the section (Fenneman 1938).

West Gulf Coastal Plain

The West Gulf Coastal Plain section is located south of the Ouachita Province and marks the contact between Cretaceous and Paleozoic rocks. Unconsolidated sediments of Cretaceous age underlie the mildly rolling West Gulf Coastal Plain. Streams are low gradient and generally follow parallel southeasterly courses.

Major River Basins

The Assessment area is drained by 10 major river basins (clockwise from the northeast): the Meramec, Upper St. Francis, Upper Black, Upper White, Ouachita-Saline, Kiamichi-Little, Arkansas, Neosho-Illinois, Osage, and Gasconade. Nested within these river basins are 50 smaller watersheds (hydrologic units) (fig. 1.2). These waters are all direct or indirect tributaries of the Mississippi River. The Black River is a tributary of the White River, which flows directly into the Mississippi River, as do the Meramec and St. Francis Rivers. The Neosho and Illinois Rivers are tributaries of the Arkansas River, which flows into the Mississippi River. The Osage and Gasconade Rivers flow into the Missouri River, which is the largest of the Mississippi River tributaries. The Kiamichi, Little, Ouachita, and Saline Rivers are tributaries of the Red River, which flows directly into the Mississippi River. Table 1.1 provides summary information about these river basins, and a more detailed description of each follows.

Figure 1.2—Major river basins and watersheds (with hydrologic unit codes) of the aquatic study area.

Table 1.1—Major river basins of the aquatic study area and their drainage areas, land uses, principal tributaries, and major reservoirs, by principle physiographic area

River basin	Total drainage area	Drainage within aquatic study area	Land use, in order of importance	Principal tributaries	Drainage area of tributaries	Major reservoirs within basin (not necessarily in named tributaries)
	- - - - - - - - - *Mi^2*	- - - - - - - - -			*Mi^2*	
				Ozark Plateaus Province		
Upper White[a]	27,800	13,000	F, P, C, U	War Eagle Creek	332	Beaver Reservoir
				Kings River	565	Table Rock Lake
				Crooked Creek	462	Lake Taneycomo
				Buffalo River	1,340	Bull Shoals Lake
				Little Red River	1,792	Norfork Lake
				James River	1,460	Greers Ferry Lake
				North Fork White River	1,830	
Neosho-Illinois	14,100	7,800	C, P, F, M	Spring River	3,510	Lake O’ the Cherokees
				Elk River	872	Lake Hudson
				Big Cabin Creek	450	Fort Gibson Lake
				Osage Creek	206	Tenkiller Ferry Lake
				Baron Fork	307	
Osage	15,300	9,600	C, P, F, M	Little Osage River	570	Truman Reservoir
				Marmaton River	1,150	Lake of the Ozarks
				South Grand River	2,040	Stockton Lake
				Sac River	1,970	Pomme de Terre Lake
				Pomme de Terre River	828	
				Niangua River	1,040	
Gasconade	3,600	3,600	F, P	Big Piney River	760	None
				Osage Fork	520	
				Roubidoux Creek	300	
				Little Piney Creek	272	
Meramec	3,980	3,960	F, P, M	Bourbeuse River	841	None
				Big River	964	
Upper St. Francis	6,480	1,310	F, P, M	NA	NA	Lake Wappapello
Upper Black	8,560	8,560	F, A, M	Current River	2,610	Clearwater Lake
				Spring River	1,230	
				Eleven Point River	1,220	
				Strawberry River	792	
				Ouachita Province		
Arkansas	160,600	12,900	F, A, U	Poteau River	1,890	Robert S. Kerr Lock/Dam
				Mulberry River	511	Wister Reservoir
				Petit Jean River	1,080	Nimrod Lake
				Cadron Creek	753	Blue Mountain Lake
				Big Piney Creek	537	Webber Falls Lock/Dam
				Fourche La Fave River	1,120	Ozark Lake
						Maumelle
				Ouachita Mountains		
Ouachita-Saline	18,900	7,100	F, A	Caddo River	477	Lake Ouachita
				Little Missouri River	2,103	DeGray Lake
				Saline River	1,716	Winona
				Hurricane Creek	312	Lake Greeson
						Lake Hamilton
Kiamichi-Little	6,000	6,000	F, A	Cossatot River	541	Millwood Lake
				Mountain Fork	865	Sardis Lake
						Broken Bow Lake
						Hugo Lake

Mi^2 = square mile; F = forest; P = pasture; C = cropland; U = urban; M = mining; A = agriculture (both pasture and cropland); NA = not applicable.

[a] Does not include the Black River Basin, which is the largest tributary of the White River; the drainage area for the Kings River does not include the small part in Missouri.

Three national forests—the Ozark, Ouachita, and Mark Twain—lie wholly or partially within the river basins of the aquatic study area. The St. Francis National Forest, administratively linked with the Ozark, lies outside of the Assessment area. Table 1.2 displays the acreage of national forest lands within each watershed of the study area and the portion of each watershed occupied by such lands. National forest lands are present in 9 of the 10 river basins and in 34 of the 50 watersheds. (Comparable data for other public lands are not presented here, primarily because, with the exception of a few counties, national forests are by far the most prominent public lands in the Highlands.)

Ozark Plateaus Province

Adamski and others (1995) describe the major river basins of much of the Ozark Plateaus. Most of the following discussion is based on that report.

Upper White River Basin

The White River, originating in the rugged terrain of the Boston Mountains of northwestern Arkansas, generally flows northward to the Arkansas-Missouri State line, then eastward through southern Missouri for about 115 miles (mi) where it again intersects the Arkansas-Missouri State line (fig. 1.3). The river meanders on either side of the Arkansas-Missouri boundary for about 30 mi, flows southeastward into Arkansas to the mouth of the Black River, and then south to its confluence with the Mississippi River. The total drainage area of the White River is 27,800 mi^2, with about 10,600 mi^2 in southern Missouri and 17,200 mi^2 in northern and eastern Arkansas (Sullavan 1974). About 13,000 mi^2 (not including the Upper Black River Basin) are in the Ozark Plateaus segment of the aquatic study area. The stream reach of the White River near the Arkansas-Missouri State line is marked by a series of reservoirs, beginning with Beaver Lake in northwestern Arkansas and proceeding downstream to Table Rock Lake, Lake Taneycomo, and Bull Shoals Lake. Norfork Lake is on a tributary of the White River downstream of Bull Shoals Lake. With the completion of the Powersite Dam on the White River in 1912, Lake Taneycomo became the first major impoundment for hydroelectric power production in Missouri (U.S. ACE 1967). The areas near these lakes in both Arkansas and Missouri are increasingly popular recreational attractions and retirement havens.

Major tributaries of the White River in Arkansas are War Eagle Creek, Kings River, Crooked Creek, and Buffalo and Little Red Rivers. Congress designated the Buffalo River as the Buffalo National River in 1972 (Public Law 92-237) "for the purposes of conserving and interpreting an area containing unique scenic and scientific features, and preserving [it] as a free-flowing stream" (Mott 1991). Headwaters of War Eagle Creek, Kings River, and Buffalo River are in the Boston Mountains, but most of the tributaries of the upper White River lie within either the Springfield Plateau (War Eagle Creek) or the Springfield Plateau and Salem Plateau (Kings River and Buffalo River). Crooked Creek lies mainly in the Salem Plateau, but its headwaters are in the Springfield Plateau. Land use in this part of the Upper White River Basin is primarily forest intermingled with pasture and some cropland.

The James and North Fork White Rivers are major tributaries of the White River in Missouri. Most of the James watershed lies within the Springfield Plateau, with the exception of the lower part of the basin where the James River or its tributaries have cut into rocks of Ordovician age in the Salem Plateau. The lower part of the James watershed is primarily forested, whereas the upper part is predominately pasture and row-crop agriculture. Springfield, MO, the largest urban area in the Ozark Plateaus, lies within the James watershed. The North Fork White watershed, about 70 percent forested, lies entirely in the Salem Plateau. The lower part of the North Fork of the White River has been impounded (dammed) to form Norfork Lake.

Neosho-Illinois River Basin

The Neosho River originates in east-central Kansas in the gently rolling hills of the Osage Plains (fig. 1.4). The river flows southeast through Kansas into Oklahoma. Below the confluence with the Spring River, a major tributary, the Neosho River follows a winding course through a chain of reservoirs before entering the Arkansas River. These reservoirs are popular recreational attractions. The lower part of the drainage, predominantly located in Missouri and Oklahoma, lies in the Springfield Plateau. The total drainage area of the

Table 1.2— Drainage area and national forest lands of aquatic study area watersheds

River basin Watershed name	Watershed code (HUC)	Drainage area	Ozark National Forest		Mark Twain National Forest		Ouachita National Forest		National forests combined	
		Acres	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*
Osage River Basin										
H.S. Truman Reservoir	10290105	774,922	0	0	0	0	0	0	0	0
Sac	10290106	1,261,757	0	0	0	0	0	0	0	0
Pomme de Terre	10290107	542,814	0	0	0	0	0	0	0	0
South Grand	10290108	1,310,460	0	0	0	0	0	0	0	0
Lake of the Ozarks	10290109	886,625	0	0	0	0	0	0	0	0
Niangua	10290110	660,126	0	0	0	0	0	0	0	0
Lower Osage	10290111	689,175	0	0	0	0	0	0	0	0
Gasconade River Basin										
Upper Gasconade	10290201	1,144,116	0	0	71,843	6	0	0	71,843	6
Big Piney	10290202	483,524	0	0	89,103	18	0	0	89,103	18
Lower Gasconade	10290203	662,392	0	0	34,214	5	0	0	34,214	5
Meramec River Basin										
Meramec	07140102	1,382,471	0	0	174,681	13	0	0	174,681	13
Bourbeuse	07140103	535,812	0	0	0	0	0	0	0	0
Big	07140104	615,790	0	0	33,606	5	0	0	33,606	5
Upper St. Francis River Basin										
Upper St. Francis	08020202	830,606	0	0	111,363	13	0	0	111,363	13
Neosho-Illinois River Basin										
Lake O' the Cherokees	11070206	588,927	0	0	0	0	0	0	0	0
Spring	11070207	1,649,846	0	0	0	0	0	0	0	0
Elk	11070208	659,861	0	0	0	0	0	0	0	0
Lower Neosho	11070209	1,414,516	0	0	0	0	0	0	0	0
Illinois	11110103	1,056,531	15,708	1	0	0	0	0	15,708	1
Arkansas River Basin										
Dirty-Greenleaf	11110102	505,247	0	0	0	0	0	0	0	0
Robert S. Kerr Reservoir	11110104	1,156,317	48,096	4	0	0	0	0	48,096	4
Poteau	11110105	1,218,490	0	0	0	0	221,213	18	221,213	18
Frog-Mulberry	11110201	805,450	230,175	29	0	0	0	0	230,175	29
Dardanelle Reservoir	11110202	1,190,733	413,769	35	0	0	0	0	413,769	35
Conway- Pt. Remove	11110203	727,472	34,365	5	0	0	0	0	34,365	5
Petit Jean	11110204	697,467	47,493	7	0	0	161,851	23	209,344	30
Cadron	11110205	492,361	0	0	0	0	0	0	0	0
Fourche La Fave	11110206	716,215	0	0	0	0	372,258	52	372,258	52
Lower Ark-Maumelle	11110207	708,178	0	0	0	0	17,589	2	17,589	2
Kiamichi-Little River Basin										
Kiamichi	11140105	1,165,716	0	0	0	0	77,798	7	77,798	7
Upper Little	11140107	901,946	0	0	0	0	4,880	1	4,880	1
Mountain Fork	11140108	547,634	0	0	0	0	64,756	12	64,756	12
Lower Little	11140109	1,263,915	0	0	0	0	69,609	6	69,609	6
Ouachita-Saline River Basin										
Ouachita Headwaters	08040101	989,322	0	0	0	0	453,041	46	453,041	46
Upper Ouachita	08040102	1,127,469	0	0	0	0	76,573	7	76,573	7
Little Missouri	08040103	1,342,083	0	0	0	0	41,313	3	41,313	3
Upper Saline	08040203	1,094,040	0	0	0	0	47,988	4	47,988	4
Upper White River Basin										
Beaver Reservoir	11010001	1,635,563	43,303	3	44,237	3	0	0	87,539	5
James	11010002	926,610	0	0	21,533	2	0	0	21,533	2
Bull Shoals Lake	11010003	1,664,274	0	0	141,472	9	0	0	141,472	9

(continued)

Table 1.2— Drainage area and national forest lands of aquatic study area watersheds (continued)

River basin Watershed name	Watershed code (HUC)	Drainage area	Ozark National Forest		Mark Twain National Forest		Ouachita National Forest		National forests combined	
		Acres	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*
Upper White River Basin *(continued)*										
Middle White	11010004	943,605	107,945	11	0	0	0	0	107,945	11
Buffalo	11010005	858,950	174,844	20	0	0	0	0	174,844	20
North Fork White	11010006	1,174,854	0	0	102,069	9	0	0	102,069	9
Little Red	11010014	1,165,347	12,323	1	0	0	0	0	12,323	1
Upper Black River Basin										
Upper Black	11010007	1,222,551	0	0	225,507	18	0	0	225,507	18
Current	11010008	1,679,700	0	0	239,375	14	0	0	239,375	14
Lower Black	11010009	499,089	0	0	11,794	2	0	0	11,794	2
Spring	11010010	779,026	0	0	0	0	0	0	0	0
Eleven Point	11010011	769,055	0	0	140,600	18	0	0	140,600	18
Strawberry	11010012	505,236	0	0	0	0	0	0	0	0
Total		47,624,186	1,128,021	116	1,441,397	135	1,608,869	181	4,178,286	

HUC = hydrologic unit code.

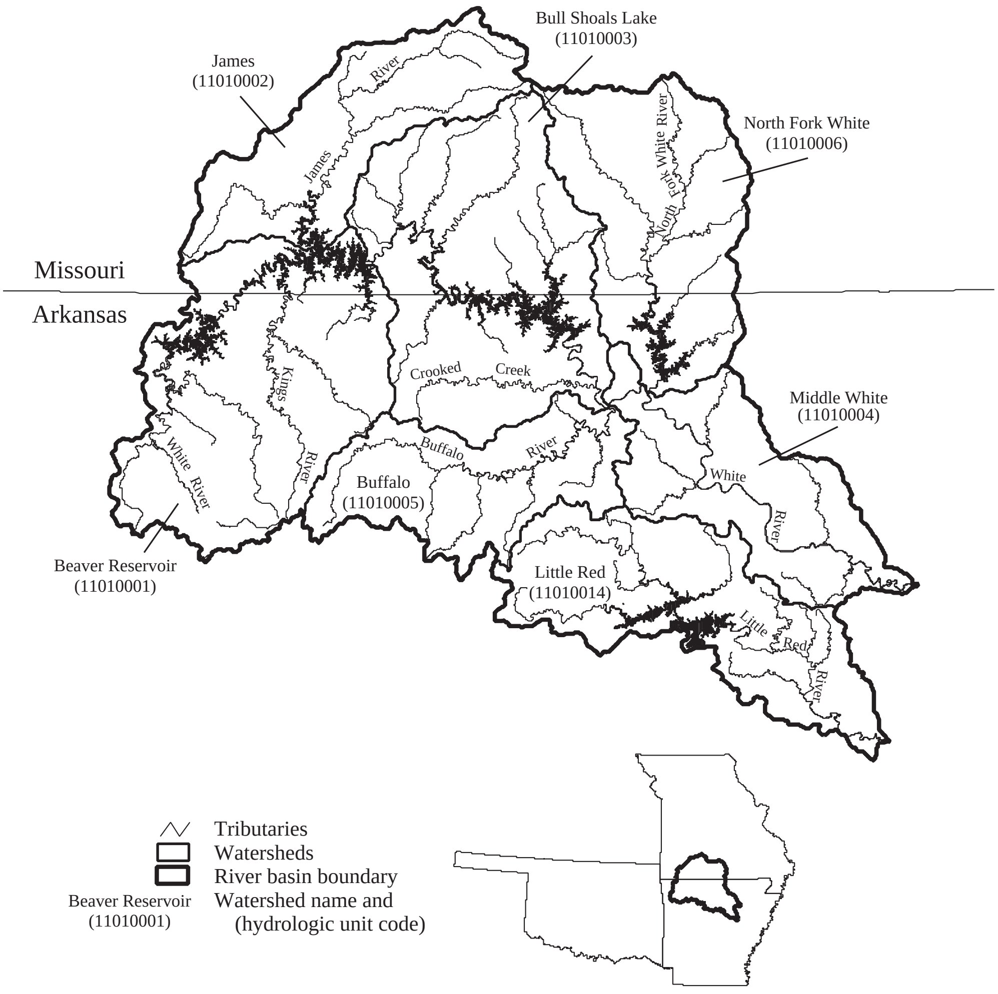


Figure 1.3—Watersheds of the Upper White River Basin with major tributaries and reservoirs.

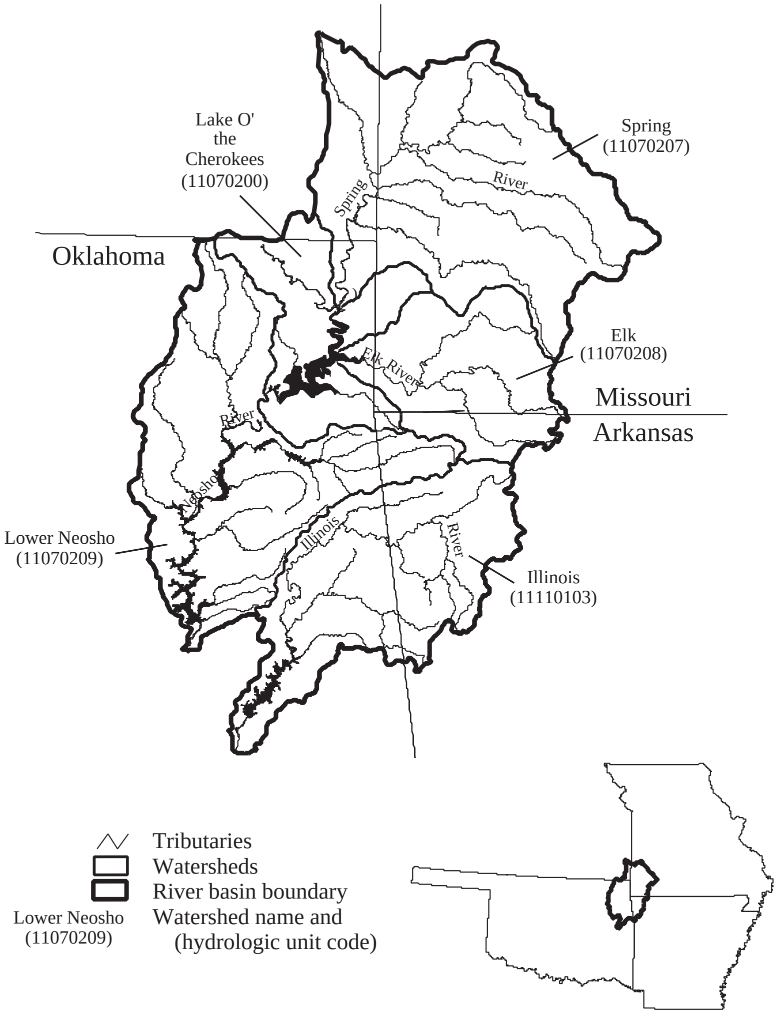


Figure 1.4—Watersheds of the Neosho-Illinois River Basin with major tributaries and reservoirs.

Neosho River is about 12,500 mi^2, of which about 6,200 mi^2 is in the aquatic study area. The Elk River, a major tributary of the Neosho River, lies entirely in the Springfield Plateau and drains pasture and forestland in northern Arkansas and southwestern Missouri. Land in the upper part of the basin within the aquatic study area is used principally for cropland and pasture, although coal and lead-zinc mining have occurred in the upper part of the basin. The largest urban area in this part of the Neosho-Illinois River Basin is Joplin, MO.

The Illinois River originates in northwestern Arkansas and flows generally northward to Oklahoma. In Oklahoma, it flows southwest into the Arkansas River (fig. 1.4). The lower part of the Illinois River is impounded and forms Tenkiller Ferry Lake. The Illinois watershed (about 1,600 mi^2) lies entirely within the aquatic study area, mostly in the Springfield Plateau. The headwaters of the watershed are in the Boston Mountains. From the Arkansas-Oklahoma State line west to the upper end of Tenkiller Ferry Lake, the Illinois River is a State-designated scenic river.

Osage River Basin

The Osage River originates in east-central Kansas, where it is called the Marais des Cygnes (Wetland of the Swans), and flows generally eastward into Missouri (fig. 1.5). The upper two-thirds of the Osage River system—

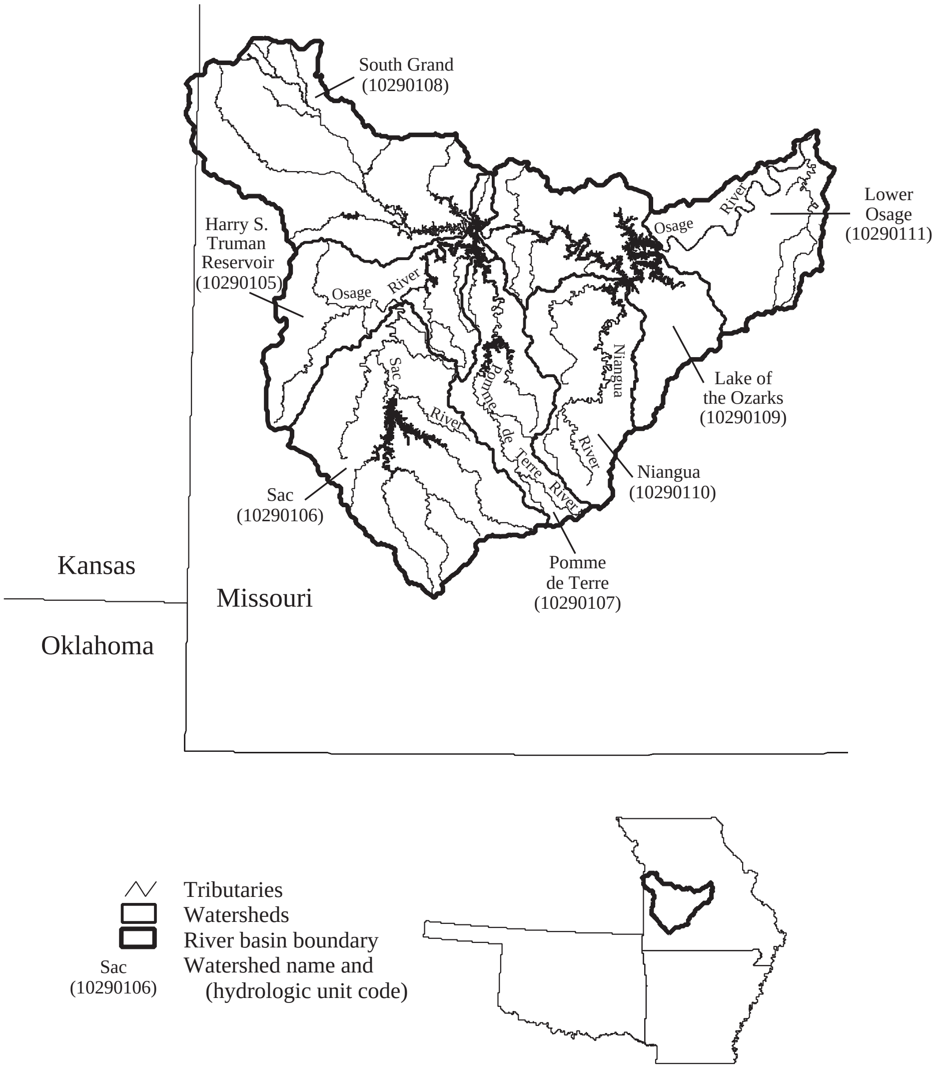


Figure 1.5—Watersheds of the Osage River Basin with major tributaries and reservoirs.

including the Little Osage, Marmaton, and South Grand Rivers—drains the gently rolling prairie land of the Osage Plains. The South Grand River is the second largest and only major south-flowing tributary of the Osage River. Land use in this part of the basin is primarily cropland and pasture, although coal mining has occurred along the western boundary of this portion of the aquatic study area.

The Osage River continues flowing eastward across the Springfield and Salem Plateaus to its confluence with the Missouri River. About 602 mi of the river have been inundated by the construction of four major reservoirs, including the Harry S. Truman Reservoir and the Lake of the Ozarks on the river's main stem (Duchrow 1984). As in the Upper White and Neosho-Illinois River Basins, these lakes are popular recreational attractions and retirement havens. The total drainage area of the Osage River Basin is 15,300 mi^2, with 10,700 mi^2 in Missouri and the remainder in Kansas. The portion of the Osage River drainage that lies in the aquatic study area is about 9,600 mi^2.

The Sac River is the only tributary of the Osage River that lies entirely within the Springfield Plateau. Stockton Lake, the third major reservoir in the Osage River Basin, is on the Sac River. About one-half of the Sac watershed is forested, with the remaining land primarily in cropland or pasture; a small part of the basin is urbanized. Withdrawals from two small lakes and a spring in the Sac watershed supply much of the drinking water for Springfield, MO, which lies near the drainage divide of the Sac River Basin.

The Pomme de Terre and Niangua Rivers are the two main Osage River tributaries that lie entirely within the Salem Plateau. Pomme de Terre Lake on the lower Pomme de Terre River is the fourth major reservoir in the Osage River Basin. The resident and tourist populations are not as large at Pomme de Terre Lake as at some of the other reservoirs in the aquatic study area. Nearly 50 percent of land use in both basins is agricultural, with activity centered primarily around livestock production.

Gasconade River Basin

The Gasconade River and its major tributary, the Big Piney River of Missouri, generally flow northeast through the rough terrain of the Salem Plateau to the Missouri River (fig. 1.6). No major reservoirs or urban areas of any size are located in the Gasconade River Basin, which lies entirely within the aquatic study area. The total drainage area of the Gasconade River Basin is 3,600 mi^2. At one time, parts of the Gasconade and Big Piney Rivers were considered for inclusion in the Wild and Scenic River System. However, because of existing shoreline development, agricultural activities, and transportation corridors, some segments of the two rivers did not meet the eligibility criteria (U.S. BOR 1973). The basin is about 75 percent forested; however, livestock and crop production are important land uses in the basin, particularly in the stream valleys.

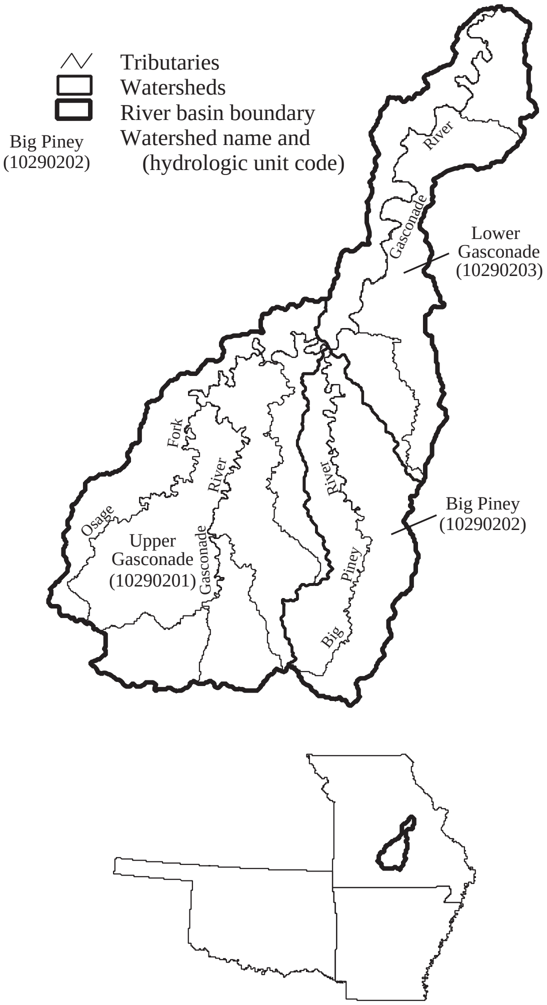


Figure 1.6—Watersheds of the Gasconade River Basin with major tributaries.

Meramec River Basin

The Meramec River Basin originates in the Salem Plateau in the northeastern part of the aquatic study area and flows northeast to the Mississippi River just south of St. Louis (fig. 1.7). Meramec Spring, the seventh largest spring in Missouri, more than doubles the flow of the Meramec River in the upper part of the basin. Most of the basin (3,960 mi^2) is in the Assessment area, with the exception of a small part in the St. Louis metropolitan area. The upper part of the basin is primarily forested but has some cropland and pasture. Small tributaries of the upper Meramec River drain part of Missouri's Viburnum Trend mining area.

The Meramec River has two major tributaries, the Bourbeuse River on the north and the Big River on the east. Much of the Bourbeuse watershed, which flows from west to east along the northern part of the Meramec River Basin, is underlain by undifferentiated deposits of Pennsylvanian age. These Pennsylvanian strata overlie and sometimes fill depressions in an ancient karst topography that developed in deposits of Ordovician age (Vineyard and others 1974). The area's gently rolling terrain is suitable for agricultural land uses, and the Bourbeuse River Basin has more pasture and tilled lands than other parts of the Meramec River Basin. The Big River originates in the St. Francois Mountains and flows northward through the Salem

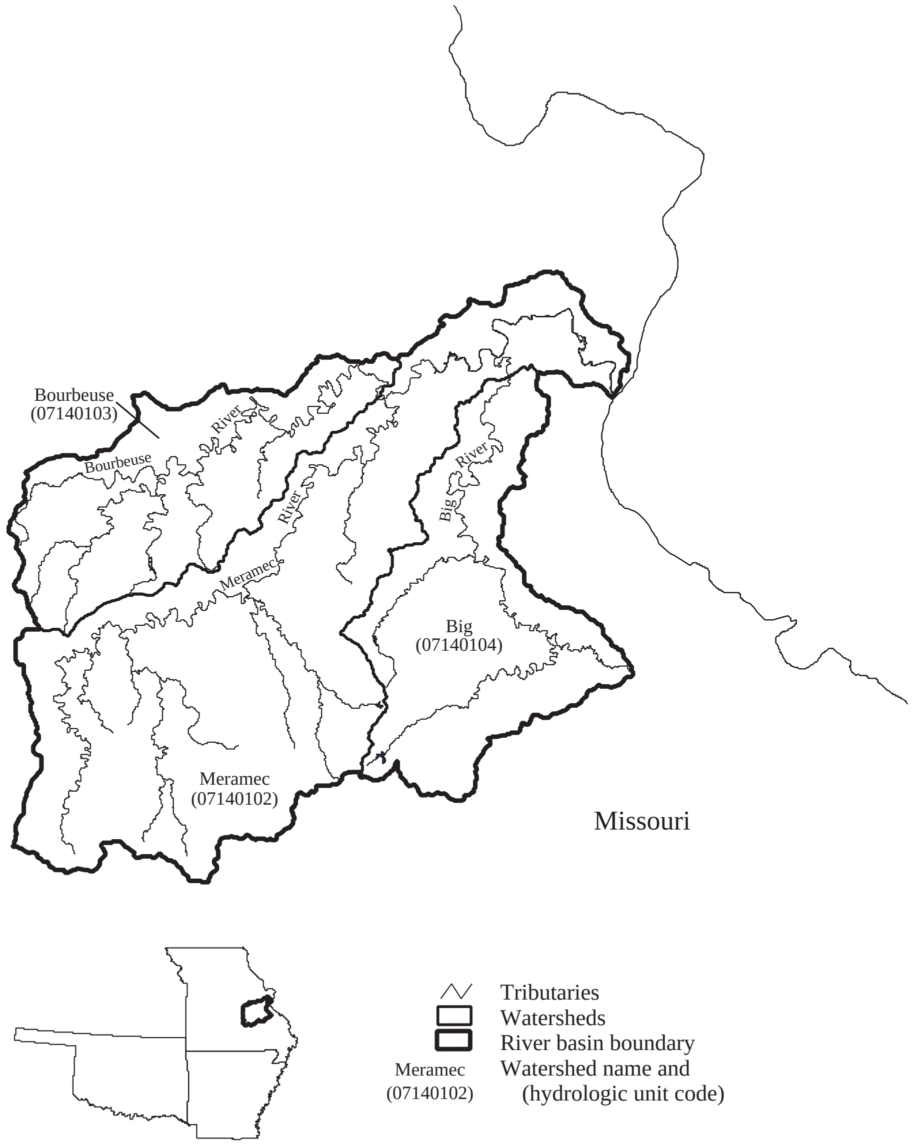


Figure 1.7—Watersheds of the Meramec River Basin with major tributaries.

Plateau to the Meramec River. The Big River Basin encompasses much of the Old Lead Belt mining area and most of the area of past and present barite mining in Missouri.

Upper St. Francis River Basin

The St. Francis River originates on the southern flank of the rugged St. Francois Mountains of southeastern Missouri and flows south through the Salem Plateau and out of the aquatic study area (fig. 1.8). The total drainage area of the basin is about 6,480 mi^2, with about 1,310 mi^2 within the aquatic study area. Lake Wappapello, located at the southeastern extent of the basin in the study area, is a major recreational area. Like other basins in the Salem Plateau, the St. Francis River Basin is predominantly forested with some pasture. Some lead and zinc mining has occurred in the upper part of the basin.

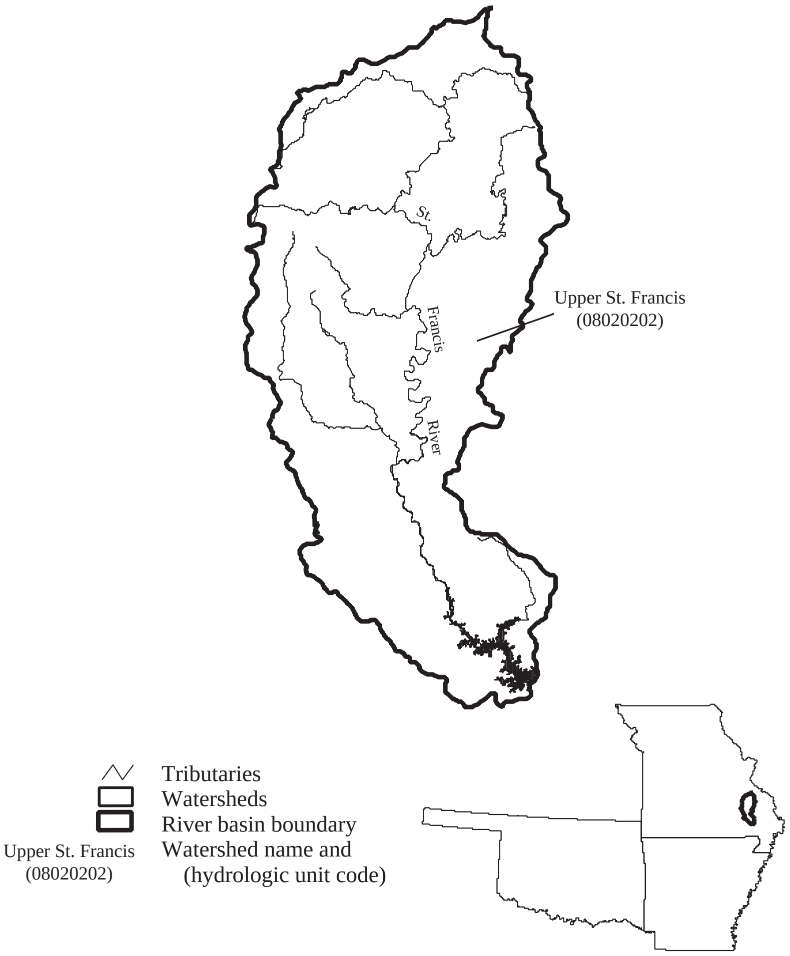


Figure 1.8—Upper St. Francis River Basin with major tributaries and reservoir.

Upper Black River Basin

The Black River is the largest tributary of the White River system with a drainage area of 8,560 mi^2. Major tributaries of the Black River include the Current, Spring, Eleven Point, and Strawberry Rivers. The Strawberry River Basin lies wholly in north-central Arkansas, but the headwaters and much of the drainage areas of the other major tributaries of the Black River are in southern Missouri. Like the St. Francis River, the Black River originates on the southern flank of the St. Francois Mountains and flows southward through the Salem Plateau into Arkansas (fig. 1.9). On the eastern side of the Black River, a small part of the drainage area is in the Mississippi Alluvial Plain. The river's other tributaries lie entirely in the Salem Plateau. The only major reservoir in the basin, Clearwater Lake, is on the Black River in Missouri. At least 50 percent of the land is forested in all of the basin's drainages, with the remainder used primarily for pasture and cropland. No major urban areas exist in this basin. Small tributaries of the upper Black River drain the southern end of Missouri's Viburnum Trend mining area.

The Upper Black River Basin is characterized by rugged, hilly countryside and numerous springs, many of which are clear and fast flowing. The three largest springs in the Assessment area are found in the Upper Black River Basin: (1) Greer Spring (on the Eleven Point River), with an average flow of 289 ft^3/s, (2) Mammoth Spring (on the Spring River), with measured flows from 240 to 431 ft^3/s, and (3) Big Spring (on the Current River), with an average flow of

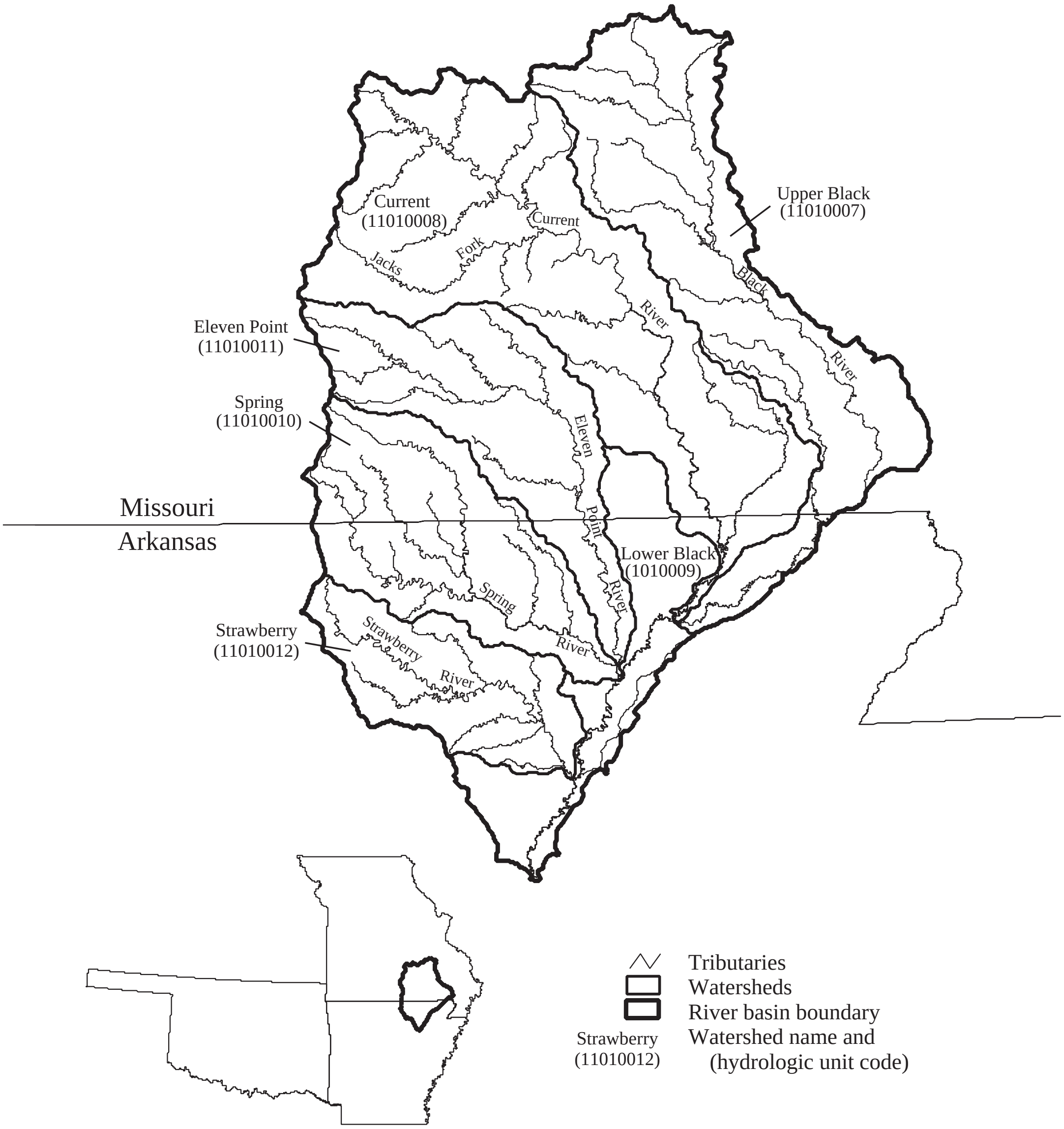


Figure 1.9—Watersheds of the Upper Black River Basin with major tributaries.

428 ft^3/s (Vineyard and others 1974). In 1974, Congress designated 134 mi of the Current River and Jacks Fork, its principal tributary, plus about 65,000 acres of adjoining land in Missouri as Ozark National Scenic Riverways (Barks 1978). This designation is intended to help preserve the natural conditions of the Current watershed and to increase recreational opportunities for anglers, canoeists, and campers. Similarly, a part of the Eleven Point River (also in Missouri) has been designated a National Scenic River.

Ouachita Province

Arkansas River Basin

Originating in central Colorado, the Arkansas River flows generally southeastward through Kansas, Oklahoma, and Arkansas to its confluence with the Mississippi River. The total drainage area of the Arkansas River is 160,600 mi^2 (Sullavan and Terry 1970). Excluding the Neosho-Illinois River Basin, about 12,900 mi^2 of Arkansas River drainage area falls within the aquatic study area (fig. 1.10). The stream reach of the Arkansas River within the aquatic study area is part of the McClellan-Kerr Navigation System, which includes a series of 12 locks and dams that extend from Webber Falls Lock and Dam, southeast of Muskogee, OK—near the western boundary of the aquatic study area—to Lock and Dam 4, east of Pine Bluff, AR—near the southeastern boundary of the study area (U.S. ACE 1976).

The principal tributaries of the Arkansas River are the Poteau River (1,890 mi^2) in eastern Oklahoma and western Arkansas; Petit Jean River (1,080 mi^2), which originates in western Arkansas; and Fourche La Fave River (1,120 mi^2), which originates in western Arkansas. The largest urban areas in the Arkansas River Basin portion of the aquatic study area are Little Rock and Fort Smith, AR. Land use in the part of the basin within the Assessment area is primarily dominated by cropland along the Arkansas River and by forest in the Highlands of the Boston Mountains (to the north) and the Ouachita Mountains (to the south). In addition to pools upstream of locks and dams on the Arkansas River, the basin includes several large reservoirs: Wister Lake (on the Poteau River), Nimrod Lake (on the Fourche La Fave River), Lake Maumelle (on Big Maumelle Creek) and Blue Mountain Lake (on the Petit Jean River).

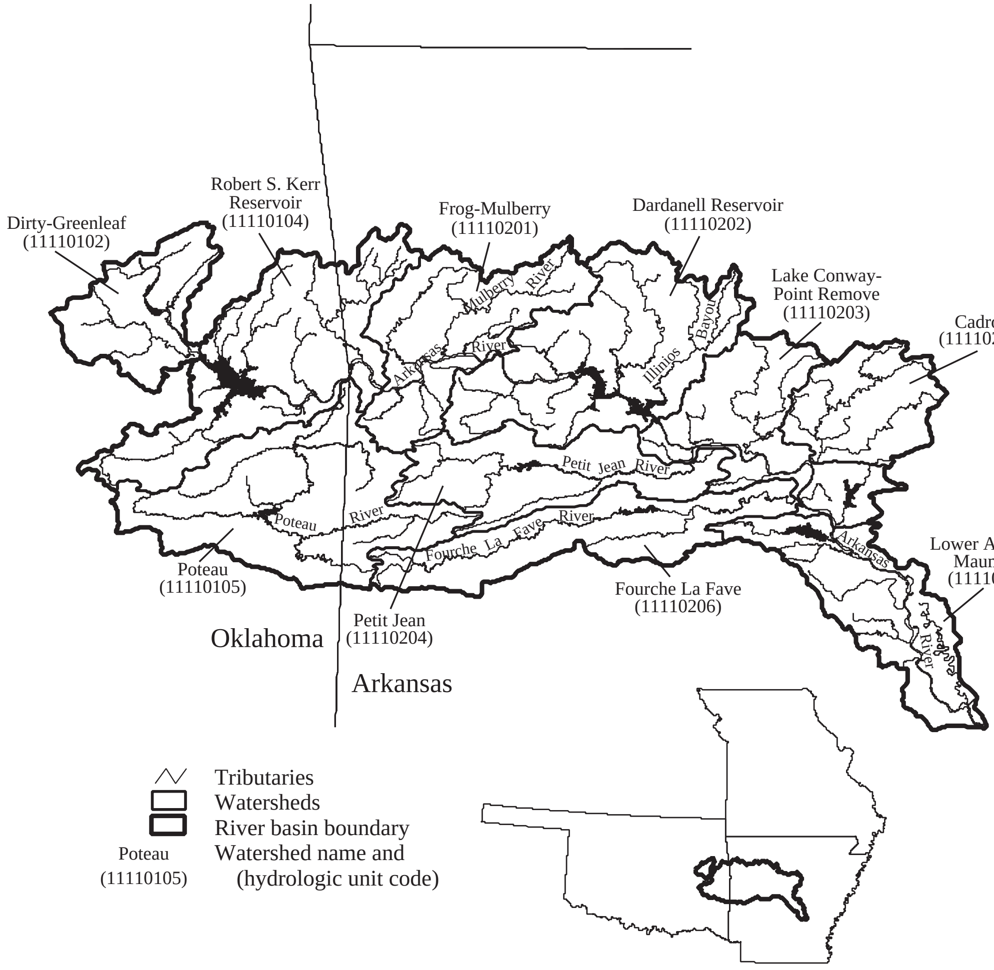


Figure 1.10—Watersheds of the Arkansas River Basin with major tributaries and reservoirs.

Ouachita-Saline River Basin

The Ouachita River originates in the Ouachita Mountains of western Arkansas and flows southeastward out of the Assessment area to the Red River in Louisiana. The drainage area of the Ouachita-Saline River Basin is about 18,900 mi^2, with about 7,100 mi^2 located within the aquatic study area (fig. 1.11). The Little Missouri (2,103 mi^2) and Caddo (477 mi^2) Rivers are principal tributaries. The largest urban area within the basin is Hot Springs, AR. Land use in the basin is dominated by forest, with some agriculture. Several reservoirs on the Ouachita River, including Lake Ouachita and Lake Hamilton, are popular recreational attractions.

The Saline River originates in the Ouachita Mountains in the central part of Arkansas and flows south or southeast to the Ouachita River in southern Arkansas. The drainage area of the Saline River is 3,250 mi^2, with about 1,716 mi^2 located in the aquatic study area. The principal tributary of the Saline River is Hurricane Creek (312 mi^2). The largest urban area within this part of the basin is Benton, AR. Lake Winona, the only major reservoir, is on Alum Fork (of the Saline River). Land use in the upper part of the basin is primarily forest, but bauxite has been mined near Benton. There is a pronounced increase in agricultural land use in the lower portions of the basin, where the river flows through the West Gulf Coastal Plain.

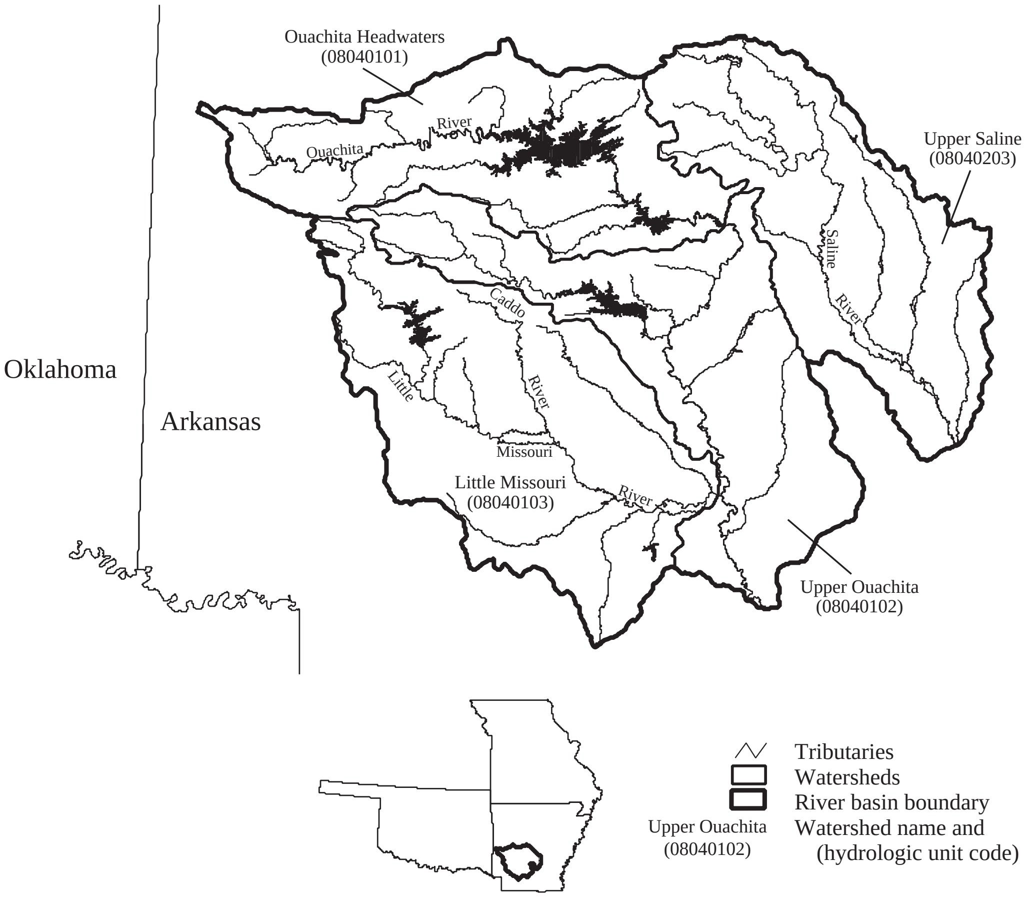


Figure 1.11—Watersheds of the Ouachita-Saline River Basin with major tributaries and reservoirs.

Kiamichi-Little River Basin

The Kiamichi River originates in the Kiamichi Mountains of southeastern Oklahoma. It flows westward through the mountains, then in a southerly direction to its confluence with the Red River, which forms the northern boundaries between Texas and Oklahoma and between Texas and Arkansas (fig. 1.12). The drainage area of the Kiamichi River, located entirely within the aquatic study area, is about 1,800 mi^2. The principal tributaries of the Kiamichi River are Ten Mile (204 mi^2) and Cedar Creeks (176 mi^2). No large urban areas are located in the Kiamichi-Little River Basin. Sardis Lake on Jackfork Creek and Hugo Lake on the Kiamichi River are the major reservoirs in this part of the basin. The Kiamichi-Little River Basin is primarily forested.

The Little River also originates in the Kiamichi Mountains of southeastern Oklahoma (fig. 1.12) and flows westward through the mountains, then generally to the southeast to its confluence with the Red River in southwestern Arkansas. The drainage area of the Little River, located entirely within the aquatic study area, is about 4,200 mi^2. The principal tributaries are the Mountain Fork (865 mi^2) and Cossatot (541 mi^2) Rivers. No large urban areas are located in this basin. Millwood Lake on the Little River and Broken Bow Lake on the Mountain Fork are the major reservoirs in this part of the basin.

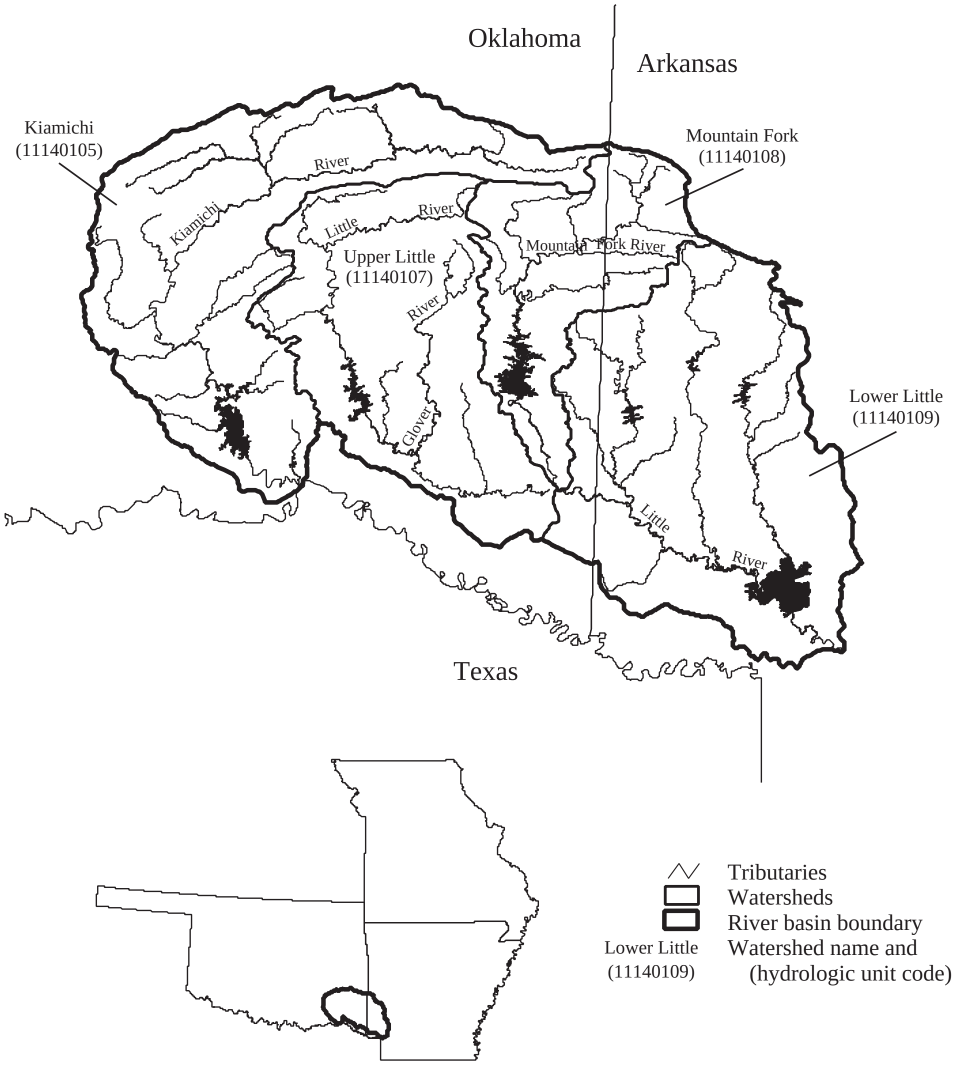


Figure 1.12—Watersheds of the Kiamichi-Little River Basin with major tributaries and reservoirs.

Major Lakes

More than 30 major Federal reservoirs are located within the aquatic study area. These reservoirs, each typically covering many thousand acres, serve many purposes, including flood control, hydroelectric power generation, water supply, and/or navigation. A second cluster of lakes includes medium- to small-sized ones built for municipal water supplies, recreational fishing and boating, and/or small watershed flood control. A third group of lakes, more appropriately called ponds, includes even smaller water bodies (often privately owned) built for recreation and/or livestock purposes.

Table 1.3 displays the number and total acres of lakes and ponds by watershed within each major river basin in the aquatic study area. This table was developed from the U.S. Environmental Protection Agency's (EPA's) River File version 3 (RF3) data base. While this data base includes water bodies as small as one-fourth acre, it does not include every water body of this size or smaller. Therefore, it is likely that large numbers of the smallest water bodies are not represented. However, while the number of lakes and ponds might easily be doubled, tripled, or more if the data base included all lakes and ponds, acreage totals would not increase significantly. The statistical influence of the larger lakes on the acreage totals in table 1.3 overwhelms whatever acres of small lakes and ponds were missed.

Because sources and methods of measurement often vary between data bases, the acreage of any given lake may differ from data base to data base. For example, one data base may show that a reservoir has several hundred acres more than another one shows, when the only real difference is that islands were included in the first measurement and excluded in the second. Reservoir acreage might also vary between data bases if the data were taken from a topographic map based on lake water elevation or from aerial photographs or satellite imagery of actual lake water surface area. A variance between data bases of 10 percent or more might be expected for the surface area figures.

Ground Water

Ground water is an abundant resource in most of the Ozark Plateaus Province. Multiple aquifers exist that can supply water to meet domestic, community, and commercial needs throughout this portion of the Assessment area. In many parts of the Ozark Plateaus, a specific site will often intersect with viable aquifers at multiple horizons. Yields from wells are commonly measured in 10's and 100's of gallons per minute (gal/min) and occasionally, more than 1,000 gal/min for some aquifers.

Within the Ouachita Province, ground water is more limited. Few large-volume users (communities, industries) rely on the area's supply of ground water. While ground water can be obtained almost everywhere in the Ouachitas, yields or "yield rates" are often low, with most wells yielding less than 50 gal/min. Wells providing more than 100 gal/min are rare, and wells supplying less than 10 gal/min are the norm (Albin 1965).

Table 1.3—Number and acres of lakes and ponds in the aquatic study area, by major river basins

River basin	All impoundments		Lakes > 1,000 acres		Lakes 10–1,000 acres		Ponds < 10 acres	
	Number	*Acres*	*Number*	*Acres*	*Number*	*Acres*	*Number*	*Acres*
Osage	1,243	158,108	9	140,586	399	13,397	835	4,126
Gasconade	213	5,474	0	0	92	4,902	121	572
Meramec	436	6,484	0	0	152	4,940	284	1,545
Upper St. Francis	134	3,068	0	0	44	2,575	90	493
Neosho-Illinois	1,035	101,478	13	69,802	335	28,252	687	3,424
Arkansas	3,061	212,254	20	150,698	896	52,999	2,145	8,557
Kiamichi-Little	779	84,728	9	65,454	242	17,354	528	1,919
Ouachita-Saline	560	81,360	6	65,382	239	13,954	315	2,024
Upper White	512	176,279	12	163,899	175	10,899	325	1,480
Upper Black	413	17,569	3	7,999	190	8,449	220	1,120
Total	8,386	846,803	72	663,821	2,764	157,722	5,550	25,260

Ground Water in the Ozark Plateaus Province

Ground water divides (places where the flow of ground water changes direction markedly) in the shallow aquifers of the Ozark Plateaus generally coincide with topographic divides. Water table surfaces can be visualized as a subdued reflection of topography. Altitudes of ground water levels are highest in the Boston Mountains and along the major topographic ridge extending across southern Missouri, which form regional ground water divides. Ground water flows away from these regional divides; water flowing in the deep part of the ground water system discharges into the major rivers of the area (fig. 1.13). Ground water moving through the shallow part of the ground water system follows short

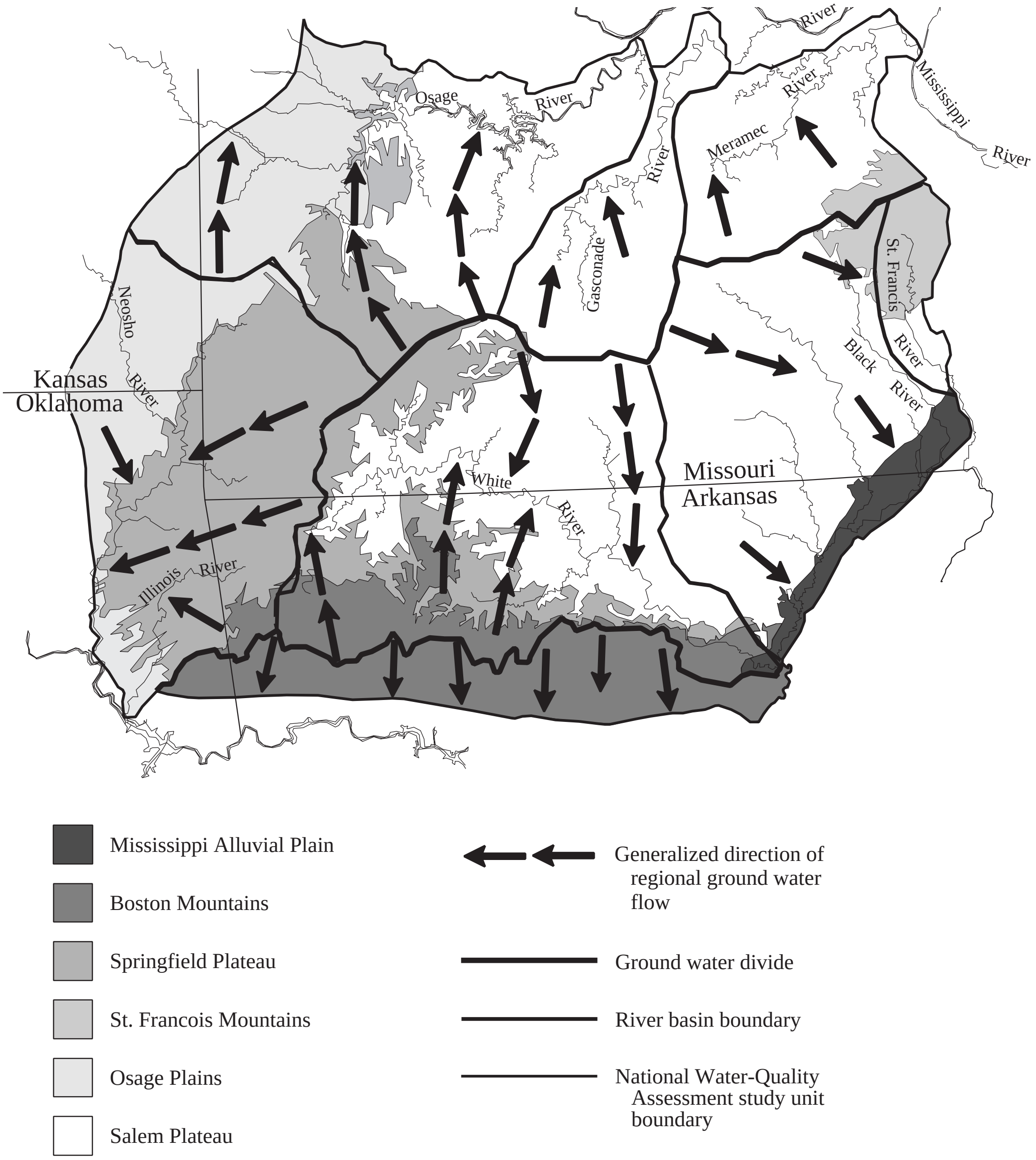


Figure 1.13—Directions of the flow of ground water in the Ozark Plateaus Province (modified from Adamski and others 1995). (The St. Francois Mountains are represented by the medium gray area on the eastern edge of the Ozark Highlands, the Springfield Plateau by the medium gray area in the western half of the Ozark Highlands and encompassing the words “Illinois River.”)

(usually less than 10 mi), local flow patterns that terminate at nearby streams (Imes and Emmett 1994).

Regional boundaries for the ground water flow system in the Ozark Plateaus and adjacent areas include the Missouri and Mississippi Rivers to the north and northeast, respectively. To the southeast, ground water discharges into the unconsolidated sedimentary strata of the Mississippi Alluvial Plain. The topographic divide along the crest of the Boston Mountains forms the southern boundary. The western boundary is formed by a broad, topographically low area where westward-flowing fresh water mixes with eastward-flowing saline water along a transition zone between regional flow systems (Imes and Emmett 1994).

The ground water system in the Ozark Plateaus can be divided into seven major hydrogeologic units based on relative rock permeabilities and yields from wells. These hydrogeologic units consist of three main aquifers and four confining units that coincide with the province's major geologic units and physiographic sections (fig. 1.14). (A confining unit is composed of relatively impervious layers of rock that separate it from other aquifers.) These units include the Western Interior Plains confining system, the Springfield Plateau aquifer,

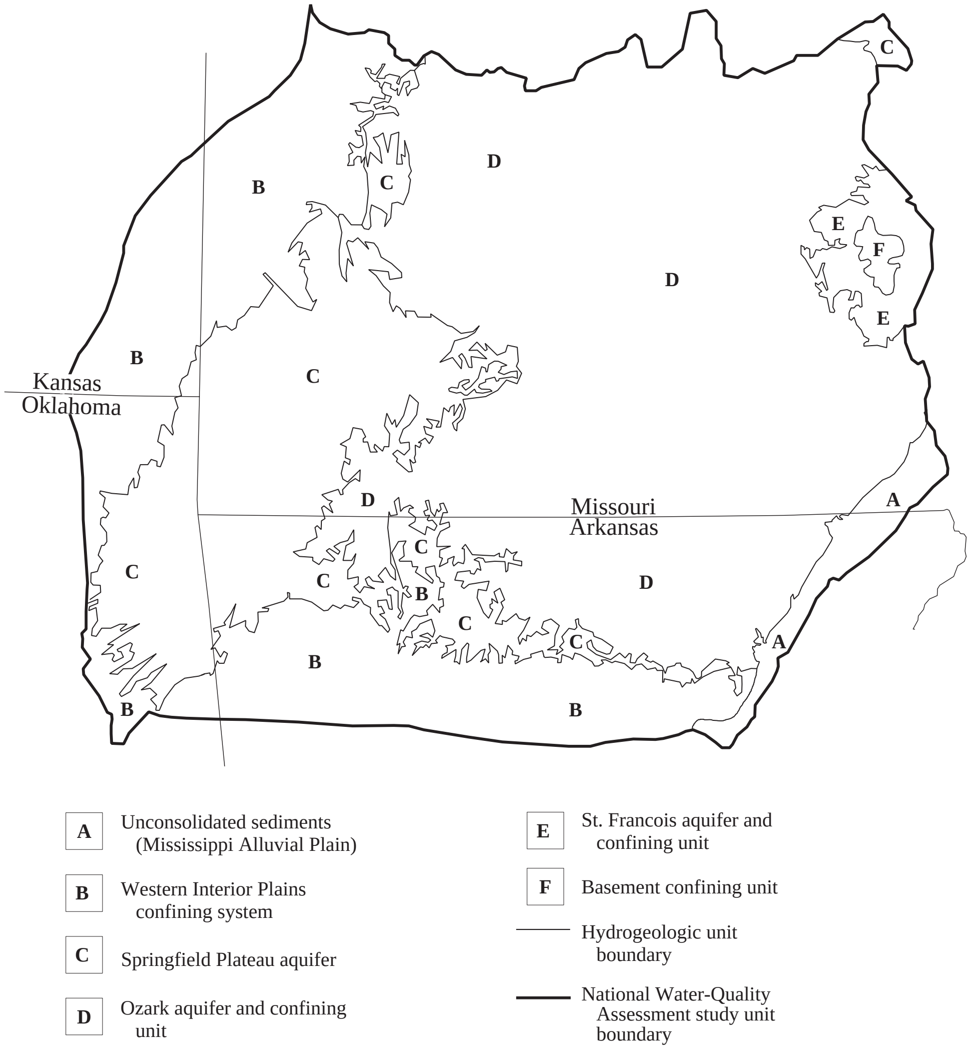


Figure 1.14—Locations of hydrogeologic units in the Ozark Plateaus (modified from Adamski and others 1995).

the Ozark confining unit, the Ozark aquifer, the St. Francois confining unit, the St. Francois aquifer, and the Basement confining unit. The middle five units compose the Ozark Plateaus aquifer system and are confined above and below by the Western Interior Plains confining system and the Basement confining unit, respectively (Imes and Emmett 1994). An eighth hydrogeologic unit is composed of unconsolidated sedimentary strata in the Mississippi Alluvial Plain, but the ground water resources of this unit will not be further discussed in this report because it is mostly outside the aquatic study area.

Western Interior Plains Confining System

The Western Interior Plains confining system (fig. 1.14) coincides with parts of two physiographic sections—the Boston Mountains section (in the southern part of the Ozark Plateaus Province) and the Osage Plains section (west of the Ozark Plateaus Province). Rock strata of late Mississippian to Pennsylvanian age form this confining system (Imes and Emmett 1994).

Altitudes at the top of the Western Interior Plains confining system range from 800 to 1,000 ft above sea level in the Osage Plains, and from 1,000 to more than 2,000 ft above sea level in the Boston Mountains. The confining system is from 40 to 800 ft thick in the Osage Plains, but averages between 1,500 and 2,000 ft thick in the Boston Mountains (Imes 1990f).

Rock types in this regional confining system include relatively permeable sandstone and limestone beds separated by thick layers of impermeable shale that together result in an overall low permeability. Hydraulic conductivities (the ability of water to move through strata of differing permeabilities while under the influence of a hydraulic gradient) generally range from 0.001 to 0.01 ft per day (ft/d) depending upon thickness and shale content (Imes and Emmett 1994).

Yields of wells in western Missouri range from 1 to 40 gal/min. Specific capacities (well yield per unit of drawdown) of these wells range from 0.1 to 3 gal/min per foot (Kleeschulte and others 1985). Yields of 16 wells completed in this confining system in northwestern Arkansas range from 2.5 to 19 gal/min (Imes and Emmett 1994).

Springfield Plateau Aquifer

Where The Springfield Plateau aquifer is unconfined, it coincides with the Springfield Plateau (fig. 1.14). The aquifer consists of limestones and cherty limestones of Mississippian age and is about 100 to 200 ft thick in most places (but can be more than 400 ft thick in southwestern Missouri). The rock strata lie flat, but regionally, they dip gently to the west and south. The rocks are often fractured and faulted. The Springfield Plateau aquifer is unconfined over most of the Springfield Plateau, but the Western Interior Plains confining system, which primarily is composed of shales of Pennsylvanian age, confines the aquifer in the Osage Plains and Boston Mountain sections. The Springfield Plateau aquifer is separated from the underlying Ozark aquifer by the Ozark confining unit, which consists primarily of black shale of Devonian age (Imes and Emmett 1994).

Altitudes at the top of the Springfield Plateau aquifer range from about 200 to 1,600 ft above sea level where the aquifer crops out and is unconfined. The dip of the beds generally is about 11 ft/mi. Thickness of the aquifer ranges from about 100 ft in south-central Missouri to about 400 ft in southeastern Kansas (Imes 1990e).

Altitudes of the potentiometric surface (the surface to which water can rise by hydrostatic pressure) of the Springfield Plateau aquifer range from more than 1,400 ft in the eastern part of the aquatic study area to less than 700 ft near the western boundary of the study area. Regionally, ground water flows from topographic divides and discharges into seeps and springs and then to major streams (fig. 1.13). Locally, the ground water can flow across topographic divides; hence, precise determination of contributing areas for wells and recharge basins for springs can be arduous (Adamski and others 1995).

Fracturing and dissolution of the limestone units in the Springfield Plateau result in karst features, such as sinkholes and caves. Karst features and springs are more abundant in the nonchert-bearing limestones, such as the St. Joe Member of the Boone Formation, than in the chert-bearing limestones.

Wells drilled into the Springfield Plateau aquifer generally have yields of less than 20 gal/min. Most wells are used primarily for domestic water supply and for watering livestock. However, several industrial wells completed in the aquifer in southwestern Missouri yield 300 to 400 gal/min (Imes and Emmett 1994).

Ozark Confining Unit

The Ozark confining unit (fig. 1.14) consists of rocks of Devonian and Mississippian age from the Chattanooga Shale through the Northview Shales and Chouteau Limestone. This confining unit consists mostly of shales and dense limestones that crop out along the Eureka Springs Escarpment in southwestern Missouri and northwestern Arkansas and underlie much of the Springfield Plateau aquifer. The Ozark confining unit averages about 60 to 80 ft thick but locally is 120 ft thick in southeastern Kansas (Imes 1990d).

Shales and dense limestones in the Ozark confining unit hydraulically separate the overlying Springfield Plateau aquifer from the underlying Ozark aquifer. Shale content ranges from about 10 to 100 percent in northwestern Arkansas. Shale is missing from the unit in parts of southwestern Missouri, northeastern Oklahoma, and southeastern Kansas (Imes 1990d). Differences in water levels of about 50 ft between the Springfield Plateau and Ozark aquifers indicate that, even where the shale is missing, the low vertical permeability of the aquifers' dense limestones effectively separates the two hydrogeologic units (Imes and Emmett 1994).

Ozark Aquifer

The Ozark aquifer, which consists of a thick sequence of dolomites, sandstones, limestones, and shales, crops out in the Salem Plateau in south-central Missouri and northern Arkansas (fig. 1.14). The highest altitude of the top of the aquifer is about 1,500 ft above sea level in south-central Missouri. Altitudes then decrease to 300 ft above sea level near the eastern boundary of the Ozark Plateaus to about sea level near the western boundary and finally to nearly 2,000 ft below sea level near the southern boundary (Imes 1990c).

Aquifer thickness ranges from about 300 ft in northeastern Oklahoma to nearly 4,000 ft in northern Arkansas. However, aquifer thickness averages between 1,500 and 2,000 ft throughout much of the Ozark Plateaus (Imes 1990c).

The configuration of the potentiometric surface of the unconfined Ozark aquifer generally mirrors the overlying topography. Levels of ground water in the wells drilled in this aquifer average about 700 to 1,000 ft above sea level over much of the Salem Plateau but are as high as 1,400 ft above sea level in south-central Missouri (Imes 1990c). Precipitation recharges the unconfined Ozark aquifer nearly everywhere. Ground water flows mostly laterally from the higher altitudes to points of discharge in springs and seeps along streams. The confined part of the Ozark aquifer is recharged by a lateral flow of ground water from the aquifer's unconfined area, and, in places, by seepage from the overlying Ozark confining unit (Imes and Emmett 1994).

Losing streams, sources of recharge to the ground water system, are common in some drainage areas overlying the Ozark aquifer. Results from dye-tracing studies of ground water indicate that water recharging the aquifer from the losing streams can discharge in springs in adjacent drainage basins. This is possible because, on a local scale, ground water divides do not always coincide with surface water divides (Harvey and others 1983).

St. Francois Confining Unit

The St. Francois confining unit hydraulically separates the Ozark aquifer from the underlying St. Francois aquifer. This confining unit consists of shales, siltstones, and dolomites of Late Cambrian age, which crop out around the St. Francois Mountains and dip radially away from the outcrop area. Maximum shale content in this part of the Assessment area is about 30 percent (Imes 1990b). In places where shale is thin or absent, impermeable siltstones and dolomites confine the St. Francois aquifer (Imes and Emmett 1994). The maximum thickness of the confining unit is about 750 ft in parts of Missouri and northern Arkansas. This confining unit is absent in parts of northwestern Arkansas, west-central Missouri, and northeastern Oklahoma (Imes 1990b).

St. Francois Aquifer

The St. Francois aquifer (fig. 1.14) consists of the Lamotte and Reagan Sandstones and the Bonneterre Dolomite of Late Cambrian age, which crop out in the

St. Francois Mountains. These units are used as a ground water resource where they are unconfined but are rarely used where overlain by the thicker Ozark aquifer. Thickness of the St. Francois aquifer is as high as 900 ft in Missouri and as high as 500 ft in northern Arkansas. Yields of wells from this aquifer commonly range from 100 to 500 gal/min (Imes 1990a).

Permeability is primary in the aquifer's loosely cemented sandstones, but is due mostly to secondary porosity in the dolomites as a result of fracturing and dissolutioning. Permeability data are sparse because the aquifer is rarely used, but the few available data indicate that horizontal hydraulic conductivity ranges from 0.1 to 8.6 ft/d. Transmissivity (the ability of an aquifer to transmit water) ranges from 8.6 to 860 square feet per day (ft^2/d) (Imes and Emmett 1994).

Basement Confining Unit

The Basement confining unit consists mostly of igneous rocks of Pre-Cambrian age, which underlie the Ozark Plateaus and crop out in the core of the St. Francois Mountains (fig. 1.14). These rocks supply some water locally where they crop out. The igneous rocks are relatively impermeable; however, some secondary permeability is generated from fractures in the rocks. Yields of wells completed in this confining unit are as large as 70 gal/min but generally are less than 10 gal/min (Imes and Emmett 1994).

Ground Water in the Ouachita Province

Ground water divides in the shallow aquifers of the Ouachita Province generally coincide with topographic divides; water table surfaces roughly conform to the topography in the plateaus. Deeper ground water in the confined sections of the system is strongly influenced by the complex structure of the area (Bedinger and others 1979). Altitudes of ground water levels are highest in the mountains of the central Ouachita Mountains, which form a regional divide. Ground water flows away from the regional divide, and water flowing in the deep part of the aquifer system discharges into the major rivers of the Assessment area. Ground water moving through the shallow part of the aquifer system follows short (usually less than 10 mi) flow paths that can be expected to end with discharge into nearby streams.

Regional boundaries for the flow of ground water in the Ouachita Mountains include the topographic divide along the crest of the Boston Mountains to the north and the Red River to the south. To the east, ground water discharges into the unconsolidated sediments of the Mississippi Alluvial Plain.

The ground water system of the Arkansas Valley physiographic section is similar to that of the Ozark Plateaus Province to the north. In the Arkansas Valley, some of the same formations are seen at the surface or in the subsurface strata, although at greater depths. The system exhibits the same lithologies (types of rock) and similar hydraulic characteristics as that of the Ozark Plateaus.

The ground water system of the Ouachita Mountains section is not formally divided into hydrogeologic units because of the extreme heterogeneity observed in rock permeability and well yield throughout the physiographic area. Rock formations of the Ouachita Mountains include, in order of abundance, shale, sandstone, novaculite, chert, conglomerate, and limestone. Many of the rocks comprising the hydrogeologic framework of the Ouachita Mountains originally had primary porosity sufficient to render excellent aquifers. However, changes in the rock fabric have decreased original porosity below levels needed for good aquifers. Existing porosity is predominantly secondary, created by mechanical fracturing of the rocks. Fractures, fault traces, joints, and bedding plane joints compose much of the porosity. Thus, minimum baseline porosities observed for all rock types in the province are quite similar, converging on very low values. The principle differences in the water-bearing and transmitting capacity of the rocks is the behavior of fractures in specific rock types, that is, since the time of compressive stress, some fractures have been preserved or enlarged by fluid flow while other fractures have sealed. Therefore, brittle rocks often provide the best aquifers in the Ouachita Mountains, and fractured sequences of differing rock types—sandstones, as well as typically poor aquifer rocks such as cherts, novaculite, and even shale—will also provide water. Areas with limited quantities of ground water are ubiquitous in the Ouachita Mountains because the entire belt has experienced the compression responsible for mountain building and fracturing, thus secondary fracture porosity has developed in all rocks. The Bigfork

Chert is the only formation in the Ouachita Mountains that is an aquifer throughout its area of occurrence.

Most wells completed in the Ouachita Mountains are less than 200 ft deep, though some wells with large yields are completed to depths between 400 and 600 ft. Aquifer tests at 10 locations across the area show that transmissivity generally is less than 135 ft^2/d and is often less than 6.7 ft^2/d. Specific capacities range from 0.013 to 0.13 ft^2/min after 90 minutes of pumping (Albin 1965, Halberg and others 1968, Cordova 1963).

Climate

The Ozark-Ouachita Highlands region in Missouri, Arkansas, and Oklahoma is characterized by a temperate climate due to its mid-latitude location in the interior of the North American continent. Air masses that move across the Assessment area generally originate from the Eastern Pacific Ocean, Western United States, the Gulf of Mexico, and Canada. The sources of moisture for the region are the Pacific Ocean and the Gulf of Mexico. Because of the general circulation characteristics of the atmosphere, weather systems generally move from west to east across the Highlands. The average temperature and precipitation patterns over the region are the result of these weather systems moving across the region as well as interactions between topography and atmosphere that introduce additional temperature and precipitation variations. For example, mountain induced lifting of air can affect local levels of precipitation. As air rises over a mountain, it cools and condenses, thus enhancing precipitation on the windward side of mountains and producing drier conditions on the leeward side.

This section provides an overview of the monthly average temperature and precipitation patterns over the Assessment area using data from the National Climate Data Center. It also includes a discussion of extreme temperature, precipitation, and wind (e.g., tornado) events (using data obtained from the National Severe Storms Laboratory), which are particularly important atmospheric disturbance factors that impact the region's natural resources and human population. The patterns of monthly average temperatures and precipitation along with the patterns of extreme temperature, precipitation, and wind events are discussed in the context of the region's topography and seasonal variations in atmospheric circulation (wind and weather patterns).

Monthly Average Maximum Temperature Patterns

Figure 1.15 shows the average daily maximum temperatures for the Assessment area for January, April, July, and October. The months of December, January, February, and March are characterized by very large north-to-south variations in maximum temperature. For example, in January, average maximum temperatures range from about 34 ºF in northern Missouri to about 54 ºF in southern Arkansas. Within the Assessment area, the largest spatial variations in maximum temperature in the winter exist along the Arkansas-Missouri border north of the Boston Mountains in Arkansas and in central Missouri just to the north of the Ozark Plateaus. These topographic features tend to inhibit the southward movement of cold air masses from the Northern United States into the southern sections of the Assessment area and pool the cold air so that relatively large temperature gradients can develop in the vicinity of these topographic features. Very little east-to-west variation in monthly average maximum temperatures is observed in winter except for east of the Ouachita Mountains in Arkansas where warm air tends to protrude northward. This tongue of slightly higher temperatures is evident in January but is most significant in March.

With the onset of the spring months and higher daily maximum temperatures, the large gradients in monthly average maximum temperatures begin to diminish. Daily maximum temperatures in northern Missouri increase more significantly than temperatures in southern Arkansas, resulting in an overall decrease in the north-to-south average maximum temperature range from winter to spring. The maximum temperature range generally decreases through the spring months. In April, average maximum temperatures range from about 64 ºF in northern Missouri to about 76 ºF in southern Arkansas (fig. 1.15). By June, average maximum temperatures range from about 83 ºF in northern Missouri to near 90 ºF in southeastern Arkansas. Even though the north-to-south temperature variations are smaller in the spring than in the winter, the most significant variations

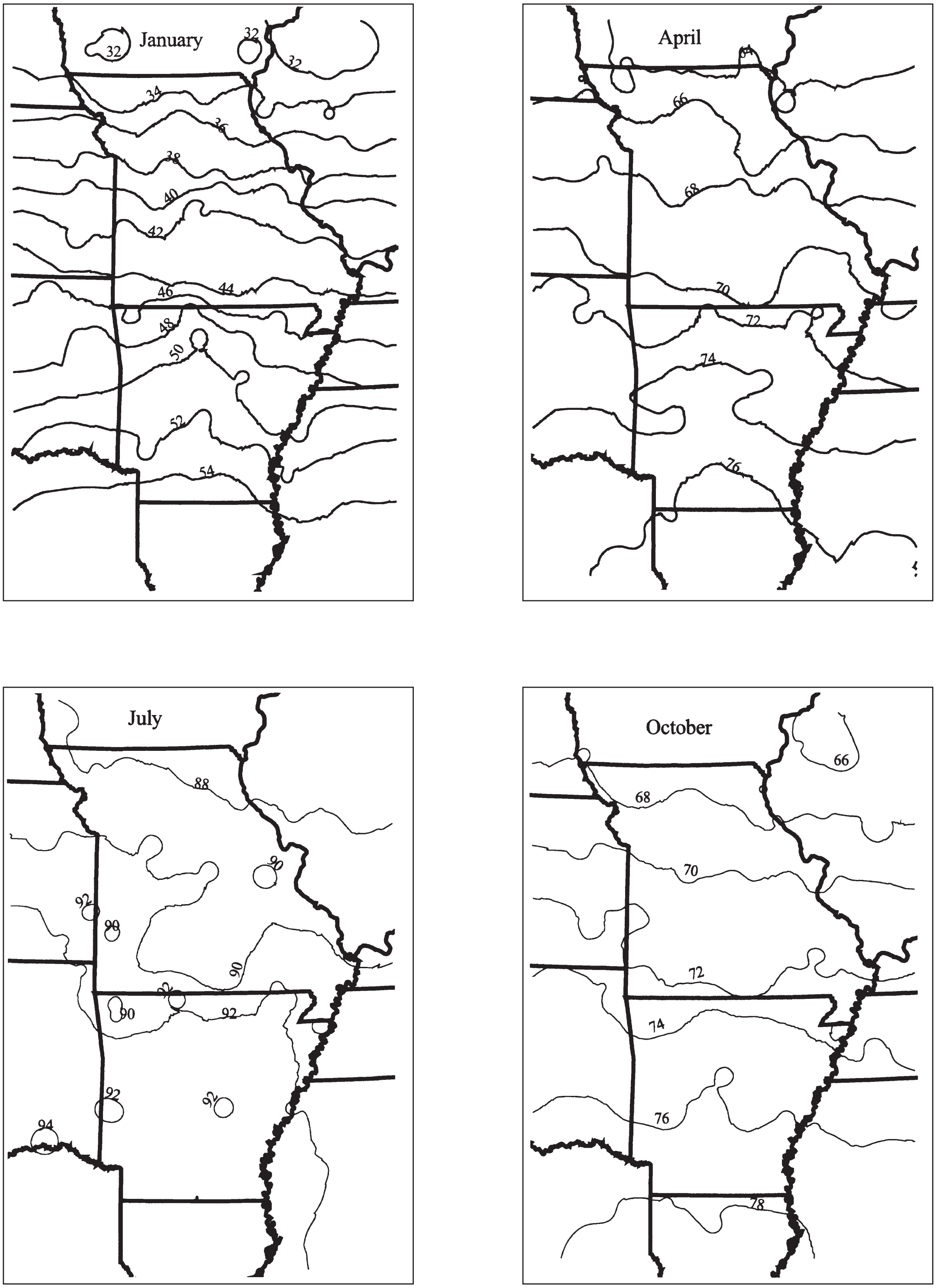


Figure 1.15—Average daily maximum temperatures (°F) during January, April, July, and October for the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

throughout the spring still occur mainly along the Missouri-Arkansas border. As in the winter months, east-to-west variations in average maximum temperatures across the Assessment area are minimal.

During the summer, very warm conditions usually develop over the southern Great Plains. Average maximum daily temperatures exceed 94 ºF in eastern Oklahoma and northeastern Texas in July and August. The very warm air masses that dominate the southern Great Plains during the summer also influence maximum daily temperatures in the western sections of the Assessment area, resulting in a general southwest-to-northeast temperature gradient over the Highlands, with average maximum daily temperatures ranging from about 94 ºF in southeastern Oklahoma to about 88 ºF in west-central Illinois in July (fig. 1.15). The terrain effects on temperature over the Ozark Plateaus are evident during the summer, with typically lower daily maximum temperatures occurring over the plateaus and a significant average maximum temperature gradient existing near the border area of northeastern Oklahoma, northwestern Arkansas, and southwestern Missouri. The elevation variations associated with the Ozark Plateaus and Ouachita Mountains tend to confine the warmest air to areas west of the Assessment area during the summer. With the onset of cooler conditions in the southern Great Plains in September, the overall maximum temperature pattern over the Highlands returns to one that is similar to the late spring pattern. East-to-west maximum temperature variations decrease in late summer and early fall, although the Ozark Plateaus still cause noticeable temperature variations from northeastern Oklahoma into southwestern Missouri and northwestern Arkansas.

Through September, October, and November, maximum daily temperatures decrease throughout the Assessment area. The decreases are more pronounced in the northern sections of the region than in the southern sections, resulting in significant temperature gradients in the north-south direction like those occurring during the winter. For example, in September, the average maximum temperature ranges from about 78 ºF in northern Missouri to about 87 ºF in southern Arkansas. However, in November, the average maximum temperature ranges from about 51 ºF in northern Missouri to about 66 ºF in southern Arkansas. The October average maximum temperature pattern is shown in fig. 1.15.

Monthly Average Minimum Temperature Patterns

Average minimum temperature patterns over the Assessment area exhibit many of the same characteristics as the maximum temperature patterns, although distinct differences exist. In the winter, most of the variation in average minimum temperature over the region is in the north-south direction as it is for the average maximum temperatures. However, the east-to-west temperature variations in Arkansas are also significant, with average minimum temperatures in the Mississippi Alluvial Plain about 3 to 4 ºF higher than minimum temperatures in the Ouachita Mountains region. Figure 1.16 shows the average January minimum temperature pattern over the area that encompasses the Assessment area and suggests the importance of topography and bodies of water in keeping nocturnal temperatures higher in the Mississippi Alluvial Plain than in the Ouachita Mountains and Ozark Plateaus. Very strong northwest-to-southeast gradients in the average minimum temperature field are observed from north central Arkansas to southeastern Missouri in the winter. Average January minimum temperatures range from about 14 ºF in northern Missouri to about 32 ºF in southern Arkansas. Average minimum temperatures remain below freezing during December, January, and February for all of the Assessment area except for the southernmost counties.

The average minimum temperature patterns over the Assessment area during the spring months of April, May, and June are similar to the patterns during the winter months, with relatively high minimum temperatures occurring in the Mississippi Alluvial Plain in Arkansas and relatively low minimum temperatures extending from the Ouachita Mountains northeastward to eastern Missouri. Average minimum temperatures for the month of April are shown in fig. 1.16. The strong northwest-to-southeast gradient in average minimum temperature is evident from north central Arkansas to southeastern Missouri. The lowest minimum temperatures during the spring months are usually observed over the eastern half of Missouri. In May, for example, average minimum

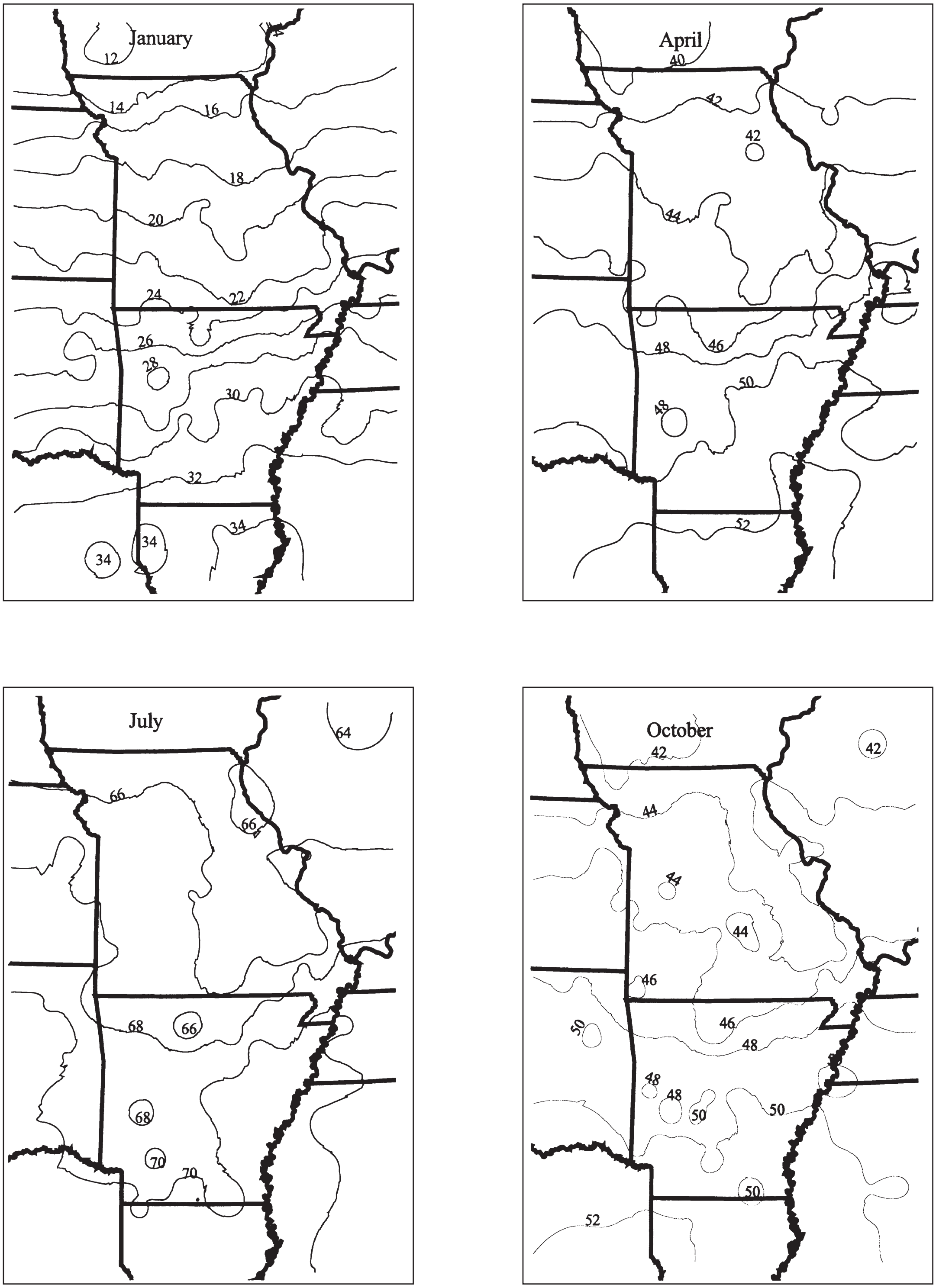


Figure 1.16—Average daily minimum temperatures (°F) during January, April, July, and October for the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

temperatures are about 51 ºF in eastern Missouri (including much of the Mark Twain National Forest) compared to average minimum temperatures of about 60 ºF in nearby northeastern Arkansas.

The highest minimum temperatures in the Assessment area typically occur during the month of July, ranging from about 66 ºF in parts of eastern and northern Missouri to about 70 ºF in the Mississippi Alluvial Plain in eastern Arkansas and in eastern Oklahoma (fig. 1.16). Through the summer, the spatial pattern of minimum temperatures in the Assessment area is very similar to the spring pattern.

The months of October (fig. 1.16), November, and December bring a return to the wintertime pattern of average minimum temperatures, when relatively strong north-to-south gradients dominate the temperature field. The prominent tongue of low average minimum temperatures extending southward through eastern Missouri in early fall becomes less prominent later in the fall. The significant minimum temperature variations in the east-west direction become less significant as winter approaches, while the average north-to-south minimum temperature variations increase dramatically. By December, the average minimum temperatures over the region range from about 20 ºF in northern Missouri to about 35 ºF in southern Arkansas. This typical minimum temperature range is much greater than the summertime range in minimum temperatures of about 6 to 8 ºF over the same region. Diurnal (day/night) variations are much more significant during the late fall and winter than during the summer because the atmospheric moisture content is much less when the air is cold. Atmospheric moisture tends to moderate diurnal temperature fluctuations.

Extreme Maximum Temperature Occurrences

Average monthly or seasonal temperature variations help determine what types of vegetation and wildlife thrive under normal conditions. However, extreme climatic events can introduce stresses that can affect the health and productivity of ecosystems. The occurrence of temperature extremes is one type of climatic disturbance that can affect the region’s natural resources. “Extreme temperature” is defined as an occurrence of daily maximum or minimum temperature greater than 20 ºF above or below normal for that particular day. Using this definition, the Aquatic Team compiled the number of abnormally high and low daily maximum temperature occurrences during the 1950 through 1993 period for the region encompassing the Assessment area.

Figure 1.17 shows the total number of days from 1950 through 1993 when the maximum temperature was observed to be 20 ºF above or below normal over and surrounding the Assessment area. As shown in fig. 1.17, most days during which maximum temperature exceeds 20 ºF above normal happen in east-central Missouri at the northern edge of the Assessment area. More than 500 extreme maximum temperature events occurred in this area from 1950 through 1993 (corresponding to about 11 events per year). Fewer than 100 extreme maximum temperature events occurred over the southern sections of the Assessment area (corresponding to about 2 events per year). Figure 1.17 suggests that the probability of extreme maximum temperature occurrences increases significantly in the region between northern Arkansas and central Missouri. Most of these extreme maximum temperature events happen during the late fall and winter. Analyses of monthly extreme maximum temperature events during winter from 1950 through 1993 show that the number of extreme events in January ranged from about 40 over the Ouachita Mountains to about 110 over east-central Missouri north of the Ozark Plateaus (including Boone and Calloway Counties). During the month of February from 1950 through 1993, the number of events ranged from about 25 over much of southern Arkansas to 85 over the same east-central area in Missouri. In March, the events ranged from about 15 to 110.

Very few episodes of anomalously (unusually) high maximum temperatures have occurred over the Assessment area during the months of May through September. Over the entire region, fewer than eight events occurred during each month between 1950 and 1993. In July, for example, the largest number of episodes of anomalously high daily maximum temperatures over the region was seven in west-central Missouri. It is not until November that the probabilities of occurrence of extreme maximum temperature increase significantly.

Figure 1.17 also shows the total number of anomalously low maximum temperature events (daily maximum temperatures 20 ºF or more below normal) that occurred from 1950 through 1993 over the Assessment area. Most of these extreme temperature events tend to occur in central Missouri and eastern Kansas and are least

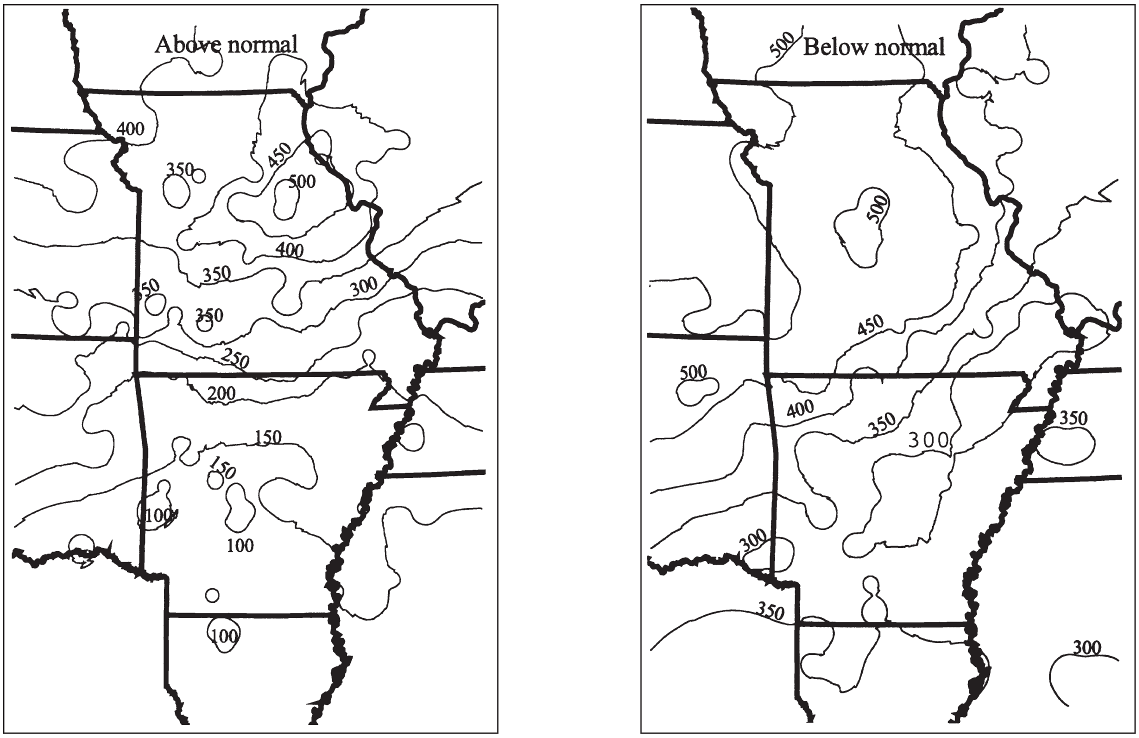


Figure 1.17—Total number of occurrences where daily maximum temperatures were 20 °F above normal and 20 °F below normal in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

likely to occur in southeastern Missouri and in the far southwestern section of Arkansas. As with anomalously high maximum temperature events, the low maximum temperature events tend to occur during the late fall and winter. However, for the entire region as a whole, there is a tendency for more anomalously low maximum temperature events than high temperature events. Figure 1.17 indicates that more than 500 extreme low maximum temperature events occurred in central Missouri from 1950 through 1993 (about 11 events per year) while about 300 events occurred in northeastern Arkansas over the same period (less than 7 events per year). The location and month of the highest probability of anomalously low maximum temperature events shifts from northwestern and western Missouri and eastern Kansas in January to central Missouri in March and April. From May until October, extremely low maximum temperature occurrences, as defined here, are fairly rare (averaging less than 0.5 events per year).

Extreme Minimum Temperature Occurrences

Using the same definition of "extreme" for determining anomalously high or low minimum temperature occurrences as that used for maximum temperatures, the Aquatic Team developed maps (fig. 1.18) of the total number of occurrences of extreme minimum temperatures over the Assessment area. Figure 1.18 shows the pattern of anomalously high minimum temperature occurrences over the Assessment area based on minimum temperature data from 1950 through 1993. Numerous relative maximums appear over much of the Assessment area, which is a reflection of the influence of specific observation sites and the limitations of the kriging (statistical interpolation method) process in determining temperatures at locations between observation sites over the region. However, the larger scale pattern over the region suggests more extreme events over the western half of Arkansas and the southern half of Missouri. Fewer extremely high minimum temperature events tend to occur in the Mississippi Alluvial Plain in Arkansas and north of the Missouri River in Missouri.

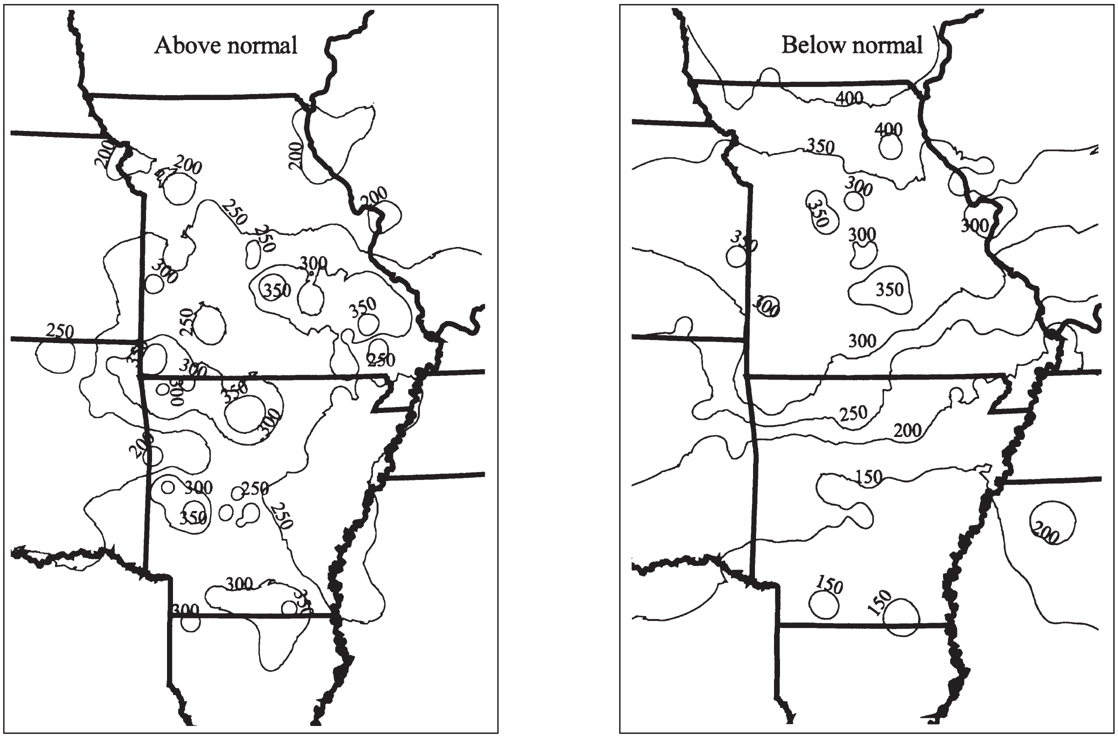


Figure 1.18—Total number of occurrences where daily minimum temperatures were 20 °F above normal and 20 °F below normal in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

As with the extreme maximum temperature events, most extreme minimum temperature events tend to occur during the late fall and winter; extremely high minimum temperatures are most likely to occur in January. From 1950 through 1993, the number of extreme minimum temperature episodes in January ranged from about 90 (average of about 2 events) in the far southeastern sections of Arkansas to about 40 to 45 (average of about 1 event) in the northern half of Missouri. Extreme events over the Assessment area are much less likely from April through the spring, summer, and early fall. No more than one extreme episode occurred from 1950 through 1993 at any observation site in the region during the months of June, July, and August.

The number of extreme cold temperature events over the Assessment area during the 44 years from 1950 through 1993 is also shown in figure 1.18. There is a general north-to-south decrease in the number of these extreme events over the region, with a significant gradient existing over the Ozark Plateaus. Northern Missouri experienced about 400 extremely low minimum temperature events during this 44-year period (about 9 events per year), while the southern half of Arkansas generally experienced less than 150 events (about 3 events per year). Over the Ozark Plateaus, the number of extreme events differed by about 100 over a distance of about 50 to 100 mi. The influence of cold air masses moving southward from Canada and the northern United States into the Assessment area is evident in the relatively large number of extreme minimum temperature events that happen during the winter. Most of the extremely cold episodes happen in December, January, and February. For example, from 1950 through 1993, northern Missouri experienced about 80 to 110 events in December, about 90 to 110 events in January, and about 70 to 90 events in February. During those same 44 years, southern Arkansas experienced about 25 to 30, 25 to 40, and 15 to 20 events in those months, respectively. With the onset of warmer conditions and higher atmospheric moisture in the spring, fewer extremely low minimum temperature episodes occur. Through the late spring, summer, and early fall, extreme minimum temperature episodes are rare over the Assessment area (less than one episode every 2 years from May to October). In November, the probability of extreme minimum temperatures increases again under the colder and normally lower atmospheric moisture conditions of late fall.

Average Monthly Precipitation Patterns

Oceans are the primary sources of atmospheric moisture that lead to precipitation events over the Earth's surface. Evaporation from inland lakes and evapotranspiration (total water loss from soil from direct evaporation and transpiration of plant moisture) from vegetation can also contribute to the moisture content of the atmosphere. Because warm air has a greater capacity for holding water vapor than cold air, air masses that originate over the warm tropical zones of oceans are responsible for the evaporation and transport of more precipitable water (water that may fall as rain or frozen precipitation) than air masses originating over the cold sections of oceans (Hirschboeck 1991). On an annual basis, the precipitable water vapor content of the atmosphere is greatest over the Southeastern United States and decreases moving northward and westward. During the summer, precipitable water contents increase over the entire United States. In July, average atmospheric precipitable water vapor content over the Assessment area is about 1.6 inches (in.), compared to average July values of about 1.9 in. and 0.7 in. over Florida and the northwestern United States, respectively (Hirschboeck 1991). The primary sources of moisture that lead to higher average precipitation over the southeastern United States, including the Assessment area, are the Gulf of Mexico and the western Atlantic Ocean. Water vapor carried aloft is transported northward by upper level winds over much of the Eastern United States from the Gulf of Mexico. The transport of water vapor by weather systems is most prominent during the spring and summer (Hirschboeck 1991).

Average yearly precipitation over the Assessment area and surrounding areas reflects the large-scale, northwest-to-southeast variation in precipitable water over the United States, with southern Arkansas averaging more than 55 in. of precipitation while northern Missouri and eastern Kansas average about 35 in./year (fig. 1.19). The topography of the Assessment area also plays a significant role in influencing precipitation in the region. A yearly average maximum of more than 55 in. of precipitation can be found in parts of the Ouachita Mountains. The decrease in yearly precipitation between Arkansas and eastern Oklahoma is quite significant. Throughout the central sections of the Assessment area, precipitation is about 40 to 45 in./year.

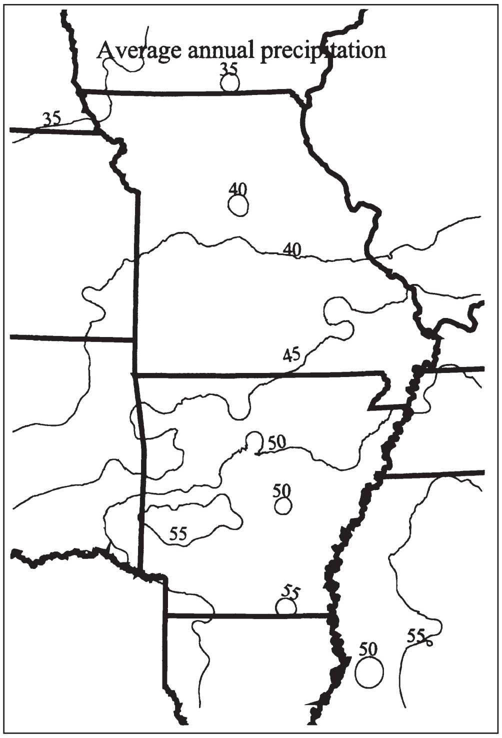


Figure 1.19—Average yearly precipitation (in inches) in the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

Figure 1.20 shows the average precipitation over the Assessment area for January, April, July, and October. During the winter, a very strong northwest-to-southeast gradient in precipitation exists over the region. In January, amounts range from about 1 inch in northwestern Missouri to more than 4.5 in. in southeastern Arkansas (fig. 1.20). The spatial change in precipitation is most significant in Arkansas and southeastern Missouri. From January to March, average monthly precipitation generally increases over the region, especially in Missouri and over the Ouachita Mountains in Arkansas. In March, precipitation ranges from 2.5 in. in northwestern Missouri to more than 5.5 in. over the Ouachita Mountains.

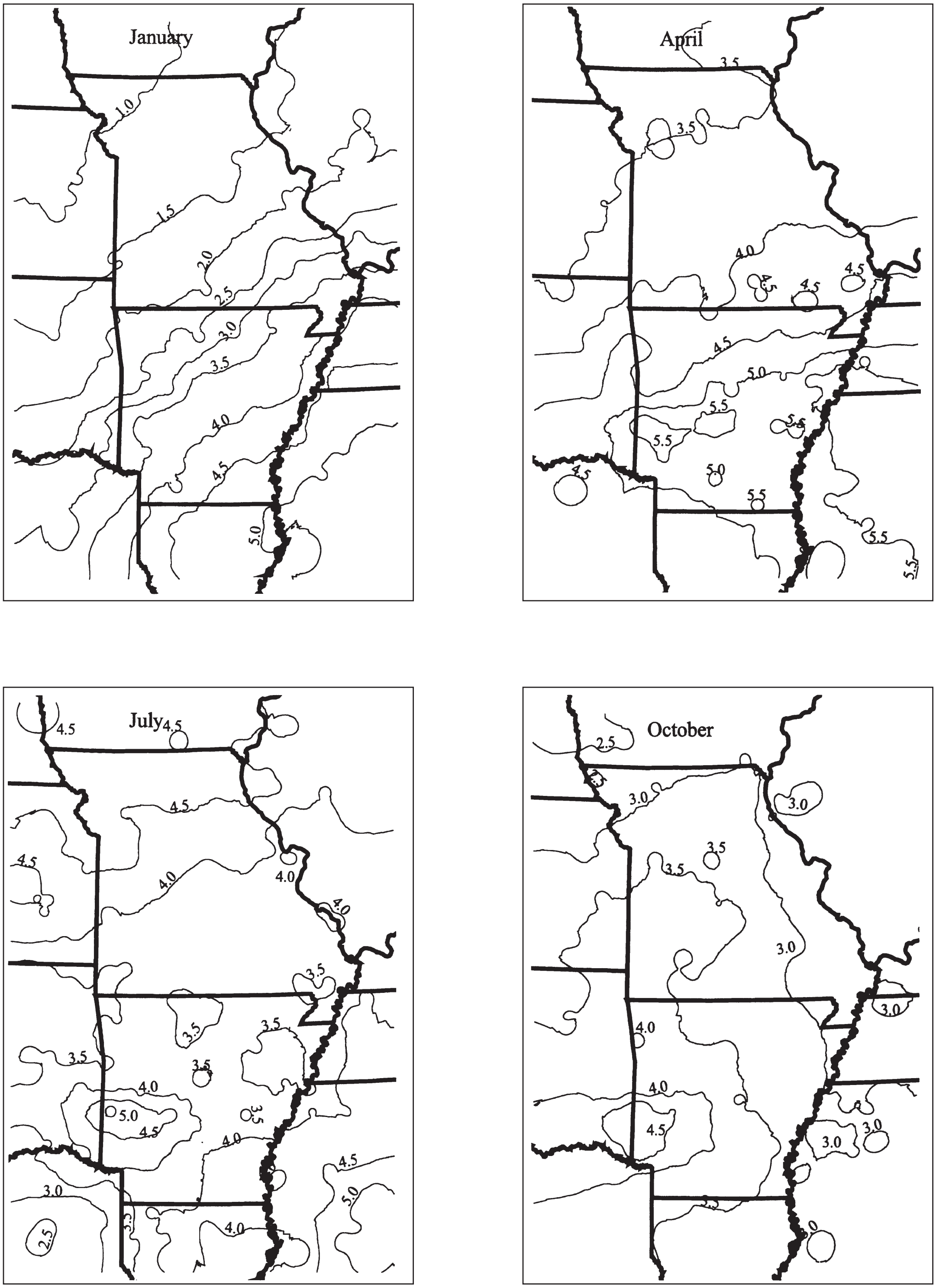


Figure 1.20—Average monthly precipitation (in inches) during January, April, July, and October in the region within and surrounding the Ozark-Ouachita Highlands Assessment area.

With the onset of higher temperatures during the spring months and more convective precipitation events (heat-induced cloud formation with associated rainfall), the average monthly precipitation patterns change dramatically from the wintertime pattern. In April and May, the area of maximum precipitation over the Assessment area shifts to the west, while precipitation over Missouri continues to increase. In April (fig. 1.20), average precipitation totals range from about 3.5 to 4.5 in. in Missouri and from about 4.0 to 5.5 in. in Arkansas. The peak in total precipitation shifts to west-central Arkansas and eastern Oklahoma in May, with amounts exceeding 6 in. in this area. The increase in convective precipitation events over the southern and central Great Plains during the spring leads to a general increase in monthly precipitation from east to west over the region. In June, the driest sections of the Assessment area generally can be found in eastern Missouri and eastern Arkansas—where precipitation totals for the month average less than 4 in.—and northeastern Arkansas and southern Missouri where there is less than 3.5 in. These totals greatly differ from precipitation totals exceeding 5 in. in western Missouri and eastern Kansas. Low precipitation also occurs over the Arkansas Valley between the Boston and Ouachita Mountains in western Arkansas; this area receives about 3.5 to 4.0 in. of rain in June.

During most of the summer, more rain tends to fall in northern Missouri than in any other part of the Assessment area, except in July when the southern slopes of the Ouachita Mountains tend to experience a peak in precipitation as well (fig. 1.20). Typical monthly precipitation totals range from about 4.5 in. in northern Missouri to 3.5 to 4.0 in. over the rest of the Assessment area in July, excluding the Ouachita Mountains region where precipitation totals in July tend to exceed 4.5 in. A sharp decrease in precipitation is evident moving southwestward into northeastern Texas, where totals in July fall below 2.5 in. By late summer, the wettest portions of the Assessment area are again the western sections of Missouri and Arkansas. In September, average precipitation ranges from 3.5 to 4.0 in. over the eastern half of Missouri and Arkansas. Average rainfall is a bit higher at 4.5 to 5.0 in. over the far western sections of Missouri and Arkansas and the far eastern sections of Kansas and Oklahoma. The east-to-west gradient in precipitation in September is similar to the precipitation gradient observed in June.

From October (fig. 1.20) to December, the location of the peak monthly precipitation moves from the southern slopes of the Ouachita Mountains to the far southeastern section of Arkansas and into Mississippi and Louisiana. By late fall, the east-to-west gradient in precipitation observed during the late summer and early fall is replaced by the normal wintertime northwest-to-southeast gradient. The relative maximum precipitation in southwestern Arkansas (> 4.5 in.) moves slightly eastward in November and increases to about 5.5 in. Average precipitation totals in November also decrease quite rapidly from southeastern Missouri (~ 4.5 in.) to northwestern Missouri (~ 1.8 in.). Most of Arkansas experiences between 4 to 5 in. of precipitation in November. December brings an overall reduction in precipitation over the entire region, ranging from less than 1.5 in. in northwestern Missouri to about 5 in. in the far southeastern sections of Arkansas. Average precipitation in December shows significant northwest-to-southeast variations over the entire region, with the largest northwest-to-southeast variation existing along a line from west-central Arkansas to north-central Arkansas.

Extreme Precipitation Occurrences

Extreme precipitation events in the Assessment area can lead to floods that can have a profound effect on the region's natural resources. For example, floods can decrease nutrient, trace metal, and organic chemical concentrations in streams and deposit gravel in streambeds, which can enhance fish spawning (USDI GS 1991). Flooding can increase the concentrations of contaminants in reservoirs and increase algal blooms (noticeable growth of fresh water algae) within them as a result of enhanced nutrient concentrations. Floods also can deposit large amounts of sediment on croplands, at times destroying food crops. Finally, property damage associated with extreme precipitation events and flooding can create severe economic stress on a region.

Extreme precipitation events that can lead to flooding depend on the amount of precipitable atmospheric water vapor present coupled with an uplift mechanism that can steer water vapor aloft to higher altitudes where condensation can occur, thereby producing clouds and eventual precipitation (Hirschboeck 1991). The lifting of moist air can be accomplished through (1) convectional processes like thunderstorms, mesoscale convective complexes (organized, multiple-celled thunderstorm systems), and tropical cyclones; (2) the large-scale convergence of air masses and associated extratropical cyclones and frontal passages; and (3) orographic (mountain-related) effects. All of these mechanisms can play a role in the occurrence of extreme precipitation events in the Assessment area.

Thunderstorm activity in the Assessment area is most common during the spring, summer, and fall. On average, thunderstorms develop in the region from 10 to 25 days during each of these seasons. The number of thunderstorms during the winter is usually fewer than 10. Although thunderstorms are relatively small in size, they can produce intense precipitation and cause flash floods in small drainage basins. Mesoscale convective complexes can produce both local and widespread intense precipitation. They can produce significant flooding because of their size (> 40,000 mi^2) and duration (6 to 36 hours). In the Assessment area, mesoscale convective complexes are most common during the spring and summer. Tropical cyclones (e.g., hurricanes, tropical storms, and tropical depressions) and associated thunderstorms embedded within them are responsible for many extreme precipitation events in the southern and eastern sections of the United States. Tropical cyclones have typical diameters on the order of 60 to 600 mi when they are fully developed, usually from June to October. Those that impact the Assessment area usually originate over the Gulf of Mexico or Caribbean Sea. Flooding from tropical cyclones can be both local and widespread.

Precipitation associated with extratropical cyclones and frontal passages is usually characterized as covering a larger geographical area and being less intense and of longer duration than the precipitation associated with convectional processes. However, the convergence of air masses along frontal boundaries can lead to significant convection, thunderstorm development, and intense precipitation. Large-scale riverine flooding and local flash flooding are possible under these conditions. Even though precipitation tends to be less intense with extratropical cyclones, such cyclones are responsible for most of the major floods that occur in large drainage basins in the conterminous United States (Hirschboeck 1991). Extratropical cyclones mostly affect the Assessment area during winter and spring. They usually originate in the Western United States and move eastward across the Great Plains into the Eastern United States.

The topographically forced lifting of air as it passes over hills or mountains can result in the formation of orographic clouds that may produce precipitation (Wallace and Hobbs 1977). As air is forced upward when prevailing winds pass over hilly or mountainous terrain, it can cool sufficiently at higher altitudes to allow for cloud formation and potential precipitation. Precipitation associated with orographic lifting is usually found along the windward slopes of hills or mountains and can be locally intense. Orographic lifting in combination with convectional processes or the convergence of air masses can result in significant precipitation events and potential flooding. Within the Assessment area, topography plays an important role in precipitation events. The Ouachita Mountains and Ozark Plateaus are important topographic features that are responsible for orographic lifting effects. Depending on the direction of prevailing winds and the moisture content of the atmosphere over the Assessment area, extreme precipitation events are possible along the windward slopes of these topographic features.

For this Assessment report, an “extreme precipitation event” is defined as an event occurring within 24 hours that results in 2 or more in. of precipitation. Large amounts of precipitation and flooding are certainly possible from longer lasting events. However, to identify areas of extreme precipitation, the Aquatic Team used this definition. Figure 1.21 shows the total number of extreme precipitation events that have occurred over the Assessment area from 1950 through 1993. West-central Arkansas experienced more than 200 extreme precipitation events during the 44 years, equivalent to about 4 or 5 events per year. In this portion of the Assessment area, orographic lifting associated with the Ouachita Mountains plays a significant role in precipitation processes. The number of extreme events was less in Missouri; the northeastern half of Missouri experienced less than 100 events during the 44 years.

The monthly distribution of extreme precipitation events over the 44-year period indicates important

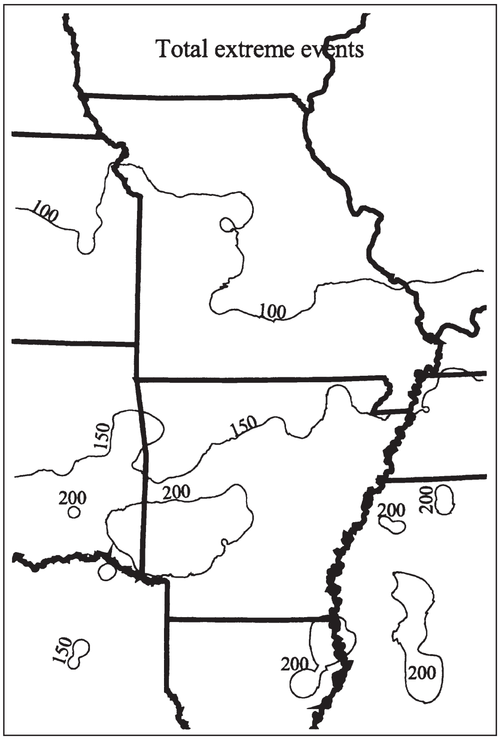


Figure 1.21—Total number of occurrences where daily precipitation was 2 inches or more in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

seasonal changes in the number and locations of these events. Figure 1.22 shows the number of extreme precipitation episodes that occurred from 1950 through 1993 over the Assessment area during January, April, July, and October. For the months of December, January, and February, more extreme events tend to occur in the southeastern quarter of Arkansas. For example, in January, 10 to 15 extreme precipitation events occurred from 1950 through 1993 over this part of Arkansas. The numbers of extreme events for December and February over this same area were slightly higher, exceeding 20 events in parts of southern and east-central Arkansas in December and in the far southeastern parts of Arkansas in February. For December, January, and February, fewer than four extreme events on average characterized most of Missouri.

During spring, more extreme precipitation events tend to occur over the entire Assessment area than during the colder winter months. As shown in fig. 1.22, more extreme events tend to occur in western Arkansas and eastern Oklahoma (Ouachita Mountains) with the onset of warmer spring weather. Although still rare, extreme precipitation events in Missouri during April also are more frequent than wintertime events. The Ouachita Mountains have experienced more heavy precipitation events in May than in any other month. More than 32 events occurred from 1950 through 1993 in this part of the Assessment area.

The summer months are characterized by a shift in locations of extreme precipitation events from southwestern Arkansas to eastern Oklahoma and Kansas and western and northern Missouri. More than 20 events have occurred in parts of northwestern and west-central Missouri, while fewer than 10 events have occurred in parts of north-central Arkansas and east-central Missouri during July. The shift in locations of the relative maximums of extreme events is consistent with the similar shift in relative maximums of average monthly precipitation totals during the summer.

With the return of cooler conditions during the fall, extreme precipitation events in Missouri become much less frequent. The maximums in the number of events that characterize the western sections of Missouri and the eastern sections of Kansas in summer disappear during the fall. In October, the preferred location for extreme precipitation is over southeastern Oklahoma and southwestern Arkansas (fig. 1.22). Very few extreme events have occurred over the eastern half of Missouri in October. In November, extreme events are rarest in the northern half of Missouri, and most common in central Arkansas. More events also tend to occur in southeastern Missouri in November than in October. By late fall, most extreme precipitation events tend to occur in southeastern Arkansas and over the Ouachita Mountains in southwestern Arkansas.

Droughts

Most definitions of drought incorporate the characteristic of abnormal dryness (McNab and Karl 1991); drought is most often recognized during seasons when substantial precipitation is expected but fails to occur (Karl and others 1987). The lack of precipitation over a region for an extended period is the result of persistent atmospheric circulation patterns that are not conducive to precipitation (Namias 1985). For example, high

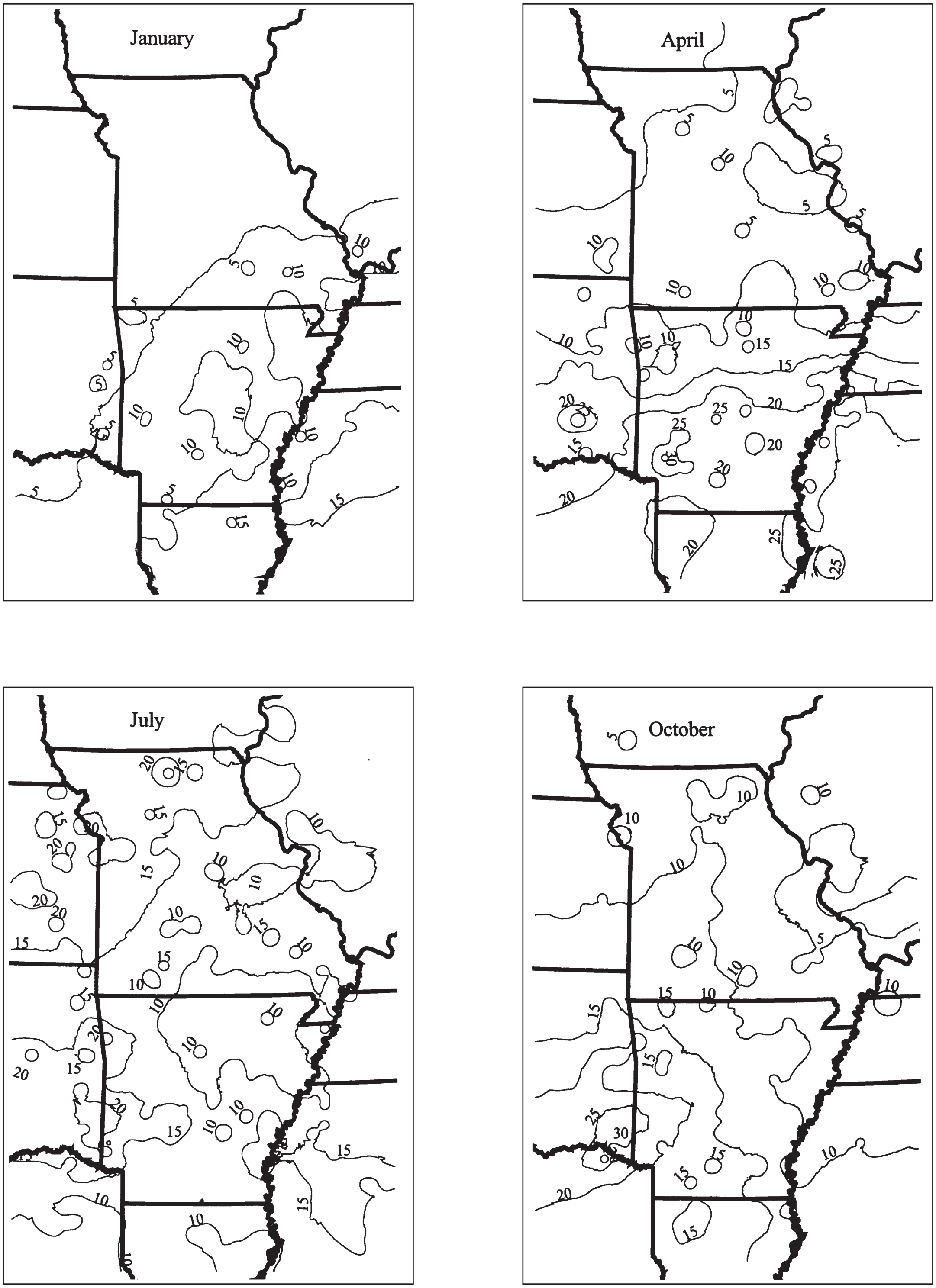


Figure 1.22—Total number of occurrences where daily precipitation was 2 inches or more in January, April, July, and October in the region within and surrounding the Ozark-Ouachita Highlands Assessment area from 1950 through 1993.

pressure (anticyclonic) circulations over a region usually result in very little precipitation. If this type of circulation pattern persists for an extended period, drought probabilities are likely to increase. Drought occurrence over a region is also possible when weather systems consistently produce only minimal precipitation (Bergman and others 1986, Karl and Young 1987).

In addition to a lack of precipitation, droughts are also associated with higher than normal surface temperatures and drier than normal atmospheric moisture contents. There are many examples of past drought occurrences where average surface air temperatures exceeded normal temperatures for an extended period of time (Bergman and others 1986; Karl and Young 1987; Namias 1982, 1983; Karl and Quayle 1981). However, some droughts are associated with lower than normal surface temperatures (Namias 1966). Relative humidity values are typically lower than normal during droughts, and these values usually characterize all levels of the atmosphere that contain substantial water vapor (Namias 1966).

Numerous droughts have occurred over the Assessment area during the past 50 years. The U.S. Department of the Interior Geological Survey (USDI GS 1991) noted that in Missouri, four major droughts occurred between 1950 and 1991: 1952 to 1957—statewide, 1962 to 1969—statewide, 1975 to 1982—statewide, and 1988—northern part of the State. In Arkansas, five major droughts occurred between 1950 and 1991: 1954 to 1956—statewide, 1963 to 1967—statewide, 1970 to 1972—statewide except southwest and northeast corners, 1976 to 1978—statewide except the north-central section, and 1980 to 1983—the northern part of the State).

The National Drought Mitigation Center (1997) examined the amount of time individual climate divisions within States experienced severe drought conditions, defined by a Palmer Drought Severity Index value of -3 or less (Palmer 1965) over 10-year periods beginning in 1900. From 1950 to the present, the most severe drought conditions over a decade in the Assessment area occurred from 1950 to 1959. During this period, the southwestern section of Missouri was under severe drought conditions 40 to 50 percent of the time while the west-central and northwestern sections of Missouri were under severe drought conditions 30 to 40 percent of the time. Less severe drought conditions were present in eastern Missouri and in Arkansas. Severe drought conditions were also prevalent throughout the southern Great Plains and eastern Rocky Mountains during the 1950's. From 1960 to the present, 10-year drought conditions have not been significant over the Assessment area, as measured by extended periods of Palmer Drought Severity Index values of -3 or less.

Tornadoes

The Assessment area is located in that portion of the United States called "Tornado Alley." This area of relatively frequent tornado occurrence encompasses the southern and central Great Plains and the lowland areas of the Mississippi, Ohio, and lower Missouri River Valleys. Specific atmospheric conditions are required for tornadoes to develop. Such favorable conditions frequently occur over the central portions of the United States and include: (1) a large supply of atmospheric moisture (northward transport of moisture from the Gulf of Mexico), (2) low-level wind shear (wind speed increase with height and wind-direction shift from southerly at low levels to southwesterly and westerly at mid-levels of the atmosphere), and (3) a dry and stable atmospheric layer above the moist low-level atmospheric layer. The atmospheric conditions that can lead to severe thunderstorm development and tornado occurrence are more frequent over "Tornado Alley" than over other parts of the Nation.

Each year in the United States, tornadic winds are responsible for death, injury, and millions of dollars in damages to property and natural resources. Wind speeds associated with tornadoes can range from about 40 mi per hour (mi/h) up to about 320 mi/h. Tornadoes are classified according to the amount and type of wind damage they cause using the Fujita Scale, which ranks tornado intensity from F0 through F5:

- F0 (40 to 72 mi/h): gale tornado that causes light losses such as damage to chimneys, breakage of tree branches, and the pushing over of shallow-rooted trees.
- F1 (73 to 112 mi/h): moderate tornado that can peel the surface off roofs, push mobile homes off their foundations or overturn them, and push autos off roads.
- F2 (113 to 157 mi/h): significant tornado that can pull roofs off frame houses, demolish mobile homes, push boxcars over, and snap or uproot large trees.

- F3 (158 to 206 mi/h): severe tornado that can tear the roof and walls off well-constructed houses, overturn trains, and uproot most trees in a forest.
- F4 (207 to 260 mi/h): devastating tornado that can level well-constructed houses, blow structures with weak foundations considerable distances, and throw cars.
- F5 (261 to 318 mi/h): incredible tornado that can lift strong frame houses off foundations and carry them considerable distances, move automobile-sized missiles through the air in excess of 100 yards, debark trees, and badly damage steel-reinforced concrete structures.

Most reported tornadoes are classified as F0, F1, or F2 tornadoes. For example, out of the 24 tornadoes reported in Arkansas in 1995, 17 were F0 tornadoes, 4 were F1 tornadoes, and 3 were F2 tornadoes. Of the 35 tornadoes that were reported in 1996 in Missouri, 22 were F0 tornadoes, 8 were F1 tornadoes, 3 were F2 tornadoes, and 2 were F3 tornadoes.

Between 1950 and 1994, 1,166 tornadoes were reported in Missouri and 854 tornadoes were reported in Arkansas. Missouri and Arkansas rank 7th and 16th, respectively, in the number of reported tornadoes from 1950 through 1994 in the entire country. During these 45 years, 279 and 155 fatalities due to tornadoes occurred in Arkansas and Missouri, respectively. Arkansas ranked third in the Nation in fatalities due to tornadoes, while Missouri ranked12th. Injuries attributed to tornadoes ranged from 3,697 in Arkansas to 2,252 in Missouri, corresponding to ranks of 5th and 15th, respectively. The dollar losses (adjusted by the Consumer Price Index) due to these tornadoes from 1950 through 1994 were about $517 million in Arkansas and $739 million in Missouri.

Figure 1.23 shows the yearly distributions of reported tornadoes in Arkansas and Missouri during the 1950 through 1995 period. Missouri tends to have slightly more tornadoes each year than Arkansas. Over the 46 years, an average of 26 tornadoes per year were reported in Missouri; Arkansas averaged 19 reported tornadoes yearly. Peak numbers of reported tornadoes in Missouri occurred in 1967, 1973, and 1982. Arkansas also experienced relatively large numbers of tornadoes in 1973, 1978, 1979, and 1982. There is no statistically significant long-term trend in the number of tornadoes occurring in this region based on the 1950 through 1995 data.

Although tornadoes have been reported during every month of the year in Arkansas and Missouri, there are certain months in which tornadoes are more likely to occur. Figure 1.24 shows the distribution by month of the number of reported tornadoes that occurred from 1950 through 1995 in these States. More tornadoes tend to occur during April and May over this region than in any other months. In Arkansas, April is the peak month for tornado activity, while in Missouri, most tornadoes

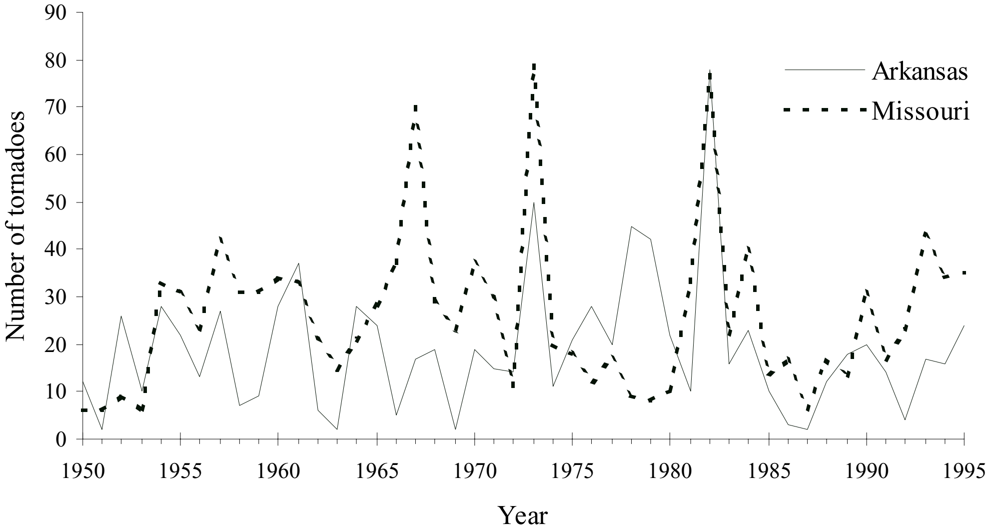


Figure 1.23—Total number of reported tornadoes in Arkansas and Missouri from 1950 through 1995.

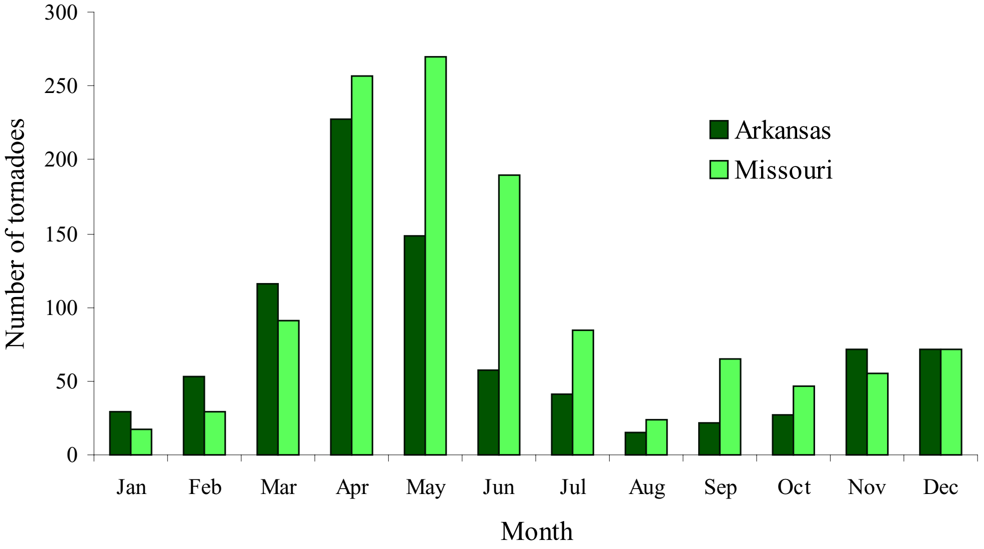


Figure 1.24—Total number of reported tornadoes each month in Arkansas and Missouri from 1950 through 1995.

are reported in May. Although Missouri typically experiences more tornadoes during an entire year, tornado activity is usually greater in Arkansas during January, February, and March. This is due to the greater probability of severe thunderstorm development in more southern latitudes during winter. By April, tornado activity in Missouri usually exceeds the activity in Arkansas and remains greater throughout the late spring to mid-autumn. The number of reported tornadoes in May and June from 1950 through 1995 was considerably larger in Missouri than in Arkansas. Figure 1.24 suggests that tornado activity in the region falls off significantly in the months of July and August. Less than 25 tornadoes were reported for the month of August from 1950 through 1995 in Arkansas and Missouri. The numbers are somewhat higher for September and show a marked decrease for January and February with the onset of the region's lowest average temperatures.

Runoff

Runoff is the water that drains from the land into stream or river channels after precipitation. Runoff volume is a function of the combined influence of precipitation, topography, geology, soil moisture, and other factors. Mean annual runoff per square mile of basin is often used to compare runoff characteristics between basins. Mean annual runoff can be computed by dividing the mean annual volume of water leaving the basin (measured as streamflow at a gauging station) by the area of that basin.

Mean annual runoff within the Ozark-Ouachita Highlands Assessment area is shown in figure 1.25 (Gebert and others 1987). Mean annual runoff generally is least in the Osage Plains, where it ranges from 8 to 10 in. Mean annual runoff in the Springfield and Salem Plateaus and St. Francois Mountains generally ranges from 10 to 15 in., although values are more variable in the eastern Salem Plateau, where they range from about 8 to 16 in. per year. Mean annual runoff in the Boston Mountains ranges from 14 to 20 in. Mean annual runoff is about 16 in. in the Mississippi Alluvial Plain at the eastern edges of the Assessment area (Gebert and others 1987). The mean annual runoff generally is greatest in the Arkansas Valley and Ouachita Mountains, where it ranges from 8 to 22 in. and 14 to 22 in., respectively.

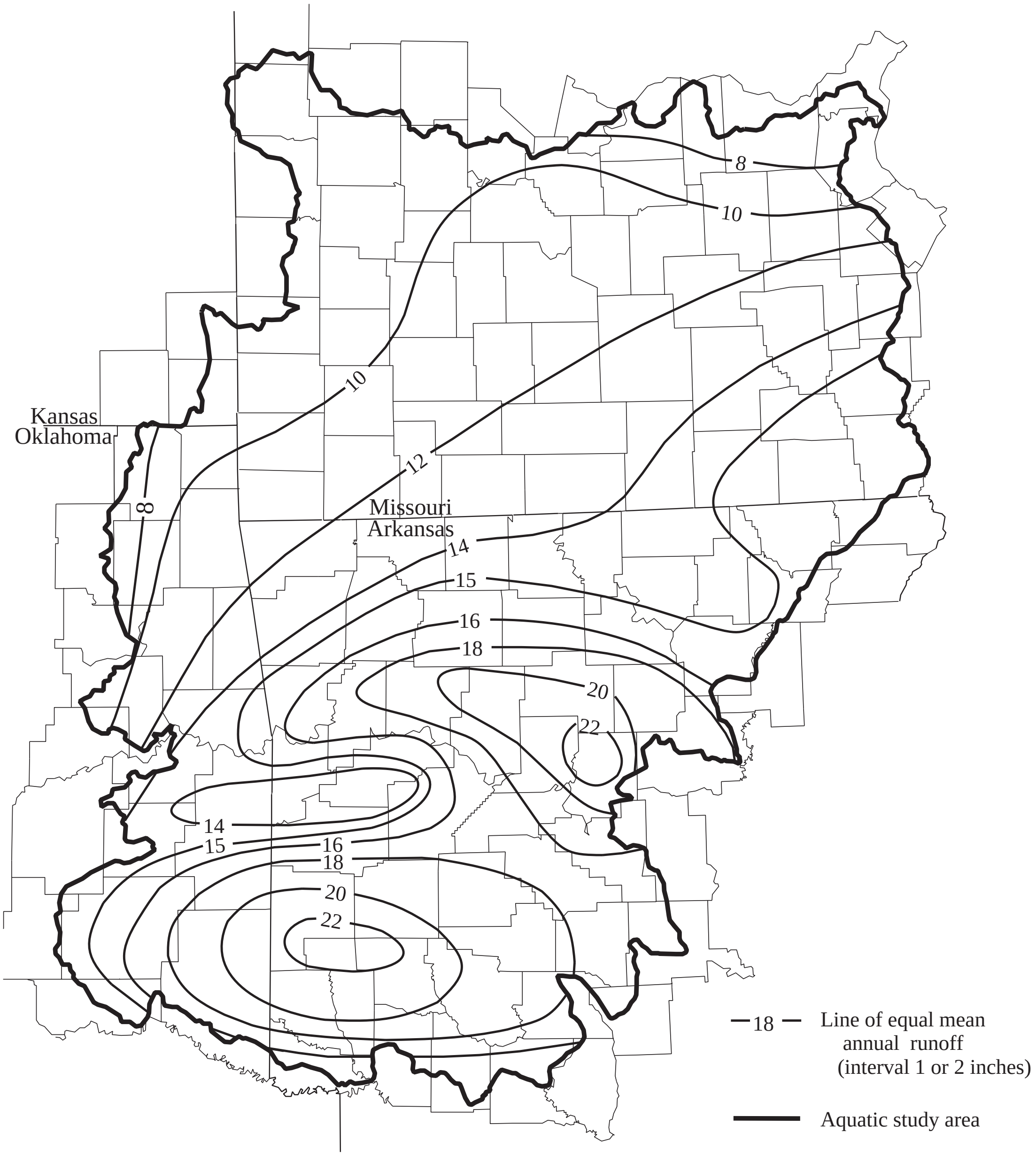


Figure 1.25—Mean annual runoff (in inches) in the aquatic study area from 1951 through 1980 (Gebert and others 1987).

Geology

The Ozark Plateaus Province is diverse in lithology, mineralogy, and structure. Rock formations include igneous, metamorphic, and sedimentary rocks. Secondary mineralization has occurred in many of the rock units, and uplifting has resulted in fracturing and faulting of the rock units. All of these factors contribute to the unique hydrogeology of the Ozark Plateaus.

The Ouachita Province geology is composed predominantly of clastic (fragmented) rock strata that have been intensely folded and faulted. Rock strata present today are the highly eroded roots of the frontal element of the Ouachita orogenic belt (a mountainous belt formed by folding of the Earth's crust). Rock formations include igneous and sedimentary rocks. Both primary and secondary mineralization has occurred in many of the Ouachita Province rock units.

Geologic Setting of the Ozark Plateaus Province

The stratigraphy of the Ozark Plateaus is complex. Its basement crystalline rocks are overlain by a sequence of sedimentary rocks of Paleozoic-age (fig. 1.26). The sedimentary-rock sequence consists of Cambrian- through Mississippian-age dolomites and limestones in some areas, and Pennsylvanian-age sandstones, shales, and some limestones in other areas.

Pre-Cambrian Units

Basement Pre-Cambrian-age igneous and metamorphic rocks underlie the Ozark Plateaus and crop out in several places in the eastern and western parts of the Assessment area (fig. 1.27). Elsewhere, these rocks are buried under as much as 5,000 ft of sedimentary rock. The igneous rocks are mainly felsic (silica rich) rocks such as granite and rhyolite with mafic (silica poor) intrusions consisting of diabase and gabbro (Kisvarsanyi 1981). Felsic rocks contain minerals such as quartz and potassium feldspar, which are resistant to weathering. In contrast, the mafic rocks contain minerals such as pyroxene and calcium plagioclase, which weather easily. The igneous rocks also contain commercially important quantities of several metals, including iron, copper, manganese, and silver (Kisvarsanyi 1981).

Cambrian and Ordovician Units

Cambrian- and Ordovician-age rocks crop out mainly in the Salem Plateau (fig. 1.27). (Refer to fig. 1.1 for province locations.) The rocks range in thickness from less than 50 ft to more than 4,000 ft and average about 2,000 ft (Imes 1990a, b, c) and consist predominantly of dolomites, cherty dolomites, sandstones, and limestones (Caplan 1960).

The basal unit of the Cambrian and Ordovician rocks, the Lamotte Sandstone (Late Cambrian age), rests unconformably (in broken sequence) on Pre-Cambrian-age igneous rocks and is a well-sorted quartz sandstone. The Bonneterre Formation is a fine- to medium-grained dolomite or limestone that crops out near the St. Francois Mountains; in southeastern Missouri, it contains abundant lead- and zinc-sulfide deposits. The Davis Formation and Derby-Doe Run Dolomite are shaley to silty glauconitic dolomites that crop out in a roughly circular band around the St. Francois Mountains (Caplan 1960) and are relatively impermeable compared to the other Cambrian- and Ordovician-age units (Imes and Emmett 1994).

The Potosi and Eminence Dolomites, which represent the top of the Cambrian section, are fine- to coarse-grained dolomites with dense chert, drusy quartz, and, in northern Arkansas, glauconitic green shale (Caplan 1960). Both units contain barite, mined in east-central Missouri (Wharton and others 1975).

The Gasconade Dolomite consists of a basal sandstone member, the Gunter Sandstone, and upper and lower dolomite members (MacDonald and others 1975). The Gunter Sandstone is a fine- to coarse-grained quartz sandstone (Caplan 1960). Chert is present in the upper minor and lower dolomite members and in some places can constitute more than 50 percent of the lower member.

The Roubidoux Formation consists of sandstones, dolomites, and cherty dolomites (Thompson 1991) and crops out extensively in central, south-central, and southeastern Missouri. The dolomites are finely to medium crystalline, and the sandstones are loosely cemented.

The Jefferson City, Cotter, and Powell Dolomites and the Smithville Formation consist of dolomite with chert, sandstone lenses, and a few shale beds. These units are pyritic, and the Smithville Formation contains lead and zinc ore. The units are exposed in southern Missouri and northern Arkansas (Caplan 1960).

The Everton Formation contains sandy dolomite and sandstone members that crop out extensively in northern Arkansas. The St. Peter Sandstone overlies the Everton Formation, crops out mainly in northern Arkansas and into eastern Missouri, and is a loosely cemented sandstone containing well-rounded quartz grains.

Silurian and Devonian Units

Silurian- and Devonian-age rocks are thin and most are not laterally continuous in the Assessment area (fig. 1.27). Most of the units in this interval exist only in northern Arkansas and parts of Missouri. The most significant unit is the black, pyritic, thinly bedded Chattanooga Shale that averages about 70 ft thick (Wise and Caplan 1979).

Erathem	System	Hydrogeologic unit	Hydrogeologic system	Ozark Plateaus Province				Ouachita Province
				Southern Missouri	Southeastern Kansas	Northeastern Oklahoma	Northern Arkansas	
			Post-Paleozoic sediments					
Paleozoic	Pennsylvanian		Western Interior Plains confining system	Kansas City Group Pleasanton Formation Marmaton Group Cherokee Shale	Kansas City Group Pleasanton Group Marmaton Group Cherokee Group	Marmaton Group Cabaniss Group Krebs Group Atoka Formation Bloyd Shale Hale Formation	Atoka Formation Bloyd Shale Hale Formation	Savanna Formation McAlester Group Hartshore Sandstone Atoka Formation Johns Valley Shale Jackfork Group
	Mississippian			Fayetteville Shale Batesville Sandstone Hindsville Limestone Carterville Formation		Pitkin Limestone Fayetteville Shale Batesville Sandstone Hindsville Limestone	Pitkin Limestone Fayetteville Shale Batesville Sandstone	Stanley Shale
				St. Louis Limestone Salem Limestone Warsaw Limestone Keokuk Limestone Burlington Limestone Elsey Formation Reeds Spring Limestone Pierson Formation	St. Louis Limestone Salem Limestone Warsaw Limestone Keokuk Limestone Burlington Limestone Fern Glen Limestone	Moorefield Formation Keokuk Limestone Boone Formation St. Joe Limestone	Moorefield Formation	
		Springfield Plateau aquifer	Ozark Plateaus aquifer system				Boone Formation St. Joe Limestone	

Figure 1.26—Stratigraphic column of the Assessment area *(continued)*.

Paleozoic	Mississippian	Ozark confining unit		Northview Shale Sedalia Limestone Compton Limestone	Chouteau Limestone	Northview Equivalent Compton Equivalent		Upper Arkansas Novaculite Formation
	Devonian			Chattanooga Shale	Chattanooga Shale	Woodford Chert Chattanooga Shale	Chattanooga Shale	
		Ozark aquifer	Ozark Plateaus aquifer system	Callaway Formation Fortune Formation		Sallisaw Formation Frisco Limestone	Clifty Limestone Penters Chert	Lower and Middle Arkansas Novaculite Formation
	Silurian					St. Clair Limestone	Lafferty Limestone St. Clair Limestone Brassfield Limestone	Missouri Mountain Formation Blaylock Sandstone
	Ordovician			Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone		Sylvan Shale Fernvale Limestone Viola Limestone Fite Limestone Tyner Formation Burgen Sandstone	Cason Shale Fernvale Limestone Kimmswick Limestone Plattin Limestone Joachim Dolomite St. Peter Sandstone	Polk Creek Shale Big Fork Chert Womble Shale

Figure 1.26—Stratigraphic column of the Assessment area *(continued)*.

Paleozoic	Ordovician	Ozark aquifer	Ozark Plateaus aquifer system	Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone	Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Van Buren Formation	Smithville Equivalent Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Van Buren Formation	Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone Van Buren Formation	Blakely Sandstone Mazarn Shale Crystal Mountain Sandstone Collier Formation
	Cambrian			Eminence Dolomite Potosi Dolomite				
		St. Francois confining unit		Derby-Doe Run Dolomite Davis Formation				
		St. Francois aquifer		Bonneterre Dolomite Reagan Sandstone Lamotte Sandstone				
		Basement confining unit		Precambrian igneous and metamorphic rocks				

Figure 1.26—Stratigraphic column of the Assessment area *(continued)*.

Mississippian Units

Mississippian-age rocks in the Ozark Plateaus are predominantly finely to coarsely crystalline limestones and cherty limestones. These units have a total thickness of about 200 to 500 ft (McFarland and others 1979) and crop out extensively in the Springfield Plateau (fig. 1.27). (Refer to figure 1.1 for province locations.) The St. Joe Limestone and the Boone Formation in northern Arkansas are equivalent to the entire lithologic sequence that ranges from the Compton Limestone to the Keokuk Limestone in southwestern Missouri.

Secondary mineralization (mineralization that occurs after a stratum is initially deposited) is extensive in the Mississippian-age limestones. Lead- and zinc-sulfide deposits are present in limestones in southwestern

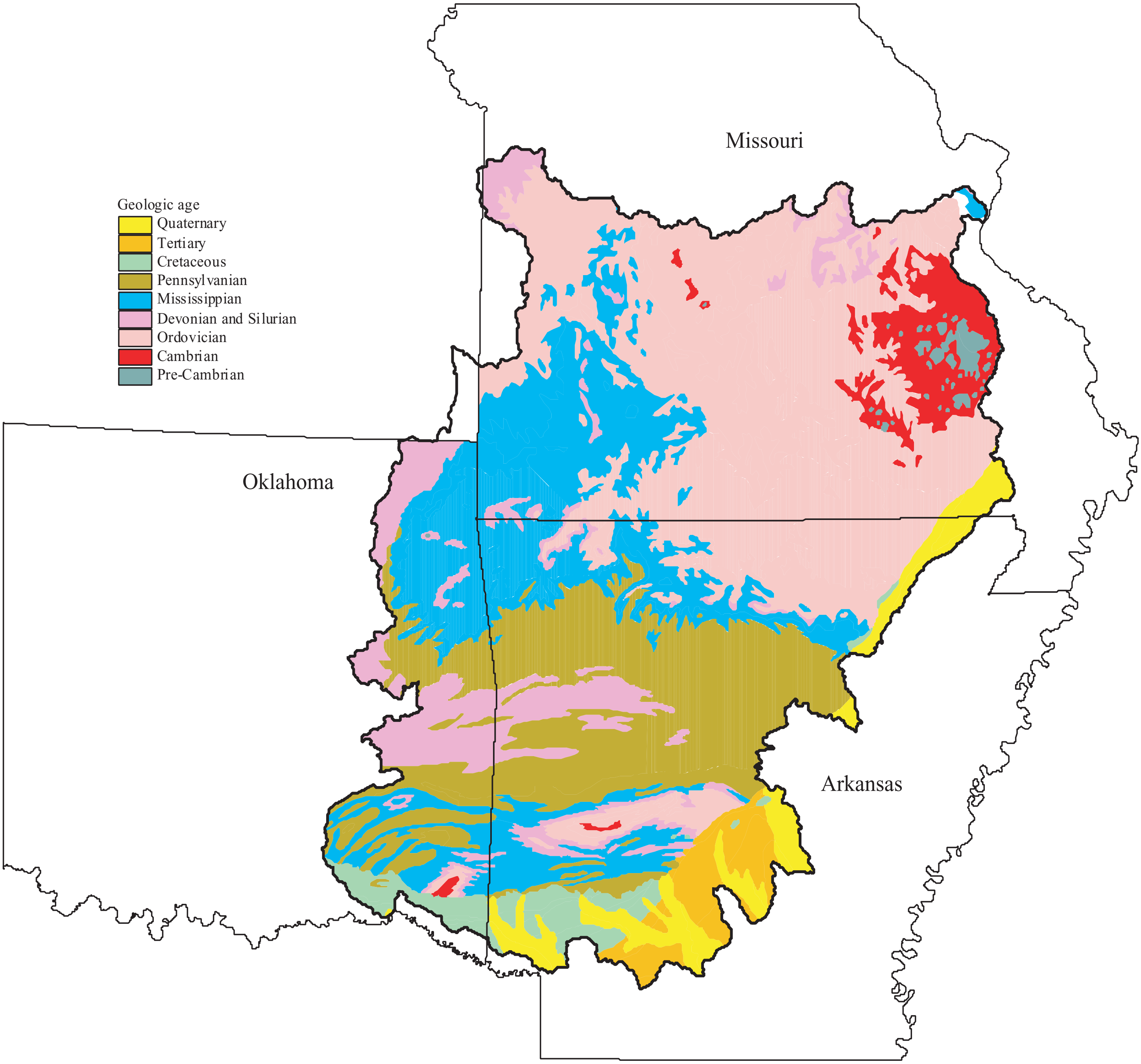


Figure 1.27—Geologic age of major formations underlying the Ozark-Ouachita Highlands and portions of some surrounding physiographic provinces. (White indicates portions of the aquatic study area for which insufficient data were available.)

Missouri, southeastern Kansas, and northeastern Oklahoma. Pyrite, lead- and zinc-carbonates, and zinc silicates are also present in these deposits (Kiilsgaard and others 1967).

Late Mississippian-age rocks overlie the Boone Formation and its equivalent units and crop out on the northern flank of the Boston Mountains. These units include the relatively permeable Hindsville and Pitkin Limestones, which are separated by the thick, impermeable Fayetteville Shale.

Pennsylvanian Units

Pennsylvanian-age rocks crop out in the Boston Mountains of northern Arkansas and in the Osage Plains of western Missouri, southeastern Kansas, and northeastern Oklahoma (fig. 1.27). In general, Pennsylvanian-age rocks rest unconformably (in broken sequence) on Mississippian-age rocks. However, in the north-central Ozark Plateaus, Mississippian-age rocks are missing, and in these locales Pennsylvanian-age rocks directly overlie Ordovician-age rocks.

In northern Arkansas, three geologic units—the Hale Formation, the Bloyd Shale, and the Atoka Formation—are of Pennsylvanian age. The Hale Formation and Bloyd Shale are massive sandstones with interbedded limestone, shale, and coal. The Atoka Formation is mostly dark shales with sandstones and sandy limestones (Caplan 1957).

Pennsylvanian-age rocks in western Missouri, southeastern Kansas, and northeastern Oklahoma consist of four groups, Cherokee, Marmaton, Pleasanton, and Kansas City. Lithologies are mostly shales and sandstones with some limestones. Black shales in this Pennsylvanian section can be uranium bearing (Coveney and others 1987). Bituminous coal beds are present in the Cherokee and Marmaton Groups (Robertson and Smith 1981). In some places, these same Pennsylvanian-age rock units yield oil and gas (Anderson and Wells 1967).

Cretaceous Through Quaternary Units

According to Fenneman (1938), Cretaceous- through Quaternary-age sedimentary strata in or adjacent to the Ozark Plateaus consist of unconsolidated sands, gravels, and clays. These sedimentary strata crop out in the Mississippi Alluvial Plain along Crowley's Ridge and the Benton Hills. Thin alluvial deposits in some of the major stream valleys in the aquatic study area, including the Mississippi Alluvial Plain, are comprised of Quaternary-age sediments (fig. 1.27). (See figure 1.1 for location of Mississippi Alluvial Plain.)

Structural Geology of the Ozark Plateaus

The Ozark Plateaus Province is underlain by a structural dome formed by a series of uplifts that have gradually occurred since Pre-Cambrian time. The total uplift is approximately 5,000 ft (McCracken 1967). The dome is asymmetrical with the dip of sedimentary rocks greater to the east-southeast than to the south, west, or north (McCracken 1967). Regional dip east of the St. Francois Mountains is 150 ft/mi (Tikrity 1968) whereas regional dip in southwestern Missouri is about 10 ft/mi. The dip to the south increases to 200 ft/mi in the southern flank of the Boston Mountains as a result of faulting in the area (Frezon and Glick 1959).

Extensive fracturing, jointing, and faulting of the rocks have resulted from the uplifting in northwestern Arkansas. Fractures generally trend northwest, northeast, and east-west (Ogden 1980, Adamski 1987, Leidy and Morris 1990). Vertically oriented joints (fractures in rock that do not displace the rock) are present in many of the Paleozoic-age rocks and trend east to west, north to south, northwest to southeast, and northeast to southwest (McCracken 1971). Major faults in the Ozark Plateaus have a northwest trend (McCracken 1967). Displacement can be as much as 1,000 ft. Some of the major faults form escarpments that are visible for several miles (Beveridge and Vineyard 1990).

Geological History of the Ozark Plateaus

Pre-Cambrian-age granitic and rhyolitic rocks cooled and crystallized about 1.2 to 1.5 billion years ago in the Ozark Plateaus and adjacent areas (Tikrity 1968). These igneous rocks form the basement lithologic complex of the Ozark Plateaus. After igneous activity ceased, the landscape was eroded prior to Late Cambrian time (McCracken 1971). The region experienced nearly continuous deposition of marine carbonates with brief periods of erosion and deposition from Late Cambrian to Middle Ordovician time (Frezon and Glick 1959). Geologic forces uplifted the Ozark Plateaus area and extensively eroded the sedimentary strata. Geologic units from the St. Peter Sandstone through Fernvale Limestone were subsequently deposited, but the uplifting limited sediment deposition from the Middle Ordovician to Early Devonian time. After the Early Devonian time, the Ozark Plateaus area was uplifted and eroded again (McCracken 1971).

Middle Devonian- and Mississippian-age sediments subsequently were deposited in the Ozark Plateaus. Mississippian-age limestones formed from sedimentary layers deposited in the shallow seas that inundated the Ozark Plateaus during that age. After Mississippian time, the northern part of the Ozark Plateaus was uplifted and tilted. Erosional processes beveled Devonian- and Mississippian-age rocks, exposing Ordovician-age rocks over much of the area (Frezon and Glick 1959, McCracken 1971).

Transgressing seas and riverine systems deposited Pennsylvanian-age sediments in the Ozark Plateaus. Periodic uplifts of these rocks formed unconformities (breaks in the depositional sequence of rock from dislocations, erosion, and nondeposition) in rocks of Pennsylvanian age. The Ozark Plateaus area was uplifted and extensively eroded after Pennsylvanian time (McCracken 1971). Fluvial and marine sediments were deposited in Late Cretaceous and Early Tertiary times. Subsequent uplifting exposed the Ozark Plateaus to erosion, generating the current topography (McCracken 1971).

Geologic Setting of the Ouachita Province

In the Ouachita Province (refer to figure 1.1), basement crystalline rocks are overlain by a sequence of Paleozoic-age and younger sedimentary rocks and thus the crystalline rocks are not exposed in the Ouachita Province (fig. 1.26). The sequence of sedimentary rocks consists of predominantly sandstones and shales of Late Cambrian through Pennsylvanian age. Strata of the Ouachita Province range in total thickness from less than 30,000 to approximately 50,000 ft. Rock types observed are, in order of decreasing abundance, shale, sandstone, siltstone, chert-novaculite, conglomerate, tuff, and limestone (Stone 1994).

In the Ouachita Mountains section of this province, sedimentary rocks of deep marine origin dominate Pre-Pennsylvanian strata. In Mid-Pennsylvanian-age strata (middle and upper Atoka Formation), intervals of shale and sandstones of shallow marine and deltaic (river mouth) origin become common. In the Arkansas Valley section, the presence of the Arkoma Basin was central to geologic evolution of the area and controlled sediment deposition. Rock of shallow marine to non-marine origin dominate from Devonian- through Pennsylvanian-age parts of the stratigraphic section in the basin.

Ordovician Units

The Cambrian- and Ordovician-age Collier Formation is the oldest rock exposed in the Ouachita Province (Ham 1959, Thomas 1977) and consists of black shale and minor layers of dark, thin-bedded limestone. The Crystal Mountain Sandstone is composed primarily of silica- and carbonate-cemented, fine- to medium-grained sandstones with thin interbedded layers of black shale. The Mazarn Shale is represented predominantly by fissile black and green shales with minor occurrences of sandstone, limestone, and chert layers. The Blakely Sandstone consists of interbedded shale and silica or carbonate cemented sandstone. The Womble Shale is black with thin beds of sandstone and limestone. The Bigfork Chert consists of thin-bedded, highly fractured, gray to black chert interbedded with varying amounts of black shale and rare sandstone and limestone. The Polk Creek Shale is a black, fissile shale.

Silurian Units

The Blaylock Sandstone is the basal Silurian-age unit which thins rapidly and disappears in the northern part of the Ouachita Province. The formation consists of fine-grained, gray sandstone and interbedded dark shale. The Blaylock Sandstone is overlain by the Missouri Mountain Formation consisting of shale and sandstone.

Devonian and Mississippian Units

The Arkansas Novaculite is a principal formation in the central Ouachita Province and composes the Devonian System part of the Mississippian System. The Arkansas Novaculite crops out almost continually from Pulaski County, AR, west to McCurtain County, OK, in a band of narrow, parallel belts trending east to west. The Stanley Shale overlies the Arkansas Novaculite and is composed of dark, fissile shale interbedded with fine-grained sandstone.

Pennsylvanian Units

Pennsylvanian System rocks in the Ouachita Province, including the Arkansas Valley, are primarily represented by the Jackfork Group, the Johns Valley Shale, the Atoka Formation, the Hartshorne Sandstone, the McAlester Group, and the Savanna Formation. These stratigraphic units compose a sequence predominantly of shales and sandstones that exceed 30,000 ft in thickness in some areas. The Jackfork Group is predominantly sandstone interbedded with a subordinate amount of dark shale. The Johns Valley Shale is a gray to black. The Atoka Formation is a dark shale that crops out across a large area of the northern part of the province but is present, in part, in the southern Athens Piedmont Plateau and elsewhere. The Hartshorne is a coarse-grained sandstone with brown silty shales and coal (Stroud and others 1969). The McAlester is a dark gritty shale with fine-grained sandstone and coal (Stroud and others 1969). The Savanna consists of sandy shale with coarse-grained sandstone and coal (Stroud and others 1969). The Boggy consists of dark clay with coarse-grained sandstone and coal (Stroud and others 1969).

Cretaceous through Quaternary Units

The sedimentary strata of the Cretaceous through Quaternary age consist of unconsolidated sands, gravels, and clays. These strata crop out as thin alluvial deposits along the Arkansas River and in some of the major stream valleys in the Assessment area.

Structural Geology of the Ouachita Province

The Ouachita Province is generally divided into two structural zones: the Ouachita Mountains proper and the Arkoma Basin, which correspond to the Ouachita Mountains and Arkansas Valley physiographic sections, respectively. The water-bearing rock formations in this area were created by three ancient geologic processes: (1) the formation of a subsiding basin into which a large mass of sediments was deposited, (2) the deformation of the resulting rocks into a complexly folded and thrust-faulted mountain belt, and (3) a long period of slow uplift and erosion (Albin 1965).

The Ouachita Mountains represent the primary outcrop region of the external fold and thrust belt of the Late Paleozoic collisional-subductional orogeny (period of tectonic mountain building). The degree of structural intensity resulting from compression during the mountain building is much greater in the Ouachita Mountains than in the rest of the Assessment area. Shortening (decrease in the original breadth of the rocks in the lateral dimension parallel to compressive forces) of the crustal rocks is about 50 percent in the central portion (Arbenz 1989a). Prominently observed structures are folds, thrust faults, and reverse faults. Folding ranges from open to tight with steeply dipping limbs. Overturned folds are common and thrust and reverse faults are densely spaced. The more brittle rocks, such as the sandstones, cherts, novaculite, and hard shales, are intensively fractured, resulting from the intense stresses experienced during mountain building.

The Arkoma Basin represents the extreme frontal element of the original orogenic belt and is a mildly compressed fold belt that diminishes in the north. Broad anticlines and synclines, normal faults, and thrust faults characterize the structural geology of the area. Shortening observed in the fold belt is on the order of 5 percent and decreases to 0 percent in the north (Arbenz 1989a). In the northern part of the basin, folds generally exhibit dips of less than 10 degrees, except near normal faults where dips are more exaggerated. In the southern part of the basin, stratigraphic dips up to and beyond vertical are common. Nonvertical southerly dipping faults comprise the major fault systems in the basin and typically have angles of 30 to 65 degrees. Most of the normal faults are growth faults. Thrust faults are common in the southern part of the basin where structural intensity was greater (Haley 1982).

The unique stratigraphy and structure of the Ouachita Province contribute to a unique hydrologic setting, influencing the character of both surface and ground water. For example, geologic structure and weathering history of strata influence the surface flow of precipitation and affect surface drainage distribution and gradients. With respect to ground water, aquifers in the Ouachita Province are generally very discontinuous because of faults and complex underlying geologic structure. The intense fracturing seen in the strata that contain aquifers facilitates the flow of ground water but causes aquifers to be heterogeneous and, thus, somewhat unpredictable with respect to their distribution and yields.

Geological History of the Ouachita Province

The Ouachita Mountains form part of a mountain range that fringed the southern and eastern margins of the North American Craton during the Late Paleozoic and Early Mesozoic eras. This tectonic belt ran somewhat continuously from the Appalachians in the Eastern United States through the Ouachitas to the Marathon Mountains in west Texas and beyond into northern Mexico.

A few wells drilled to basement rock in the Ouachita Province show that Pre-Cambrian basement rock in the area is similar to the Pre-Cambrian igneous rocks exposed in the St. Francois Mountains. From Late Cambrian to Early Mississippian time, the southern margin of the North American continental plate (the area defining the Ouachita Mountains) was passive tectonically. It received sediments from shallow- and deep-water deposition at a stable and relatively slow rate, which formed rocks of these geologic ages now seen in the Ouachita Mountains. The Late Paleozoic orogeny began to affect sedimentation in the southern marginal area in Mid-Mississippian time. Deep-water sedimentation began at very high rates and continued through Middle Pennsylvanian time, resulting in total thicknesses of strata over basement rock as great as 50,000 ft. Major deformation, thrusting, and folding of basinal rock strata began during Middle Pennsylvanian time; collision of continental plates and resultant thrusting pushed these rocks onto the continental shelf (Arbenz 1989b). During Late Pennsylvanian time, the Arkoma Basin Formation sediments were mildly compressed, forming the milder structural deformation observed in the Arkansas Valley section. The Ouachita Mountains area rose as a result of epeirogenic uplift (relief-producing crustal deformation) since the climax of orogenic deformation in Middle Pennsylvanian time. However, erosional rates were comparable to or exceeded uplift rates, and the area was reduced to a peneplain (a vast area with slight relief shaped by erosion) by the end of the Mesozoic Era. Renewed uplift and rapid erosion of less resistant layers of rock lying between belts of more resistant rock resulted in the present-day Ouachita physiography of long, even-crested ridges and flat, intermontane basins. The Athens-Piedmont Plateau and the floors of the larger basins in the Ouachita Mountains are parts of the younger Hot Springs Peneplain that had formed by Early Tertiary time (Albin 1965).

Soils

Soils vary throughout the Assessment area due to differences in climate, parent material (e.g., sandstone, limestone, shale), topography (contour of the land), time of soil development, and soil organisms. Following is a general description of the soils of the ecological sections or zones that make up the Assessment area.

The State Soil Geographic (STATSGO) data base provided the majority of the information for this section. The USDA Natural Resources Conservation Service designed STATSGO for regional, multi-State, river basin, State, and multi-county resource planning, management, and monitoring purposes. STATSGO consists of statewide soil maps and a relational data base with attributes. The soil maps are compiled by generalizing more detailed soil survey maps and contain delineations of map units from 1 to 21 components. Each component consists of a phase of a soil series. There are 60 soil properties and interpretations for 84 different data elements (for example, flooding) associated with each component.

Ozark Plateaus Province Soils

The soils of the Ozark Plateaus Province are typically moderately well-drained to well-drained and have moderate to slow permeability. North of the Boston Mountains, most of the soils developed in loess (a loamy material derived from glaciers and transported by the wind) and in cherty limestone. The soils are generally old, shallow, stony, highly weathered and acidic, except on some of the broad ridges and bottomlands. Some of the soils on broad ridges and bottomlands are neutral to slightly alkaline compared to the other soils in this section. Arkana, Moko, Cassville, Viraton, Clarksville, and Lebanon are names of soil series (groups of soils with similar characteristics) commonly found in the Ozark Plateaus. These soils are forested with mixed oaks, hickories, maples, and eastern red cedar with areas of native grasses where the trees are sparse. Farmers use cleared areas as pasture or for growing corn, small grains, sorghum, and hay.

- The Arkana series includes moderately deep, very slowly permeable soils that formed in clayey materials. This series weathered from cherty limestone bedrock on gently sloping to steep ridges and side slopes.

- The Moko series includes shallow, well-drained, moderately permeable soils that formed in thin loamy residuum (material that is weathered in place) from underlying limestone on gently sloping to steep benches and ridgetops.
- The Cassville series includes moderately deep, well-drained, very slowly permeable soils that formed in materials weathered from limestone, siltstone, and shale on nearly level to moderately steep slopes on the tops and sides of hills.
- The Viraton series includes deep, moderately well-drained loamy soils underlain by cherty limestone residuum or colluvium, gravelly material derived from cherty residuum and transported by gravity to foot slopes and alluvial fans.
- The Clarksville series includes deep, somewhat excessively drained soils formed in residuum and locally transported colluvial-alluvial materials (material moved downslope by gravity and erosion combined with stream-deposited material). This series was weathered from cherty dolomite or cherty limestone on steep side slopes and narrow ridgetops.
- The Lebanon series consists of moderately well-drained soils formed in loess underlain by cherty limestone on gently to moderately sloping uplands.

The soils of the Boston Mountains physiographic unit are typically well drained and have moderate permeabilities. Most of these soils developed in interbedded acidic sandstones and shales and are old, highly weathered, and low in both organic matter and natural fertility.

Some of the common soil series in the Boston Mountains are Linker, Enders, Nella, Mountainburg, Ceda, and Kenn. The upland soils are forested with mixed oaks, hickories, sweet gum, and shortleaf pine. Farmers use cleared areas in the uplands for pasture and growing cotton, corn, small grains, peaches, and sorghum. The floodplain soils are forested with mixed oaks, American sycamore, sweetgum, and shortleaf pine. Cleared portions of the floodplain are used for pasture.

- The Linker series includes moderately deep, well-drained, moderately permeable soils that formed in loamy residuum weathered from limestone on broad plateaus, mountains, hilltops, and benches.
- The Enders series includes well-drained, very slowly permeable soils that formed in loamy material and clayey residuum weathered from shale or interbedded shale and sandstone on crests and side slopes of mountains.
- The Nella series includes well-drained, moderately permeable soils on sideslopes, footslopes, and terraces that formed in colluvium (material moved downslope by gravity and erosion) from weathered sandstone and shale.
- The Mountainburg series includes soils characterized by their moderately rapid permeability. They are well-drained, shallow, and usually found on ridge tops and side slopes. They were formed in sandstone residuum.
- The Ceda series includes deep, well-drained, rapidly permeable soils that formed in loamy alluvium on nearly level to very gently sloping floodplains.
- The Kenn series includes deep, well-drained, moderately permeable soils that formed in loamy alluvium on nearly level to gently sloping floodplains.

Ouachita Province Soils

The soils of the Ouachita Mountains are mostly well drained and have moderate to slow permeabilities. The soils are highly weathered, acidic, and formed on surfaces that are 10,000 to 15,000 years old or older. They formed in material weathered from shale, sandstone, novaculite, and chert. The basins, valley floors, and lower hills formed in the softer, less resistant shale, chert, and impure sandstone. The mountains, ridges, and peaks formed in more resistant novaculite and relatively pure sandstone.

Some of the common soil series are Carnasaw, Sherless, Endsaw, Bengal, Avant, and Neff. These soils are forested with shortleaf pine, red oak, white oak, black oak, post oak, blackjack oak, hickories, sweetgum, and blackgum on the uplands and with green ash, water oak, and willow oak on the floodplains. Farmers use cleared areas for pastures, and some parts of terraces and floodplains are used for soybean production.

- The Carnasaw series includes deep, well-drained, slowly permeable soils formed in material weathered from tilted shale and sandstone on uplands.
- The Sherless series consists of moderately deep, well-drained, moderately permeable soils that formed in residuum of interbedded shale and sandstone on the tops and sides of low ridges.

- The Endsaw series includes deep, well-drained, slowly permeable soils that formed in material weathered from shale on uplands.
- The Bengal series consists of moderately deep, well-drained, slowly permeable soils that formed in colluvium and residuum weathered from shale.
- The Avant series includes moderately deep, well-drained, moderately permeable soils that formed in residuum from highly fractured chert bedrock on mountaintops, sideslopes, and ridges.
- The Neff series consists of deep, somewhat poorly drained, slowly permeable soils formed in thick alluvium on floodplains.

The soils of the Arkansas Valley are mostly moderately well to well drained and have moderate to very slow permeabilities. These soils formed in loamy and clayey material that weathered from sandstone and shale. Some of the soils formed in material that was deposited by streams. The soils in the hills are low in organic matter and fertility. The soils on the terraces and floodplains are low to high in organic matter and fertility.

Some of the common soil series are Leadvale, Spadra, Crevasse, Roxana, and Roellen. The terrace soils are forested with oaks, hickories, maple, elm, shortleaf pine, and sweetgum. The floodplain soils are forested with cottonwood, American sycamore, willow, and green ash. Cleared areas are used by farmers for pasture and for growing soybeans, grain sorghum, truck crops, small grains, alfalfa, and rice.

- The Leadvale series includes deep, moderately well-drained, slowly permeable soils that formed in loamy sediment weathered from sandstone and shale on colluvial footslopes and on old stream terraces in broad valleys.
- The Spadra series includes deep, well-drained, moderately permeable soils that formed in loamy alluvium on stream terraces and alluvial fans.
- The Crevasse series consists of deep, excessively drained, rapidly permeable soils that formed in sandy alluvial sediments along stream channels.
- The Roxana series includes deep, well-drained, moderately permeable soils that formed in sandy and silty alluvial sediments on natural levees along streams.
- The Roellen series includes deep, poorly drained, slowly permeable soils that formed in clayey alluvium on floodplains and low terraces.

Changing Land Conditions

Prior to European settlement, the Ozark Plateaus were primarily oak-hickory forests and oak savannas on the hilly portions and bluestem prairies on the undissected plateaus. Lowland forests had a greater variety of species than upland forests and included sycamores, cottonwoods, maple, black walnut, butternut, hackberry, poplar, and bur oak. Prairies were common only in small patches in the eastern part of the Ozark Plateaus, but about 50 percent of the western part was in prairie. Trees were not well established in these prairies because American Indians and lightning periodically burned the vegetation. Early settlers continued the practice of burning to provide pastureland. After the Civil War, however, many of the prairies were allowed to grow up in trees (Rafferty 1980).

A majority of the woodlands of the Ozark Plateaus are now second or third growth because of repeated logging through the years. However, tree species in the woodlands are similar to those European settlers encountered.

Land conditions in the Ozark Plateaus today are primarily those of forest and pasture plus some cropland (fig. 1.28). (Refer to figure 1.1 for province locations.) Deciduous forests, mostly oak and hickory, predominate in the Salem Plateau and Boston Mountains, but mixed oak-pine occurs in the Upper White River Basin. Pastureland, which is mostly fescue (used as hay) and Kentucky blue grass, is found in the river bottoms and on gentle to steep slopes of the uplands on the Springfield Plateau. Cropland is the predominant land condition (and land use) in the Osage Plains and Mississippi Alluvial Plain. Soybeans and sorghum with some corn, wheat, grains, and other field crops are grown in the Osage Plains, with rice dominating in the Mississippi Alluvial Plain.

Poultry, beef and dairy cattle, and hogs are the dominant livestock raised in the pasturelands of the Ozark Plateaus. Large concentrations of poultry farms exist in the southwestern area of the Ozark Plateaus and in a small area in the north central Ozark Plateaus. Intensive poultry farming started mainly around northwestern Arkansas in the 1930's and has expanded greatly in recent decades, with intensive operations now extending into southwestern Missouri and

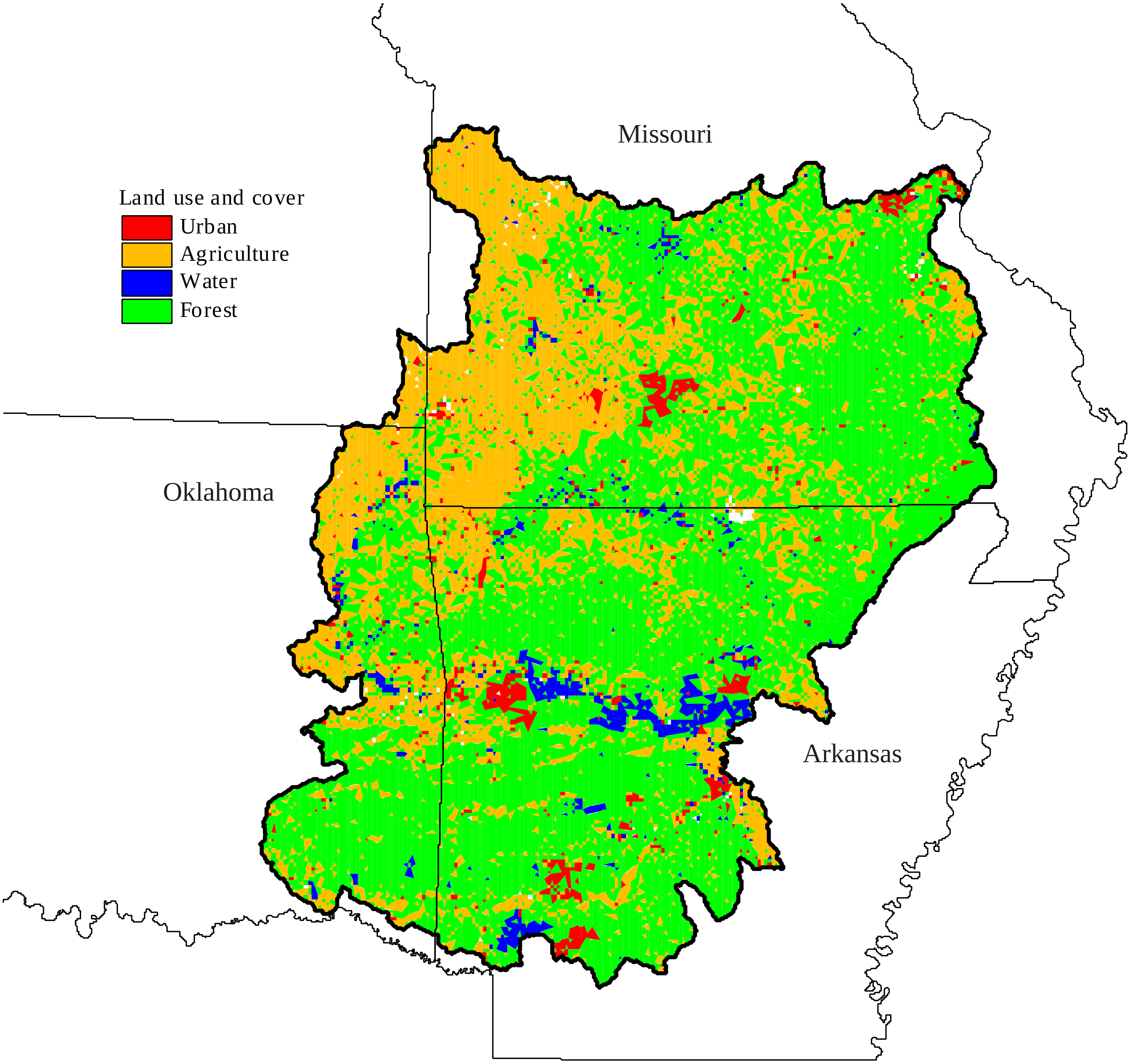


Figure 1.28—Land conditions in the Assessment area.

northeastern Oklahoma (Rafferty 1980). Dairy cattle farming is a major land use in the southwestern part and to a lesser extent in the central part of the Ozark Plateaus. Commercial dairy farming grew rapidly from the early through the mid-1900's in southwestern Missouri and northwestern Arkansas. In recent years, dairy farming in the Ozark Plateaus has declined slightly. Beef cattle and hogs are raised throughout most of the Ozark Plateaus Province (Rafferty 1980).

Mining has been a major land use in parts of the Ozark Plateaus. Major deposits of lead, zinc, iron, barite, and coal and minor deposits of copper, silver, manganese, and tungsten are located in the Ozark Plateaus. Mining activities in the Ozark Plateaus have occurred primarily in four main lead-zinc mining districts: the Southeastern District (Old Lead Belt, Viburnum Trend, and the Fredericktown subdistricts of southeastern Missouri), the Tri-State District (Kansas-Oklahoma-Missouri State line), the Central District (north-central Ozark Plateaus), and the North Arkansas District. By far, the most important ore deposits were in the Tri-State District and the Southeastern District (Wharton and others 1975). The Southeastern District was primarily a lead producer, and the Tri-State District was primarily a zinc and lead producer (Wharton and others 1975). The Central and the North Arkansas Districts contained relatively small, scattered ore deposits that were not mined as actively as were deposits in the two major lead-zinc mining districts (Rafferty 1980). The Viburnum Trend subdistrict is the only area still actively mined for lead and zinc (Wharton and others 1975).

Bituminous coal deposits underlie the northwestern part of the Assessment area. The coal is present in numerous beds, all associated with rocks of Pennsylvanian age (Robertson and Smith 1981). Historically, coal production in this area has fluctuated with national and international economic conditions. Until 1925, most of the coal was mined underground. Approximately two-thirds of the coal mined is used to produce electricity (Searight 1967).

Prior to European settlement, the Ouachita Mountains and the Arkansas Valley were mostly mixed pine and hardwood forests, with pines dominating southern slopes and mixed hardwoods being more common on northern slopes and in the bottomlands (Foti and Glenn 1991). Prairies and glades were common across the Ouachita Mountains but were more extensive in the western portion. By the late 19th century, Europeans had settled the Ouachita Mountains and cultivated the best land (Smith 1986). Around 1890, the logging industry moved into the Ouachita Mountains, and most of the virgin timber had been cut by 1920. Virtually all forests in the Ouachitas have been cut at some time in the past (Smith 1986). However, tree species in the woodlands are similar to those of the old-growth forests (Devall and Rudis 1991).

Currently, land conditions in the Ouachita Mountains and the Arkansas Valley (fig. 1.28) consist primarily of forest, pasture, and some cropland (the latter concentrated primarily along the Arkansas River floodplain). Deciduous forest, mostly oak and hickory, is the major forest type in the Arkansas Valley and bottomlands; pines are more common to the south in the Ouachita Mountains. Pastureland is mostly in fescue and bermuda grasses. Cropland is abundant along the Arkansas River floodplain with soybeans, corn, rice, and other field crops most common.

Poultry, beef and dairy cattle, and hogs are the dominant livestock raised in the area's pasturelands. Large concentrations of poultry farms are in the central and western part of the Ouachita Mountains. Beef cattle are raised throughout most of the Ouachita Province. Dairy and hog farming are less common in the Ouachita Mountains but are important locally.

Mining has been a major land use in parts of the Ouachita Mountains and Arkansas Valley. Deposits of bauxite, antimony, mercury, barite, titanium, lead, and zinc have been mined in the Ouachita Mountains. Bauxite mining is limited to Pulaski and Saline Counties, AR. Historically, Arkansas supplied 90 percent or more of the bauxite mined annually in the United States since discovery of the ore bodies in 1887 (AR GC 1985). Currently, many of the mines are inactive because of the low economic return on remaining ore. Cinnabar, the primary ore of mercury, has been mined in Pike, Clark, and Howard Counties, AR; Lake Greeson now covers a large portion of the mercury district. Barite, a barium sulfate mineral, has been mined in Hot Spring, Montgomery, and Polk Counties, AR. Stibnite, the sulfide ore of antimony, has been mined in Sevier County, AR. Rutile and brookite, ores of titanium, have been mined in Hot Spring County, AR. Lead and zinc ores, predominantly galena and sphalerite, have been mined in the west-central Arkansas mineral belt, including parts of Pulaski, Saline, Hot Spring, Garland, Montgomery, Polk, Howard, Pike, and Sevier Counties.

In the Arkansas Valley, major deposits of coal, natural gas, and oil are developed. Commercial mining of coal on a major scale began in 1870. Coal was mined in a belt about 33 mi wide and 60 mi long in parts of Crawford, Franklin, Johnson, Logan, Pope, Sebastian, and Scott Counties (Stroud and others 1969). The Arkoma Basin of the Arkansas Valley has been a major source for production of natural gas and some oil. Natural gas and condensates are found throughout the Arkansas Valley. Additional information about land cover and land use history is provided in the *Ozark-Ouachita Highlands Assessment: Social and Economic Conditions* (USDA FS 1999a, Chapters 1, 7, and 8), and Terrestrial Vegetation and Wildlife (USDA FS 1999b, Chapter 2).

Chapter 2: Status of Aquatic Resources

The first chapter of this report was a general introduction to the physical characteristics of the Assessment area. Chapter 2 examines two broad categories of the aquatic ecosystem in the Highlands. “Water Quality” includes information about the chemical characteristics of streams, lakes, and ground water. “Aquatic Animals and their Habitats,” the second major section, discusses the biological components of water including the status of fish, mussels, crayfish, aquatic insects, and species of special concern; commercial and recreational roles of aquatic species; aquatic habitats; riparian areas; and wetlands.

Water Quality

Surface Water Quality (Streams)

Question 2.1: What are the status and apparent trends of the water quality of streams in the Highlands?

This section describes the quality of the moving (lotic) surface water in streams of the Assessment area; the discussion focuses on nutrients, suspended sediment, and suspended solids. The Aquatic Team defines nutrients in this report as the various forms of nitrogen and phosphorus. Natural sources of these nutrients in Highlands streams include: (1) fixation of atmospheric nitrogen by plants and bacteria, (2) deposition of atmospheric nitrogen (from lightning), (3) dissolution of rocks or minerals, and (4) dissolution of soil organic matter and decaying plants and animals. Anthropogenic sources (originating from human activities) of nitrogen and phosphorus include sewage and septic tank discharges, fertilizer applications, and animal waste.

Background concentrations of nitrogen and phosphorus in streams are generally low because dissolved forms of the two elements are assimilated rapidly by plants and bacteria. Aquatic vegetation, particularly algae, requires nitrogen and phosphorus to grow. When concentrations of these nutrients in streams or lakes increase beyond normal levels, they can contribute to a dense growth of algae (algal blooms). Bacterial decomposition of dead algal cells after an algal bloom can deplete dissolved oxygen in the water body and negatively affect aquatic life (e.g., kill fish).

Nitrogen occurs in surface water as nitrite (NO_2^-), nitrate (NO_3^-), and ammonium (NH_4^+) ions and in dissolved solutions (Hem 1985). The ammonium ion is in chemical equilibrium with un-ionized ammonia, which is toxic to aquatic life under certain conditions. Ammonium ions predominate at pH values of less than 9.2, which is above the pH of most natural water (Hem 1985); in other words, ammonia predominates in most natural water. (The relative measure of how basic or acidic a substance is the pH; anything above a pH of 7 is considered basic, anything below 7 is considered acidic.)

Nitrite and organic forms are unstable in aerated water, ammonium cations (positively charged ions) tend to adsorb (bond molecularly) on mineral surfaces, and nitrate is readily transported in water and is stable over a wide range of aquatic conditions. The reduced forms of nitrogen (nitrite, ammonium, and organic forms) are oxidized to nitrate in most aerobic (oxygen-rich) environments, but in oxygen-poor streams and aquifers, a substantial portion of the total nitrogen content may be these reduced forms. High nitrate concentrations are undesirable in domestic or public water supplies because of potential health hazards, particularly for infants and small children. Because of these potential health risks associated with water-borne nitrates, the U.S. Environmental Protection Agency (EPA) has established a maximum contaminant level (MCL) of 10 milligrams per liter (mg/L) of nitrate as nitrogen in drinking water (U.S. EPA 1987).

The most common phosphorus compound in water is the fully oxidized orthophosphate ion (PO_4^{3-}), but forms of organic phosphate synthesized by plants and animals also constitute a substantial part of the phosphorus in natural waters (Hem 1985). The orthophosphate ion is the phosphorus form most readily available for use by aquatic plants because of its solubility in water. However, most compounds containing phosphorus are relatively insoluble; thus they tend to precipitate or be adsorbed onto suspended solids in water.

Key Findings

1. Median concentrations of nitrite plus nitrate, ammonia, total nitrogen, and total phosphorus collected at stream sites near sewage treatment plants in most physiographic areas were significantly higher than at any other type of site.
2. Within the Boston Mountains, Springfield and Salem Plateaus, and Arkansas Valley, nitrite plus nitrate concentrations at stream sites increased significantly with more intensive uses of land (e.g., acres of "forest-pasture mix" had more of these concentrations than did "forest" acres).
3. Where more intensive uses of land occurred in the Springfield and Salem Plateaus, Arkansas Valley, and Ouachita Mountains, ammonia concentrations in streams generally increased significantly. Within basins that have significant "agriculture" land use, total phosphorus concentrations were highest at stream sites in the Arkansas Valley where land was used for a mix of agriculture and forest activities.
4. Concentrations of suspended solids were highest at stream sites in the Osage Plains (just outside the Highlands).
5. From 1970 through 1990 at most stream sites in the Ozark Plateaus Province, concentrations of nitrogen and phosphorus forms and suspended solids did not change substantially; this was also true from 1975 through 1995 for streams in the Arkansas Valley and Ouachita Mountains.

Data Sources and Methods of Analysis

Presently, 6 Federal and 15 State agencies from Arkansas, Kansas, Missouri, and Oklahoma collect and maintain records of the water quality of various portions of the Assessment area (see table 2.1). Many other local agencies and private organizations collect data about water quality, but much of it is in paper files rather than in computerized data bases, making it impractical for use in this analysis. For most of the discussions of stream water quality in the Assessment area, the Aquatic Team used Federal or State data. Data concerning the Ozark Plateaus Province were derived from Davis and others (1995).

Most of the available data on water quality for the Assessment area are in three national data bases: (1) the USDI Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) (Hutchison 1975, Maddy and others 1991), (2) the EPA's STOrage and RETrieval system (STORET) (Hoelman 1989), and (3) the U.S. Department of Energy's National Uranium Resources Evaluation (NURE) program. All data used for analyses in this report are stored in WATSTORE.

The Aquatic Team used water quality data from 3 Federal and 4 State agencies for this analysis, representing a total of 137 water quality sampling sites (table 2.2). For surface water data, the forms of nitrogen and phosphorus considered in this report were (1) nitrite plus nitrate, (2) ammonia (includes both ammonium ions and un-ionized ammonia), (3) total ammonia plus organic nitrogen, (4) total nitrogen (the sum of the nitrogen forms), (5) total phosphorus, and (6) orthophosphate. Because nitrite rapidly oxidizes to nitrate in most surface water, the team assumed that nitrite concentrations were negligible; thus they analyzed nitrite plus nitrate instead of the individual forms. Because nitrate is soluble in water, the team first considered dissolved nitrite plus nitrate (filtered samples). When dissolved nitrite plus nitrate data were unavailable, the Aquatic Team substituted total nitrite plus nitrate (whole water samples).

Ammonia is less soluble than nitrate, but the team made the same substitution when dissolved data were unavailable because samples for ammonia analyses do not undergo rigorous digestion prior to analysis. For surface water, total nitrogen is typically calculated using total nitrite plus nitrate and total ammonia plus organic nitrogen. For this analysis, the team did not substitute dissolved ammonia plus organic nitrogen data for missing total ammonia plus organic nitrogen data because the Kjeldahl method used involves rigorous sample digestion. The Aquatic Team substituted dissolved nitrite plus nitrate values in the total nitrogen calculation when total nitrite plus nitrate data were unavailable. The orthophosphate ion, like nitrate, is very soluble. In cases where dissolved orthophosphate data were unavailable, total orthophosphate data were substituted.

Because of the substitution and combination of certain measurements of water quality for other

Table 2.1—Federal and State agency sources and major water quality data collection purpose, type, and accessibility for the Assessment area

Agency	Data collection purpose, type, and accessibility
	Federal
USDI National Park Service	Resource assessment on National Park Service lands; data are collected seasonally in cooperation with the USDI Geological Survey and universities; data include organic and coliform bacteria counts; data are computerized, some in WATSTORE; some streamflow data available.
U.S. Army Corps of Engineers	Resource assessment on Corps-developed projects; variety of water quality data, sometimes collected in cooperation with other Federal agencies; data available from STORET and/or WATSTORE.
U.S. Department of Energy	National Uranium Resources Evaluation (NURE) Program; assesses uranium resources of the Nation; data are computerized, all data are inorganic; some data available on location, depth, and casing length of water well.
U.S. Environmental Protection Agency	Regulatory; wide variety of water quality data, sometimes collected in cooperation with State agencies; all data in STORET; information on construction of water wells and streamflow available.
USDA Forest Service	Resource assessment on national forest lands; some data are computerized, some are paper files only; data include inorganic and biological analyses, and results of water dye-tracing tests; some streamflow information available.
USDI Geological Survey	Water resources assessment and research; limited monitoring network for ground and surface water quality; inorganics and some organics; all data are computerized in WATSTORE including some State agency data; information available on streamflow and water wells construction.
	Arkansas
Arkansas Department of Health	Monitoring of public water supply system; most samples collected after municipal treatment, although some raw water sampled; samples analyzed for inorganics, organic, radiochemical, and biological constituents; most data in paper files, although will soon be computerized; no streamflow data.
Arkansas Department of Pollution Control and Ecology	Regulatory monitoring of 110 surface water sites statewide; samples analyzed for inorganic compounds with some pesticide data and fish tissue analyses for trace elements and organic compounds; data are computerized in WATSTORE and STORET; information available on streamflow.
Arkansas Geological Commission	Geologic mapping and mineral assessment with some water resources research; data are collected in cooperation with the USDI Geological Survey and are computerized; information available on well construction.
	Kansas
Kansas Department of Health and Environment	Monitoring network of surface and ground water quality originally in cooperation with the USDI Geological Survey, but in-house since 1990; 20 years of records with virtually all data in STORET; chemical and biological analyses for approximately 240 surface water sites statewide, about 30-40 percent have streamflow data.
Kansas Department of Wildlife and Parks	Monitoring of surface water quality; data include inorganic analyses and are published, but not computerized.

(continued)

Table 2.1—Federal and State agency sources and major water quality data collection purpose, type, and accessibility for the Assessment area (continued)

Agency	Data collection purpose, type, and accessibility
Kansas Geological Survey	Geological investigations and limited ground water resources research; data are computerized; information available on well construction, particularly for wells drilled after 1975.
	Missouri
Missouri Department of Conservation	Monitoring contaminants in fish; analysis of fish tissue for organic compounds, lead, cadmium, and mercury; samples collected at between 75-125 sites statewide; large volume of data, only some computerized.
Missouri Department of Health	Regulatory monitoring of ground water quality; data include coliform bacteria analyses on private wells statewide, and nitrate and pesticide analyses in west central Missouri; also some tritium analyses; data are collected in cooperation with the USDI Geological Survey and are computerized; information available on water well construction.
Missouri Department of Natural Resources—Division of Environmental Quality	Regulatory and some ambient (environmental) monitoring; data include chemical, radiochemical, and microbiological analyses of community and noncommunity water supply wells; analyses of stream water quality done in cooperation with the USDI Geological Survey; surface water and microbiological data are computerized, ground water data are being computerized; information about construction of water wells available mostly for wells drilled after 1975.
Missouri Department of Natural Resources—Division of Geology and Land Survey	Geologic and water resources research, generally site specific; inorganic and some pesticide analyses; some data are computerized, some only in paper files; information on construction of water wells includes drillers' logs for about 30,000 wells statewide, some are computerized.
	Oklahoma
Oklahoma Conservation Commission	Ambient monitoring, as well as prioritization of basins for cost share assistance; data include nutrients, specific conductance (a measure of the ability of water to conduct an electrical current), pH, and dissolved oxygen, with some biological data on fish, periphyton (surface attached organisms), and algae; data are computerized in STORET and WATSTORE.
Oklahoma Department of Environmental Quality	Monitoring ambient water quality and assessing hazardous waste sites; most data in STORET or other computerized data base; some sites are water supply systems with samples taken after municipal treatment; ground water samples generally are raw; analyses include inorganic, and some fish tissue, sediment, and pesticide data; some streamflow information is available; information on construction of water wells is available from the Oklahoma Water Resources Board.
Oklahoma Geological Survey	All water quality work done in cooperation with the USDI Geological Survey; all data are computerized; information on well site characteristics and construction available for most sampling sites.
Oklahoma Scenic River Commission	Monitoring ambient water quality of the Illinois, Flint, and Baron Fork Rivers; analyses include nutrients, suspended solids, chloride, sulfate, hardness, turbidity, and chemical oxygen demand; all data in STORET.
Oklahoma Water Resources Board	Monitoring network to establish trends and set water quality standards; 300 water wells statewide; all data in STORET; analyses primarily include inorganics; water well construction information available as supplied from drillers' logs.

Table 2.2—Summary by Federal and State agency of the number of sites, collection methods, and frequency of surface water quality samples utilized in this report

Agency	Number of sites	Collection method	Collection frequency
U.S. Army Corps of Engineers	3	GB	M, D
USDI Geological Survey	63	EWI	PD
USDI National Park Service	1	GB	M
Arkansas Department of Pollution Control and Ecology	67	GB	PD
Kansas Department of Health and Environment	2	GB	B-M, M
Missouri Department of Natural Resources	0[a]	NA	NA
Oklahoma Department of Environmental Quality	7	GB	M, W
Total	137[b]		

GB = grab; M = monthly; D = daily; NA = not available; EWI = equal width increment; PD = project dependent frequency; B-M = bimonthly; W = weekly.

[a] Several of the USDI Geological Survey sites were sampled in cooperation with the MO DNR.

[b] Includes six sites that were sampled jointly by two agencies.

measurements (e.g., total nitrite plus nitrate for dissolved nitrite plus nitrate), the resulting data for a constituent (nitrite plus nitrate, for example) often included results of analyses performed on filtered and whole water samples. For these constituents, the "total" and "dissolved" adjectives are not included in the following discussions. The Aquatic Team did not combine data for total ammonia plus organic nitrogen and total phosphorus in surface water samples with data for filtered samples; therefore, the "total" adjective is retained. However, the "total" in "total nitrogen" refers to a summation of values for the various forms of nitrogen, some of which may be from analyses of filtered samples.

The movement of suspended sediment in streams is an important factor in the transport and fate of chemicals in the environment. (Suspended sediment, which can be transported in the water column or can settle to the streambed, is particulate matter consisting of soil and rock particles eroded from land.) The suspended particles can absorb or adsorb nutrients, trace elements, and organic compounds. Fecal bacteria also can be associated with suspended sediment.

The sediment available for transport by a stream is determined by a combination of factors including soil type, vegetative cover, topography, land use, and the intensity or frequency of precipitation. Overland runoff of precipitation usually delivers sediment to streams. Intense storms that increase stream discharge, erosion, and resuspension of streambed sediments often create high concentrations of suspended sediments. In addition, row-crop agriculture, animal grazing, timber harvesting, mining, road construction and maintenance, and urbanization can increase land erosion and create concentrations of sediment in streams. Excess suspended sediment can adversely affect the quality of surface water.

Turbid (murky or clouded) streams are aesthetically unsatisfactory for swimming and other recreational activities and are biologically less productive because light cannot penetrate to drive photosynthesis by algae and other plants. Higher than normal concentrations of suspended sediment can affect fish populations, either directly or indirectly, by preventing the successful development of fish eggs and larvae or by decreasing the available food supply (by blocking photosynthesis which affects the entire food chain). Deposits of sediment in reservoirs decrease the storage capacity for water supply or flood control. Mechanical removal of such sediment from water supplies is expensive.

The Aquatic Team considered both suspended sediment and suspended solids for this report. These two measures are not considered to be comparable because of differences in collection and analytical techniques. The Aquatic Team used suspended sediment data in this analysis when these data were available. When the team did use suspended solids data, they did not compare that data directly to suspended sediment data.

The initial data set for the quality of stream surface water examined by the Aquatic Team contained approximately 80,000 samples for 2,300 sites for the water years 1970 through 1990 (Ozark Plateaus Province) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains). (A water year is defined as a 12 month period from October 1st through September 30th. The water year is designated by the calendar year in which it ends. For example, the 1990 water year was from October 1, 1989 through September 30, 1990.) Some of these 2,300 sites, particularly in the Ozark Plateaus, were sampled by more than one agency; therefore, the data selected by the team have the best temporal, seasonal, or hydrologic distribution or were collected, processed, preserved, or analyzed using preferred techniques. The Aquatic Team applied screening criteria (described below) to the data set, decreasing the numbers to about 27,000 samples and 137 sites (table 2.2).

Because of the scarcity of data available for the Arkansas Valley and the Ouachita Mountains, the team limited screening of samples to the discarding of all but one of multiple samples collected on the same day at a specific site. The team performed additional screening on data from the Ozark Plateaus and removed those data not meeting the specified criteria. Data were acceptable if: (1) site-specific information regarding location, type, number, and seasonal and hydrologic distributions of samples was available; (2) sample collection, processing, preservation, and analytical techniques were appropriate; and (3) quality assurance and quality control practices were used by the agencies that collected and analyzed samples.

Sample processing and preservation techniques are used by many agencies to stabilize the sample so that it retains as much of its original character as possible. These procedures involve filtering or adding reagents to stop biological action. Samples collected for nutrient analysis are generally preserved with mercuric chloride (Geological Survey's method) or sulfuric acid (EPA's approved method) and then chilled, or they are preserved by chilling alone. All samples that contributed to data sets used in this report were preserved prior to analysis.

The methods used to analyze samples are another important consideration. For the past decade or so, most laboratories have used auto-analyzers to determine presence and concentrations of nitrite, nitrate, ammonia, phosphorus, and orthophosphate, and have used the Kjeldahl method to determine ammonia plus organic nitrogen (Clesceri and others 1989). The Aquatic Team used only the period including water years 1980 through 1995 for the discussion of the conditions of stream quality in the Assessment area. Before 1980, other methods may have been used, potentially resulting in a positive or negative analytical bias. Data collected before water year 1980 are shown as part of the discussion of long-term trends.

Treatment of censored data. Limitations in laboratory analytical techniques and equipment determine the lower limit below which constituent concentrations cannot be accurately determined or reported. When the actual concentration is less than this lower limit, the concentration is reported as less than the detection limit or minimum reporting level of the analytical method. Some of the data reported in this analysis as less than a certain concentration may actually represent method detection limits rather than minimum reporting levels. In the following discussions, "detection limit" will be used to describe the lower limit of an analytical method. Data are considered "censored" if greater than 5 percent of the total number of data values are flagged as less than a certain detection limit or as not detected. A particular constituent may have censored values with several different detection limits because analytical techniques vary among laboratories or have changed over time. How these censored data are handled in statistical analysis varies with each method. When dealing with censored values, the objective is to maximize information without losing statistical integrity. The specific treatment of censored data will be discussed in the descriptions of the individual statistical methods.

Timespan for the assessment of conditions. To minimize the potential effects of long-term trends and the number of changes in detection limits, the Aquatic Team chose relatively short and recent periods to assess current conditions of surface water in Highlands streams: water years 1980 through 1990 (Ozark Plateaus Province) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains). This 11-year period is short enough because (1) only in extreme cases would long-term trends affect the overall description of current conditions found, and (2) detection limits have been fairly consistent throughout these 11-years, and nutrient concentrations are frequently at or less than detection limits.

Descriptive statistics. The Aquatic Team used descriptive statistics to show the central tendency and variation in the water quality data. They calculated the minimum, maximum, 10th, 25th, 50th (median), 75th, and 90th percentiles, choosing the median to represent the central tendency of the data because the median is less sensitive to extreme values than the mean. The 25th and 75th percentiles provide more information on the central tendency and with the 10th and 90th percentiles provide information on the typical variations in the data. When the team calculated summary statistics for individual surface water sites, they estimated percentiles for censored data by using a log-probability regression procedure described by Gilliom and Helsel (1986) and Helsel and Cohn (1988). The team did not report estimated percentiles if fewer than five observations higher than the detection limit existed.

The team graphically displayed distributions of selected nutrient concentrations for surface water data using side-by-side boxplots. A boxplot is a useful tool for visually examining the central tendency and variation of a group of data or for comparing two or more groups of data (Tukey 1977).

Hypothesis tests. The Aquatic Team used the nonparametric Kruskal-Wallis analysis-of-variance test (Helsel and Hirsch 1992) to test for differences in the distributions of two or more groups of data. The distributions of the groups are considered significantly different from one another if there is a probability (*P* value) of less than 5 percent (< 0.05) that the observed difference occurs by chance.

Analysis of long-term trends. The Aquatic Team plotted data from selected sites as time series and added a line of central tendency or "smooth." The smoothing technique used is called the LOWESS (LOcally WEighted Scatterplot Smoothing) procedure (Cleveland 1979). The purpose of smoothing is to highlight trends or patterns that exist in the data but are difficult to see when data are plotted as scatterplots only. Scatterplots and LOWESS allow a visual examination of trend patterns for sites with data available for different time periods and illustrate patterns of similarity or variation in constituent concentrations between two or more water quality sites. No statistical trend tests were performed for this report.

Spatial and temporal distributions of surface water quality data. Data on nutrients and suspended solids were available for more than 2,300 surface water sites located in the Assessment area. Figure 2.1 shows the locations of the 137 sites selected; table 2.3 shows the names of the sites. Spatial distribution of the sites is not uniform, because long-term sampling programs have not been conducted in the headwaters of streams draining several physiographic areas (e.g., the Salem Plateau, and the St. Francois, Boston, and Ouachita Mountains). However, the sites selected collectively represent a wide range of the physiography and major land uses present in the Assessment area.

A land-use type was assigned to each site based on physiographic area and land use or proximity to a sewage treatment plant (STP). All sites have (1) drainage basins with relatively homogeneous physiography and land use and (2) identifiable factors influencing water quality. The team used Geographic Information Retrieval and Analysis System (GIRAS) data (USDI GS 1990) to determine the major land uses in each basin and found the categories "forest" and "agriculture" predominate throughout the Assessment area. To reflect the different agricultural practices found in the Ozark Plateaus, "agriculture" was subdivided into "cropland," "pasture," and "forest-pasture mix" (defined as greater than one-third but less than two-thirds pasture); poultry, cattle, and swine are commonly raised on these pasturelands. Other sites were categorized as STP sites because of the close proximity of STP discharges.

Figure 2.1—Locations of surface water sampling sites in the aquatic study area.

Table 2.3—Surface water sites for nutrient and suspended solids data (sites mapped in fig. 2.1)

Site number	Site name and location	Site number	Site name and location
1	Little Osage River at Fulton, KS	47	Little Black River below Fairdealing, MO
2	Osage River above Schell City, MO	48	Current River near Pocahontas, AR
3	Sac River near Dadeville, MO	49	Black River at Pocahontas, AR
4	Little Sac River near Walnut Grove, MO	50	South Fork Spring River at Saddle, AR
5	Pomme de Terre River near Polk, MO	51	Spring River at Ravenden, AR
6	South Grand River at Urich, MO	52	Eleven Point River near Bardley, MO
7	West Fork Tebo Creek near Lewis, MO	53	Eleven Point River near Pocahontas, AR
8	Niangua River at Bennett Springs, MO	54	Black River at Black Rock, AR
9	Osage River below St.Thomas, MO	55	Strawberry River near Smithville, AR
10	Big Piney River at Devil’s Elbow, MO	56	Neosho River near Parsons, KS
11	Gasconade River above Jerome, MO	57	Lightning Creek near McCune, KS
12	Meramec River near Sullivan, MO	58	Spring River near Waco, MO
13	Bourbeuse River above Union, MO	59	Turkey Creek near Joplin, MO
14	Big River near Richwoods, MO	60	Shoal Creek near Galena, KS
15	Meramec River near Eureka, MO	61	McKisic Creek tributary near Bentonville, AR
16	St. Francis River near Saco, MO	62	Butler Creek near Sulphur Springs, AR
17	St. Francis River at Fisk, MO	63	Elk River near Tiff City, MO
18	West Fork White River east of Fayetteville, AR	64	Spavinaw Creek near Cherokee City, AR
19	White River near Goshen, AR	65	Neosho River at Fort Gibson Lake, Fort Gibson, OK
20	Richland Creek at Goshen, AR	66	Illinois River at Savoy, AR
21	Holman Creek near Huntsville, AR	67	Osage Creek near Elm Springs, AR
22	White River Beaver Dam near Eureka Springs, AR	68	Illinois River near Siloam Springs, AR
23	Osage Creek southwest of Berryville, AR	69	Baron Fork at Dutch Mills, AR
24	Osage Creek west of Berryville, AR	70	Illinois River at Highway 64 Bridge, OK
25	Kings River near Berryville, AR	71	Baron Fork at Eldon, OK
26	James River near Wilson Creek, MO	72	Illinois River near Tahlequah, OK
27	James River near Boaz, MO	73	Buffalo River at wilderness boundary, AR
28	Long Creek near Denver, AR	74	Illinois River near Watts, OK
29	White River at Table Rock Dam near Branson, MO	75	Neosho River above Industrial Park, OK
30	White River at Bull Shoals Dam near Flippin, AR	76	Flint Creek near West Siloam Springs, OK
31	Crooked Creek at Harrison, AR	77	Neosho River near Langley, OK
32	Crooked Creek near Harrison, AR	78	Spring River near Thayer, MO
33	Crooked Creek at Yellville, AR	79	Little Sugar Creek at Caverna, MO
34	Buffalo River near St. Joe, AR	80	Spring River at Devils Prominade Bridge, OK
35	Hicks Creek near Mountain Home, AR	81	Neosho River near Chetopa, KS
36	White River near Norfork, AR	82	Marmaton River near Fort Scott, KS
37	North Fork River near Tecumseh, MO	83	Osage River below Truman Dam at Warsaw, MO
38	North Fork River at Norfork Dam near Norfork, AR	84	Poteau River east of Waldron, AR
39	White River at Calico Rock, AR	85	Poteau River northwest of Waldron, AR
40	Mill Creek near Melbourne, AR	86	Poteau River at Cauthron, AR
41	North Sylamore Creek near Fifty Six, AR	87	Poteau River at Loving, OK
42	White River at Oil Trough, AR	88	Black Fork below Big Creek near Page, OK
43	Black River below Annapolis, MO	89	Black Fork at Hodgen, OK
44	Black River at Clearwater Dam, MO	90	Fourche Maline near Red Oak, OK
45	Black River at Poplar Bluff, MO	91	Fourche Maline near Le Flore, OK
46	Current River at Doniphan, MO	92	Holson Creek at Summerfield, OK

(continued)

Table 2.3—Surface water sites for nutrient and suspended solids data (sites mapped in fig. 2.1) (continued)

Site number	Site name and location	Site number	Site name and location
93	James Fork near Hackett, AR	116	Little Missouri River near Langley, AR
94	Poteau River near Panama, OK	117	Alum Fork Saline River near Reform, AR
95	Mulberry River at I40 near Mulberry, AR	118	Saline River west of Benton, AR
96	Short Mountain Creek west of Paris, AR	119	Saline River near Shaw, AR
97	Short Mountain Creek north of Paris, AR	120	Kiamichi River near Big Cedar, OK
98	Big Piney Creek at Highway 164 near Dover, AR	121	Mountain Fork near Hatfield, AR
99	Illinois Bayou near Dover, AR	122	Rolling Fork River below DeQueen Dam, AR
100	Whig Creek near Dardanelle, AR	123	Bear Creek near Horatio, AR
101	Petit Jean River near Booneville, AR	124	Little River near Horatio, AR
102	Petit Jean River near Waveland, AR	125	Cossatot River near Vandervoort, AR
103	Dutch Creek at Shark, AR	126	Cossatot River near Umpire, AR
104	Chickalah Creek near Chickalah, AR	127	Cossatot River below Gillham Dam, AR
105	White Oak Creek near Atkins, AR	128	Cossatot River near Lockesburg, AR
106	Fourche La Fave River near Gravelly, AR	129	Saline River near Burg, AR
107	Fourche La Fave River near Nimrod, AR	130	Saline River below Dierks Dam, AR
108	South Fourche La Fave River at Hollis, AR	131	Holly Creek east of Dierks, AR
109	Stone Dam Creek near Conway, AR	132	Holly Creek at Dierks, AR
110	Maumelle River at Williams Junction, AR	133	Saline River near Lockesburg, AR
111	Ouachita River near Mount Ida, AR	134	Prairie Creek near Mena, AR
112	Ouachita River near Malvern, AR	135	Prairie Creek at Murfreesboro, AR
113	Ouachita River near Donaldson, AR	136	Prairie Creek near Murfreesboro, AR
114	South Fork Caddo River at Fancy Hill, AR	137	Hurricane Creek near Sardis, AR
115	Caddo River near Amity, AR		

For the Arkansas Valley and Ouachita Mountains, the team categorized land use as "agriculture-forest mix" (i.e., greater than one-third but less than two-thirds agriculture).

Depending upon the agency and program, sampling can occur on different schedules. For example, nitrite plus nitrate samples were collected somewhat uniformly at monthly or bimonthly intervals. The selected 83 sites in the Ozark Plateaus represent sampling programs conducted by Federal and State agencies and are generally characteristic of this part of the Assessment area. The 54 sites in the Arkansas Valley and Ouachita Mountains were sampled as part of more variable sampling programs. A seasonal component (e.g., sampling for streamflow during summer and early fall months) at some locations resulted in additional water quality samples.

Patterns

The Aquatic Team identified the factors affecting concentrations of nutrients and suspended solids in surface water by analyzing the water quality in relation to various basin characteristics. Based on physiographic area and category of land use, the team combined the 11 years of data for individual stream sites (see "Timespan for the assessment of conditions" on page 61). The team considered differences in water quality within a physiographic area that had multiple categories of land use and between physiographic areas with categories of "forested" or "agricultural" land uses. Because of the availability of data for only a small group of sites in the Boston, St. Francois, and Ouachita Mountains, the results of these analyses may not always be representative of widespread ambient conditions in these physiographic areas.

The analyzed nutrient forms include: (1) nitrite plus nitrate, (2) ammonia, (3) total ammonia plus organic nitrogen, (4) total nitrogen, (5) total phosphorus, and (6) orthophosphate. Summary statistics of the nutrient data for all indicator basins grouped by physiographic area and land use are shown in table 2.4.

Nitrite plus nitrate. Nitrite plus nitrate concentrations differed significantly among samples from streams draining basins with different land uses within seven physiographic areas (fig. 2.2). Median concentrations at STP sites were significantly higher than at any other type of site except for the Ouachita Mountains. Within the Boston Mountains and Springfield and Salem Plateaus, nitrite plus nitrate concentrations increased significantly with more intensive land uses ("forest" compared to "forest-pasture mix" compared to "pasture"), indicating a strong association between percent "pasture" and nitrite plus nitrate concentrations. With the exception of STP sites, the highest concentrations of nitrite plus nitrate were found in samples from streams draining Springfield Plateau "forest-pasture mix" and "pasture" sites, where some of the highest densities of poultry, cattle, swine, and agricultural operations in the Assessment area are located.

Significant differences in nitrite plus nitrate concentrations also occurred between samples from "forested land use" and "agricultural land use" located in different physiographic areas (fig. 2.2). Concentrations were lowest at "forested" sites in the Springfield Plateau, Arkansas Valley, and Ouachita Mountains. Significant differences between "forested" sites in the Springfield and Salem Plateaus would not be expected, but the two basins representing Springfield Plateau "forested land use" are 85 percent or more forested. In contrast, the 11 Salem Plateau sites are as much as 33 percent "pasture." Nitrite plus nitrate concentrations can be expected to increase as forest lands are converted to pasture. Concentrations in the forested Boston Mountains sites were higher than in the other physiographic areas. The Salem Plateau "forest-pasture mix" sites and the Arkansas Valley and Ouachita Mountains "agriculture-forest mix" sites had lower nitrite plus nitrate concentrations than "cropland" sites in the Osage Plains. All three had concentrations significantly lower than either of the Springfield Plateau "agricultural land uses"—"forest-pasture mix" and "pasture."

Ammonia. Ammonia concentrations, like nitrite plus nitrate concentrations, were significantly higher in samples from STP sites in all of the physiographic areas except for the Ouachita Mountains (fig. 2.3). Ammonia concentrations for sites in the Springfield and Salem Plateaus generally increased significantly with more intensive land uses, with the exception of samples from "forest-pasture mix" sites in the Springfield Plateau. Ammonia concentrations differed significantly among sites with different land uses in the Ouachita Mountains, but the "agriculture-forest mix" site had a slightly higher median than the STP sites. Ammonia concentrations in these instances were significantly higher than those from basins where "pasture" is the dominant land use.

Significant differences in ammonia concentrations also occurred between samples from "forested land use" and "agricultural" land use" located in different physiographic areas. When comparing data about "forested land use" among the physiographic areas of the Assessment area, samples from the Arkansas Valley and the Boston and Ouachita Mountains forested sites had significantly higher ammonia concentrations than was measured at sites in the other physiographic areas (fig. 2.3). Most of the samples representing Boston Mountains forest sites were collected at one site, located in a primarily forested basin on the West Fork White River east of Fayetteville, AR (site 18 on table 2.3). However, there was a substantial amount of pastureland adjacent to the stream for 15 to 20 mi upstream of the site. In addition, an STP about 15 river miles upstream and urban nonpoint sources also probably contributed to the higher ammonia concentrations. Samples from "forest-pasture mix" sites in the Salem Plateau generally had the lowest ammonia concentrations, and samples from "agriculture-forest mix" sites in the Ouachita Mountains had the highest concentrations.

Total ammonia plus organic nitrogen. Fewer total ammonia plus organic nitrogen data were available for all physiographic areas in the Assessment area; therefore, fewer comparisons could be made. The patterns for total ammonia plus organic nitrogen were not as definite as those for nitrite plus nitrate and ammonia (fig. 2.4). Samples of total ammonia plus organic nitrogen from STP sites had significantly higher concentrations than samples from other sites within the same physiographic area. Also, median concentrations at sites

Table 2.4—Nutrients and suspended solids measured at surface water quality sites in the aquatic study area, by physiographic area and land use

Surface water site	Nitrate + nitrate	Ammonia	Ammonia + organic nitrogen, total	Nitrogen, total	Phosphorus, total	Ortho-phosphate	Suspended solids
	mg/L as nitrogen				*mg/L as phosphorus*		*mg/L*
			Ozark Plateaus Province and part of the Osage Plains				
Osage Plains							
All sites							
Median	0.50	0.07	—	—	0.12	—	42
Minimum	<0.10	<0.01	—	—	<0.01	—	<1
Maximum	11	8.2	—	—	8.7	—	2,990
Number of samples	633	628	—	—	627	—	373
Cropland							
Median	0.46	0.06	0.80	1.1	0.11	0.04	40
Minimum	<0.10	<0.01	<0.10	0.10	<0.01	<0.01	<1
Maximum	5.5	0.51	3.0	6.8	1.2	0.19	2,990
Number of samples	514	510	229	241	510	110	262
STP							
Median	0.67	0.18	—	—	0.19	—	44
Minimum	<0.10	<0.01	—	—	0.01	—	<1
Maximum	11	8.2	—	—	8.7	—	2,480
Number of samples	119	118	0	0	117	0	111
Boston Mountains							
All sites							
Median	0.64	0.10	0.80	1.6	0.14	0.08	15
Minimum	<0.10	<0.01	<0.10	0.23	<0.01	<0.01	<1
Maximum	25	18	26	32	6.8	4.9	429
Number of samples	376	340	168	165	371	367	319
Forest							
Median	0.32	0.05	0.50	0.80	0.07	0.03	18
Minimum	<0.10	<0.01	<0.10	0.23	0.01	<0.01	1
Maximum	6.1	2.5	3.5	9.6	0.87	0.45	316
Number of samples	125	134	55	53	124	120	121
Mix							
Median	0.50	—	—	—	0.03	0.01	—
Minimum	<0.10	0.01	0.70	0.94	<0.01	<0.01	—
Maximum	1.6	0.25	1.3	2.9	0.32	0.23	—
Number of samples	24	5	4	5	24	24	0
STP							
Median	0.90	0.21	0.92	2.3	0.32	0.20	12
Minimum	0.10	<0.01	<0.10	0.46	<0.01	<0.01	<1
Maximum	25	18	26	32	6.8	4.9	429
Number of samples	227	201	109	107	223	223	198
Springfield Plateau							
All sites							
Median	1.5	0.04	0.35	1.6	0.10	0.06	6
Minimum	<0.10	<0.01	<0.10	<0.10	<0.01	<0.01	<1
Maximum	32	15	6.5	18	14	13	480
Number of samples	2,348	2,099	999	879	2,410	1,348	2,250
Forest							
Median	0.10	0.03	0.20	0.31	0.01	0.01	3
Minimum	<0.10	<0.01	<0.10	<0.10	<0.01	<0.01	<1
Maximum	0.58	0.34	6.4	6.5	0.32	0.13	228
Number of samples	189	188	144	132	200	169	128
Mix							
Median	1.2	0.04	0.33	1.3	0.09	0.05	5
Minimum	0.10	<0.01	<0.10	0.26	<0.01	<0.01	<1
Maximum	5.5	1.4	4.0	5.4	2.2	0.55	480
Number of samples	740	522	397	337	775	258	704

(continued)

Table 2.4—Nutrients and suspended solids measured at surface water quality sites in the aquatic study area, by physiographic area and land use (continued)

Surface water site	Nitrate + nitrate	Ammonia	Ammonia + organic nitrogen, total	Nitrogen, total	Phosphorus, total	Ortho-phosphate	Suspended solids
	- - - - - - - - - - - - - mg/L as nitrogen			*- - - - - - - - - - - - - -*	*- - - mg/L as phosphorus - - -*		*mg/L*
			Ozark Plateaus Province and part of the Osage Plains (continued)				
Pasture							
Median	1.6	0.04	0.40	2.1	0.08	0.06	8
Minimum	0.10	<0.01	<0.10	0.60	<0.01	<0.01	<1
Maximum	32	1.6	2.8	4.7	3.4	1.7	480
Number of samples	732	686	318	276	752	515	781
STP							
Median	2.1	0.06	0.52	3.0	0.62	0.40	7
Minimum	<0.10	<0.01	<0.10	1.0	<0.01	<0.01	<1
Maximum	20	15	6.5	18	14	13	370
Number of samples	687	703	140	134	683	406	637
Salem Plateau							
All sites							
Median	0.38	0.03	0.46	1.0	0.03	0.02	7
Minimum	<0.10	<0.01	<0.10	<0.20	<0.01	<0.01	1
Maximum	18	8.0	9.0	19	7.2	5.7	523
Number of samples	1,751	1,799	385	370	1,854	1,124	1,733
Forest							
Median	0.30	0.02	0.40	0.70	0.02	0.01	6
Minimum	<0.10	<0.01	<0.10	<0.20	<0.01	<0.01	1
Maximum	6.5	0.63	3.1	3.2	0.99	0.19	288
Number of samples	656	615	156	155	651	189	582
Mix							
Median	0.37	0.03	0.38	0.72	0.03	0.01	8
Minimum	<0.10	<0.01	<0.10	0.30	<0.01	<0.01	1
Maximum	1.5	0.87	4.0	4.3	1.9	1.7	523
Number of samples	784	867	86	86	872	621	795
STP							
Median	0.94	0.08	0.56	1.6	0.11	0.07	6
Minimum	<0.10	<0.01	<0.10	0.62	<0.01	<0.01	1
Maximum	18	8.0	9.0	19	7.2	5.7	263
Number of samples	311	317	143	129	331	314	356
St. Francois Mountains							
Forest (All sites)							
Median	0.20	0.02	—	—	0.04	—	5
Minimum	<0.10	<0.01	—	—	<0.01	—	<1
Maximum	1.3	0.44	—	—	0.31	—	38
Number of samples	66	66	0	0	66	0	65
				Ouachita Province			
Arkansas Valley							
All sites							
Median	0.12	0.12	0.70	1.10	0.05	—	44
Minimum	<0.10	<0.01	<0.10	0.14	<0.01	—	<1
Maximum	52	52	32	54	28.5	—	618
Number of samples	1,570	2,017	986	610	1,564	—	2,197
Forest							
Median	0.08	0.08	0.40	0.59	0.04	0.02	5
Minimum	<0.10	<0.01	<0.10	0.14	<0.01	<0.01	<1
Maximum	1.1	1.2	4.1	4.2	2.0	0.13	618
Number of samples	837	1,149	353	143	1,063	152	1,151

(continued)

Table 2.4—Nutrients and suspended solids measured at surface water quality sites in the aquatic study area, by physiographic area and land use (continued)

Surface water site	Nitrate + nitrate	Ammonia	Ammonia + organic nitrogen, total	Nitrogen, total	Phosphorus, total	Ortho-phosphate	Suspended solids
	mg/L as nitrogen				*mg/L as phosphorus*		*mg/L*
Ouachita Province (continued)							
Mix							
Median	0.1	0.1	0.60	0.80	0.06	—	14
Minimum	<0.10	<0.01	<0.10	0.15	<0.01	—	2
Maximum	3.7	3.7	6.6	8.3	8.5	—	479
Number of samples	316	365	161	127	320	—	503
Agriculture							
Median	0.11	0.12	1.0	1.3	—	—	22
Minimum	<0.10	<0.01	0.40	0.54	—	—	1
Maximum	0.69	0.69	32	25	—	—	306
Number of samples	94	111	81	56	—	—	124
STP							
Median	0.78	0.78	1.3	4.5	0.64	—	14
Minimum	<0.10	<0.01	<0.10	0.31	<0.01	—	1
Maximum	52	52	32	54	28.5	—	280
Number of samples	323	392	391	284	181	—	419
Ouachita Mountains							
All sites							
Median	0.13	0.13	0.50	0.83	0.04	—	5
Minimum	<0.10	<0.01	<0.10	0.13	<0.01	—	<1
Maximum	7	7	19	19	8.3	—	3,230
Number of samples	1,846	2,216	888	692	2,209	—	1,934
Forest							
Median	0.10	0.09	0.41	0.73	0.04	0.01	4
Minimum	<0.10	<0.01	<0.10	0.13	<0.01	<0.01	<1
Maximum	1.6	1.6	19	19	6.4	0.04	3,230
Number of samples	1,186	1,438	597	443	1,498	18	1,195
Mix							
Median	0.21	0.2	0.20	0.85	0.05	—	6
Minimum	<0.10	<0.01	<0.10	0.25	<0.01	—	1
Maximum	1	1	0.80	2.7	0.47	—	95
Number of samples	153	185	19	14	277	—	177
STP							
Median	0.19	0.19	0.75	1.4	0.06	—	8
Minimum	<0.10	<0.01	<0.10	0.18	<0.01	—	<1
Maximum	7	7	12	15	8.3	—	360
Number of samples	507	593	272	235	434	—	562

mg/L = milligrams per liter; — = insufficient data available; STP = sewage treatment plant; Mix = forest-pasture mix.

in forested basins within the Springfield and Salem Plateaus and Arkansas Valley were equal to or significantly lower than concentrations at sites in basins with "agriculture" or "agriculture-forest mix" land uses.

Figure 2.4 indicates that the Springfield Plateau had the lowest concentrations of total ammonia plus organic nitrogen in samples from basins with "forest" land use and the Boston Mountains had the highest concentrations. Total ammonia plus organic nitrogen concentrations differed significantly among samples from basins with "agricultural land use" in the Arkansas Valley and Ouachita Mountains. Samples from the Springfield "forest-pasture mix" and Ouachita Mountains "agriculture-forest mix" had the lowest total ammonia plus organic nitrogen concentrations and samples from the Arkansas Valley had the highest concentrations. Total ammonia plus organic nitrogen concentrations did not differ significantly among samples from basins with "agricultural land use" in the Springfield and Salem Plateaus, but all of these constituents were significantly lower than concentrations in samples collected from streams in the Osage Plains "cropland" areas.

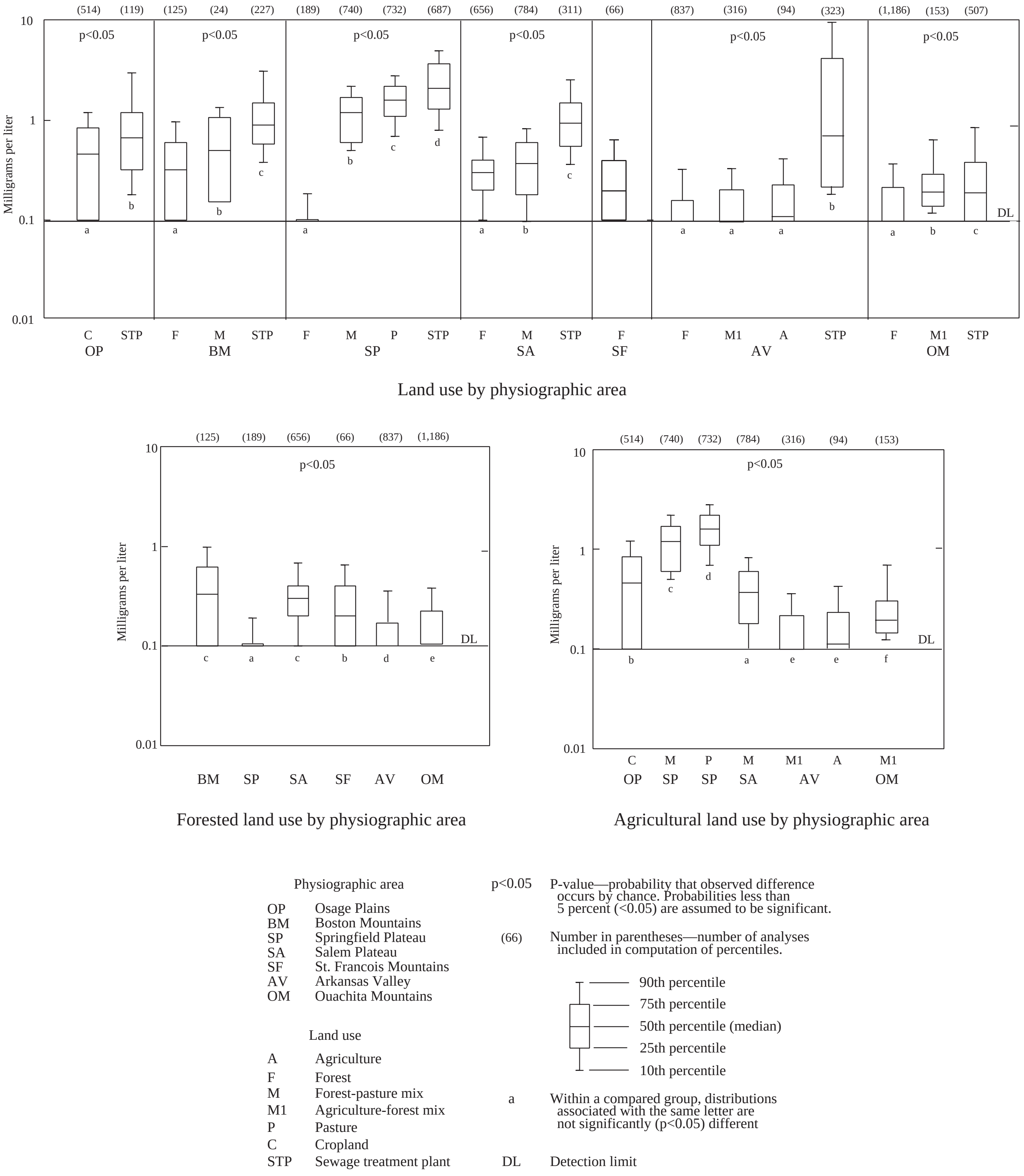
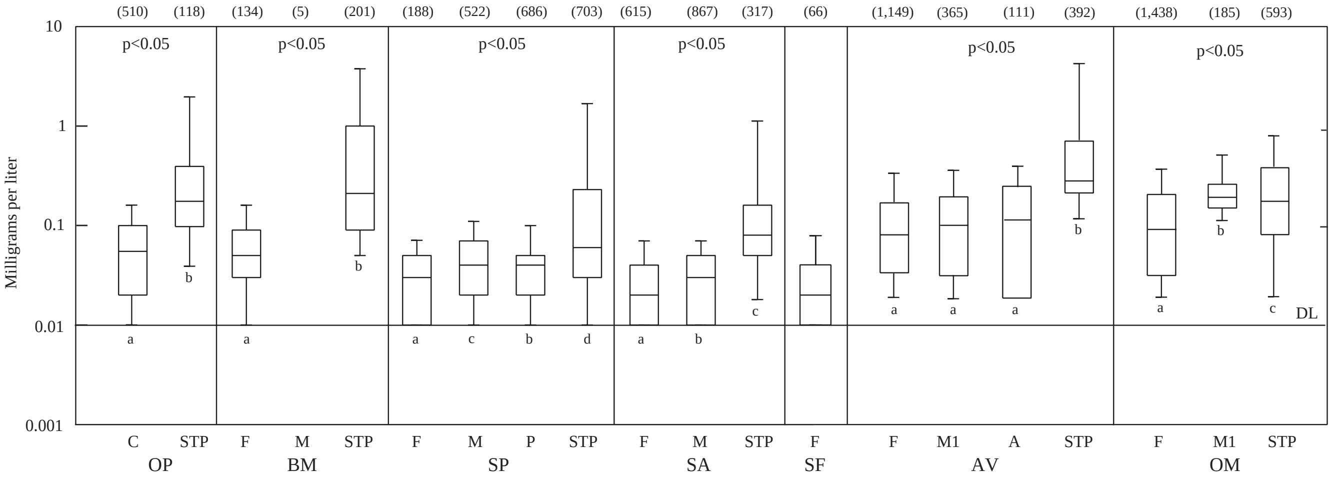
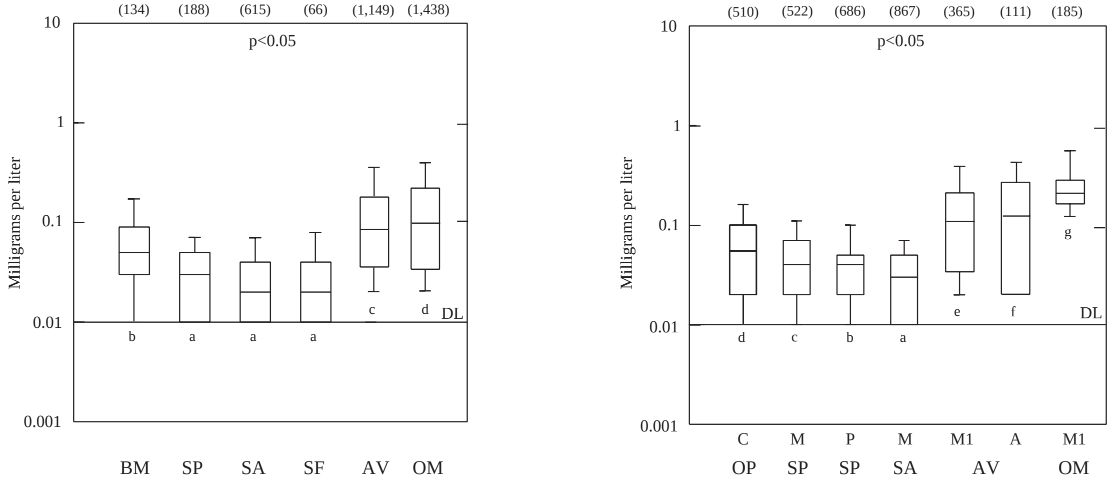


Figure 2.2—Statistical distribution of nitrite plus nitrate concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).



Land use by physiographic area



Forested land use by physiographic area

Agricultural land use by physiographic area

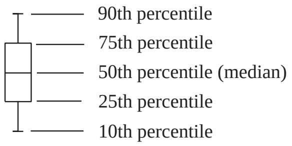
Physiographic area

OP	Osage Plains
BM	Boston Mountains
SP	Springfield Plateau
SA	Salem Plateau
SF	St. Francois Mountains
AV	Arkansas Valley
OM	Ouachita Mountains

Land use

A	Agriculture
F	Forest
M	Forest-pasture mix
M1	Agriculture-forest mix
P	Pasture
C	Cropland
STP	Sewage treatment plant

p<0.05	P-value—probability that observed difference occurs by chance. Probabilities less than 5 percent (<0.05) are assumed to be significant.
(66)	Number in parentheses—number of analyses included in computation of percentiles.



a	Within a compared group, distributions associated with the same letter are not significantly (p<0.05) different
DL	Detection limit

Figure 2.3—Statistical distribution of ammonia concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).

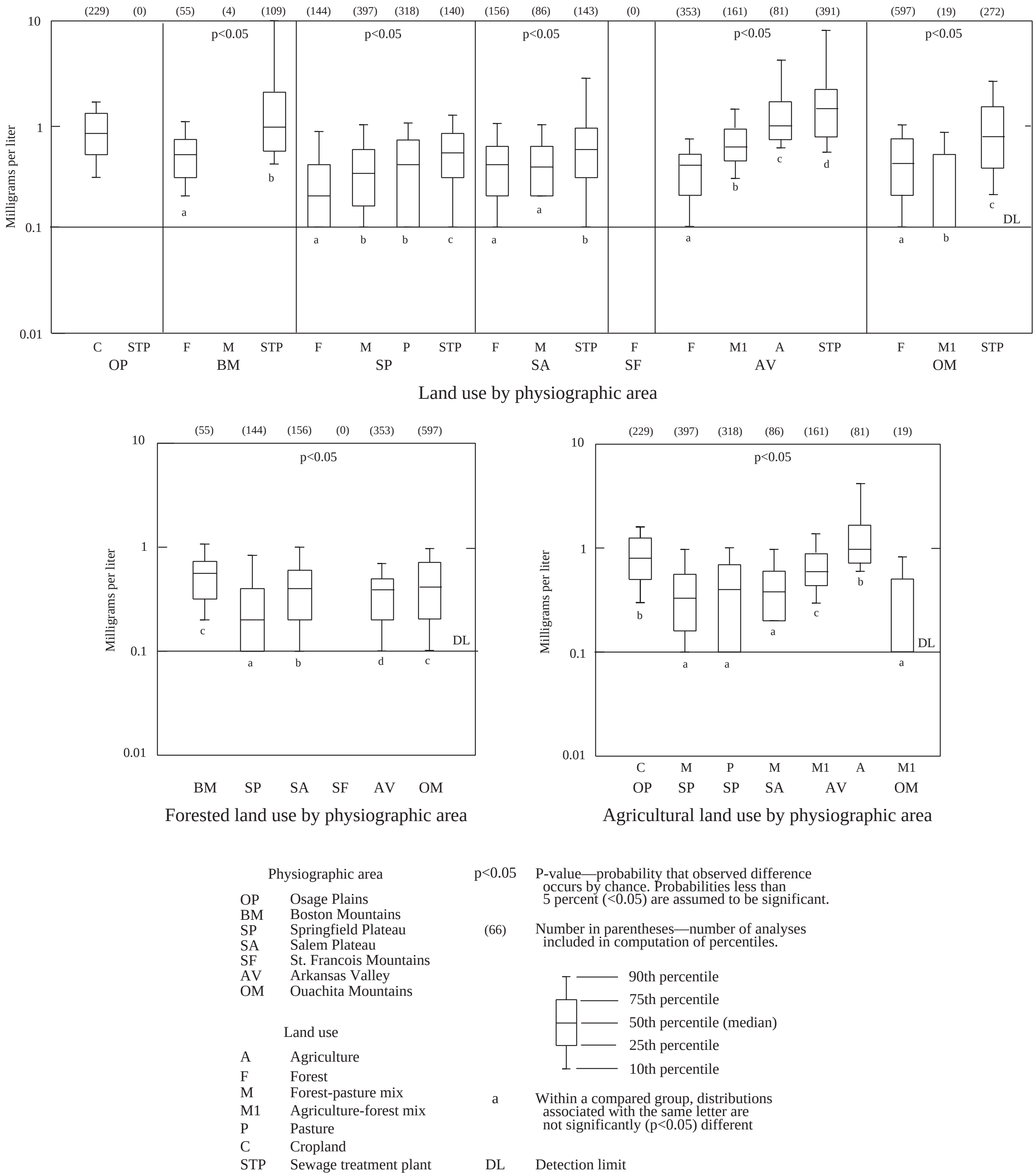


Figure 2.4—Statistical distribution of total ammonia plus organic nitrogen concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).

Total nitrogen. The best indicator of nitrogen loads in a stream is the total nitrogen concentration, which is the sum of all nitrogen forms (nitrite, nitrate, ammonia, and organic nitrogen). Total nitrogen also is the preferred measure to use for comparisons between land uses and physiographic areas. However, as with total ammonia and organic nitrogen, fewer total nitrogen analyses were available from monitoring agencies and organizations. Fewer analyses were available because total nitrogen generally is a calculated value and thus requires values for all the various forms that contribute to total nitrogen concentrations. Because total ammonia plus organic nitrogen was not determined for many of the samples, total nitrogen values could not be calculated for all samples.

Total nitrogen concentrations differed significantly among samples from streams draining basins with different land uses within five physiographic areas. Median concentrations at STP sites were significantly higher than at any other type of site (fig. 2.5). Within the Springfield Plateau, total nitrogen concentrations increased significantly with more intensive land uses ("forest" compared to "forest-pasture mix" to "pasture") and in the Arkansas Valley and Ouachita Mountains ("agriculture-forest mix" compared to "agriculture"). For samples from forested basins, the pattern with nitrite plus nitrate and total ammonia plus organic nitrogen was repeated.

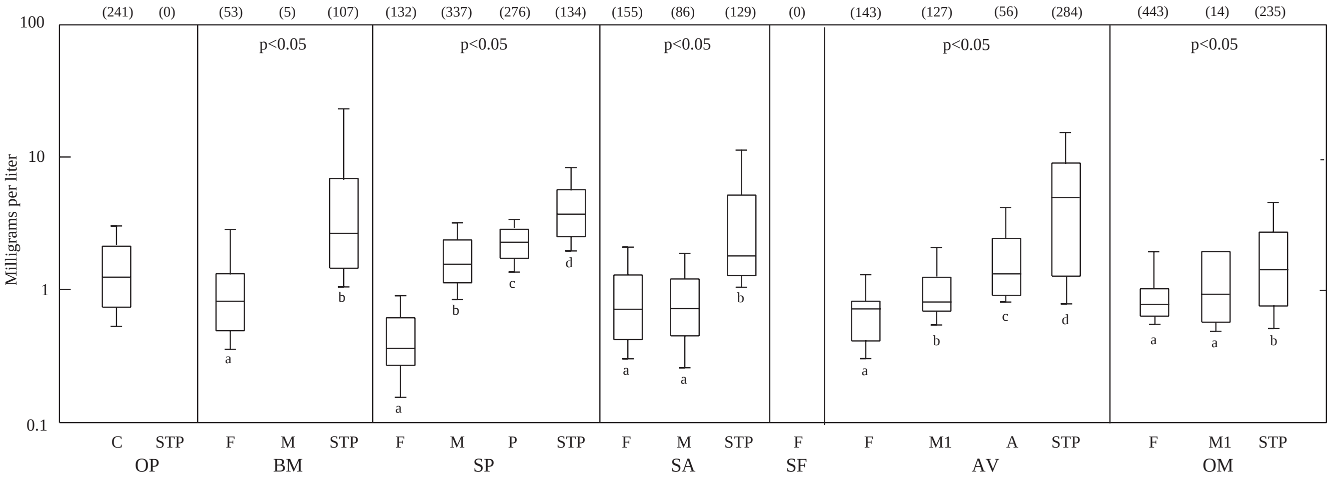
Within "agricultural land use," streams in Salem Plateau "forest-pasture mix" sites had the lowest total nitrogen concentrations, whereas streams in the Springfield Plateau "pasture" and Arkansas Valley "agriculture" sites had the highest concentrations (fig. 2.5). In previous comparisons between samples collected from streams in agricultural areas in the Osage Plains and Springfield Plateau, samples from the Osage Plains "cropland" sites had the lowest nitrite plus nitrate concentrations and the highest ammonia and total ammonia plus organic nitrogen concentrations. Total nitrogen concentrations in the Osage Plains were significantly higher than in the Salem Plateau "forest-pasture mix," Arkansas Valley, and Ouachita Mountain "agriculture-forest mix" sites but lower than either of the Springfield Plateau "forest-pasture mix and pasture" sites or Arkansas Valley "agricultural" Sites.

Total phosphorus. Total phosphorus concentrations include phosphorus in solution and adsorbed to sediment particles. Total phosphorus concentrations differed significantly between streams sampled in different land-use settings in seven physiographic areas of the Assessment area (fig. 2.6). As with the various nitrogen forms, concentrations at STP sites were significantly higher than at sites with other land uses. Within the Springfield Plateau, total phosphorus concentrations at sites in "forested land use" basins were significantly lower than concentrations at sites in "agricultural land use" basins. This difference did not occur in the Salem Plateau**.** Within the Arkansas Valley, total phosphorus concentrations at sites in "forested" basins were significantly lower than concentrations at sites in basins with "agriculture-forest mix."

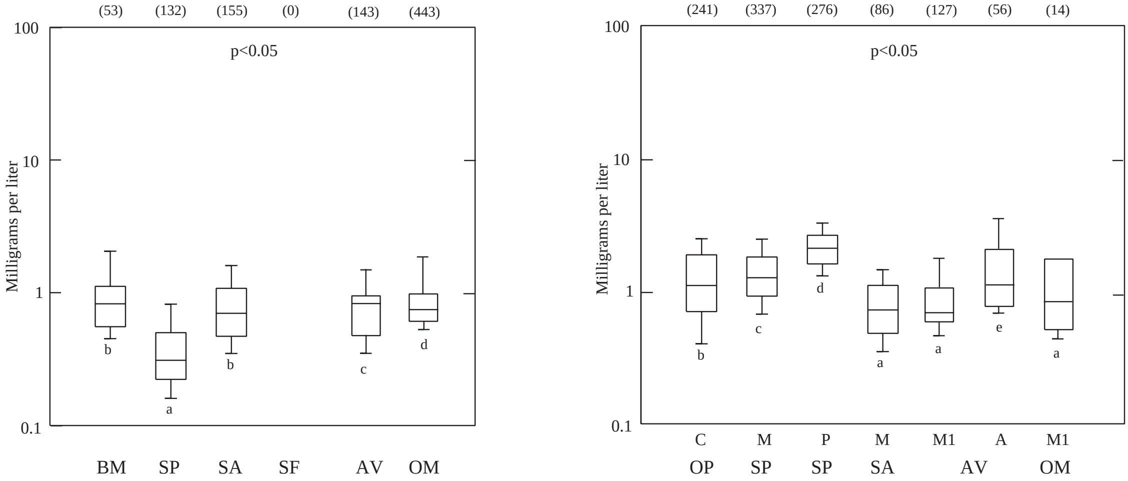
Significant differences in total phosphorus concentrations in different physiographic areas in the Assessment area also occurred in samples from "forested land use" and "agricultural land use" (fig. 2.6). Concentrations were lowest from streams in forested parts of the Springfield Plateau, Arkansas Valley, and Ouachita Mountains. Total phosphorus concentrations in samples from the forested Boston Mountains probably were higher compared to the other physiographic areas because of the adjacent pastureland and the STP located upstream from one of the sites. Within "agricultural land use" basins, the Salem Plateau "forest-pasture mix" sites had the lowest total phosphorus concentrations and the Osage Plain "cropland" sites had the highest concentrations.

Orthophosphate. Orthophosphate is the most common phosphorus ion detected in solution in natural waters. Agencies do not routinely carry out orthophosphate analysis, and consequently fewer data were available than for total phosphorus. Orthophosphate concentrations nonetheless had virtually the same pattern as concentrations of total phosphorus for various land uses within the physiographic areas (fig. 2.7), except that concentrations from Springfield Plateau "pasture" streams were significantly higher than those from the "forest-pasture mix" streams in the Springfield Plateau.

Patterns similar to those for total phosphorus were also seen for orthophosphate concentrations from "forested land use" and "agricultural land use" settings among the Ozark Plateaus physiographic areas (fig. 2.7). An exception is that concentrations for "cropland" streams in the Osage Plains were significantly lower than those from either of the agricultural land uses in the



Land use by physiographic area



Forested land use by physiographic area

Agricultural land use by physiographic area

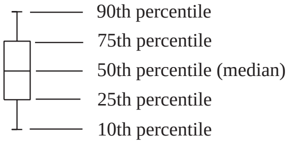
Physiographic area

OP	Osage Plains
BM	Boston Mountains
SP	Springfield Plateau
SA	Salem Plateau
SF	St. Francois Mountains
AV	Arkansas Valley
OM	Ouachita Mountains

Land use

A	Agriculture
F	Forest
M	Forest-pasture mix
M1	Agriculture-forest mix
P	Pasture
C	Cropland
STP	Sewage treatment plant

p<0.05	P-value—probability that observed difference occurs by chance. Probabilities less than 5 percent (<0.05) are assumed to be significant.
(66)	Number in parentheses—number of analyses included in computation of percentiles.



a	Within a compared group, distributions associated with the same letter are not significantly (p<0.05) different
DL	Detection limit

Figure 2.5—Statistical distribution of total nitrogen concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).

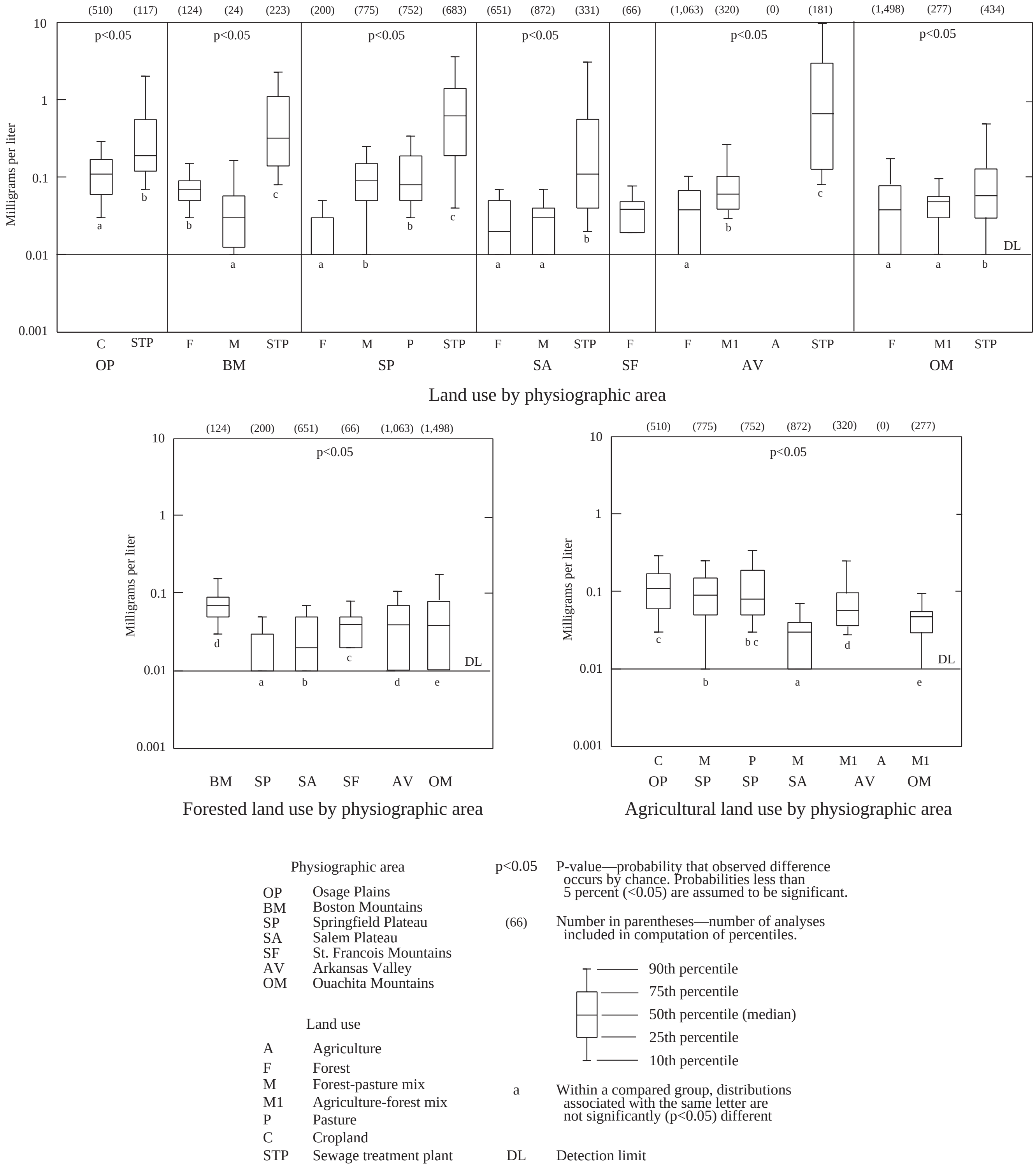


Figure 2.6—Statistical distribution of total phosphorus concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).

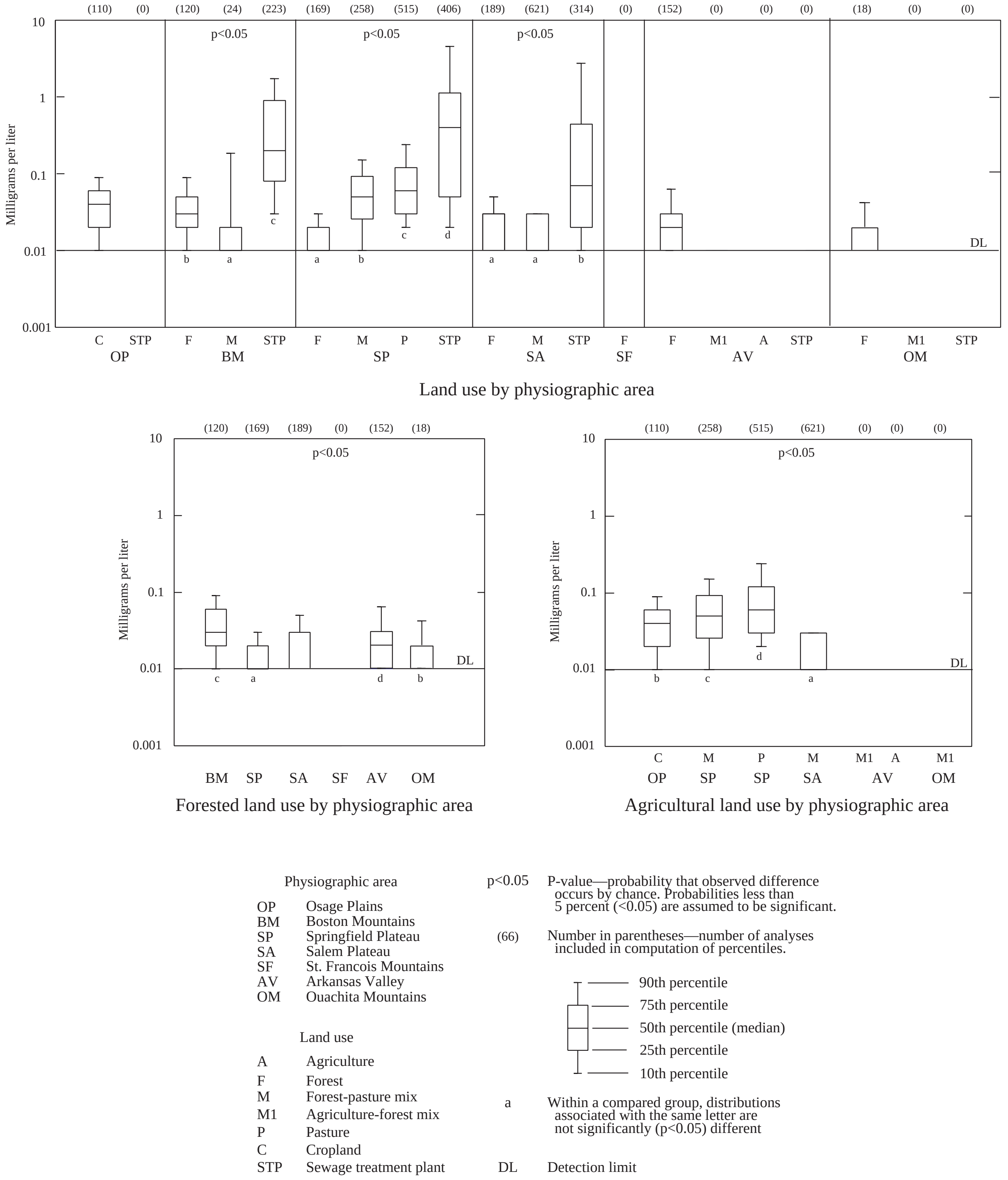


Figure 2.7—Statistical distribution of orthophosphate concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).

Springfield Plateau. These results support the idea that much of the phosphorus in the Osage Plains "cropland" streams was associated with sediment particles, whereas much of the phosphorus in the Springfield Plateau "forest-pasture mix" and "pasture" streams was in solution as orthophosphate.

Suspended sediment and suspended solids. Suspended sediment data are considered more accurate than suspended solids data as indicators of actual stream concentrations of inorganic material because of differences in collection and analytical methods. However, only 26 of the 137 sites had suspended sediment data, so the Aquatic Team used suspended solids data for this report.

Concentrations of suspended solids were highest in the Osage Plains because of easily erodible soils and intensive field- and row-crop agriculture (fig. 2.8). The slightly higher concentrations in the Boston Mountains, as compared to the Springfield and Salem Plateaus and St. Francois Mountains, may be because data were available for only a small group of possibly unrepresentative sites in the Boston Mountains. Concentrations of suspended solids concentrations differed significantly among samples from different land uses in the Springfield and Salem Plateaus; concentrations increased with more intensive land uses ("forest" compared to "forest-pasture mix" compared to "pasture"). In the Arkansas Valley and Ouachita Mountains, concentrations of suspended solids in basins with "agricultural land use" were significantly higher than concentrations in forested basins. Concentrations in the samples from STP sites are most likely related to land uses in the basin and not to STP effluents.

Significant differences in concentrations of suspended solids in different physiographic areas of the Assessment area also occurred among samples from "forested land use" and "agricultural land use" (fig. 2.8). Concentrations were significantly higher at "forested" sites in the Salem Plateau; St. Francois, Boston, and Ouachita Mountains; and Arkansas Valley than in the Springfield Plateau. Concentrations of suspended solids in samples collected at Springfield Plateau "pasture" sites, Arkansas Valley "agriculture" and "agriculture-forest mix" sites, and at Salem Plateau "forest-pasture mix" sites were significantly higher than the concentrations in samples collected at Springfield Plateau "forest-pasture mix" sites.

Trends

In addition to the previously discussed water quality patterns, the analysis of long-term trends provides another method to assess water quality. The following section describes changes in the quality of surface water during water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains).

Water quality trends over time have been a subject of a number of investigations of streams in the Assessment area (AR DPCE 1980, 1984, 1986, 1992; KS DHE 1988; Brown and others 1991; Mott 1991; Davis and Schumacher 1992; Petersen 1992; Davis and Howland 1993; Kenney and Snethen 1993; Kurklin and Jennings 1993; Petersen and others 1993; Yu and Zou 1993; Ford 1992; and Wright 1994).

Because of differing trend analysis methods, periods of time, and sampling station densities used in these various investigations, it is difficult to make generalizations and comparisons that would apply to the entire Assessment area. For example, most of the sites for which data have been analyzed for trends are in Arkansas, southwestern Missouri, and the Illinois River Basin in northeastern Oklahoma. Nonetheless, it appears that concentrations of nitrite plus nitrate, phosphorus, and orthophosphate have increased at a disproportionately higher number of sites in northwestern Arkansas, northeastern Oklahoma, and southwestern Missouri than in the study area as a whole. Statistically significant downward trends in total phosphorus concentrations have occurred at several sites in the Spring River Basin of southwestern Missouri. The downward trends at most of these sites in the Spring River Basin can be attributed to the aging of two large phospho-gypsum waste piles, which has resulted in decreasing phosphorus concentrations in the leachate from the sites (Davis and Schumacher 1992). In Arkansas, where most of the sites are located for which the data have been analyzed (Petersen 1992), about one-third of the sites had downward trends in total ammonia concentrations.

Apparent trends can be caused not only by changes in ambient concentrations but also by changes in field and laboratory methods. For example, Alexander and others (1993) studied quality assurance records and found that a higher positive bias existed for ammonia,

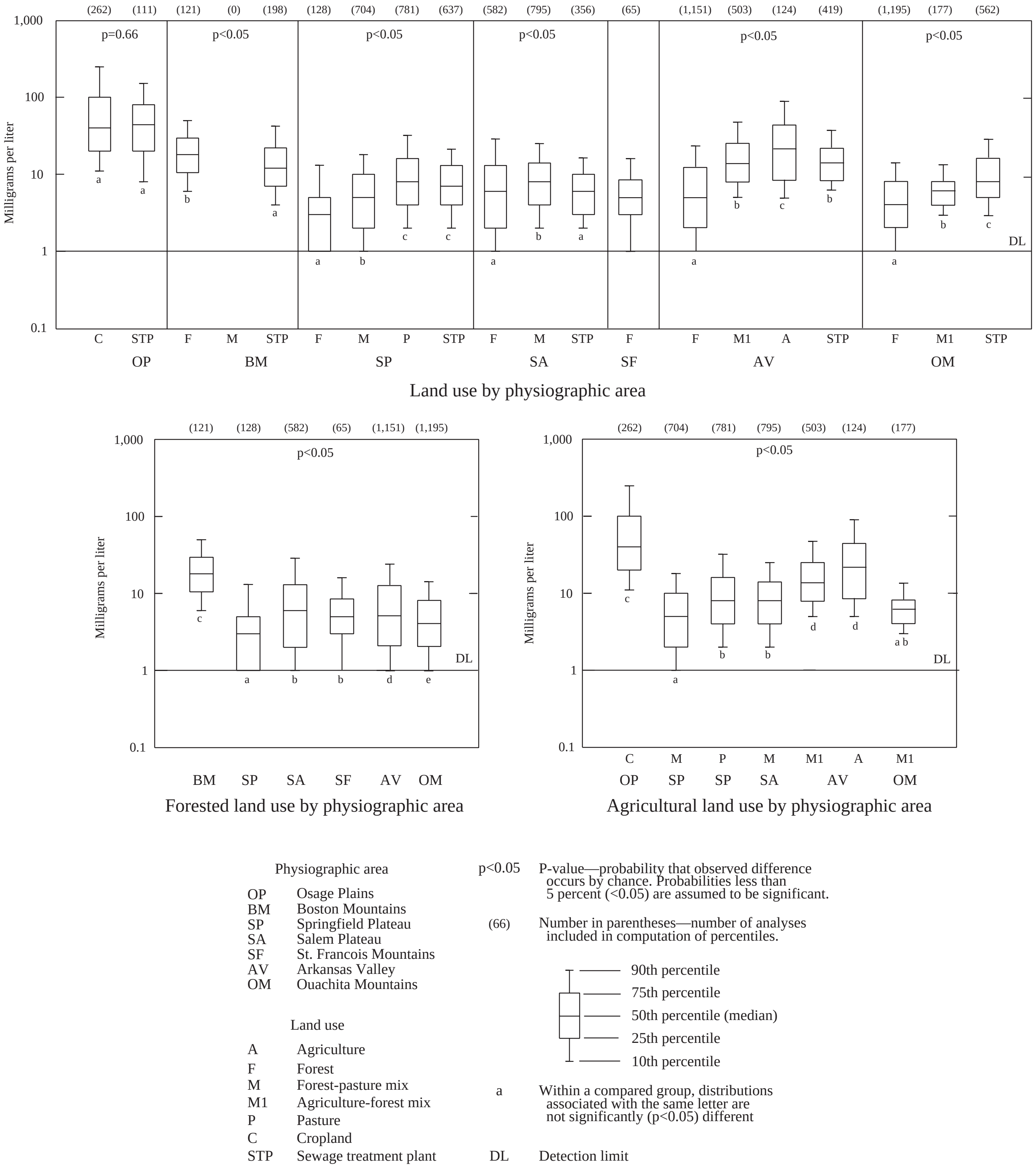


Figure 2.8—Statistical distribution of suspended solids concentrations at surface water sites for water years 1980 through 1990 (Ozark Plateaus) and 1985 through 1995 (Arkansas Valley and Ouachita Mountains) (modified from Davis and others 1995).

ammonia plus organic nitrogen, and phosphorus in the early 1980's compared to recent periods. Airborne ammonia contamination in the laboratory may be one cause; the source of the phosphorus contamination is unknown. Improvements in field and laboratory methods that decrease the amount of positive bias would create a trend analysis that indicates a greater downward trend than actually occurred. In addition, a change in laboratory methods at the Arkansas Department of Pollution Control and Ecology for analysis of nitrite, nitrate, ammonia, and total phosphorus occurred in March 1977 (Thompson 1990). Because other monitoring agencies also changed laboratory and field methods between 1970 and 1990, these changes must be considered in any analyses of time trends when using that data.

The Aquatic Team selected 38 sites for subsequent examination of changes in water quality for water years 1970 through 1990 and 1975 through 1995 (table 2.5). The team based site selection primarily on the length of time for which data were available. Sites with the longest continuous periods of data coverage for the selected constituents of interest were chosen. Some chosen sites have little data for one or more of the constituents. The Aquatic Team did not include sites that they considered were substantially affected by STP discharges or that were immediately downstream of reservoirs.

Available water quality data (concentrations of nitrite plus nitrate, ammonia, total ammonia plus organic nitrogen, total phosphorus, orthophosphate, suspended sediment, and suspended solids) for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) were plotted for all 38 sites. The Aquatic Team used the LOWESS procedure to draw an "inferred concentration trend line" on plots. To avoid misrepresenting the data, this procedure does not draw a concentration trend line when the proportion of censored values is high. Therefore, lines were not drawn on some plots.

Table 2.5— Sampling stations for nutrient and suspended solids examined for long-term changes in water quality

Physiographic area	Site numbers (fig. 2.1 and table 2.3)
Springfield Plateau	26, 34, 41, 60, 63, 64, 66, 69, 71, 72
Salem Plateau	10, 11, 12, 23, 33, 45, 50, 51, 53, 55
Boston Mountains	18, 20
St. Francois Mountains	16
Osage Plains	1, 2, 7, 56, 57, 81
Arkansas Valley	87, 97, 101, 105, 106
Ouachita Mountains	111, 113, 118, 125

Rather than including plots for all 38 sites in this report, the Aquatic Team selected a group of sites representative of most physiographic areas, land uses, and collecting agencies For several sites the higher concentrations were not plotted, however the team included all data for a site in the calculations used to draw the inferred concentration trend lines.

No statistical tests for trends were performed for this report: therefore, the Aquatic Team subjectively determined the decreasing or increasing trends mentioned in the following sections by inspection of the plots of concentration for all 38 sites. Factors not always considered include laboratory and field method changes and the effects of streamflow on constituent concentrations. The team also inspected plots of concentrations adjusted for streamflow (Helsel and Hirsch 1992) and, in general, determined that the "flow-adjusted concentration trend lines" were similar to the concentration trend lines. However, because a substantially lower number of sites had sufficient streamflow data available, the flow-adjusted data are not shown.

Nitrogen. The concentrations of most forms of nitrogen did not increase between water years 1970 through 1990 or 1975 through 1995, yet nitrogen fertilizer application rates substantially increased between 1965 and 1985 in all of the major river basins of the Assessment area. A complete discussion of nitrogen fertilizer can be found in Chapter 4.

Concentrations of nitrite plus nitrate did not change substantially at most sites investigated (e.g., sites 1 and 53 in fig. 2.9). However, decreases occurred at most sites in the Osage Plains (sites 1, 2, 7, 56, and 81). Data indicate increases occurred at some sites in the Springfield Plateau (sites 64, 66, and 69), but the causes of these changes are unknown. The Aquatic Team considered none of the sites to be substantially affected by discharges from STP's, even though several of the sites (2, 9, 15, 56, 64, 66, 80, and 81) are downstream from STP's. The decreases at sites in the Osage Plains may be the result of some change in agricultural practices.

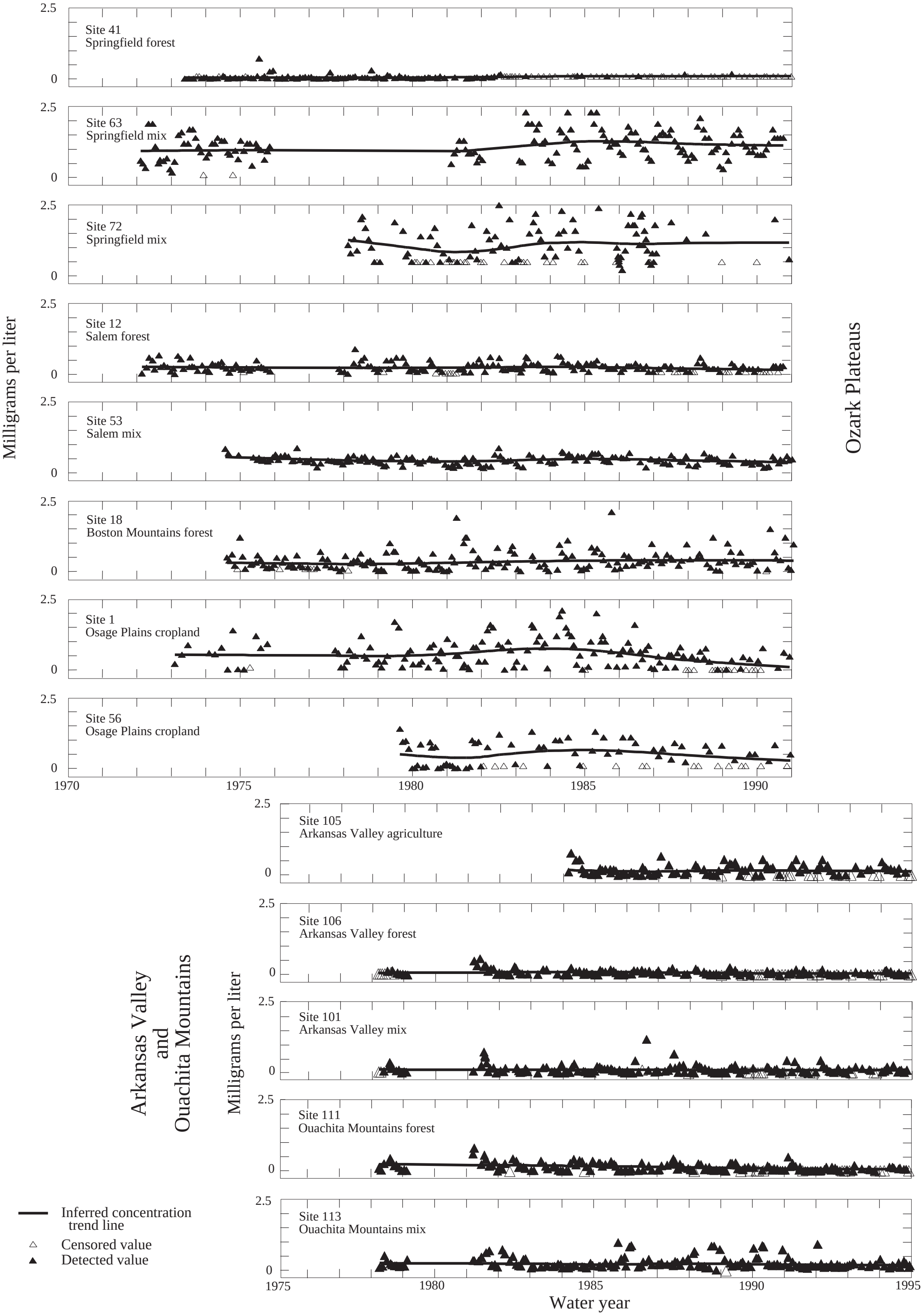


Figure 2.9—Concentrations of nitrite plus nitrate for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) at selected surface water sites.

The sites in the Springfield Plateau, where concentrations of nitrite and nitrate appear to have increased, are in drainage basins with substantial amounts of agricultural activity.

Concentrations of ammonia decreased at several sites (fig. 2.10). Many of these decreases were relatively small and occurred in concentrations that were near the detection or reporting limits near which analytical variance may be greater. Decreases occurred at all of the sites in the Osage Plains (sites 1, 2, 7, 56, 57, and 81) and at four or more sites in the Salem Plateau (sites 50, 51, 53, and 55). The causes of these decreases in concentration are unknown. Although the team did not consider these sites to be substantially affected by STP discharges, some are downstream from STP's that might be affecting concentrations enough to contribute to these changes in water quality by reducing ammonia. Some sites (1, 7, 50, 53, 55, and 57) are in agricultural basins and are not downstream from STP's. Most sites in the Salem Plateau showing decreases are sampled by the Arkansas Department of Pollution Control and Ecology (sites 50, 51, 53, and 55) and began showing decreasing concentrations in the late 1970's. Differing field or laboratory methods of the two agencies (such as the early 1980's bias of Geological Survey data) may partially explain the decreases in reported concentrations.

Concentrations of total ammonia plus organic nitrogen seem to have decreased at a few sites and increased at others (fig. 2.11). Most of these decreases were in the Springfield Plateau (sites 34, 64, 71, and 72) and Osage Plains (sites 2, 7, and 56). Concentrations of total ammonia plus organic nitrogen seem to have increased at site 101 in the Arkansas Valley and at site 118 in the Ouachita Mountains. The causes of these decreases and increases in concentration are unknown. Although the sites were not considered to be substantially affected by STP's, some sites are downstream from STP's that might be affecting concentrations enough to contribute to these changes in water quality. Some sites (2, 7, and 101) are in agricultural basins and not downstream from any STP's.

Phosphorus. The Aquatic Team concluded that concentrations of total phosphorus have not changed substantially at most sites (fig. 2.12). Increases in total phosphorus concentrations have occurred at about one-half of the sites in the Springfield Plateau (sites 64, 66, 69, 71, 72; and site 60) since about 1980. All of the Springfield Plateau sites with increasing concentrations are "pasture" or "forest-pasture mix" sites. Decreases in total phosphorus concentrations have occurred at about one-third of the sites in the Salem Plateau (sites 10, 11, and 12); most of these sites with are Salem Plateau "forest" sites. The Geological Survey laboratory bias in the early 1980's may at least partially explain these decreases. These Salem Plateau sites also are downstream from STP's, although the STP's are not considered to be substantially affecting the water quality at these sampling sites.

Concentrations of orthophosphate have not changed substantially at most sites (fig. 2.13). The relatively few number of sites and limited orthophosphate data make any determination of spatial or land-use patterns affecting water-quality trends difficult. The team concluded that, although data are limited, concentrations might have decreased at some sites in the Osage Plains in the time for which data are available (sites 2, 56, and 57).

Suspended sediment and suspended solids. Little data concerning suspended sediment concentrations were available. Concentrations have not changed substantially at sites for which data were available.

Similarly, concentrations of suspended solids have not changed substantially at most sites (fig. 2.14). However, decreases have occurred at the two sites representative of the Osage Plains (sites 1 and 81). Decreases in concentrations also have occurred at several sites in the Salem Plateau (sites 50, 51, 53, 55, and possibly others) and Arkansas Valley (site 105). The decreasing concentrations may be the result of some change in agricultural practices that has decreased the amount of soil and other suspended particles transported into streams.

Implications and Opportunities

On the whole, the Ozark-Ouachita Highlands are blessed with clean water. Moreover, the analysis of trends indicates that these conditions are substantially unchanged since the 1970's. However, it is also evident that sewage treatment plants and more intensive land uses have a greater effect on stream chemistry than other land use activities. These more intensive land uses can lead to impairment (adverse change) in streams. (See Chapter 4 for a discussion of impaired waters.)

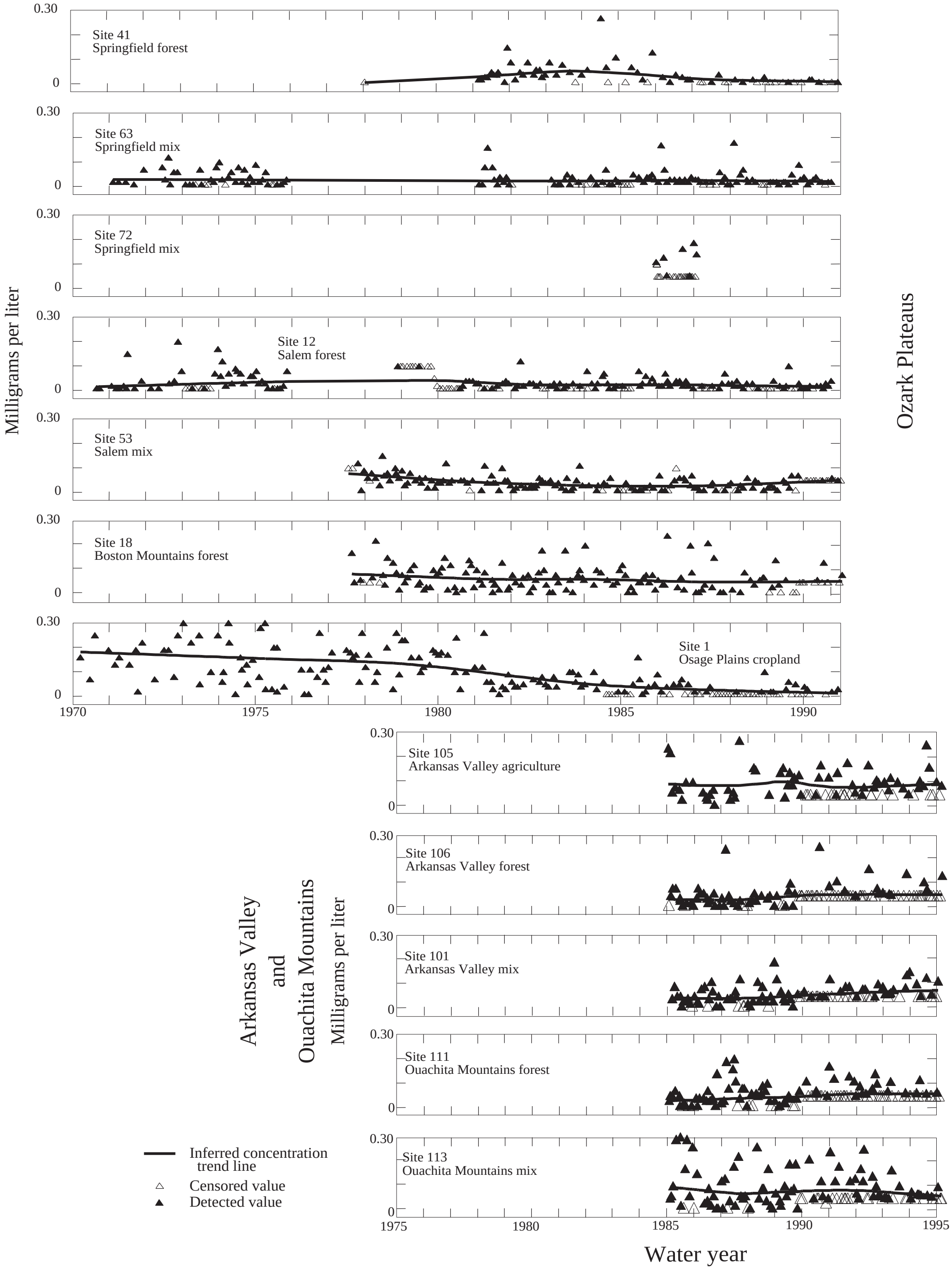


Figure 2.10—Concentrations of ammonia for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) at selected surface water sites.

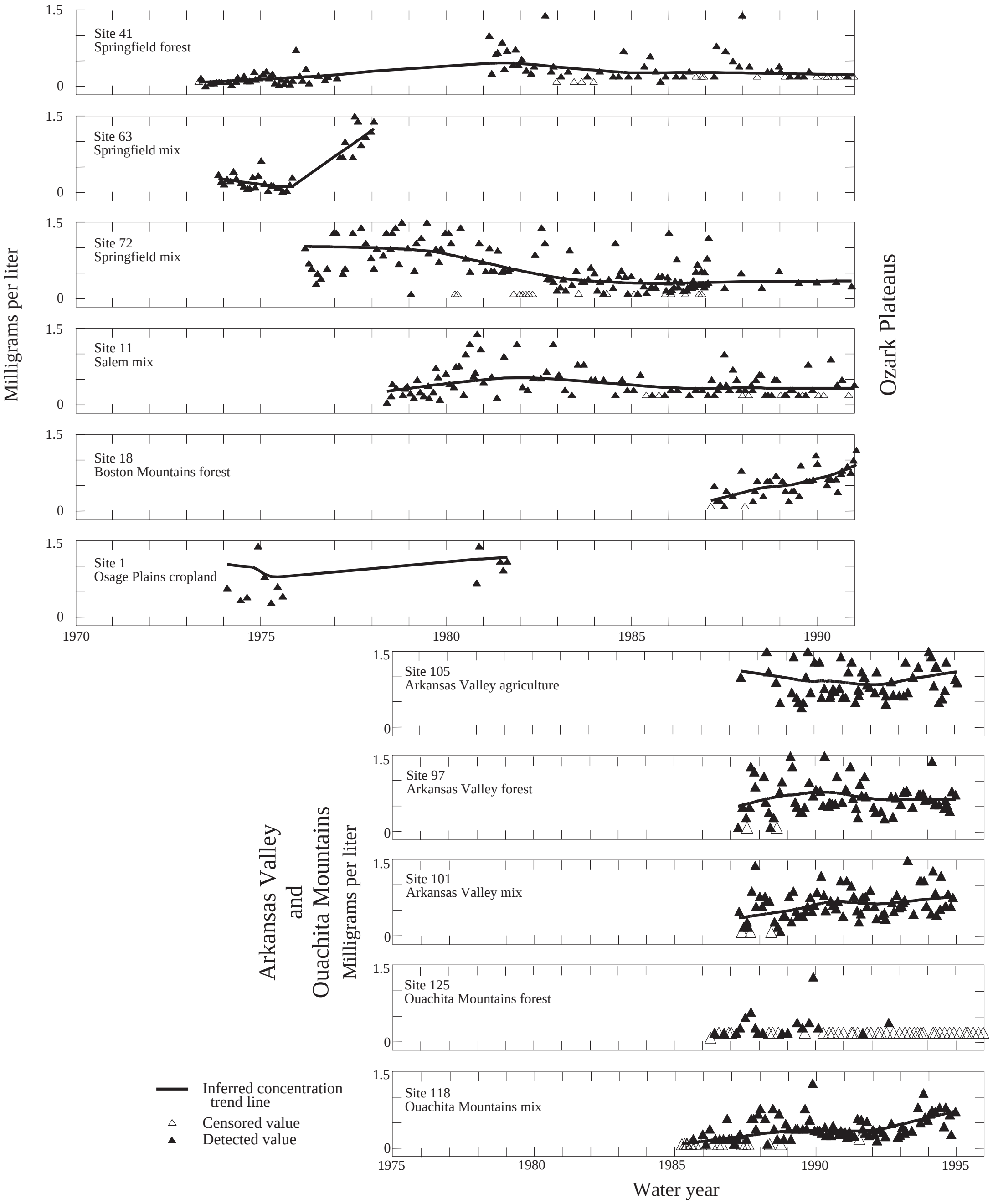


Figure 2.11—Concentrations of total ammonia plus organic nitrogen for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) at selected surface water sites.

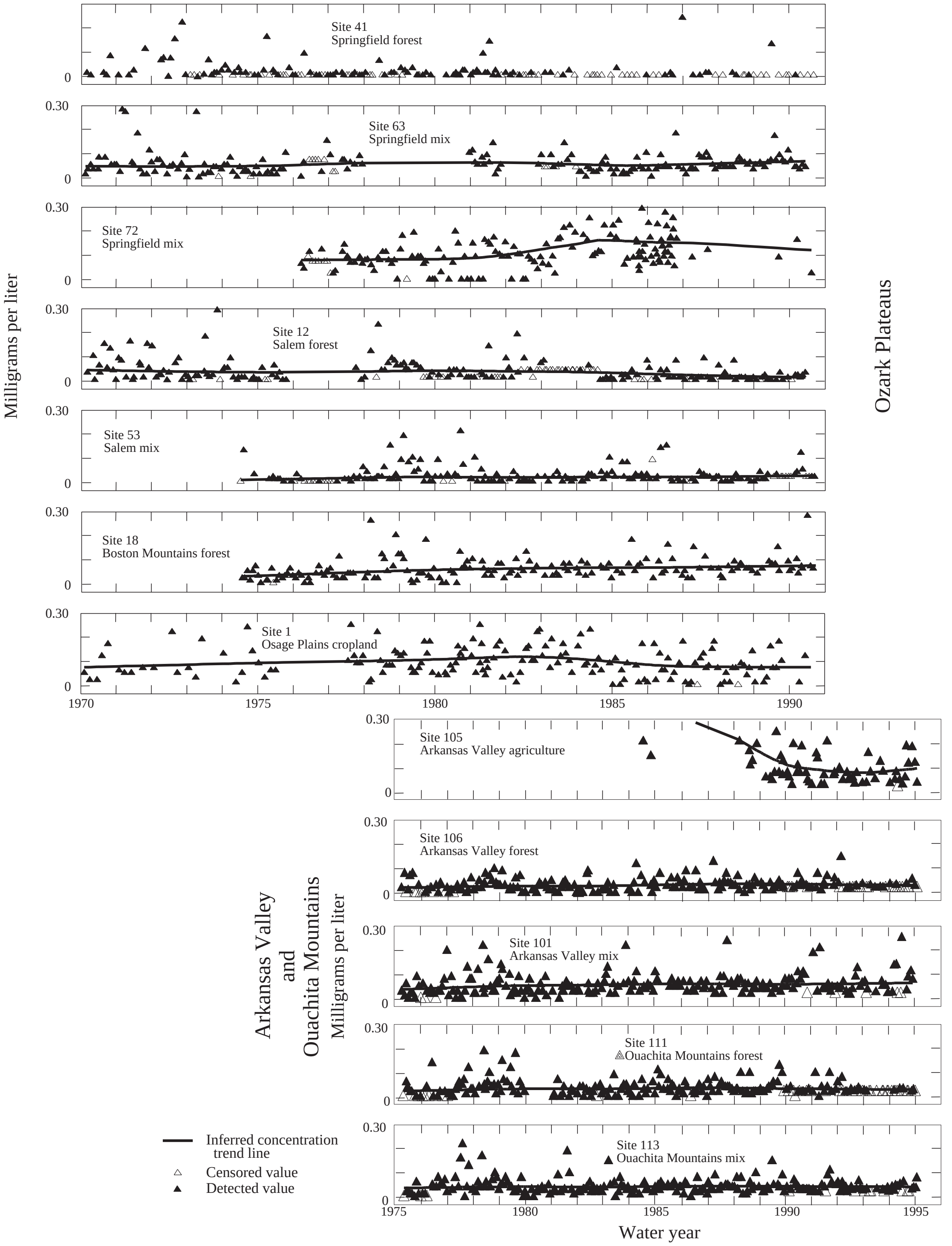


Figure 2.12—Concentrations of total phosphorus for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) at selected surface water sites.

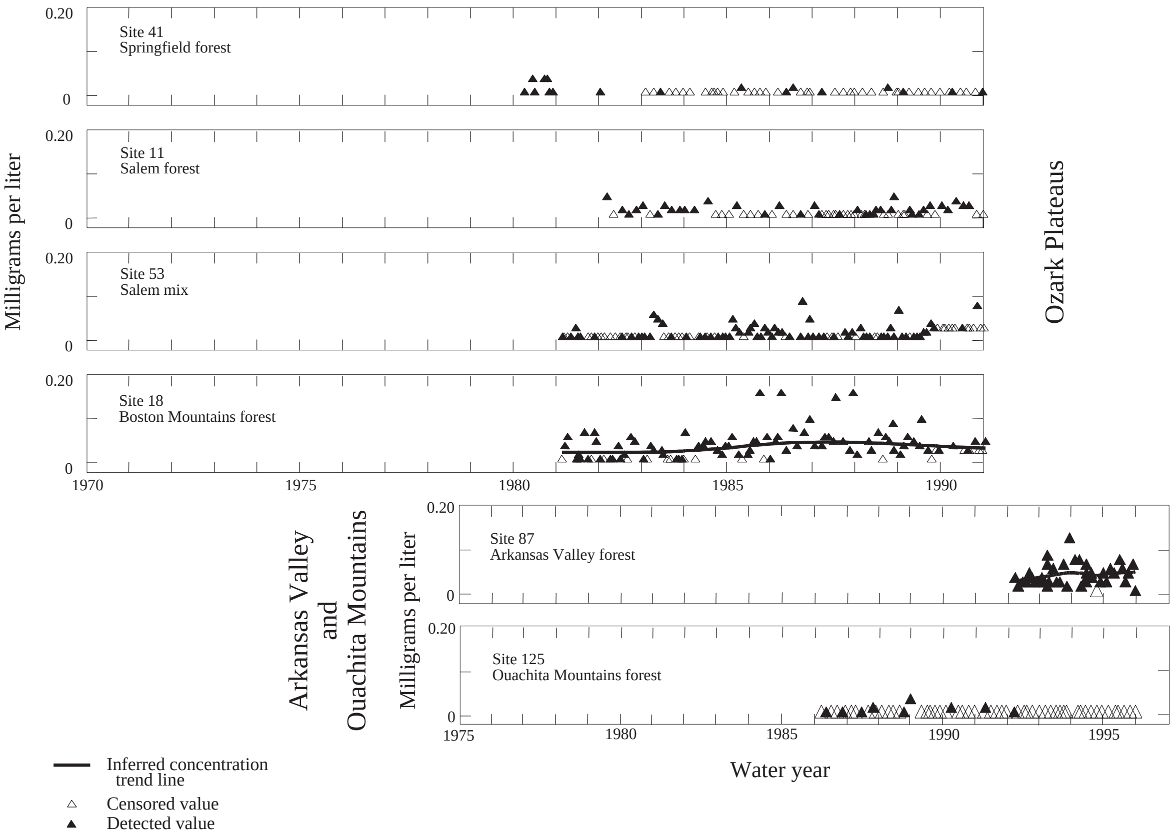


Figure 2.13—Concentrations of orthophosphate for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) at selected surface water sites.

Forest lands serve as the source of the cleanest waters within the Assessment area. In order to ensure that they continue to do so, managers will need to actively implement best management practices (BMP's) to prevent decreases in water quality. Opportunities exist for Federal agencies to continue to work closely with State and local agencies and private landowners to protect and promote water quality.

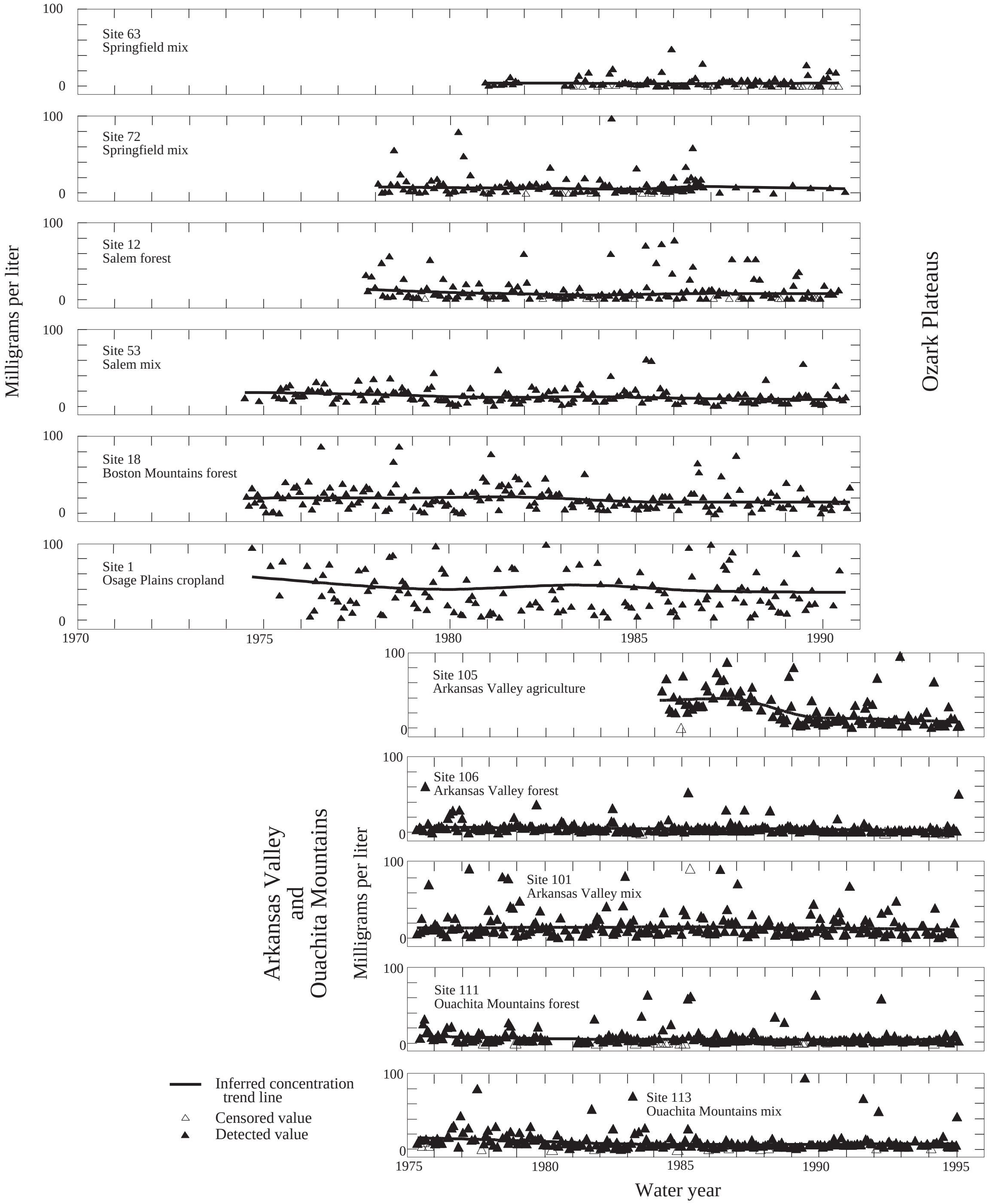


Figure 2.14—Concentrations of suspended solids for water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Arkansas Valley and Ouachita Mountains) at selected surface water sites.

Surface Water Quality (Lakes)

Question 2.2: What is the status of the surface water quality of lakes within the Assessment area?

As is true of surface water quality data concerning streams, a great quantity of data is also available to assess the water quality of lakes within the Assessment area. To get as much useful information as possible in the time allotted, the Aquatic Team investigated studies where a sizable number of lakes in the Assessment area were sampled by the States of Arkansas, Missouri, or Oklahoma under the requirements of the Clean Water Act (AR DPCE 1996, MO DNR 1994, OK DEQ 1996).

As part of the section 305(b) reporting process, the Clean Water Act (CWA) requires that each State submit a biennial assessment of the water quality of its lakes—including their trophic status. Trophic status is defined as the degree of eutrophication (see the following explanations) of a lake and provides insight into the lake's productivity and its future. In natural lakes, a correlation exists between the age of a lake and its trophic status. Reservoirs, because of their generally higher inflow and outflow rates, do not function in the same manner as natural lakes, but determining their trophic status does assist in understanding water quality problems affecting them (OK DEQ 1996).

Eutrophication is a cumulative process by which lakes receive (1) agricultural runoff (nutrients such as nitrogen and phosphorus), (2) rural and urban sewage and industrial effluents, and (3) natural nutrients (such as leaves and fallen trees). All these constituents support increased algal and other aquatic plant growth and gradually fill lakes with sediment and decaying organic matter. Trophic status describes how far a particular lake has advanced in the eutrophication process and includes the following classifications:

- Oligotrophic: lakes that receive low levels of nitrogen, phosphorus, and other nutrients and thus have little algae or other aquatic plant growth;
- Mesotrophic: lakes that have received somewhat more nutrients and have greater aquatic plant growth.
- Eutrophic lakes that have accumulated high levels of nitrogen, phosphorus, and other nutrients and thus are often very green due to large algal blooms.
- Hypereutrophic: lakes (the most advanced stage of eutrophication) that have received exceptionally large amounts of nitrogen, phosphorus, and other nutrients and consequently have very heavy growths of algae and other aquatic plants.

Trophic status is not necessarily a measure of lake use. People who use lakes for sightseeing, picnicking, swimming, or water skiing prefer oligotrophic lakes with good water clarity. Anglers prefer slightly more eutrophic lakes because they tend to have more species and larger fish due to enhanced aquatic plant communities (MO DNR 1994). The team selected trophic status as a suitable indicator of overall lake water quality.

Key Findings

1. Within the Assessment area in Arkansas, 35 percent of the 48 lakes were classified as mesotrophic, 63 percent eutrophic, and 2 percent (1 lake) as hypereutrophic.
2. Within the Assessment area in Missouri, 13 percent of the lakes were classified as oligotrophic, 32 percent as mesotrophic, and 55 percent as eutrophic.
3. Of the 30 Oklahoma lakes within the Assessment area, 3 percent were classified as oligotrophic, 30 percent mesotrophic, 43 percent eutrophic, 17 percent hypereutrophic, and 7 percent (2 lakes) as silt dominated.

Data Sources and Methods of Analysis

The Aquatic Team requested and received water chemistry data for the major Federal reservoirs in the Assessment area from the Arkansas, Missouri, and Oklahoma offices of the Geological Survey. Originally, the Aquatic Team selected a small list of four to six water-chemistry parameters for each water body. To minimize sampling bias, samples were taken around the first of each year near the surface of each lake close to the dam. The Aquatic Team intended to analyze these data in order to establish trends, but found that for meaningful analysis, they did not have data from similar testing methodologies (e.g., testing dates, methods, and sites) for enough reservoirs. This approach was therefore abandoned in favor of investigating data from the Arkansas, Missouri, and Oklahoma 305(b) reports previously noted.

Patterns and Trends

In 1989 and 1994, the Arkansas Department of Pollution Control and Ecology (AR DPCE 1996) sampled lakes across the State to determine their trophic status as part of the required 305(b) report analysis. To provide a relative ranking index, the Arkansas Department of Pollution Control and Ecology used the following: (1) total phosphorus values converted to micrograms per liter (µg/L) added to (2) chlorophyll-A values in µg/L (chlorophyll-A is a measure of algal standing crop and primary productivity) divided by (3) secchi depth in inches (secchi depth is a visibility measurement underwater at which equal black and white quarters of a disk cannot be distinguished from each other by the human eye). The Arkansas Department of Pollution Control and Ecology collected data for this index from most of the Arkansas lakes between mid-July and the end of August. Table 2.6 shows the lakes selected, location, size, trophic status, total phosphorus, chlorophyll-A, secchi depth, Carlson Trophic State Index, and type. Lake types include size, average depth, and ecoregion. Note on table 2.6 that lakes within the Assessment area generally fall into “A,” “B,” and “E.” Type “C” and “E” lakes in the section 305(b) report are all Arkansas Valley lakes. These lake “types” are as follows:

- **Type A**—larger lakes, usually several thousand acres in size, with average depths from 30 to 60 feet (ft). These deep lakes are located in the Ozark Plateaus, Ouachita Mountains, or Boston Mountains and have land cover dominated by forests.
- **Type B**—smaller lakes, around 500 acres (ac) or less in size, with average depths ranging from 10 to 25 ft. Most of these lakes—probably the most heterogeneous group—are in the Ozark Plateaus, Ouachita Mountains, and Boston Mountains; however, several are in the more mountainous areas of the Arkansas Valley. Their watersheds are normally dominated by forestlands.
- **Type C**—smaller lakes, generally ranging from 300 to 1,000 ac, with average depths normally less than 10 ft. These lakes are in the lowland or flatter terrain areas of the Arkansas Valley and West Gulf Coastal Plain physiographic areas. Watersheds of these lakes include timberlands of both lowland hardwoods and pines; some watersheds are broken by pasture lands and small farms.
- **Type D**—generally 200 to 500 ac in size with average depths of around 5 ft, including small impoundments in the delta area of the State plus two similar type lakes from the large river alluvium (sediment) of the West Gulf Coastal Plain.
- **Type E**—ranging from several thousand to over 30,000 ac in size with average depths usually less than 10 ft, these are large lowland lakes of the West Gulf Coastal Plain and the large alluvial areas of the Arkansas Valley.

Arkansas ranks its lakes using the above system and does not determine trophic status. However, by using the chlorophyll-A and total phosphorus data for lakes and reservoirs (table 2.6), the team assigned a trophic status to them using Missouri’s classification scheme (MO DNR 1994). The Carlson Trophic State Index is a commonly used formula to derive trophic status: 9.8 natural log [chlorophyll-A] + 30.6. Based on the index, the team classified each lake with a trophic status (see table 2.7). Where the chlorophyll-A and total phosphorus values were in different trophic classification levels, the total phosphorus value was used as the deciding factor for classifying the particular Arkansas lake. In at least half of the occurrences where chlorophyll-A and total phosphorus values for an individual lake gave differing trophic levels, the phosphorus value gave a trophic status of eutrophic and the chlorophyll-A value gave an oligotrophic status. In these situations, the likely explanation is that something is limiting plankton production, such as turbidity from suspended solids (OK DEQ 1996).

When the Aquatic Team assigned a trophic status to the 48 Arkansas lakes in the data base, 35 percent were classified as mesotrophic, 63 percent eutrophic, and 2 percent (1 lake) as hypereutrophic. Most of the mesotrophic lakes were borderline eutrophic, and at least half of the eutrophic lakes were borderline mesotrophic. Most of the large Federal reservoirs, with

Table 2.6—Surface area and trophic status of selected Arkansas lakes in the aquatic study area

Lake	County	Size	Trophic status	TP	CHL-A	Secchi	Index[a]	Lake type[b]
		Acres		- - - - *µg/L* - - - -		*In.*		
Atkins	Pope	750	E	87	12.82	39	2.57	C
Bailey	Conway	124	E	87	13.62	40	2.52	C
Barnett	White	245	M	30	0.33	62	0.25	B
Beaver	Benton	28,200	E	48	0.8	107	0.46	A
Beaverford	Faulkner	900	E	77	3.2	81	1.27	B
Blue Mt.	Logan	2,900	E	77	3.2	17.5	4.57	E
Bobb Kidd	Washington	200	E	55	6.45	46	1.34	B
Brewer	Conway	1,165	E	77	0.53	90	0.86	B
Bull Shoals	Marion	45,440	M	30	1.34	146	0.11	A
Catherine	Hot Spring	1,940	E	56	3	42	1.4	A
Charles	Lawrence	562	E	69	25.63	19	4.99	B
Columbia	Columbia	2,950	E	78	1.34	44	1.8	E
Conway	Faulkner	6,700	E	76	26.7	15.8	6.52	E
Cove	Logan	160	M	30	2.94	68	0.26	B
Cox Creek	Grant	300	E	76	1.42	31	2.5	C
Crystal	Benton	60	E	45	5.07	74	0.68	B
Degray	Clark	13,200	E	158	3.2	74	2.18	A
Dequeen	Sevier	1,680	M	30	9.5	59	0.42	A
Dierks	Howard	1,360	E	50	15	47	0.64	A
Elmdale	Washington	180	E	45	1.46	66	0.7	B
Fayetteville	Washington	196	E	86	8.81	53	1.8	B
Ft. Smith	Crawford	416	M	30	1.34	112	0.15	B
Gillham	Howard	1,370	M	30	14	55	0.74	A
Greers Ferry	Cleburne	31,500	E	59	1.07	245	0.25	A
Greeson	Pike	7,200	E	48	0.01	74	0.65	A
Hamilton	Garland	7,300	M	30	2.13	54	0.97	A
Harris Brake	Perry	1,300	E	35	2.7	37	1.02	C
Hinkle	Scott	965	E	47	1.34	81	0.6	B
Horsehead	Johnson	100	M	30	2.8	89	0.2	B
Hurricane	Saline	300	M	30	10.3	31	0.82	C
Lee Creek	Crawford	634	M	30	1.07	72	0.22	B
Maumelle	Pulaski	8,900	E	35	2.1	35	1.06	A
Millwood	Little River	29,500	E	51	8.4	27.3	2.19	E
Nimrod	Yell	3,600	E	49	7.2	37	1.52	E
Norfork	Baxter	22,000	M	30	1.87	142	0.12	A
Ouachita	Garland	40,100	E	47	0.27	183	0.26	A
Overcup	Conway	1,025	E	87	14.14	31	3.27	C
Pine Bluff	Jefferson	500	H	138	26	25.5	6.43	D
Sequoyah	Washington	500	E	55	7.38	35	1.79	B
Shepherd Springs	Crawford	552	M	30	1.34	112	0.15	B
Shores	Franklin	82	M	30	2.4	77	0.23	B
Spring	Yell	82	M	30	2.14	72	0.24	B
Sugarloaf	Sebastian	250	E	47	1.34	77	0.63	B
Swepco	Benton	531	M	30	4.2	61	0.31	B
Wedington	Washington	102	M	30	2.67	108	0.16	B
Wilhelmena	Polk	200	E	77	0.1	37.5	2.06	B
Winona	Saline	1,240	M	30	0.1	134	0.11	A
Wright	Sebastian	350	E	67	6.87	44	1.68	B

µg/L = micrograms per liter; in. = inches; E = eutrophic; M = mesotrophic; TP = total phosphorus; CHL-A = chlorophyll-A; Secchi = visibility measurement.

[a] The Carlson Trophic State Index; see text for description.

[b] AR DPCE lake types; see text for definitions.

Source: AR DPCE (1996).

Table 2.7—Trophic status as determined by chlorophyll-A, total phosphorous, and the Carlson Trophic State Index

Trophic class	CHL-A	Total phosphorus	Carlson Trophic State Index[a]
	- - - - - - - µg/L - - - - - - -		
Oligotrophic	<3	<10	<40
Mesotrophic	3–10	10–30	40–50
Eutrophic	11–56	31–100	50–60
Hypereutrophic	>56	>100	>60

µg/L = micrograms per liter; CHL-A = chlorophyll-A.
[a] The Carlson Trophic State Index; see text for description.
Source: MO DNR (1994), OK DEQ (1996).

high flow-through, fell into these borderline situations while the smaller lakes fell into the higher value range of the eutrophic category (due to low flow-through). Lakes managed by the Arkansas Game and Fish Commission fall within the eutrophic category due in part to ongoing fertilization programs to improve fish production and shade out rooted aquatic weeds by increasing plankton production.

Missouri also classified trophic levels of its lakes using the chlorophyll-A and total phosphorus ranges presented in table 2.7. These values were derived from trophic classifications for reservoirs in Midwestern States. Table 2.8 presents the names, locations, trophic status, total phosphorus, chlorophyll-A, and total nitrogen of selected Missouri lakes. Research is ongoing in Missouri to relate algal production in reservoirs to lake retention times (period of time until the lake water volume is replaced entirely by new water), turbidity, nutrients, and fish production (MO DNR 1994). Trophic status correlated strongly with the physiographic area of the State. In the northern and western agricultural parts of Missouri, most lakes with known trophic status were eutrophic, while in the Highlands the trophic status was equally divided between eutrophic and mesotrophic or oligotrophic. All known hypereutrophic lakes were in historically glaciated northern Missouri while all oligotrophic lakes were in unglaciated, highly weathered Ozark terrain in southern Missouri (MO DNR 1994).

Within the Assessment area in Missouri, 13 percent of the lakes were classified as oligotrophic; these mostly occurred in the mountainous area of St. Francois County. Thirty-two percent of the selected Missouri lakes and reservoirs were classified as mesotrophic and 55 percent as eutrophic.

The two most important water quality parameters sampled under the Oklahoma Conservation Commission's lake sampling program were turbidity and chlorophyll-A (OK DEQ 1996). In some parts of the United States, measures of water clarity like secchi depth or turbidity will often correlate strongly with levels of chlorophyll-A. Usually algae will be the main constituent reducing water clarity and will account for the bulk of measured turbidity. When a strong correlation exists between water transparency and algae, the water-clarity parameter provides a convenient indirect measure of the degree of each lake's trophic status. Based upon 5 years of monitoring data, the Oklahoma Conservation Commission determined, that measurements of water clarity parameters, such as turbidity, were not as highly reliable for evaluating the associated levels of algae as that measured through chlorophyll-A for conditions in Oklahoma lakes and reservoirs. For low turbidity values (< 5 nephelometric turbidity units (NTU's)) and for high turbidity values (> 100 NTU's), the chlorophyll-A values were generally less than 10 parts per billion. Over most of the range of turbidity values encountered in sampled Oklahoma lakes, a given level of turbidity occurring on different lakes could correspond to widely divergent levels of algae. Since chlorophyll-A data were collected directly, they were converted to Carlson Trophic State Index numbers; trophic status was assigned using the relationship given in table 2.7.

Of the 28 Oklahoma lakes within the aquatic study area, 3 percent were classified as oligotrophic, 30 percent mesotrophic, 43 percent eutrophic, 17 percent hypereutrophic, and 7 percent (2 lakes) as silt dominated (table 2.9). Fort Gibson Reservoir was hypereutrophic-silt dominated, and Wister Reservoir was eutrophic-hypereutrophic. Oklahoma lakes were unusual with respect to their colloidal clay content. Resuspension of colloidal clays can produce very high levels of turbidity, a condition found in many Oklahoma lakes. In addition, most of Oklahoma's larger lakes were characterized by a large degree of horizontal mixing. Because of these conditions, the Oklahoma Water Board is exploring alternative ways to determine trophic status.

Table 2.8—Trophic status of selected Missouri lakes in the aquatic study area

Lake	County	Trophic status	TP	CHL-A	TN
			- - - - - - - - -	-μg/L - - - - - - - - -	
Atkinson	St. Clair	E	83	40	1,047
Austin	Texas	M	18	—	501
Binder	Cole	E	50	12	719
Bull Shoals	Taney	M	18	7	359
Council Bluff	Iron	M	9	3	298
Creve Couer	St. Louis	E	148	53	1,090
Fourche	Ripley	O	10	2	255
Fredericktown City	Madison	E	67	33	801
Goose Creek	St. Francois	M	14	4	399
H.S. Truman	Benton	E	44	12	1,120
Harrisonville	Cass	E	42	16	830
Indian Hills	Crawford	E	27	11	562
Lake Capri	St. Francois	O	7	1	314
Lake Carmel	St. Francois	O	8	1	326
Lake Forest (Lake Ann)	Ste. Genevieve	E	39	18	654
Lake Killarney	Iron	E	70	32	692
Lake Marseilles	St. Francois	O	10	2	356
Lake Northwoods	Gasconade	M	24	6	462
Lake of the Ozarks (Lower)	Miller	E	26	12	578
Lake of the Ozarks (Mid)	Camden	E	44	16	618
Lake Taneycomo	Taney	M	24	4	815
Lake Tishomingo	Jefferson	M	19	6	488
Lake Turner	Dent	E	20	18	—
Lake Wapapello	Wayne	E	35	18	525
Lake Wauwanoka	Jefferson	M	14	3	935
Lake Ziske	Dent	E	25	175	—
Lamar	Barton	E	82	46	1,015
Little Prairie	Phelps	E	29	8	501
Loggers	Dent	M	9	4	230
Macs	Dent	E	24	24	630
Miller	Carter	M	18	6	494
Monsanto (St. Joe State Park)	St. Francois	O	10	2	374
Montrose	Henry	E	195	68	1,295
Noblett	Douglas	M	20	5	247
Norfork	Ozark	M	24	6	614
North	Cass	E	64	25	850
Pleasant Valley	Gasconade	E	31	26	882
Pomme de Terre	Hickory	E	25	14	523
Pomona	Howell	E	50	10	605
Raintree	Cass	E	55	23	991
Ripley County	Ripley	E	38	35	904
Roby	Texas	M	16	4	434
Shane	Dent	O	7	1	393
Shawnee	Dent	E	32	28	656
Sims Valley	Texas	E	28	12	484
Spring Fork	Pettis	E	134	46	1,186
Stockton	Cedar	M	14	—	391
Sunnen	Washington	M	11	2	264
Table Rock	Stone	M	13	6	408
Tebo (Westmoreland)	Pettis	M	18	4	592
Timberline	St. Francois	O	10	2	309
Wanda Lee	Ste. Genevieve	E	63	30	64
Winnebago	Cass	E	50	19	799

E = eutrophic; M = mesotrophic; O = oligotrophic; TP = total phosphorus; CHL-A = chlorophyll-A; TN = total nitrogen; μg/L = micrograms per liter; — = data unavailable.
Source: MO DNR (1994).

Table 2.9—Surface area and trophic status of selected Oklahoma lakes in the aquatic study area

Lake	County	Surface area	Trophic status
		Acres	
Broken Bow	McCurtain	14,200	M
Brown	Pittsburg	319	SD
Carl Albert	Latimer	183	M
Cedar (Mena)	Le Flore	78	M
Church (Lloyd)	Latimer	160	E
Clayton (Old)	Pushmataha	66	M
Eucha	Delaware	2,860	H
Fort Gibson	Cherokee	14,900	H, SD
Greenleaf	Muskogee	920	M
Hudson	Mayes	10,900	E
Hugo	Choctaw	13,250	E
John Wells	Haskell	194	O
Kerr	Le Flore	43,800	E
Grand Lake O' the Cherokees	Mayes	46,500	E
Nanih Waiya	Pushmataha	131	E
Ozzie Cobb	Pushmataha	116	E
Pine Creek	McCurtain	3,750	E
Raymond Gary	Choctaw	263	E
Sardis	Pushmataha	13,610	M
Spavinaw	Mayes	1,584	E
Spiro (New)	Le Flore	254	E
Spiro (Old)	Le Flore	34	H
Stillwell	Adair	188	M
Talihina	Latimer	23	E
W.R. Holway	Mayes	715	M
Wayne Wallace	Latimer	94	M
Webbers Falls	Muskogee	11,600	H
Wister	Le Flore	7,333	E, H

E = eutrophic; M = mesotrophic; O = oligotrophic;
H = hypereutrophic; SD = silt dominated.
Source: OK DEQ (1996).

Only the 1996 *Arkansas Water Quality Inventory Report* (AR DPCE 1996) contained a trend analysis (comparing 1989 versus 1994 data). The Aquatic Team noted no significant trends in these data, which consist of only one or two measurements during the 6 years.

Within the Assessment area, Oklahoma had a slightly higher percentage (78 percent) of Federal reservoirs that were eutrophic or hypereutrophic compared to Missouri at 44 percent and Arkansas at 75 percent. Had the two main stem lock and dam reservoirs on the Arkansas River in Arkansas (at Ozark and Dardanelle, AR) been classified, then Oklahoma and Arkansas would have had nearly the same percentage split between eutrophic and mesotrophic reservoirs. All large lakes and reservoirs in the Arkansas Valley drainage were eutrophic or hypereutrophic. The reservoirs of all other Assessment-area river basins were more evenly split between eutrophic and mesotrophic.

Implications and Opportunities

Given the concerns discussed earlier in this section about turbidity or secchi visibility and chlorophyll-A measurements not being the most accurate measures to determine aquatic productivity or trophic status, additional research is certainly appropriate. While the use of a standardized formula to calculate trophic status for lakes across the Nation might be quite useful for some purposes, it is a very weak analytical tool at a more localized level. The research being conducted on trophic classification by Missouri and Oklahoma may provide better monitoring tools for the Ozark-Ouachita Highlands. States in the Assessment area will continue to strive for better ways of determining trophic status and water quality of lakes.

Ground Water Quality

Question 2.3: What are the status and apparent trends of the quality of ground water in the Highlands?

Dissolved, colloidal, and suspended constituents in ground water define water quality with respect to the various potential uses of the resource. The presence of many dissolved constituents at low concentrations is acceptable and even desirable for most uses. However, concentrations above certain threshold levels (depending upon the particular constituent and specific water use) can impair water quality. Chemical constituents that define water quality derive from (1) natural geochemical processes occurring in the hydrologic cycle, (2) general biological activity, and (3) human activities. The quality of ground water varies widely from one location to another, often on a local scale, and even from one subsurface horizon to another at the same site. Indeed, the very definitions of good water quality versus poor water quality are subjective and vary at the regional and even local scale. For example, administrators of water use in some municipalities might consider chloride concentrations of more than 1,000 mg/L or nitrate concentrations of 7 mg/L as nitrogen as "acceptable." However, other administrators, whose aquifers yield water with less than 20 mg/L chloride and less than 0.2 mg/L nitrate, might consider the former values unacceptable. Thus, analysis of data on the quality of ground water must include regional and local hydrologic conditions, land uses, definitions, and human effects on water chemistry and water use.

With the advent of industrial fixation of nitrogen for fertilizers, the amount of global atmospheric nitrogen that is converted each year to a form accessible for use by living organisms on land has doubled during this century (Smil 1997). The results of this historic environmental change—coupled with increasing human population, conversion of land to agricultural use, and greatly increased reliance upon nitrogen- and phosphorous-bearing fertilizers within the Ozark Plateaus and Ouachita Provinces—has led to notable changes in water quality in some parts of the Assessment area. This section of Chapter 2 includes discussions of the distribution of inorganic substances and nutrients in ground water and other influential factors related to these resulting effects on the water quality in the Highlands.

Key Findings

1. The Springfield Plateau aquifer, the Ozark aquifer, and aquifers of the Ouachita Province generally provide water of excellent quality, though substantial differences in basic water chemistry occur among these three settings.
2. Ground water from springs differed substantially in quality from that from wells in the Ozark aquifer, the Springfield Plateau aquifer, and the aquifers of the Ouachita Province. Springs in the Springfield Plateau and Ozark aquifers are more susceptible to contamination from surface sources.
3. Wide-ranging, inorganic concentrations observed in aquifers in the Ouachita Province are indicative of both the province's diverse geochemical environments and, for some water quality measures, the influential land uses that are present.
4. Background concentrations of nutrients in the Springfield Plateau and Ozark aquifers are low; nutrient concentrations were below detection limits in many samples collected from sites in heavily forested areas.
5. Nitrite plus nitrate was detected more often and in greater concentrations than any of the other nutrients. Concentrations were greater than background concentrations in many samples from the Springfield Plateau and Ozark aquifers and were positively correlated to the percent of agricultural land use around each site. Values ranged from less than 0.05 to 25 milligrams per liter (mg/L) as nitrogen, with a median of 1.6 mg/L in samples from the Springfield Plateau and Ozark aquifers.
6. In the Springfield Plateau and Ozark aquifers, median nitrite plus nitrate concentrations generally were greater in samples from springs than in samples from wells.
7. Concentrations of nitrite, ammonia, and ammonia plus organic nitrogen were affected by land use in the Springfield Plateau and Ozark aquifers.
8. Background concentrations of nutrients in ground water of the Ouachita Province are low; nutrient concentrations were below detection limits in many ground water samples. Nitrite plus nitrate was detected in samples of ground water from sites in the Ouachita Province at concentrations ranging from below detection limits to 4.7 mg/L as nitrogen, with a median of 0.16 mg/L.
9. The occurrence of nutrients in ground water in the Ouachita Province did not show a statistically significant correlation with the percentage of agricultural land use or urban land use around each site.

Data Sources and Methods of Analysis

The Geological Survey began full implementation of the National Water-Quality Assessment (NAWQA) program in 1991 to provide a nationally consistent description of the water quality for a large part of the Nation's water resources. Results contained in this report for the Ozark Plateaus are from a NAWQA study of data collected from 1993 through 1995 (Adamski 1997a, b). The NAWQA program is described in reports by Hirsch and others (1988), Leahy and others (1990), and Freiwald (1991) and is found on the following Web site: <http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html>.

Previous investigations of the regional hydrogeology and movement and quality of ground water in the Ozark Plateaus were part of the Geological Survey's central Midwest analysis of the regional aquifer system (RASA) (Imes and Emmett 1994, Baker and Leonard 1995). Feder (1979) investigated the geochemistry of the ground water of Missouri. The hydrogeology and water quality of northwestern Arkansas were investigated by Lamonds (1972), Steele and others (1986), Steele and Adamski (1987), Leidy and Morris (1990), and Adamski and others (1995).

The limited number of studies of ground water quality in the Ouachita Province have been more localized in scope and have not involved uniform sampling and analysis methods to ensure comparability of results as have the NAWQA studies. Marcher and others (1987) and Bryant and others (1983) described regional hydrology pertaining to coal mining. Independent assessments of local and regional ground water resources and potential mining effects in the western Ouachita Mountains and Arkansas Valley have been conducted and presented in a series of reports by Marcher and others (1981; 1983a, b, c), Slack (1983), and Christenson (1995). Bedinger and others (1979) investigated the ground water hydrology of the Hot Springs, AR, area. Ground water in the Arkansas Valley was studied by Bedinger and others (1963) and Cordova (1963). Albin (1965), Plebuch and Hines (1967), and Halberg and others (1968) described ground water resources at a local scale in the eastern Ouachita Mountains. Cavalier and Lavy (1987) conducted sampling for the Forest Service to monitor the quality of ground water across the central area of the Ouachita Mountains.

In the Ozark Plateaus Province, 229 samples of ground water were collected from 215 sites as part of the Ozark Plateaus NAWQA study unit (Adamski 1997a). Samples were collected from 1993 through 1995 using a network of springs and wells that were randomly selected within the Springfield Plateau and Ozark aquifers. (The unconfined parts of the Ozark aquifer coincide with the Salem Plateau (Adamski 1997b). Samples were analyzed for field-measured parameters (temperature, specific conductance, pH, and alkalinity), major ions, nutrients, dissolved organic carbon, methylene blue active substances, tritium, and 88 pesticides including metabolites. Using descriptive and statistical methods, the Aquatic Team analyzed water quality data from 199 sites for inorganics and nutrients from the NAWQA study.

In the Ouachita Province, data were available from 107 sites, which included 33 springs and 74 wells (fig. 2.15). These data were derived for this report from Geological Survey and Forest Service data bases for 1970 to 1994. Many of these samples were collected between 1977 and 1986, but comprehensive data were not available for all sites. Temperature and specific conductance data were available for 103 sites, pH for 107 sites, alkalinity for 45 sites, sulfate for 107 sites, and dissolved solids for 53 sites. Ammonia and nitrite data were available for 12 sites, nitrite plus nitrate for 45 sites, and orthophosphorous for 20 sites.

The Aquatic Team analyzed these data to identify factors affecting the geochemistry of the aquifer. The team used the non-parametric Kruskal-Wallis analysis-of-variance test (Helsel and Hirsch 1992) to identify statistically significant differences in the medians of inorganics and nutrients between samples from different physiographic areas and site types (springs and wells). The difference is assumed to be significant if the probability (*P* value) is less than 5 percent (< 0.05) that the observed difference occurs by chance. In other words, if the differences in the median values between the two groups are greater than would be expected by chance, these data will be described as statistically significant.

Patterns

Following is a brief, general discussion of the inorganic constituents of the Springfield Plateau and Ozark aquifers and the aquifers of the Ouachita Province. Nutrients in the ground water of these areas are discussed next. Pesticide use affecting ground water quality is presented in detail in Chapter 4 of this report.

Inorganics. Water samples for inorganics were collected from 59 springs and 49 domestic wells in the Springfield Plateau aquifer from 1993 through 1995. The water type throughout most of this aquifer is calcium or

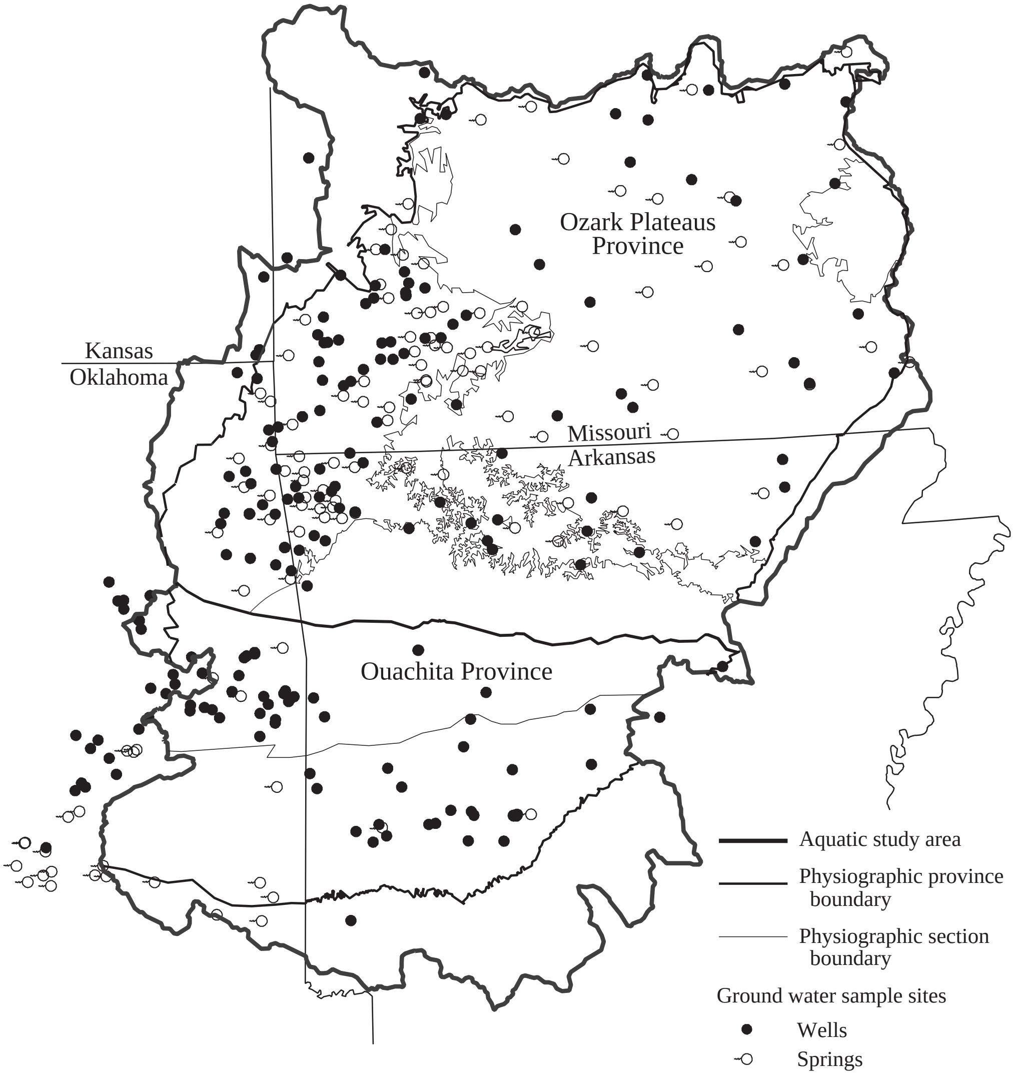


Figure 2.15—Location of ground water sampling sites in the aquatic study area.

calcium-magnesium bicarbonate. The first third of table 2.10 shows that water temperatures ranged from 12.2 to 25 °C and specific conductance ranged from 81 (at 12.5 °C) to 1,553 microsiemens per centimeter (µS/cm) at 25 °C in the Springfield Plateau aquifer. Values of pH varied from 5.2 (acidic) to 7.9 (slightly basic). Alkalinity ranged from 16 to 297 mg/L as calcium carbonate ($CaCO_3$), sulfate from 0.7 to 180 mg/L as SO_4, and concentrations of dissolved solids ranged from 55 to 872 mg/L.

Water from Springfield Plateau aquifer springs was geochemically different from water from wells in the Springfield Plateau aquifer. In general, median specific conductance, pH, alkalinity, and dissolved solids as well as concentrations of calcium and magnesium were statistically greater in samples from wells than in samples from springs in the Springfield Plateau aquifer. In contrast, concentrations of dissolved oxygen, potassium, chloride, and silica were statistically greater in spring samples than in well samples. Locally high concentrations of other ions in ground water, including sodium, chloride, and sulfate, probably result from the ground water interacting with nearby Pennsylvanian-age shales.

As shown on the middle third of table 2.10, water samples for inorganics were collected from 32 springs and 60 domestic wells in the Ozark aquifer from 1993

Table 2.10—Ground water quality data for major aquifers in the Assessment area

Sites	Water temper-ature	Specific conduct-ance	pH, field test	Alka-linity	Sulfate, dissolved	Dissolved solids	Ammonia	Nitrite	Nitrate + nitrate, dissolved	Ortho-phos-phate
	°C	*µS/cm at 25 °C*		*mg/L as* $CaCO_3$	*mg/L as* SO_4	*mg/L*	*- - - - - -mg/L as nitrogen - - - - - -*			*mg/L as P*
Springfield Plateau aquifer										
All sites										
Mean	14.9	358	7.0	155	11.6	206	0.02	0.01	2.60	0.02
Median	14.8	345	7.0	159	4.1	193	0.02	0.01	2.0	0.01
Minimum	12.2	81	5.2	16	0.7	55	0.01	0.01	0.03	0.01
Maximum	25	1,553	7.9	297	180	872	0.15	0.08	25	0.16
Number of samples	107	102	108	108	107	107	107	108	108	107
Wells										
Mean	15.8	391	7.0	171	17.8	225	0.02	0.01	2.17	0.01
Median	15.4	366	7.1	183	5.5	214	0.02	0.01	1.1	0.01
Minimum	12.5	81	5.2	16	0.7	55	0.01	0.01	0.03	0.01
Maximum	25	1,553	7.9	284	180	872	0.15	0.08	25	0.16
Number of samples	49	49	49	49	48	48	48	49	49	48
Springs										
Mean	14.2	327	6.9	141	6.47	190	0.02	0.01	2.95	0.02
Median	14	327	7.0	134	4.0	178	0.01	0.01	2.6	0.02
Minimum	12.2	83	6.0	24	1.8	61	0.01	0.01	0.3	0.01
Maximum	18.8	570	7.6	297	33	382	0.06	0.02	8.3	0.13
Number of samples	58	53	59	59	59	59	59	59	59	59
Ozark aquifer										
All sites										
Mean	15.6	498	7.3	243	15.3	278	0.03	0.01	0.84	0.01
Median	15.3	468	7.3	237	7.65	259	0.02	0.01	0.21	0.01
Minimum	9.5	225	6.7	116	0.20	133	0.01	0.01	0.03	0.01
Maximum	24.2	1,825	8.2	478	190	1,220	0.36	0.18	5.2	0.03
Number of samples	92	87	92	87	90	90	91	91	91	91
Wells										
Mean	16.4	529	7.3	241	19.5	299	0.04	0.01	0.78	0.01
Median	15.9	511	7.4	230	11	275	0.02	0.01	0.10	0.01
Minimum	9.5	225	6.8	116	0.20	133	0.01	0.01	0.03	0.01
Maximum	24.2	1,825	8.2	478	190	1,220	0.36	0.18	5.2	0.02
Number of samples	60	57	60	57	59	59	60	60	60	60
Springs										
Mean	14.3	437	7.1	244	7.2	238	0.02	0.01	1.0	0.01
Median	14.2	453	7.0	248	5.5	250	0.02	0.01	0.5	0.01
Minimum	12.9	247	6.7	146	1.5	143	0.01	0.01	0.03	0.01
Maximum	16.9	637	7.7	365	36	332	0.04	0.01	4.2	0.03
Number of samples	32	30	32	30	31	31	31	31	31	31
Ouachita Province aquifers										
All sites										
Mean	21	754	6.8	155	90	404	0.09	0.01	0.43	0.03
Median	19.5	475	7.0	116	16	219	0.06	0.01	0.16	0.01
Minimum	6.9	23	3.2	1	0.05	15	0.02	0.01	0.01	0.0
Maximum	61.5	6,380	12.2	604	2,900	5,170	0.3	0.01	4.74	0.3
Number of samples	103	103	104	45	107	53	12	12	45	20

(continued)

Table 2.10—Ground water quality data for major aquifers in the Assessment area (continued)

Sites	Water temper-ature	Specific conduct-ance	pH, field test	Alka-linity	Sulfate, dissolved	Dissolved solids	Ammonia	Nitrite	Nitrate + nitrate, dissolved	Ortho-phos-phate
	°C	*µS/cm at 25 °C*		*mg/L as $CaCO_3$*	*mg/L as SO_4*	*mg/L*	*- - - - - -mg/L as nitrogen - - - - - -*			*mg/L as P*
					Ouachita Province aquifers (continued)					
Wells										
Mean	20	971	7.0	191	116	497	0.13	0.01	0.27	0.03
Median	19.3	639	7.0	128	22.5	292	0.09	0.01	0.09	0.01
Minimum	6.9	56	3.2	1.0	0.05	42	0.02	0.01	0.01	0.0
Maximum	30	6,380	12.2	604	2,900	5,170	0.3	0.01	1.10	0.3
Number of samples	70	70	71	25	74	33	7	7	19	15
Springs										
Mean	23	291	6.5	109	29	249	0.04	0.01	0.54	0.03
Median	19.8	171	6.7	65	10	161	0.04	0.01	0.20	0.01
Minimum	10	23	4.8	2.3	1.2	15	0.02	0.01	0.02	0.01
Maximum	61.5	2,010	8.0	360	450	1,290	0.08	0.01	4.74	0.12
Number of samples	33	33	33	20	33	20	5	5	26	5

°C = degrees Celsius; µS/cm = microsiemens per centimeter at 25 °C; mg/L = milligrams per liter; $CaCO_3$ = calcium carbonate; P = phosphorus; SO_4 = sulfate.

through 1995. Water type throughout most of the Ozark aquifer is calcium or calcium-magnesium bicarbonate. Temperatures ranged from 9.5 to 24.2 °C, specific conductance from 225 to 1,825 µS/cm, pH from 6.7 to 8.2, alkalinity from 116 to 478 mg/L as $CaCO_3$, sulfate from 0.2 to 190 mg/L as SO_4, and concentrations of dissolved solids ranged from 133 to 1,220 mg/L.

Water from Ozark aquifer springs was geochemically different than water from wells in the Ozark aquifer. In general, median temperature, pH, and sulfate concentrations were statistically greater in samples from wells than in samples from springs in this aquifer.

As shown on the last third of table 2.10, data on inorganic characteristics were available for 33 springs and 74 wells sampled since 1970 in the Ouachita Province aquifers, and water temperatures ranged from 6.9 to 61.5 ºC. Specific conductance ranged from 23 to 6,380 µS/cm, pH from 3.2 to 12.2, alkalinity from 1 to 604 mg/L as $CaCO_3$, sulfate from 0.05 to 2,900 mg/L, and concentrations of dissolved solids from 15 to 5,170 mg/L.

Nutrients. Data about ground water quality compiled for this study were analyzed for nitrite, nitrite plus nitrate, ammonia, ammonia plus organic nitrogen, phosphorus, and orthophosphate. Summary statistics of selected nutrient data for the ground water samples compiled during this study are listed in table 2.10. Sufficient data for statistical comparisons between aquifers of the Ozark Plateaus and Ouachita Provinces only exist for nitrite plus nitrate. No data existed in the Ouachita Province for ammonia plus organic nitrogen and phosphorus.

Background concentrations of nutrients in ground water of the Springfield Plateau and Ozark aquifers—determined from concentrations in samples from reference sites and forested areas—were below detection limits in many samples (Adamski 1997a). In samples collected from 25 heavily forested sites (where the forest cover is greater than or equal to 90 percent of the area within a 1-mile radius of the site), the 90th-percentile concentrations (assumed to represent maximum background concentrations) for nutrients were as follows: ammonia, 0.02 mg/L; nitrite, less than 0.01 mg/L; nitrite plus nitrate, 0.98 mg/L; ammonia plus organic nitrogen, less than 0.20 mg/L; phosphorus, 0.02 mg/L; and orthophosphate, 0.01 mg/L.

Background concentrations of nitrite plus nitrate in ground water of Ouachita Province aquifers were estimated at 0.4 mg/L as nitrogen, based on five samples from heavily forested areas in the Ouachita Province. Not enough data on other nutrient forms exist in the Ouachita Province to determine background concentrations.

Nitrite. Nitrite concentrations generally were low in samples of ground water in the Springfield Plateau and Ozark aquifers. About 80 percent of the nitrite concentrations in these aquifers were less than the detection limit of 0.01 mg/L as nitrogen. The source of nitrite in ground water of the Springfield Plateau and Ozark aquifers appears to be related to land use. Results of Kruskal-Wallis test indicated that the percentage of agricultural land use was greater around sites where nitrite was detected than around sites where nitrite was not detected.

Nitrite concentrations in samples from the Springfield Plateau and Ozark aquifers were inversely correlated with dissolved oxygen, particularly for wells in the Springfield Plateau aquifer. Dissolved oxygen in most samples was high, ranging from less than 0.1 to 12 mg/L, with a median of 6.8 mg/L. Nitrite is unstable in aerated water (Hem 1985); hence, most of the nitrite in ground water of the Springfield Plateau and Ozark aquifers probably oxidizes rapidly to nitrate.

Nitrite probably is more common and more stable in deep parts of the Springfield Plateau and Ozark aquifers than in shallow parts. Nitrite concentrations in samples from three deep monitoring wells were greater than 0.1 mg/L, whereas nitrite concentrations in samples from all but one of the shallow monitoring wells were less than 0.04 mg/L. In addition, nitrite was detected more often in samples from wells than in samples from springs.

Data exist for only 12 nitrite analyses of the Ouachita Province aquifers. None of the samples showed concentrations above the 0.10 mg/L detection limit.

Nitrite plus nitrate. Median nitrite plus nitrate concentrations were statistically greater in Springfield Plateau wells and springs than in wells and springs in the Ozark and Ouachita Province aquifers (fig. 2.16). Median nitrite plus nitrate concentrations were 2 mg/L as nitrogen for the Springfield Plateau sites and 0.21 and 0.16 mg/L as nitrogen for all sites in the Ozark and Ouachita Province aquifers, respectively.

In the Springfield Plateau and Ozark aquifers, nitrite plus nitrate was detected in ground water samples more often and in greater concentrations than any other form of nitrogen. Because nitrite was below the detection limit in most samples, nitrite plus nitrate in ground water samples consisted primarily of nitrate.

Nitrite plus nitrate concentrations in the Springfield Plateau and Ozark aquifers commonly exceeded background levels. Nitrite plus nitrate concentrations were greater than 0.98 mg/L as nitrogen in 57 percent of the samples. Nitrite plus nitrate concentrations in samples from four sites exceeded the maximum contaminant level (MCL) of 10 mg/L as nitrogen for nitrate in drinking water. These results indicate that (1) elevated concentrations of nitrite plus nitrate in ground water of the Springfield Plateau and Ozark aquifers are widespread, particularly in areas where land use is predominantly agricultural, and (2) ground water in both aquifers is vulnerable to surface contamination. Susceptibility of the aquifers to such contamination stems from

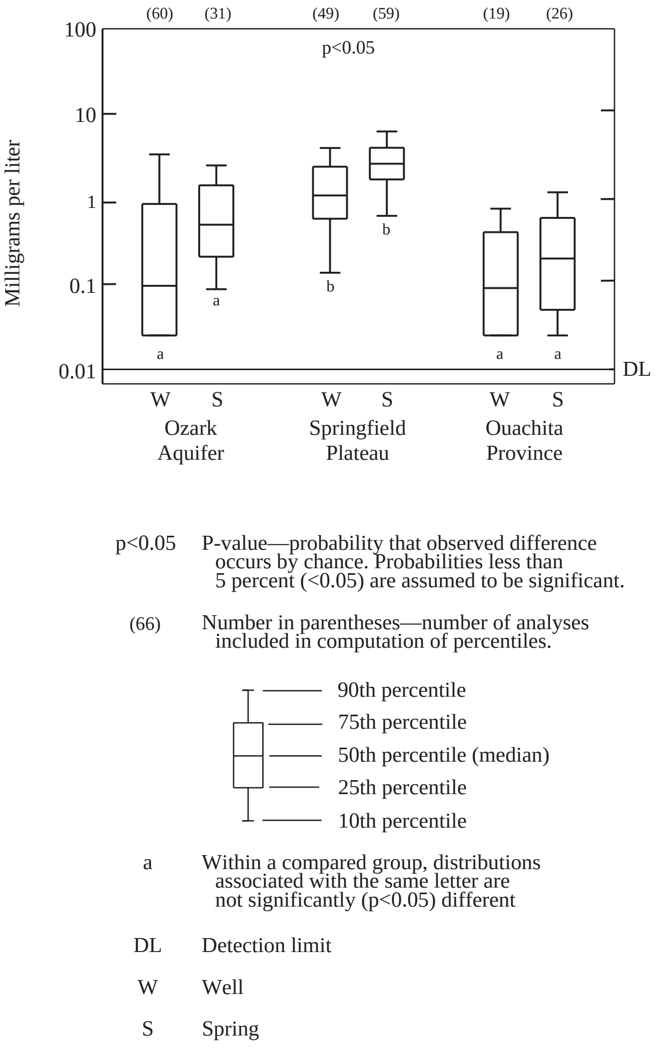


Figure 2.16—Concentrations of nitrite plus nitrate concentrations in wells and springs in the three major aquifers of the Assessment area.

the region's permeable soils and the fractures and solution openings in the bedrock that allow rapid recharge of the ground water by percolation (the slow passage of a liquid through a filtering medium).

Nitrite plus nitrate concentrations in ground water of the Ozark Plateaus were negatively correlated with percent forest cover within a 1-mi radius and positively correlated with agriculture use. These correlations are strong considering the complexities of the Ozark Plateaus hydrogeology and the difficulty and potential degree of error in determining the exact recharge areas of springs and contributing areas to wells. These results indicate that concentrations of nitrite plus nitrate in ground water increase as percent of agricultural land use around the site increases. The correlation was stronger for samples from springs than for samples from wells.

Median concentrations of nitrite plus nitrate were statistically greater in samples collected from springs in the Springfield Plateau aquifer than in samples collected from springs in the Ozark and Ouachita Province aquifers (fig. 2.16). These results probably are related to the substantially greater agricultural land use overlying the Springfield Plateau aquifer compared to the Ozark and Ouachita aquifers. Median agricultural land use around spring sites in the Springfield Plateau aquifer was 67 percent compared to 9 percent agricultural land use around spring sites in the Ozark aquifer.

Median nitrite plus nitrate concentrations were not statistically different between samples from wells and samples from springs in the aquifers (fig. 2.16). Median nitrite plus nitrate concentrations for samples from both springs and wells in the Ozark aquifer were less than 1 mg/L, which is within background levels, because most sites, particularly springs, have a large percent of forest cover associated with them.

In the Ouachita Province, nitrite plus nitrate was detected in ground water samples more often and in greater concentrations than any other form of nitrogen. Nitrite plus nitrate concentrations in the aquifers of the Ouachita Province exceeded the background level of 0.4 mg/L in 13 of 45 samples (29 percent). Nitrite plus nitrate did not commonly exceed 1 mg/L (5 of 45 samples, 11 percent). Nitrite plus nitrate concentrations did not exceed the MCL of 10 mg/L as nitrogen for nitrate in drinking water in any sample.

Agricultural or urban land uses did not appear to be significant factors affecting nitrite plus nitrate concentrations in the Ouachita Province. Nitrite plus nitrate concentrations in samples showed no correlation to the percentages of agricultural or urban land uses around each sampled site.

Median nitrite plus nitrate concentrations were greater in samples collected from springs (0.2 mg/L) compared to samples collected from wells (0.09 mg/L); however, the difference is not statistically significant. Land use around well and spring sites was not statistically different, either.

Ammonia. As with nitrite plus nitrate, ammonia concentrations in most samples of ground water in the Springfield Plateau and Ozark aquifers were low (table 2.10). Ammonia concentrations were less than the detection limit of 0.01 mg/L as nitrogen in 22 percent of the samples. Ammonia concentrations were less than or equal to the background concentration of 0.02 mg/L as nitrogen in 76 percent of the samples. Thirty samples had ammonia concentrations greater than 0.03 mg/L.

As with nitrite and nitrite plus nitrate, the source of ammonia in ground water samples in the Springfield Plateau and Ozark aquifers probably was related to land use, however, concentrations of ammonia in samples did not statistically correlate with percent agricultural land use around sites. Data exist for only 12 ammonia analyses for the Ouachita Province aquifers. Only one concentration was detected above the detection limit.

Ammonia plus organic nitrogen. As with nitrite and ammonia, concentrations of ammonia plus organic nitrogen in samples from Springfield Plateau and Ozark aquifers were low. Ammonia plus organic nitrogen was detected in less than 10 percent of the samples.

The ammonia plus organic nitrogen detected in the samples in the Springfield Plateau and Ozark aquifers consisted primarily of organic nitrogen. Organic nitrogen ranged from 27 to 98 percent of the concentration, with a median of 75 percent. The presence of organic nitrogen in water indicates contamination by sewage or other organic wastes (Hem 1985). Because most of these samples were from sites near pastures and livestock operations, the source of organic nitrogen in the samples probably was animal wastes.

Like nitrite and ammonia, organic nitrogen is unstable in water with high concentrations of dissolved oxygen

(Hem 1985) and is probably oxidized rapidly to nitrate. Samples from springs and domestic wells, even sites located in or near pastures, commonly had concentrations of nitrite, ammonia, and organic nitrogen less than the detection limit. This result is consistent with the high concentrations of dissolved oxygen common in samples from Ozark Plateaus sites.

Phosphorus and orthophosphate. Concentrations of phosphorus and orthophosphate (table 2.10) were low in ground water samples collected in the Springfield Plateau and Ozark aquifers. Phosphorus and orthophosphate were less than the detection limit of 0.01 mg/L as phosphorus in 41 percent of the samples. Phosphorus was greater than the background concentration of 0.02 mg/L in about 15 percent of the samples; orthophosphate was greater than the background concentration of 0.01 mg/L as phosphorus in 30 percent of the samples. Twenty-one samples had phosphorus or orthophosphate concentrations greater than or equal to 0.05 mg/L as phosphorus.

Phosphorus concentrations in samples were measured as the sum of all phosphorus forms present, including orthophosphate. The median of the differences between phosphorus and orthophosphate concentrations in samples in the Springfield Plateau and Ozark aquifers was less than 0.01 mg/L as phosphorus. With few exceptions, phosphorus in samples consisted primarily of orthophosphate.

Median orthophosphate concentrations were statistically greater in samples from Springfield Plateau springs (0.02 mg/L) than in samples from Ozark aquifer springs (0.01 mg/L). As with nitrite plus nitrate, the differences in orthophosphate concentrations between samples from the two aquifers probably resulted from differences in land use overlying the aquifers.

Median phosphorus and orthophosphate concentrations were statistically different between samples from springs (0.02 mg/L) and samples from domestic wells (less than 0.01 mg/L) in the Springfield Plateau aquifer. The results, which correspond with the results of nitrite plus nitrate analyses, indicate that water from springs generally is more susceptible to surface contamination than water from wells.

In the Ouachita Province aquifers, data exist for only 20 samples for orthophosphate; 2 concentrations were detected above the detection limit. There was no statistical difference between orthophosphate concentrations between aquifers in the Ozark Plateaus and Ouachita Province.

The solubility of phosphorus is affected by pH and concentrations of other ions in the water. Phosphorus can form insoluble residues with calcium and with aluminum and iron hydroxides. Phosphorus also can be absorbed and/or adsorbed onto clay minerals such as kaolinite (Brady 1984). Hence, most of the phosphorus applied to pastures in the Assessment area could either remain in the soil or be transported with particulates in the water.

Implications and Opportunities

Ground water from springs differed substantially from wells in the Springfield Plateau, the Ozark, and the Ouachita Province aquifers. Differences observed may be attributed to shallower and shorter average flow paths for water discharging in springs, closer proximity to recharge areas, and greater contact with the surface environment. These data indicate that springs are more susceptible to contamination from surface sources. Wide-ranging, inorganic water quality values observed in the Ouachita Province are indicative of the Province's diverse geochemical environments and, for some water quality resources, influential land uses that are present.

Nutrient concentrations in ground water were related to land use in the Springfield Plateau and Ozark aquifers. Median concentrations of nutrients were greater in samples from the Springfield Plateau aquifer, where agricultural land use predominates, than in samples from the Ozark aquifer, where forested land cover predominates. Nitrite plus nitrate concentrations positively correlated to percent agricultural land use around each site. The presence of organic nitrogen in some samples indicates contamination by organic wastes—likely from manure.

In the Ouachita Province, nitrite plus nitrate was detected in ground water at concentrations ranging from below detection limits to 4.7 mg/L as nitrogen, with a median of 0.16 mg/L. Background concentrations of nutrients in ground water of the Ouachita Province were low; nutrient concentrations were below detection limits in many samples. Nutrient data from forested sites in the Ouachita Province may be used to define background concentrations of nitrite plus nitrate. The occurrence of nutrients in the Ouachita Province did not show a statistically valid correlation with percent agricultural land use or urban land use around each sampled site.

The Springfield Plateau, Ozark, and Ouachita Province aquifers generally provide water of excellent quality, though substantial differences exist in the basic water chemistry of these settings. With minimal treatment, the water in these aquifers generally is usable for demanding applications (e.g., municipal water supply and agricultural use). However, quantities are very limited in some areas, particularly in the Ouachita Province. In addition, all the aquifers are locally affected by land uses such as mining, agriculture, and urbanization.

Aquatic Animals and Their Habitats

This section addresses the biology of aquatic systems and, to a lesser degree, the kinds and types of aquatic and riparian habitats within the Assessment area. In contrast to the preceding portions of this chapter, the following discussion does not make use of physiographic provinces. Instead, the Aquatic Team chose to use ecological sections to provide a more ecologically refined way to examine patterns across the watersheds of the Assessment area (as explained in the "Data Sources and Methods of Analysis" subsection).

Diversity of Fishes

Question 2.4: What are the status and distribution of fishes within the Assessment area?

The Ozark-Ouachita Highlands are part of a region—the Southern United States plus the Missouri Ozarks—that harbors the richest freshwater fish fauna on the North American continent (Warren and Burr 1994). The Highlands' streams and rivers alone are home to at least 190 native fish species, representing 51 percent of the native freshwater fishes of the entire Mississippi River Basin, about 24 percent of those of the Continental United States, and 18 percent of all native freshwater fishes of North America (Burr and Mayden 1992, Warren and Burr 1994). Arkansas, Missouri, and Oklahoma each have a higher diversity of fishes than any other State of comparable size west of the Mississippi River (Warren and Burr 1994). A major portion of that diversity is concentrated in the Assessment area (Pflieger 1975, Cross and others 1986, Robison and Buchanan 1988).

The fishes of the aquatic study area reside within a much larger natural region that encompasses geographically disparate and large tributaries of the western Mississippi Alluvial Basin (e.g., the Missouri, Arkansas, and Red Rivers) and borders or encompasses all or part of eight ecological sections (see "Data Sources and Methods of Analysis"). Complex drainage histories beginning prior to the Pleistocene Age set the stage for the division, isolation, and mixing of fish faunas that in large part account for the richness and distinctiveness of the region's fishes (Mayden 1985, 1987a, b; 1988a, b; Cross and others 1986; Robison 1986). The Highlands are drained by several major river basins emptying into the Mississippi Alluvial Basin. These may be divided into two major groups: easterly flowing tributaries (primarily the Gasconade, Osage, Meramec, St. Francis, Black, White, and Arkansas Rivers) and southerly flowing tributaries (primarily the Kiamichi, Little, and Ouachita Rivers).

The Forest Service's national hierarchical framework for classifying and mapping aquatic ecological units (Maxwell and others 1995) places the Assessment area in the Arctic-Atlantic subzone, Mississippi region, Interior Highlands subregion. As major rivers flow into or out of the Highlands, most breach or border one or more major ecotones (transitional zones between ecological communities) that influence diversity and composition of fishes (Pflieger 1971, 1975; Matthews and Robison 1988). To the north and west, the region is bounded by the Central Lowlands and to the south and east, by the West Gulf Coastal Plain and Mississippi Alluvial Plain, respectively. These factors—numerous river systems with varied histories and ecological settings—provide the backdrop for the uniqueness and high diversity of fishes in the Ozark-Ouachita Highlands.

Key Findings

1. Twenty-four fish families are represented by native species in the Assessment area, with five families containing about 78 percent of the fish fauna of the region; two families—the perches (Percidae) and minnows (Cyprinidae)—comprise more than half of the fish fauna.
2. The fish faunas of the aquatic study area have been classified into four distinct geographical regions based on species composition as follows: the Ozark Fish Faunal Region, Southern Ozark and Ouachita Mountain Fish Faunal Region, Big River Fish Faunal Region, and a Lowlands Fish Faunal Region—West Gulf Coastal Plain-Mississippi Delta (Mississippi Alluvial Basin).
3. In the northeastern part of the Assessment area, native fish species richness is concentrated in the Upper St. Francis River, Upper Black River, and Upper White River drainages; in the west, it is concentrated in the drainages of the Neosho-Illinois Rivers and western portions of the Arkansas River.
4. Native fish species density varies across the Assessment area, with the highest densities of fish species associated with ecological-hydrologic units that are generally small and species rich or small and adjacent to species-rich units.
5. Conservatively, at least 14 percent of the fish fauna is endemic to the Assessment area (restricted to a particular geographic area); endemic species are distributed among five fish families, with highest endemicity among darters and minnows. Endemic fishes are concentrated in 2 ecological sections: the Ozark Highlands (16 endemic fish species) and the Ouachita Mountains (7 endemic fish species).

Data Sources and Methods of Analysis

To examine the distribution of fish species, each of the 10 major basins within the Assessment area was subdivided into hydrologic units (watersheds) according to standard eight-digit hydrologic unit codes (HUC's) (fig. 1.2). The Aquatic Team further subdivided 32 of these 50 watersheds to form 2 or 3 "ecological-hydrologic units" by digitally overlaying ecological sections (slightly modified from Keys and others 1995).

From north to south on figure 2.17, the four ecological sections in the Assessment area are the Ozark Highlands (OZ), Boston Mountains (BM), Arkansas Valley (AV), and Ouachita Mountains (OM). Some watersheds within the aquatic study area lie partially in sections outside the Highlands (those italicized in the following tabulation). The following tabulation shows how the ecological sections used in this analysis and in the remainder of this chapter are roughly equivalent to all or portions of the various physiographic units used earlier in this chapter and elsewhere in this report:

Ecological section	**Physiographic unit**
Ozark Highlands	Ozark Plateaus Province minus Boston Mountains
Boston Mountains	Boston Mountains section of Ozark Plateaus Province
Arkansas Valley	Arkansas Valley section of Ouachita Province
Ouachita Mountains	Ouachita Province minus Arkansas Valley section
Mississippi Alluvial Basin	Mississippi Alluvial Plain section of Coastal Plains Province
Middle Coastal Plains, Western	West Gulf Coastal Plain section of Coastal Plains Province
Cross Timbers and Prairie	Small part of Osage Plains section of Central Lowland Province
Osage Plains	Portion of Osage Plains section of Central Lowland Province

The distribution of fishes within a particular ecological-hydrologic unit was determined primarily from maps in Pflieger (1971, 1975), Miller and Robison (1973), and Robison and Buchanan (1988). The determination of a species' occurrence within a unit depended on the temporal (time) coverage, quality, and scale of source distribution maps. Distributions in both Pflieger (1975) and Robison and Buchanan (1988) were presented as drainage maps for each species with dots indicating the occurrence of a fish species at that point within the drainage. The drainage maps allowed the team to make relatively unambiguous interpretations of fish distributions.

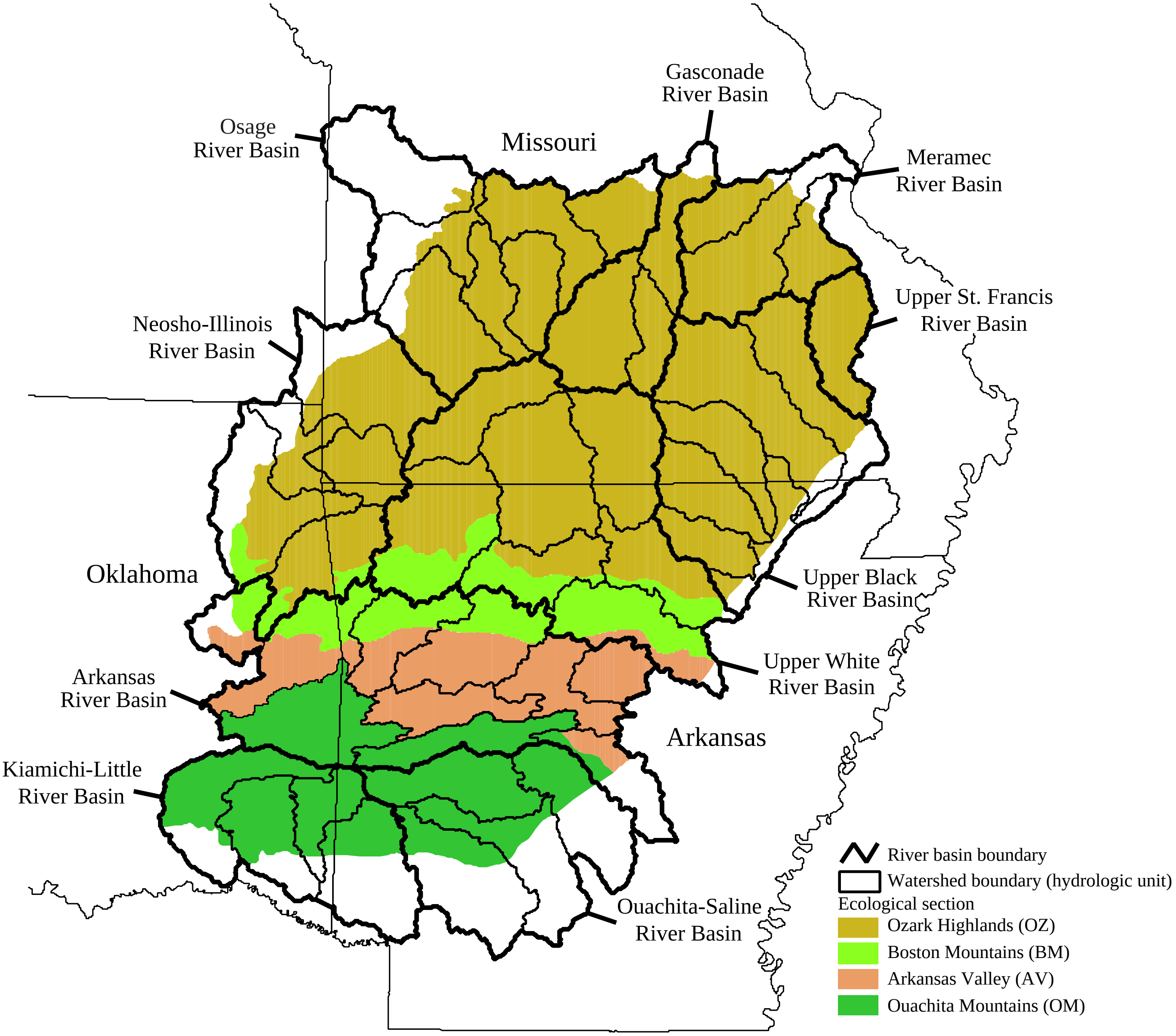


Figure 2.17—River basins, watersheds, and ecological sections of the aquatic study area (showing derivation of ecological-hydrologic units).

Miller and Robison (1973) also used drainage maps for each species, but distributions were shaded rather than indicated by discrete points of occurrence. Nevertheless, the quality and scale of these maps along with textual descriptions of distributions permitted an accurate delineation of a species' occurrence within an ecological-hydrologic unit. Pflieger (1975) reported known collections of fishes in Missouri from about 1905 to 1969. Miller and Robison (1973) are current through the early 1970's for Oklahoma. Robison and Buchanan (1988) covered all known and verified collections of fishes in Arkansas before 1987.

Information from these primary sources was augmented with fish distributional information presented in Lee and others (1980), Cross and others (1986), and Page and Burr (1991). Scientific and common names of fishes generally follow that of Mayden and others (1992). Distributions of species described subsequent to the previously cited works were obtained from Harris (1986, Ozark chub); Mayden (1988a, cardinal shiner); and Humphries and Cashner (1994, rocky shiner). The undescribed darter, *Percina* species, documented by Robison and Buchanan (1988) from the Ouachita River drainage, is included here under the longnose darter.

During late stages of preparation of this chapter, Ceas and Page (1997) described one new species (brook darter) and elevated two subspecies to species status (strawberry and current darters). These last three species are included here under the orangethroat darter.

Fish species were noted as present or absent within each ecological-hydrologic unit and classified as native, endemic, or introduced. Fishes occurring in peripheral (outside the Highlands) ecological-hydrologic units also were noted. The status of a fish species reflects its known historical presence within a unit but does not necessarily indicate its continued present-day occurrence in a unit. Information to account for changes to the fauna is inadequately synthesized for area-wide analysis. Fishes were considered native if the Assessment area is within their known historical range and no evidence of their having been artificially introduced is available. Scientists define endemic fishes as those species that have a restricted range within one locale. Introduced fishes are defined as those that have been intentionally or accidentally released in a locale. Some species can be described as native, endemic, and introduced. For example, Ozark bass initially were found only in the Upper White River Basin drainage where they are native and endemic. Ozark bass have also been introduced to the Illinois watershed. Therefore, Ozark bass occur in all three categories.

Diversity was analyzed using native fish species richness, native fish species density, and number of endemic species. Native fish species richness is the number of native fish species within each ecological-hydrologic unit. Ecological-hydrologic units vary in areal extent, and fish species richness often increases with increases in stream size or area drained. To examine the effect of areal additivity (increases in area may be accompanied by an increase in species), native species richness was divided by the number of square miles (multiplied by 100) to produce native fish species density values for each unit. In addition, the log of native fish species richness was regressed on the log area of ecological-hydrologic units to examine the relationship between species richness and unit size. Native fish species richness, native fish species densities, and regional endemicity were plotted on separate ecological-hydrologic unit maps. Three levels of relative richness, density, and endemicity were recognized among ecological-hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 15 to 17 units (depending on tied scores) with the highest values; secondary levels were assigned to the next highest 15 to 21 units; and tertiary levels, to the remaining units. Hence, primary levels approximate values in the fourth quartile or top 25 percent; secondary levels approximate values in the third quartile or second 25 percent; and tertiary levels approximate values in the first and second quartiles or bottom 50 percent.

Fish faunal composition among drainages of the region was taken from existing works for Arkansas (Matthews and Robison 1988, Matthews and others 1992) and Missouri (Pflieger 1971). Although methods of analysis varied among these authors, each relied on comparing distributions of native fish species and classifying the resulting similarity patterns into fish faunal regions. The fish faunal regions recognized by these authors are highly compatible and generally congruent even along the shared Missouri-Arkansas border. For Assessment purposes, the Aquatic Team assumed that sections of drainages not included in these previous works (e.g., units wholly in eastern Oklahoma) are classified in the same fish faunal regions as adjacent drainages in Arkansas.

Patterns and Trends

Fish faunal composition. Native fish diversity is divided unevenly among families in the Assessment area. Twenty-four fish families are represented by native species within the region (table 2.11). Five families contain about 78 percent of the fish fauna: minnows (69 native species), perches (41), suckers (18), sunfishes and basses (16), and bullhead catfishes (16). Over 52 percent of the native fish fauna is comprised of darters (perch family) and minnows. Some families have fewer representatives, but the Assessment area supports a significant number of North American species in these families. For example, about 25 percent of all topminnows (Fundulidae) and lampreys (Petromyzontidae) from North America are recorded from the Assessment area (Mayden and others 1992).

Analyses of fish faunal composition have been independently undertaken for Arkansas (Matthews and Robison 1988, Matthews and others 1992) and Missouri (Pflieger 1971). The study by Matthews and Robison (1988) used smaller drainage units than used here and

Table 2.11—Native, endemic, and introduced fishes of the aquatic study area

Family	Species	Common name	Native	Endemic	Introduced[a]
Acipenseridae	*Acipenser fulvescens*	Lake sturgeon	X		
Acipenseridae	*Scaphirhynchus platorynchus*	Shovelnose sturgeon	X		
Amblyopsidae	*Amblyopsis rosae*	Ozark cavefish	X	X	
Amblyopsidae	*Typhlichthys subterraneus*	Southern cavefish	X		
Amiidae	*Amia calva*	Bowfin	X		
Anguillidae	*Anguilla rostrata*	American eel	X		
Aphredoderidae	*Aphredoderus sayanus*	Pirate perch	X		
Atherinidae	*Labidesthes sicculus*	Brook silverside	X		
Atherinidae	*Menidia beryllina*	Inland silverside	X		
Catostomidae	*Carpiodes carpio*	River carpsucker	X		
Catostomidae	*Carpiodes cyprinus*	Quillback	X		
Catostomidae	*Carpiodes velifer*	Highfin carpsucker	X		
Catostomidae	*Catostomus commersoni*	White sucker	X		X
Catostomidae	*Cycleptus elongatus*	Blue sucker	X		
Catostomidae	*Erimyzon oblongus*	Creek chubsucker	X		
Catostomidae	*Erimyzon sucetta*	Lake chubsucker	X		
Catostomidae	*Hypentelium nigricans*	Northern hog sucker	X		X
Catostomidae	*Ictiobus bubalus*	Smallmouth buffalo	X		
Catostomidae	*Ictiobus cyprinellus*	Bigmouth buffalo	X		
Catostomidae	*Ictiobus niger*	Black buffalo	X		
Catostomidae	*Minytrema melanops*	Spotted sucker	X		
Catostomidae	*Moxostoma anisurum*	Silver redhorse	X		
Catostomidae	*Moxostoma carinatum*	River redhorse	X		
Catostomidae	*Moxostoma duquesnei*	Black redhorse	X		
Catostomidae	*Moxostoma erythrurum*	Golden redhorse	X		
Catostomidae	*Moxostoma macrolepidotum*	Shorthead redhorse	X		
Catostomidae	*Moxostoma poecilurum*	Blacktail redhorse	X		
Centrarchidae	*Ambloplites ariommus*	Shadow bass	X		
Centrarchidae	*Ambloplites constellatus*	Ozark bass	X	X	X
Centrarchidae	*Ambloplites rupestris*	Rock bass	X		X
Centrarchidae	*Centrarchus macropterus*	Flier	X		
Centrarchidae	*Lepomis auritus*	Redbreast sunfish			X
Centrarchidae	*Lepomis cyanellus*	Green sunfish	X		X
Centrarchidae	*Lepomis gibbosus*	Pumpkinseed			X
Centrarchidae	*Lepomis gulosus*	Warmouth	X		
Centrarchidae	*Lepomis humilis*	Orangespotted sunfish	X		
Centrarchidae	*Lepomis macrochirus*	Bluegill	X		X
Centrarchidae	*Lepomis marginatus*[b]	Dollar sunfish	X		
Centrarchidae	*Lepomis megalotis*	Longear sunfish	X		X
Centrarchidae	*Lepomis microlophus*	Redear sunfish	X		X
Centrarchidae	*Lepomis miniatus*	Redspotted sunfish	X		
Centrarchidae	*Lepomis symmetricus*[b]	Bantam sunfish	X		
Centrarchidae	*Micropterus coosae*	Redeye bass			X
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	X		X
Centrarchidae	*Micropterus punctulatus*	Spotted bass	X		
Centrarchidae	*Micropterus salmoides*	Largemouth bass	X		X
Centrarchidae	*Pomoxis annularis*	White crappie	X		X
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	X		
Clupeidae	*Alosa alabamae*	Alabama shad	X		
Clupeidae	*Alosa chrysochloris*	Skipjack herring	X		
Clupeidae	*Dorosoma cepedianum*	Gizzard shad	X		X
Clupeidae	*Dorosoma petenense*	Threadfin shad	X		X
Cottidae	*Cottus carolinae*	Banded sculpin	X		X
Cottidae	*Cottus hypselurus*	Ozark sculpin	X	X	
Cyprinidae	*Campostoma anomalum*	Central stoneroller	X		X
Cyprinidae	*Campostoma oligolepis*	Largescale stoneroller	X		
Cyprinidae	*Carassius auratus*	Goldfish			X
Cyprinidae	*Ctenopharyngodon idella*	Grass carp			X

(continued)

Table 2.11—Native, endemic, and introduced fishes of the aquatic study area (continued)

Family	Species	Common name	Native	Endemic	Introduced[a]
Cyprinidae	*Cyprinella camura*	Bluntface shiner	X		
Cyprinidae	*Cyprinella galactura*	Whitetail shiner	X		
Cyprinidae	*Cyprinella lutrensis*	Red shiner	X		
Cyprinidae	*Cyprinella spiloptera*	Spotfin shiner	X		
Cyprinidae	*Cyprinella venusta*	Blacktail shiner	X		
Cyprinidae	*Cyprinella whipplei*	Steelcolor shiner	X		
Cyprinidae	*Cyprinus carpio*	Common carp			X
Cyprinidae	*Ericymba buccata*	Silverjaw minnow	X		
Cyprinidae	*Erimystax harryi*	Ozark chub	X	X	
Cyprinidae	*Erimystax x-punctatus*	Gravel chub	X		
Cyprinidae	*Hybognathus argyritis*	Western silvery minnow	X		
Cyprinidae	*Hybognathus nuchalis*	Mississippi silvery minnow	X		
Cyprinidae	*Hybognathus placitus*	Plains minnow	X		
Cyprinidae	*Hypophthalmichthys molitrix*	Silver carp			X
Cyprinidae	*Hypophthalmichthys nobilis*	Bighead carp			X
Cyprinidae	*Luxilus cardinalis*	Cardinal shiner	X		
Cyprinidae	*Luxilus chrysocephalus*	Striped shiner	X		
Cyprinidae	*Luxilus pilsbryi*	Duskystripe shiner	X	X	
Cyprinidae	*Luxilus zonatus*	Bleeding shiner	X	X	
Cyprinidae	*Lythrurus fumeus*	Ribbon shiner	X		
Cyprinidae	*Lythrurus snelsoni*	Ouachita Mountain shiner	X	X	
Cyprinidae	*Lythrurus umbratilis*	Redfin shiner	X		
Cyprinidae	*Macrhybopsis aestivalis*	Speckled chub	X		
Cyprinidae	*Macrhybopsis meeki*[b]	Sicklefin chub	X		
Cyprinidae	*Macrhybopsis storeriana*	Silver chub	X		
Cyprinidae	*Nocomis asper*	Redspot chub	X		
Cyprinidae	*Nocomis biguttatus*	Hornyhead chub	X		
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	X		X
Cyprinidae	*Notropis amblops*	Bigeye chub	X		X
Cyprinidae	*Notropis amnis*	Pallid shiner	X		
Cyprinidae	*Notropis atherinoides*	Emerald shiner	X		
Cyprinidae	*Notropis atrocaudalis*	Blackspot shiner	X		
Cyprinidae	*Notropis bairdi*[b]	Red river shiner	X		
Cyprinidae	*Notropis blennius*	River shiner	X		
Cyprinidae	*Notropis boops*	Bigeye shiner	X		
Cyprinidae	*Notropis buchanani*	Ghost shiner	X		
Cyprinidae	*Notropis chalybaeus*[b]	Ironcolor shiner	X		
Cyprinidae	*Notropis dorsalis*[b]	Bigmouth shiner	X		
Cyprinidae	*Notropis girardi*	Arkansas River shiner	X		
Cyprinidae	*Notropis greenei*	Wedgespot shiner	X	X	
Cyprinidae	*Notropis heterolepis*	Blacknose shiner	X		
Cyprinidae	*Notropis hubbsi*[b]	Bluehead shiner	X		
Cyprinidae	*Notropis maculatus*	Taillight shiner	X		
Cyprinidae	*Notropis nubilus*	Ozark minnow	X		X
Cyprinidae	*Notropis ortenburgeri*	Kiamichi shiner	X	X	
Cyprinidae	*Notropis ozarcanus*	Ozark shiner	X	X	
Cyprinidae	*Notropis perpallidus*	Peppered shiner	X	X	
Cyprinidae	*Notropis potteri*[b]	Chub shiner	X		
Cyprinidae	*Notropis rubellus*	Rosyface shiner	X		X
Cyprinidae	*Notropis sabinae*	Sabine shiner	X		
Cyprinidae	*Notropis shumardi*	Silverband shiner	X		
Cyprinidae	*Notropis stramineus*	Sand shiner	X		
Cyprinidae	*Notropis suttkusi*	Rocky shiner	X	X	
Cyprinidae	*Notropis telescopus*	Telescope shiner	X		
Cyprinidae	*Notropis texanus*	Weed shiner	X		
Cyprinidae	*Notropis volucellus*	Mimic shiner	X		
Cyprinidae	*Opsopoeodus emiliae*	Pugnosed minnow	X		

(continued)

Table 2.11—Native, endemic, and introduced fishes of the aquatic study area (continued)

Family	Species	Common name	Native	Endemic	Introduced[a]
Cyprinidae	*Phenacobius mirabilis*	Suckermouth minnow	X		
Cyprinidae	*Phoxinus erythrogaster*	Southern redbelly dace	X		
Cyprinidae	*Pimephales notatus*	Bluntnose minnow	X		X
Cyprinidae	*Pimephales promelas*	Fathead minnow	X		X
Cyprinidae	*Pimephales tenellus*	Slim minnow	X		
Cyprinidae	*Pimephales vigilax*	Bullhead minnow	X		
Cyprinidae	*Platygobio gracilis*[b]	Flathead chub	X		
Cyprinidae	*Semotilus atromaculatus*	Creek chub	X		X
Elassomatidae	*Elassoma zonatum*	Banded pygmy sunfish	X		
Esocidae	*Esox americanus*	Grass pickerel	X		
Esocidae	*Esox lucius*	Northern pike			X
Esocidae	*Esox masquinongy*	Muskellunge			X
Esocidae	*Esox niger*	Chain pickerel	X		
Fundulidae	*Fundulus blairae*	Western starhead topminnow	X		
Fundulidae	*Fundulus catenatus*	Northern studfish	X		X
Fundulidae	*Fundulus chrysotus*	Golden topminnow	X		
Fundulidae	*Fundulus dispar*	Northern starhead topminnow	X		
Fundulidae	*Fundulus notatus*	Blackstripe topminnow	X		
Fundulidae	*Fundulus olivaceus*	Blackspotted topminnow	X		
Fundulidae	*Fundulus sciadicus*	Plains topminnow	X		
Fundulidae	*Fundulus zebrinus*	Plains killifish	X		
Hiodontidae	*Hiodon alosoides*	Goldeye	X		
Hiodontidae	*Hiodon tergisus*	Mooneye	X		
Ictaluridae	*Ameiurus catus*	White catfish			X
Ictaluridae	*Ameiurus melas*	Black bullhead	X		
Ictaluridae	*Ameiurus natalis*	Yellow bullhead	X		X
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead			X
Ictaluridae	*Ictalurus furcatus*	Blue catfish	X		
Ictaluridae	*Ictalurus punctatus*	Channel catfish	X		X
Ictaluridae	*Noturus albater*	Ozark madtom	X	X	
Ictaluridae	*Noturus eleutherus*	Mountain madtom	X		
Ictaluridae	*Noturus exilis*	Slender madtom	X		X
Ictaluridae	*Noturus flavater*	Checkered madtom	X	X	
Ictaluridae	*Noturus flavus*	Stonecat	X		
Ictaluridae	*Noturus gyrinus*	Tadpole madtom	X		
Ictaluridae	*Noturus lachneri*	Ouachita madtom	X	X	
Ictaluridae	*Noturus miurus*	Brindled madtom	X		
Ictaluridae	*Noturus nocturnus*	Freckled madtom	X		
Ictaluridae	*Noturus placidus*	Neosho madtom	X		
Ictaluridae	*Noturus taylori*	Caddo madtom	X	X	
Ictaluridae	*Pylodictis olivaris*	Flathead catfish	X		
Lepisosteidae	*Atractosteus spatula*	Alligator gar	X		
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	X		
Lepisosteidae	*Lepisosteus osseus*	Longnose gar	X		
Lepisosteidae	*Lepisosteus platostomus*	Shortnose gar	X		
Moronidae	*Morone chrysops*	White bass	X		
Moronidae	*Morone mississippiensis*	Yellow bass	X		
Moronidae	*Morone saxatilis*	Striped bass			X
Mugilidae	*Mugil cephalus*	Striped mullet	X		
Percidae	*Ammocrypta clara*	Western sand darter	X		
Percidae	*Ammocrypta vivax*	Scaly sand darter	X		
Percidae	*Crystallaria asprella*	Crystal darter	X		
Percidae	*Etheostoma asprigene*	Mud darter	X		
Percidae	*Etheostoma blennioides*	Greenside darter	X		
Percidae	*Etheostoma caeruleum*	Rainbow darter	X		
Percidae	*Etheostoma chlorosomum*	Bluntnose darter	X		
Percidae	*Etheostoma collettei*	Creole darter	X		
Percidae	*Etheostoma cragini*	Arkansas darter	X		

(continued)

Table 2.11—Native, endemic, and introduced fishes of the aquatic study area (continued)

Family	Species	Common name	Native	Endemic	Introduced[a]
Percidae	*Etheostoma euzonum*	Arkansas saddled darter	X	X	
Percidae	*Etheostoma flabellare*	Fantail darter	X		X
Percidae	*Etheostoma fusiforme*[b]	Swamp darter	X		
Percidae	*Etheostoma gracile*	Slough darter	X		
Percidae	*Etheostoma histrio*	Harlequin darter	X		
Percidae	*Etheostoma juliae*	Yoke darter	X	X	
Percidae	*Etheostoma microperca*	Least darter	X		
Percidae	*Etheostoma moorei*	Yellowcheek darter	X	X	
Percidae	*Etheostoma nianguae*	Niangua darter	X	X	
Percidae	*Etheostoma nigrum*	Johnny darter	X		
Percidae	*Etheostoma pallididorsum*	Paleback darter	X	X	
Percidae	*Etheostoma parvipinne*[b]	Goldstripe darter	X		
Percidae	*Etheostoma proeliare*	Cypress darter	X		
Percidae	*Etheostoma punctulatum*	Stippled darter	X	X	
Percidae	*Etheostoma radiosum*	Orangebelly darter	X		
Percidae	*Etheostoma spectabile*	Orangethroat darter	X		X
Percidae	*Etheostoma stigmaeum*	Speckled darter	X		
Percidae	*Etheostoma tetrazonum*	Missouri saddled darter	X	X	
Percidae	*Etheostoma whipplei*	Redfin darter	X		
Percidae	*Etheostoma zonale*	Banded darter	X		
Percidae	*Percina caprodes*	Logperch	X		X
Percidae	*Percina copelandi*	Channel darter	X		
Percidae	*Percina cymatotaenia*	Bluestripe shiner	X	X	
Percidae	*Percina evides*	Gilt darter	X		
Percidae	*Percina maculata*	Blackside darter	X		
Percidae	*Percina nasuta*	Longnose darter	X	X	
Percidae	*Percina pantherina*	Leopard darter	X	X	
Percidae	*Percina phoxocephala*	Slenderhead darter	X		
Percidae	*Percina sciera*	Dusky darter	X		
Percidae	*Percina shumardi*	River darter	X		
Percidae	*Percina uranidea*	Stargazing darter	X		
Percidae	*Percina vigil*	Saddleback darter	X		
Percidae	*Stizostedion canadense*	Sauger	X		
Percidae	*Stizostedion vitreum*	Walleye	X		X
Percopsidae	*Percopsis omiscomaycus*[b]	Trout-perch	X		
Petromyzontidae	*Ichthyomyzon castaneus*	Chestnut lamprey	X		
Petromyzontidae	*Ichthyomyzon fossor*	Northern brook lamprey	X		
Petromyzontidae	*Ichthyomyzon gagei*	Southern brook lamprey	X		
Petromyzontidae	*Lampetra aepyptera*	Least brook lamprey	X		
Petromyzontidae	*Lampetra appendix*	American brook lamprey	X		
Poeciliidae	*Gambusia affinis*	Western mosquitofish	X		X
Polyodontidae	*Polyodon spathula*	Paddlefish	X		
Salmonidae	*Oncorhynchus clarki*	Cutthroat trout			X
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout			X
Salmonidae	*Salmo trutta*	Brown trout			X
Salmonidae	*Salvelinus fontinalis*	Brook trout			X
Salmonidae	*Salvelinus namaycush*	Lake trout			X
Sciaendae	*Aplodinotus grunniens*	Freshwater drum	X		

[a] Species "native" to the Assessment area (as a whole) may be classified as "introduced" in certain watersheds where they did not occur naturally.

[b] Denotes a fish species found within the aquatic study area but outside of the Ozark-Ouachita Highlands.

Source: Miller and Robison (1973), Pflieger (1975), Robison and Buchanan (1988).

provided an extensive and detailed analysis. These studies also were limited to the political boundaries of the respective States and varied in the level of classification achieved. A summary of their primary results is presented here; for details, the reader is referred to the original studies.

Analyses in Arkansas and Missouri identified a clear split in fish distributions that separates lowland from upland fishes. Most of the Assessment area is dominated by upland fish species; however, distinct groupings of fishes exist within the uplands. Both studies identified an Ozark Fish Faunal Region, consisting of fish assemblages in the Osage, Gasconade, Meramec, and Upper St. Francis Rivers, much of the Upper White and Upper Black Rivers, and the Neosho-Illinois drainages. The Ozark Fish Faunal Region is the largest and most distinctive such region in the Ozark-Ouachita Highlands (Pflieger 1971, Matthews and Robison 1988).

Matthews and Robison (1988) also identified a Southern Ozark and Ouachita Fish Faunal Region. It includes several of the easternmost tributaries of the Ozark uplift in Arkansas (e.g., the Eleven Point, Strawberry, and lowermost Spring Rivers and portions of the Middle Fork White River), the White River below Batesville, and the Little Red River. The Southern Ozark and Ouachita Fish Faunal Region also includes most of the tributaries of the Arkansas River that drain the southern flanks of the Boston Mountains. Virtually all the streams on the Ouachita Mountains also were included, as the name implies (Matthews and Robison 1988). The drainages included in this faunal region indicate that a strong similarity of fishes occurs among drainages from southwestern to northeastern Arkansas. Furthermore, although some of these rivers drain areas that are geologically Ozarkian, the fishes of those rivers have more affinity with fishes on the Ouachita uplift than with more northern Ozark fishes. Mayden (1985) suggested a continuous pre-glacial connection existed between the Ozarks and Ouachitas before the area was topographically split by headwater erosion of the Arkansas River. This view is supported by present-day similarities in upland fishes of the Ouachita Mountains and southern Ozarks (Matthews and Robison 1988).

At least two other fish faunal regions were identified by both Matthews and Robison (1988) and Pflieger (1971) that either occur within or exert substantial influence on fish composition in the Assessment area: a Big River Fish Faunal Region and a Lowlands (West Gulf Coastal Plain-Mississippi Delta) Fish Faunal Region. Within the Ozark-Ouachita Highlands, the Big River Fish Faunal Region is represented primarily by the Arkansas River main stem. To the north, the big river fish fauna of the Missouri River and Mississippi River main stems exerts influence on the fish species composition of the lower reaches of the Meramec, Gasconade, and Osage Rivers. Likewise, lowland fishes influence composition of faunas in drainages extending beyond the Assessment area. This is particularly true for the lower reaches of the Upper St. Francis, Upper Black, and Upper White River drainages in the northeast and the Ouachita and Kiamichi-Little River drainages in the south.

Native fish species richness and density. The number of native fish species is not evenly distributed among the ecological-hydrologic units (fig. 2.18), nor is it oriented to a simple geographical axis or direction. Species richness averaged 75 fish species per ecological-hydrologic unit and ranged from 22 to 114 species. Most units, however, showed diverse fish faunas—57 of the 61 units in the Highlands have more than 50 species.

Two separate geographical centers with primary levels of fish species richness (89 to 114 species) are apparent (fig. 2.18). One occurs near the western edge and the other along the northeastern edge of the Assessment area. The western center is comprised of units within the Neosho-Illinois drainage (Lake O' the Cherokees (OZ), Lower Neosho (OZ), and Illinois (OZ and BM) units) and the Arkansas River drainage (Dirty-Greenleaf (BM), Kerr Reservoir (AV), Kerr Reservoir (BM), Dardanelle Reservoir (AV), and Poteau units). The northeastern center is comprised of the Upper St. Francis River Basin and units of the Upper Black River Basin (Current (OZ), Upper Black (OZ), Spring (OZ), and Strawberry (OZ)). The Lower Little River (OM) and Upper Ouachita (OM) units along the southern edge of the area also show primary levels of richness.

Units with secondary levels of fish species richness (75 to 87 species) generally are located in the southern two-thirds of the Assessment area, and those with tertiary levels, in the northern one-third (fig. 2.18). Two exceptions are the Meramec unit (Meramec River drainage (OZ)) and Lower Osage unit (Osage River drainage (OZ)), which show secondary levels of richness. Aggregations of secondary-level richness occur in units of the Upper White River drainage (e.g., Little Red (BM),

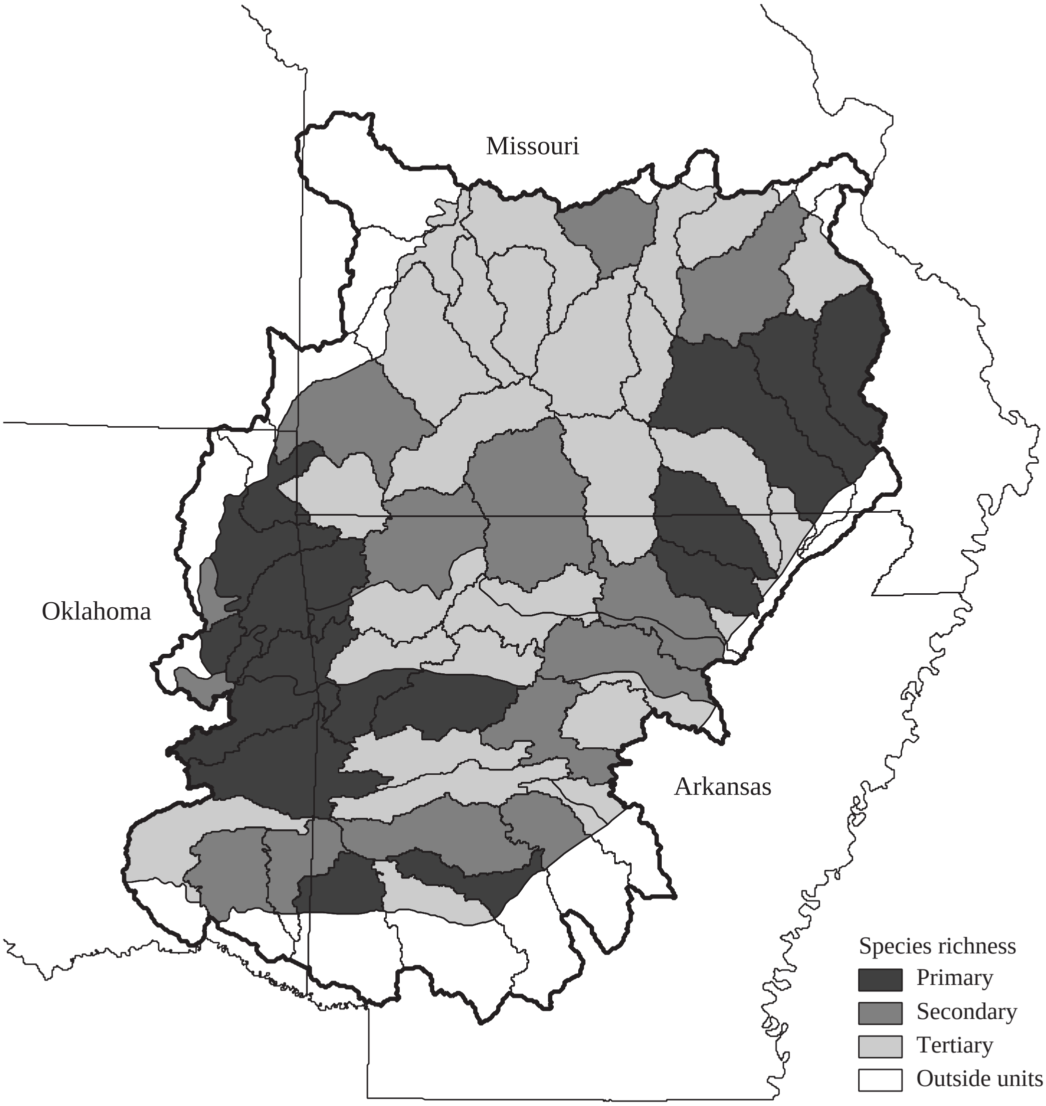


Figure 2.18—Levels of native fish species richness by ecological-hydrologic unit.

Middle White (BM), Middle White (OZ), Bull Shoals (OZ) and Beaver Reservoir units (OZ)); Ouachita-Saline drainage (Upper Saline (OM) and Ouachita Headwater (OM) units); and Kiamichi-Little drainage (Mountain Fork (OM) and Upper Little (OM) units). Most units in the Gasconade and Osage River Basins show tertiary levels of richness (less than 75 species).

Ecological-hydrologic units positioned as ecotones tended to be associated with primary levels of richness. The cluster of primary levels of richness observed in the northeastern units reflects their ecotonal position between the uplands of the eastern Ozarks and lowlands of the Mississippi Alluvial Basin. These drainages are enriched by having representatives of both upland and lowland fish species and by high numbers of endemic fishes (Pflieger 1971, Cross and others 1986, Matthews and Robison 1988). Likewise, the primary richness levels observed along the western edge of the Assessment area reflect a major shift from prairie to upland complemented by the influence of the lowland and big river fish fauna of the Arkansas Valley (Matthews and Robison 1988). Fish diversity increases generally from west to east across the Prairie Division, which lies immediately west and northwest of the

Assessment area, and reaches its highest levels in the Assessment area (Pflieger 1971, Miller and Robison 1973, McAllister and others 1986). The aggregation of units with tertiary levels of richness in the Gasconade and Osage Rivers reflects the relatively sparse prairie fish fauna of the Missouri River Basin as well as effects of Pleistocene Age glaciation (Cross and others 1986). The fish fauna in these units is not enriched to the extent of other units that are positioned as ecotones.

The density of native fish species was highly variable among ecological-hydrologic units ranging from 3 to 36 and averaging 10.5 native species per 100 square miles (mi^2). The density of native species in a unit was correlated negatively with unit area ($r = -0.71$, $P < 0.0001$). Regression of the log of native species richness with the log of square miles in units also was statistically significant ($P < 0.0007$). However, the relationship accounted for only 18 percent of the variation in native species richness (where log (species richness) = 1.29 + 0.193 log (unit area) and $r^2 = 0.18$).

Primary levels of fish species density (13 to 36 fish species per 100 mi^2) were associated generally with smaller units (fig. 2.19). Twelve of the 15 units with primary levels of density were less than 600 mi^2 in area. In contrast, 48 units with varying levels of density were greater than 600 mi^2 in area. Ten of the units with primary density levels also had primary or secondary levels of species richness (fig. 2.18). For example, units in the species-rich Neosho-Illinois drainage (Lake O' the Cherokees (OZ), Lower Neosho (BM), and Illinois (BM) units) showed primary levels of fish species density as did units along the southern and eastern edges (e.g., Lower Little (OM), Upper Ouachita (OM), and Middle White (BM) units) of the Assessment area. One unit in the relatively species-poor Osage River drainage was an exception to these patterns—the South Grand (OZ) unit showed primary levels of species density but not primary or secondary levels of species richness.

Secondary levels of species density (8 to 12 fish species per 100 mi^2) (fig. 2.19) were associated with units along the boundary of the Assessment area and near the Arkansas and Missouri Rivers. Nine of 18 units showing secondary levels of species density also had primary or secondary levels of species richness. Six units along the southern and eastern boundaries showed secondary levels of species density: the Upper Little (OM), Little Missouri (OM), Upper Saline (OM), Middle White (OZ), Strawberry (OZ), and Spring (OZ) units. Six of these also showed primary or secondary levels of species richness. Secondary levels occurred within four units in the Arkansas River drainage (Cadron (AV), Dardanelle Reservoir (AV), Frog-Mulberry (BM), and Kerr Reservoir (AV) units); three of these units coincided with primary or secondary levels of richness. Finally, five units in the northern drainages of the Assessment area showed secondary levels of species density: the Harry S. Truman Reservoir (OZ) (Osage River drainage), Lower Osage River (OZ), Bourbeuse (OZ) (Meramec River drainage), Lower Gasconade (OZ), and Big Piney (OZ) units (both Gasconade River drainages). None of these, with the exception of the Lower Osage (OZ) unit, had primary or secondary levels of species richness.

Small ecological-hydrologic units within the Ozark-Ouachita Highlands may show high native fish species densities because these units are influenced by the fish fauna of surrounding units (Sheldon 1987). Put simply, the high densities in these units would be predicted to decline if these units were isolated from surrounding units. This hypothesis is supported by the strong negative correlation between density of native fishes and area and by the weak relationship between number of native species and area. Nevertheless, units with primary or secondary levels of both native fish richness and density may be considered exceptional areas of fish diversity within the Assessment area.

Endemic fishes. Conservatively, at least 26 species of fishes (14 percent of the fish fauna) are endemic to the Assessment area. Ongoing studies indicate that several currently recognized species are, in fact, two or more distinct species. For example, Eisenhour (1996) indicated that at least two distinct species now included under the name speckled chub inhabit the Assessment area. Likewise, the stippled darter consists of additional distinct, but not yet formally described, species (Robison and Buchanan 1988), as do the Ozark madtom (Grady and LeGrande 1992) and longnose darter (Robison and Buchanan 1988). Several other subspecies of fishes in the area likely will be recognized as distinct endemic species after further study (Cross and others 1986, Robison and Buchanan 1988, Mayden and others 1992).

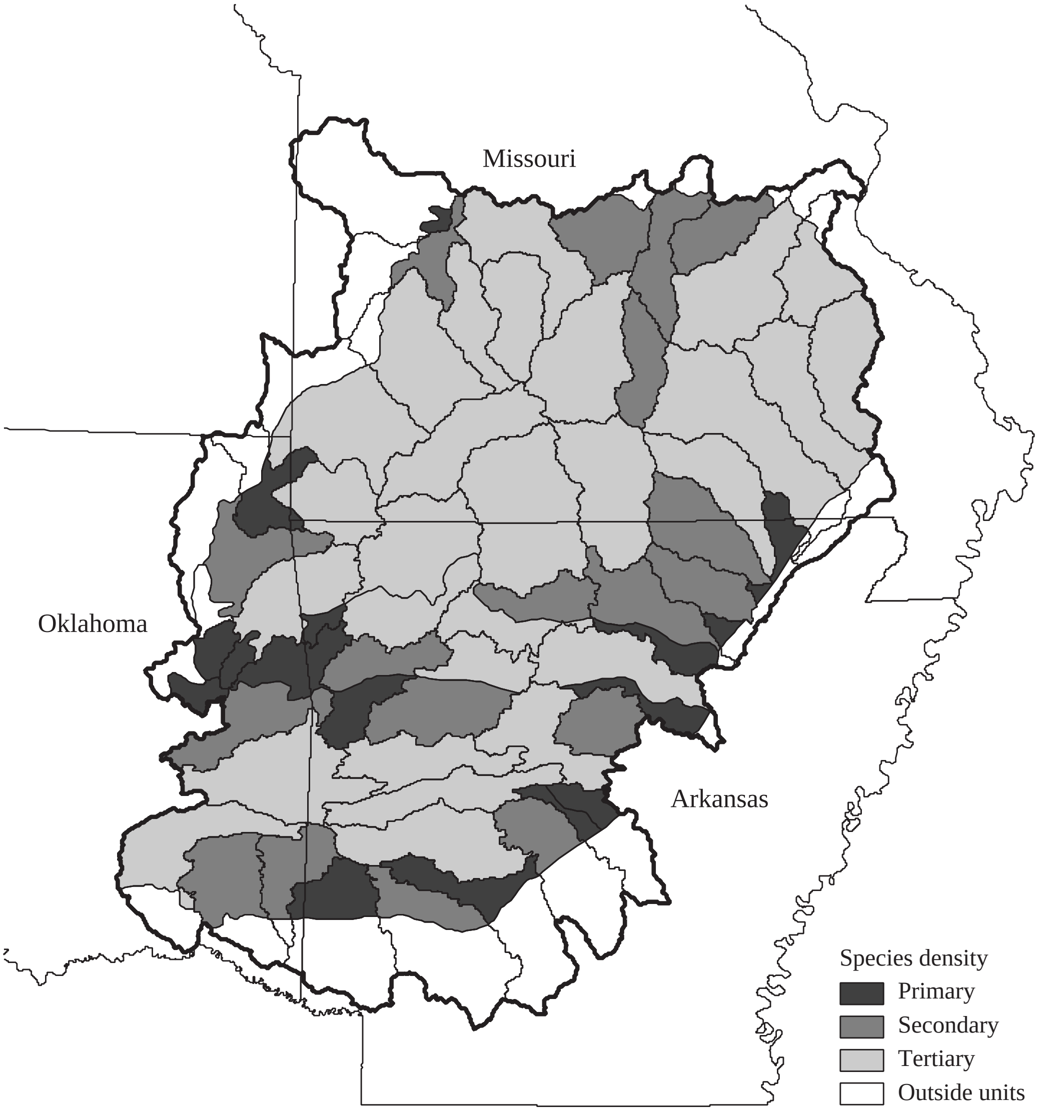


Figure 2.19—Levels of native fish density by ecological-hydrologic unit.

Endemic fishes within the Assessment area represent six fish families: the perch, minnow, catfish, sculpin, cavefish, and sunfish (table 2.11). The perch (all darters) and minnow families have the highest numbers of endemic species with 10 and 9, respectively. Hence, within these two largest families, 24 percent of all darters and 16 percent of all minnows within the area are endemic. In addition, the Assessment area harbors at least four endemic madtom catfishes (Caddo, checkered, Ouachita, and Ozark madtoms), one endemic sculpin (Ozark sculpin), one endemic cavefish (Ozark cavefish), and one endemic sunfish (Ozark bass).

At least one endemic fish species is found in 57 of the 61 ecological-hydrologic units in the Assessment area (table 2.12). Endemicity averaged 4.6 endemic species per unit and ranged from 0 to 13. Primary levels of endemicity (7 to 13 endemic fishes) were aggregated around the Upper White and Upper Black River drainages (fig. 2.20). The number of endemic species was highest in units of the Upper White River drainage (9 to 13 endemic species), including Beaver Reservoir (OZ and BM), James (OZ), Middle White (OZ and BM), Bull Shoals (OZ), North Fork White (OZ), Little Red (OZ), and Buffalo (OZ) units. The next highest the

Table 2.12—Native, endemic, and introduced fish species of the aquatic study area, by basin and ecological-hydrologic unit

River basin Ecological-hydrologic unit name	Watershed code (HUC)	Area	Native species	Endemic species	Introduced species
		Mi²			
Osage River Basin					
Harry S. Truman Reservoir - OZ	10290105	497	59	2	1
Harry S. Truman Reservoir - OA	10290105	714	29	0	0
Sac - OZ	10290106	1,716	62	7	2
Sac - OA	10290106	255	18	0	0
Pomme de Terre - OZ	10290107	848	61	3	3
South Grand - OZ	10290108	89	22	0	1
South Grand - OA	10290108	1,959	37	0	2
Lake of the Ozarks - OZ	10290109	1,385	65	4	5
Niangua - OZ	10290110	1,031	67	7	5
Lower Osage - OZ	10290111	952	75	6	4
Lower Osage - OA	10290111	124	60	5	3
Gasconade River Basin					
Upper Gasconade - OZ	10290201	1,788	61	6	3
Big Piney - OZ	10290202	756	61	6	4
Lower Gasconade - OZ	10290203	865	68	6	3
Lower Gasconade - OA	10290203	170	49	1	1
Meramec River Basin					
Meramec - OZ	07140102	1,815	77	4	6
Meramec - OA	07140102	345	78	4	1
Bourbeuse - OZ	07140103	785	63	3	1
Bourbeuse - OA	07140103	52	44	1	1
Big - OZ	07140104	806	56	4	1
Big - OA	07140104	156	50	3	1
Upper St. Francis River Basin					
Upper St. Francis - OZ	08020202	1,298	94	6	2
Neosho-Illinois River Basin					
Lake O' the Cherokees - OZ	11070206	586	90	3	2
Lake O' the Cherokees - OA	11070206	334	74	1	1
Spring - OZ	11070207	1,793	87	2	4
Spring - OA	11070207	785	40	0	1
Elk - OZ	11070208	1,031	57	4	32
Lower Neosho - OZ	11070209	1,028	91	3	8
Lower Neosho - BM	11070209	238	86	2	5
Lower Neosho - OA	11070209	944	69	1	5
Illinois - OZ	11110103	1,329	97	4	8
Illinois - BM	11110103	321	99	2	6
Arkansas River Basin					
Dirty-Greenleaf - BM	11110102	288	95	3	2
Dirty-Greenleaf - AV	11110102	229	77	1	1
Dirty-Greenleaf - OA	11110102	273	65	0	1
Robert S. Kerr Reservoir - BM	11110104	732	100	4	2
Robert S. Kerr Reservoir - AV	11110104	1,074	105	4	4
Poteau - OM	11110105	1,904	95	2	5
Frog-Mulberry - BM	11110201	719	56	3	2
Frog-Mulberry - AV	11110201	539	89	1	4
Dardanelle Reservoir - BM	11110202	668	39	3	2
Dardanelle Reservoir - AV	11110202	1,193	91	2	6
Lake Conway-Point Remove - AV	11110203	1,137	77	0	7
Petit Jean - AV	11110204	1,090	73	1	7
Cadron - AV	11110205	769	67	1	0
Fourche La Fave - OM	11110206	1,119	69	3	5

(continued)

Table 2.12—Native, endemic, and introduced fish species of the aquatic study area, by basin and ecological-hydrologic unit (continued)

River basin Ecological-hydrologic unit name	Watershed code (HUC)	Area	Native species	Endemic species	Introduced species
		Mi²			
Arkansas River Basin (continued)					
Lower Arkansas-Maumelle - AV	11110207	280	68	0	5
Lower Arkansas-Maumelle - OM	11110207	197	29	0	1
Lower Arkansas-Maumelle - OA	11110207	630	72	0	6
Kiamichi-Little River Basin					
Kiamichi - OM	11140105	1,316	68	2	1
Kiamichi - OA	11140105	506	84	1	1
Upper Little - OM	11140107	1,010	82	3	1
Upper Little - OA	11140107	399	100	3	3
Mountain Fork - OM	11140108	787	85	4	2
Mountain Fork - OA	11140108	69	94	3	1
Lower Little - OM	11140109	674	92	4	3
Lower Little - OA	11140109	1,301	114	4	7
Ouachita-Saline River Basin					
Ouachita Headwaters - OM	08040101	1,546	75	6	9
Upper Ouachita - OM	08040102	673	89	4	9
Upper Ouachita - OA	08040102	1,089	105	2	4
Little Missouri - OM	08040103	613	68	4	8
Little Red - BM	11010014	1,320	83	8	6
Little Red - AV	11010014	411	54	3	2
Little Red - OA	11010014	90	18	0	1
Upper Black River Basin					
Upper Black - OZ	11010007	1,439	101	5	3
Upper Black - OA	11010007	471	68	0	0
Current - OZ	11010008	2,453	105	9	5
Current - OA	11010008	172	64	3	0
Lower Black - OZ	11010009	490	72	5	2
Lower Black - OA	11010009	289	63	2	3
Spring - OZ	11010010	1,217	114	8	9
Eleven Point - OZ	11010011	1,202	71	7	2
Strawberry - OZ	11010012	789	89	4	4

HUC = hydrologic unit code; mi² = square mile; OZ = Ozark Highlands section; BM = Boston Mountains section; AV = Arkansas Valley section; OM = Ouachita Mountains section; OA = Outside the Highlands Assessment area.

was in the drainage of the Upper Black River (7 to 9 endemic species), including the Current (OZ), Spring (OZ), and Eleven Point (OZ) units. Together, these two drainages are outstanding with regard to endemicity in the Assessment area as well as within the entire western Mississippi River Basin (Cross and others 1986). The Sac (OZ) and Niangua (OZ) units on the Osage River also showed primary levels for endemicity (seven endemic fishes each). Secondary levels of endemicity (4 to 6 endemic fishes) include 21 units scattered broadly across the Assessment area (fig. 2.20).

Few endemic fishes are widespread within the Assessment area and most occur naturally only in limited geographic areas or drainages. Two general geographical distributions of endemic species may be recognized: Ozark Highlands endemics and Ouachita Mountains endemics. The wedgespot shiner, Kiamichi shiner, and longnose darter are apparent exceptions to this generalization, occurring in streams of both the Ozark Highlands and Ouachita Mountains.

About 16 regionally endemic fish species occur only in streams of the Ozark Highlands. Of these, six are restricted to the Upper White and/or Upper Black River

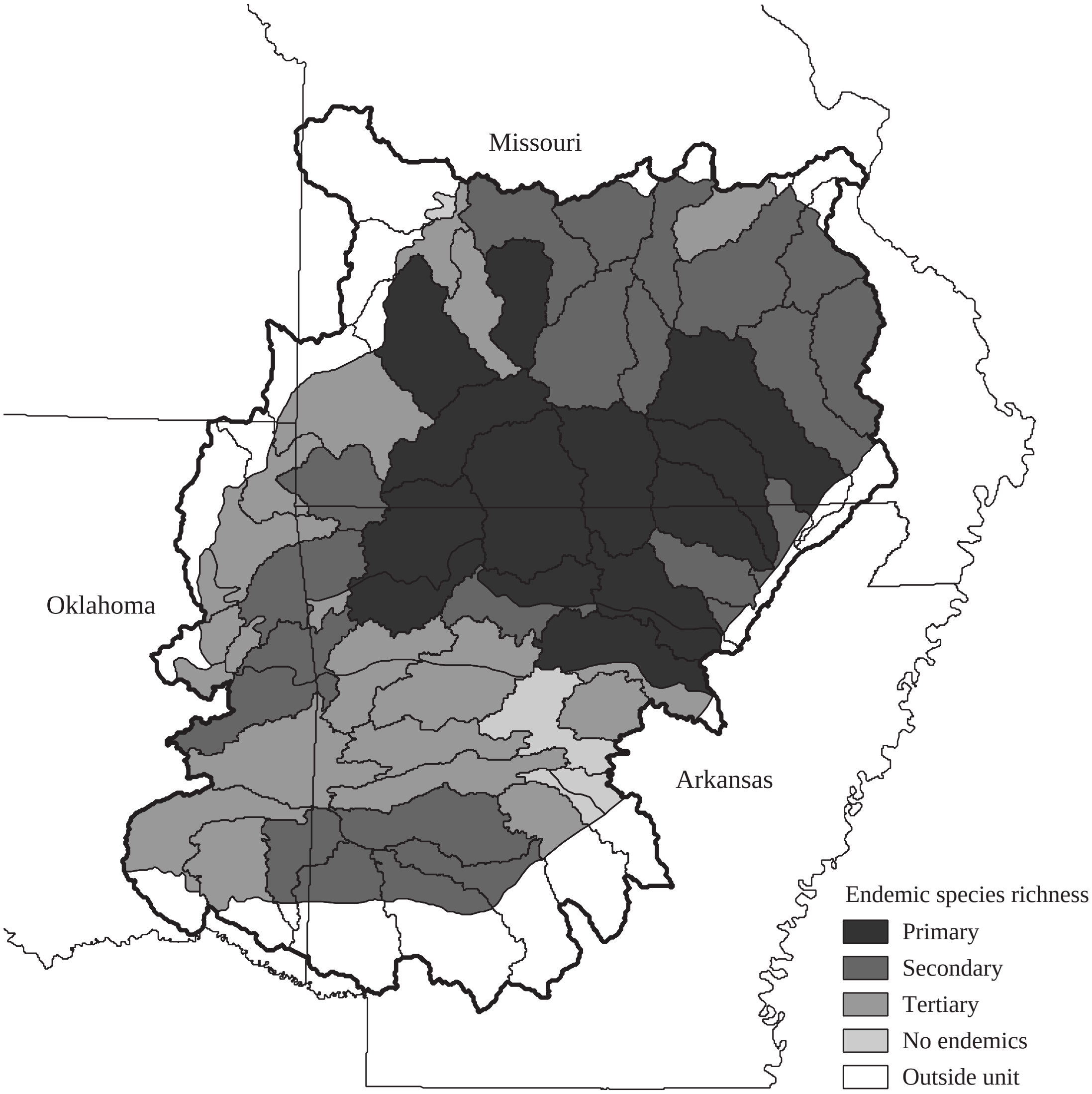


Figure 2.20—Levels of endemic fish species richness by ecological-hydrologic unit.

Basins (i.e., duskystripe shiner, checkered madtom, Ozark bass, yellowcheek darter, yoke darter, and Arkansas saddled darter). The Ozark chub and Ozark madtom are exclusively shared between these two drainages and the Upper St. Francis; the Ozark minnow is shared among the Upper White, Upper Black, Upper St. Francis, and Illinois River drainages. The remaining seven Ozark Highlands endemic fishes are found as follows: (1) relatively widely distributed in the Ozark Highlands (e.g., Ozark sculpin, bleeding shiner, stippled darter), (2) only in the Ozark Highlands in Missouri and/or in Meramec River tributaries (e.g., Niangua darter, bluestripe darter, Missouri saddled darter), or (3) extremely limited in distribution (e.g., Ozark cavefish occur only in karst areas—areas dominated by limestone geology—of the Salem Plateau subsection of the Ozark Highlands).

Seven regionally endemic fishes are essentially restricted to streams of the Ouachita Mountains. Three of these—the Ouachita Mountain shiner, rocky shiner, and leopard darter—occur only in units of the Kiamichi-Little drainage within the Assessment area. The Caddo madtom, Ouachita madtom, and paleback darter have very restricted ranges in Ouachita River tributaries of the Ouachita-Saline drainage. The peppered shiner is the only Ouachita Mountain endemic that occurs in both the Kiamichi-Little and Ouachita-Saline drainages.

Implications and Opportunities

The Aquatic Team synthesized information on the geographic patterns of fish distribution within the Assessment area. The synthesis revealed that the Ozark-Ouachita Highlands supports a large portion of continental, national, and regional fish species diversity, including a substantial number of endemic fish species. The Aquatic Team was able to examine these rich fish faunas on a relatively large and coarse scale only (i.e., presence or absence of fishes in ecological-hydrologic units). The synthesis did not account for declines in fish populations in recent times even though evidence is available that some fish species have experienced a reduction in range or fragmentation of populations within the Assessment area (Robison and Buchanan 1988). Many fishes in the Assessment area are found in waters under Federal management (e.g., in national forests). Given the trend toward continued human population growth and accompanying modification of aquatic habitats across the Assessment area, waters on Federally managed lands are becoming increasingly important for the continued existence of viable populations and communities of native fishes.

The effect of forest management practices on fishes is an important, but little understood, component of land management within the Assessment area. The response of salmonid fishes to forest disturbance has been examined extensively in the Pacific Northwest (e.g., Meehan 1991). As yet, no comparable body of literature exists for fishes of the Assessment area, even though the fishes of the Assessment area are the best known members of the aquatic community (Pflieger 1971, Cross and others 1986, Robison and Buchanan 1988).

The Aquatic Team considers the synthesis of data about the distribution of fish to be a starting point for identifying and prioritizing information needs that can then be used to better conserve fish diversity.

Diversity of Mussels

Question 2.5: What are the status and distribution of unionacean bivalves (mussels, clams, naiads, or unionids) within the Assessment area?

Unionacean bivalves (Mollusca: Bivalvia: Pelecypoda: Unionaceae)—commonly referred to as freshwater clams, mussels, naiads, or unionids—are found worldwide. Their greatest diversity is in North America, with about 297 recognized taxa (281 species and 16 subspecies) (Williams and others 1993). Seventy-five native freshwater mussel species and subspecies occur or have occurred in Arkansas (Gordon and others 1980, Williams and others 1993, Posey and others 1996); 65 mussel species are recognized from Missouri (Oesch 1984, Williams and others 1993); and 55 freshwater mussel taxa have occurred historically within Oklahoma (Branson 1973, 1982, 1983, 1984; Williams and others 1993). There are now 73 native freshwater mussel species in the Assessment area, representing 26 percent of the native North American mussel fauna.

The Assessment area encompasses 10 major river basins that include the main stems of and tributaries to the Missouri, Arkansas, Red, Ouachita, White, and St. Francis River systems. Within the Assessment area, these drainage systems traverse 24 ecological subsections of 4 ecological sections: (1) the Ozark Highlands, (2) the Boston Mountains, (3) the Arkansas Valley, and (4) the Ouachita Mountains.

Because freshwater mussels require a fish host to complete the early stages of their life cycle, distributions of fishes and mussels have coevolved. As discussed in the previous section on fish diversity, complex drainage histories beginning prior to the Pleistocene Age have provided for division, isolation, and mixing of these two aquatic faunas. Both the diversity of habitats and histories of drainage evolution have resulted in a unique and species-rich aquatic biota within the Ozark-Ouachita Highlands.

Key Findings

1. Seventy-three species of native freshwater mussels representing 37 genera occur within the Assessment area. Eleven species are endemic to the Assessment area, and there are two introduced species—the Asian clam and the zebra mussel.
2. Twenty-four freshwater mussel species are widely distributed across the Assessment area; 16 species occurring within the Assessment area are restricted to streams draining the Ozark Highlands, and 8 species are restricted to streams draining the Ouachita Mountains.
3. North American conservation status rankings for freshwater mussel species in the Assessment area reveal that 40 species are considered currently stable, 18 species are of special concern, 9 are ranked as threatened, and 6 are listed as endangered.
4. Ecological-hydrologic units with relatively high species richness and density occur primarily in tier-like clusters in the northeastern, central, and southern portions of the Assessment area and appear to be associated with hydrologic units possessing both headwater and main stem habitats.
5. The Aquatic Team calculated a relative importance index value to rank hydrologic units in terms of combined mussel species richness, species density, and habitat availability for rare species. The five highest ranking hydrologic units were the Spring and Strawberry Rivers (Upper Black River Basin), the Bourbeuse and Big Rivers (both in the Meramec River Basin), and the Upper Ouachita River (Ouachita-Saline River Basin).

Data Sources and Methods of Analysis

As in the preceding section—"Diversity of Fishes"—the Aquatic Team subdivided each of the major drainages within the Assessment area using the watersheds indicated in Chapter 1 (fig. 1.2). The team further subdivided 32 of the 50 hydrologic units within the Assessment area by overlaying ecological unit boundaries of the Ozark Highlands, Boston Mountains, Arkansas Valley, and Ouachita Mountains. Sixty-one ecological-hydrologic units were recognized within the four ecological sections. The team categorized an additional 25 hydrologic units or watersheds that extended outside the borders of the Assessment area as "peripheral," making a total of 86 ecological-hydrologic units within the aquatic study area (fig. 2.17).

The team noted freshwater mussels as present or absent within each ecological-hydrologic unit and, using the conservation rank for individual species given by Williams and others (1993), rated them as (1) currently stable, (2) of special concern, (3) threatened, or (4) endangered. Finally, the team combined the ecological-hydrologic units into their respective hydrologic units with associated presence or absence and conservation-rank data. They omitted the introduced Asian clam and zebra mussel from these analyses. Only data for existing freshwater mussels (i.e., records of live individuals or fresh dead shells taken within the past 30 years) were used in this analysis. Nomenclature and species concepts generally follow Turgeon and others (1988), as modified by Williams and others (1993).

The team analyzed diversity of freshwater mussels using species richness, conservation-rank species richness, species density, and conservation-rank species density. Unionacean bivalve richness is defined as the total number of freshwater mussel species within an ecological-hydrologic unit or hydrologic unit. Ecological-hydrologic and hydrologic units vary in areal extent, and freshwater mussel richness may increase as stream size, stream length, or drainage area increases.

To examine the effect of drainage area size, the Aquatic Team divided freshwater mussel richness by drainage area size to produce freshwater mussel density values (expressed as density per 100 mi^2) for each unit. The team totaled species conservation ranks for both ecological-hydrologic and hydrologic units to arrive at the conservation-rank species richness. For example, if an ecological-hydrologic unit contained one stable species (rank = 1), one species of special concern (rank = 2), and one threatened or endangered species (rank = 3), then the conservation-rank species richness for that unit would be 6 (1 + 2 + 3 = 6). The team then divided conservation-rank species richness by drainage unit area to determine conservation-rank species density.

Forty-five hydrologic units and 47 ecological-hydrologic units had sufficient data to use for analysis of freshwater mussel spatial patterns (species distribution), species richness, and density. Three levels of relative richness and density were recognized among ecological-hydrologic and hydrologic units: primary, secondary, and tertiary. Ecological-hydrologic and hydrologic unit values for richness, density, conservation-rank richness, and conservation-rank density were sorted and ranked, and levels were assigned based on breaks in sequence. The Aquatic Team assigned primary levels to grouped ecological-hydrologic and hydrologic units with the highest parameter values (e.g., for richness and density), secondary levels to the next highest natural group of units, and tertiary levels to the remaining units. Hence, primary levels approximate values in the fourth quartile (top 25 percent); secondary levels, values in the third quartile (second 25 percent); and tertiary levels, values in the first and second quartiles (bottom 50 percent). The team plotted species richness, species density, and conservation-rank species richness on both ecological-hydrologic and hydrologic maps of the Assessment area to show patterns of distribution, richness, and density. Individual rank orders of hydrologic units for species richness, species density, conservation-rank species richness, and conservation-rank species density were added together to provide a value of the relative importance of hydrologic units as a freshwater mussel habitat in the Assessment area.

The Aquatic Team determined distributions of freshwater mussels within ecological-hydrologic units from an array of data sources. Johnson (1980) presented mussel presence or absence data for drainages encompassing much of the Assessment area. For drainages in Missouri, dot distribution maps provided by Oesch (1984) were the primary data source. The team used Buchanan (1980) extensively to determine mussel distributions within the Meramec River Basin. Gordon (1980) and Clarke and Obermeyer (1996) provided data about mussel distribution in the Spring and Elk Rivers (Neosho-Illinois Basin) in Missouri. Warren (1991) discussed the mussels of the upper Eleven Point River (Upper Black River Basin). Gordon and others (1980) summarized the distributional data for Arkansas mussels, and Gordon (1980) discussed the systematics and zoogeography (geographic distribution of animals) of the Mollusca in Arkansas.

Several studies of mussels have taken place in the large Upper White and Upper Black River drainages of Arkansas. Freshwater mussel distributions for the Spring and Black Rivers were reported by the Arkansas Highway and Transportation Department (AR HTD 1984), Gordon and others (1984), Miller and Nelson (1984), Miller and Hartfield (1986), Rust (1993), and Davidson and others (1997). Rust (1993) also surveyed mussel distributions and population structures in portions of the Strawberry and Current Rivers. Buchanan (1993) and Sietman and Sadler (1994) surveyed selected sites in northeast Arkansas and southwest Missouri to monitor the declining status of the Curtis pearlymussel. Meek and Clark (1912) first studied the distribution of freshwater mussels in the Buffalo River, and Harris (1996) resurveyed the same Buffalo River reaches to determine if population densities and distributions had remained stable. Miller and Harris (1987), Harris (1987, 1994b, 1995), and Christian (1995) studied mussel distributions in the main stem of the White River downstream of its confluence with the Black River. Gordon (1980) surveyed the mussels of the White River upstream from Beaver Reservoir, and Gordon (1982) summarized the available data for the main stem of the White River in Arkansas and Missouri. Freshwater mussel distributions within the Little Red River (Upper White River Basin) were documented by Clarke (1987) and Harris (1992a, 1993).

Little published data are available for mussel distributions in rivers and streams draining the Arkansas Valley. Relatively large Arkansas River tributaries such as the Illinois Bayou, Fourche La Fave River, Petit Jean River, Point Remove Creek, Cadron Creek, Maumelle River, and Little Maumelle River have not been surveyed to determine mussel species composition and distribution. Limited data about mussel distribution are available for the Neosho River of Oklahoma, e.g., Branson (1973, 1982, 1983, 1984), White (1977), Shepard and Covich (1982), Mather (1990), and Vaughn (1996a). Gordon (1979) and Harris (1991c, 1997b) surveyed mussel distributions within the Illinois River (Neosho-Illinois Basin) in Arkansas, and Vaughn (1995) provided distributional data for the Oklahoma portion of the Illinois River. Gordon (1980, 1985) surveyed the mussels of Frog Bayou, and Stoeckel and others (1996) investigated the mussel fauna of the

Mulberry River (Frog-Mulberry watershed). Davidson (1997) surveyed the Ozark and Dardanelle reservoirs of the Arkansas River (also known as the Kerr-McClellan Navigation System) for mussels, and Harris (1991a) surveyed a portion of Dardanelle Reservoir. Harris (1992b, 1994c, respectively) also surveyed the mussel populations in a short reach of the South Fourche La Fave River and tributaries (Arkansas River Basin) and the freshwater mussel distribution in the Arkansas reach of the Poteau River.

Freshwater mussel distributions in the Kiamichi-Little River drainage of Oklahoma were taken from Branson (1982, 1983, 1984), Clarke (1987), Mehlhop and Miller (1989), Vaughn and others (1993, 1994, 1996), Vaughn and Pyron (1995), and Vaughn (1996a, 1996b, 1997). Gordon and Harris (1983) and Clarke (1987) studied the mussels of the Red River and tributaries in southwestern Arkansas.

Mussels of the Ouachita River drainage were first reported by Wheeler (1918); Gordon and Harris (1983) summarized the results of surveys in several Ouachita River tributaries. Harris and Gordon (1988) provided the most comprehensive data set regarding mussels of the upper Ouachita River system during their status survey of the Arkansas fatmucket. Additional studies (Harris 1989a, 1991b, 1994a; Burns and McDonnell 1992a, 1992b) to elucidate the status of the Arkansas fatmucket provided data about the distribution of mussel species associates. The mussels of portions of the Little Missouri and Ouachita River main stems were surveyed by Davidson (1997) and Posey (1997).

Distributional data for mussels in the Upper St. Francis River came primarily from Oesch (1984) and Ecological Consultants, Inc. (1984). Additional distributions in the St. Francis River Basin were obtained from Ahlstedt and Jenkinson (1987) and Jenkinson and Ahlstedt (1987 [synthesized in Ahlstedt and Jenkinson (1991)]).

Patterns and Trends

Composition of freshwater mussel species. The Aquatic Team determined that 73 native mussel species representing 37 genera (the first part of each species name) occur within the Assessment area (table 2.13). Twenty-one genera (57 percent) are represented by a single species. The genera having the most species within the Assessment area are *Lampsilis* and *Quadrula*, represented by 11 and 7 species, respectively. Within the subfamilies of the Unionidae, the following number of species occur in the Assessment area: 37 lampsilines, 23 amblemines, 12 anodontines, and 1 cumberlandine (table 2.13).

North American conservation ranks of the 73 native species occurring within the Assessment area (Williams and others 1993) reveal that 40 are considered stable, 18 are of special concern, and 9 are federally listed as threatened and 6 as endangered (table 2.13). Average species richness for the 10 major river basins ranged from a high of 51 in the Upper Black River Basin to a low of 31 in the Upper St. Francis River Basin. In descending order, average species richness for the remaining 8 major basins was as follows: Kiamichi-Little (49), Meramec (47), Ouachita (47), Upper White (47), Osage (45), Neosho-Grand (39), Arkansas (35), and Gasconade (33). Twenty-four species are distributed broadly across the Assessment area—mucket, elktoe, threeridge, spike, fatmucket, threehorn wartyback, round pigtoe, giant floater, monkeyface, pimpleback, mapleleaf, squawfoot, lilliput, pistolgrip, fawnsfoot, deertoe, fragile papershell, butterfly, yellow sandshell, fluted-shell, paper pondshell, pondhorn, washboard, and spectaclecase.

Analysis of species distributions within the Assessment area showed that there are 16 species of Ozarkian fauna found in the Ozark Highland streams of the Missouri, Neosho, St. Francis, and/or White River systems: the Arkansas broken-ray, bleedingtooth mussel, Curtis pearlymussel, elephant-ear, ellipse, long-solid, Neosho mucket, Ohio pigtoe, Ozark pigtoe, pink heelsplitter, purple wartyback, salamander mussel, sheepnose, slippershell, snuffbox, and speckled pocketbook. The elephant-ear and sheepnose mussels were restricted to the Missouri River system; the long-solid, Curtis pearlymussel, Ohio pigtoe, and speckled pocketbook were found only in White River system streams; and the Neosho mucket was restricted to the Neosho River Basin.

The Ouachita fauna of the Assessment area was composed of those species found in the Ouachita Mountains streams of the Red River, Ouachita River, and/or Arkansas River systems. This fauna included the following eight species: Arkansas fatmucket, Louisiana fatmucket, Ouachita creekshell, Ouachita rock-pocketbook, sandbank pocketbook, southern mapleleaf, southern pocketbook, and winged mapleleaf. Most of

Table 2.13—Native and introduced mussels of the Ozark-Ouachita Highlands and their conservation status

Family Subfamily	Species	Common name	Native	Endemic	Intro-duced	Conservation rank: Currently stable	Special concern	Threat-ened	Endan-gered
Corbiculidae	*Corbicula fluminea*	Asian clam			X				
Dreissenidae	*Dreissena polymorpha*	Zebra mussel			X				
Unionidae									
Ambleminae	*Amblema plicata*	Threeridge	X			X			
Ambleminae	*Cyclonaias tuberculata*	Purple wartyback	X				X		
Ambleminae	*Elliptio crassidens*	Elephant-ear	X			X			
Ambleminae	*Elliptio dilatata*	Spike	X			X			
Ambleminae	*Fusconaia ebena*	Ebonyshell	X			X			
Ambleminae	*Fusconaia flava*	Wabash pigtoe	X			X			
Ambleminae	*Fusconaia ozarkensis*	Ozark pigtoe	X	X			X		
Ambleminae	*Fusconaia subrotunda*	Long-solid	X				X		
Ambleminae	*Megalonaias nervosa*	Washboard	X			X			
Ambleminae	*Plectomerus dombeyanus*	Bankclimber	X			X			
Ambleminae	*Plethobasus cyphus*	Sheepnose	X					X	
Ambleminae	*Pleurobema coccineum*	Round pigtoe	X			X			
Ambleminae	*Pleurobema cordatum*	Ohio pigtoe	X				X		
Ambleminae	*Pleurobema pyramidatum*	Pyramid pigtoe	X					X	
Ambleminae	*Quadrula apiculata*	Southern mapleleaf	X			X			
Ambleminae	*Quadrula cylindrica*	Rabbitsfoot	X					X	
Ambleminae	*Quadrula fragosa*	Winged mapleleaf	X						X
Ambleminae	*Quadrula metanevra*	Monkeyface	X			X			
Ambleminae	*Quadrula nodulata*	Wartyback	X			X			
Ambleminae	*Quadrula pustulosa*	Pimpleback	X			X			
Ambleminae	*Quadrula quadrula*	Mapleleaf	X			X			
Ambleminae	*Tritogonia verrucosa*	Pistolgrip	X			X			
Ambleminae	*Uniomerus tetralasmus*	Pondhorn	X			X			
Anodontinae	*Alasmidonta marginata*	Elktoe	X				X		
Anodontinae	*Alasmidonta viridis*	Slippershell	X				X		
Anodontinae	*Anodonta suborbiculata*	Flat floater	X			X			
Anodontinae	*Anodontoides ferussacianus*	Cylindrical papershell	X			X			
Anodontinae	*Arcidens confragosus*	Rock-pocketbook	X			X			
Anodontinae	*Arkansia wheeleri*	Ouachita rock-pocketbook	X	X					X
Anodontinae	*Lasmigona complanata*	White heelsplitter	X			X			
Anodontinae	*Lasmigona costata*	Fluted shell	X			X			
Anodontinae	*Pyganodon grandis*	Giant floater	X			X			
Anodontinae	*Simpsonaias ambigua*	Salamander mussel	X				X		
Anodontinae	*Strophitus undulatus*	Squawfoot	X			X			
Anodontinae	*Utterbackia imbecillis*	Paper pondshell	X			X			
Cumberlandinae	*Cumberlandia monodonta*	Spectaclecase	X					X	
Lampsilinae	*Actinonaias ligamentina*	Mucket	X			X			
Lampsilinae	*Cyprogenia aberti*	Western fanshell	X	X				X	
Lampsilinae	*Ellipsaria lineolata*	Butterfly	X				X		
Lampsilinae	*Epioblasma curtisi*	Curtis pearlymussel	X	X					X
Lampsilinae	*Epioblasma triquetra*	Snuffbox	X					X	
Lampsilinae	*Lampsilis abrupta*	Pink mucket	X						X
Lampsilinae	*Lampsilis cardium*	Pocketbook	X				X		
Lampsilinae	*Lampsilis hydiana*	Louisiana fatmucket	X			X			
Lampsilinae	*Lampsilis ornata*	Southern pocketbook	X				X		
Lampsilinae	*Lampsilis powelli*	Arkansas fatmucket	X	X				X	
Lampsilinae	*Lampsilis rafinesqueana*	Neosho mucket	X	X				X	
Lampsilinae	*Lampsilis reeveiana*	Arkansas broken-ray	X	X			X		
Lampsilinae	*Lampsilis satura*	Sandbank pocketbook	X				X		
Lampsilinae	*Lampsilis siliquoidea*	Fatmucket	X			X			
Lampsilinae	*Lampsilis streckeri*	Speckled pocketbook	X	X					X
Lampsilinae	*Lampsilis teres*	Yellow sandshell	X			X			
Lampsilinae	*Leptodea fragilis*	Fragile papershell	X			X			

(continued)

Table 2.13—Native and introduced mussels of the Ozark-Ouachita Highlands and their conservation status (continued)

						Conservation rank			
Family Subfamily	Species	Common name	Native	Endemic	Introduced	Currently stable	Special concern	Threatened	Endangered
Lampsilinae	*Leptodea leptodon*	Scaleshell	X						X
Lampsilinae	*Ligumia recta*	Black sandshell	X				X		
Lampsilinae	*Ligumia subrostrata*	Pondmussel	X			X			
Lampsilinae	*Obliquaria reflexa*	Threehorn wartyback	X			X			
Lampsilinae	*Obovaria jacksoniana*	Southern hickorynut	X				X		
Lampsilinae	*Obovaria olivaria*	Hickorynut	X			X			
Lampsilinae	*Potamilus alatus*	Pink heelsplitter	X			X			
Lampsilinae	*Potamilus ohiensis*	Pink papershell	X			X			
Lampsilinae	*Potamilus purpuratus*	Bleufer	X			X			
Lampsilinae	*Ptychobranchus occidentalus*	Ouachita kidneyshell	X	X				X	
Lampsilinae	*Toxolasma lividus*	Purple lilliput	X				X		
Lampsilinae	*Toxolasma parvus*	Lilliput	X			X			
Lampsilinae	*Toxolasma texasensis*	Texas lilliput	X			X			
Lampsilinae	*Truncilla donaciformis*	Fawnsfoot	X			X			
Lampsilinae	*Truncilla truncata*	Deertoe	X			X			
Lampsilinae	*Venustaconcha ellipsiformis*	Ellipse	X				X		
Lampsilinae	*Venustaconcha pleasi*	Bleedingtooth mussel	X	X			X		
Lampsilinae	*Villosa arkansasensis*	Ouachita creekshell	X	X			X		
Lampsilinae	*Villosa iris*	Rainbow	X			X			
Lampsilinae	*Villosa lienosa*	Little spectaclecase	X			X			

Source: see "Data Sources and Methods of Analysis" of this section.

these species have primarily southern distributions and may also be found in Gulf Coastal Plain and Mississippi Alluvial Plain streams. The winged mapleleaf has a somewhat unique distributional pattern, with disjunct relict populations (isolated populations) apparently remaining in the upper Mississippi River Valley outside the Assessment area and in the Kiamichi and Ouachita Rivers within the Assessment area.

The least widely distributed freshwater mussels in the Assessment area were the cylindrical papershell, known only from the Bourbeuse River hydrologic unit; the Curtis pearlymussel, which persists only in the Current River hydrologic unit; and the speckled pocketbook, which is endemic to the Little Red River hydrologic unit (Upper White River Basin).

Mussels species richness and density. Data for mussel species richness and species density were available for 47 of 61 ecological-hydrologic units within the Assessment area (77 percent). When peripheral ecological-hydrologic units were included, sufficient data were available for 67 of the 86 total ecological-hydrologic units (78 percent). When ecological-hydrologic units were combined within their respective hydrologic units, data were available for 45 of 50 hydrologic associated with the Assessment area units (90 percent).

Ecological-hydrologic units. The species richness mean was 24.5 mussel species per ecological-hydrologic unit within the Assessment area (table 2.14). Of the ecological-hydrologic units for which data were available within the Assessment area, 53.2 percent (25 of 47 units) have 25 or more species. The average species richness was highest for ecological-hydrologic units in the Ozark Highlands (28 species in 28 units) and Boston Mountains (21.8 species in 4 units). Species density was highest for ecological-hydrologic units in the Ozark Highlands (3.1 species per 100 mi^2 in 28 units), Boston Mountains (2.7 species per 100 mi^2 in 4 units), and Ouachita Mountains (2.2 species per 100 mi^2 in 10 units) (table 2.14).

The distribution of ecological-hydrologic units with respect to species richness levels—primary (6 units with a range of 35 to 46 species), secondary (19 units with a range of 25 to 33 species), and tertiary (22 units with a range of 7 to 24 species)—revealed that one large geographically contiguous area and several smaller, separate areas of high species richness (primary and secondary levels) are within the Assessment area (fig. 2.21). The six ecological-hydrologic units with primary

Table 2.14—Average mussel species richness and density for sections within the Assessment area

Section or area	Richness	Conservation-rank species richness	Density	Conservation-rank species density	Number of ecological-hydrologic units
			- - Species per 100 mi^2 - -		
Ozark Highlands	28.0	42.0	3.1	4.5	28
Boston Mountains	21.8	31.5	2.7	3.7	4
Arkansas Valley	14.0	15.0	1.7	1.8	5
Ouachita Mountains	21.1	29.2	2.2	2.9	10
Assessment area	24.5	35.5	2.7	3.8	47
Peripheral area	26.1	36.2	13.4	18.5	20
All ecological-hydrologic units	25.0	35.7	5.9	8.2	67

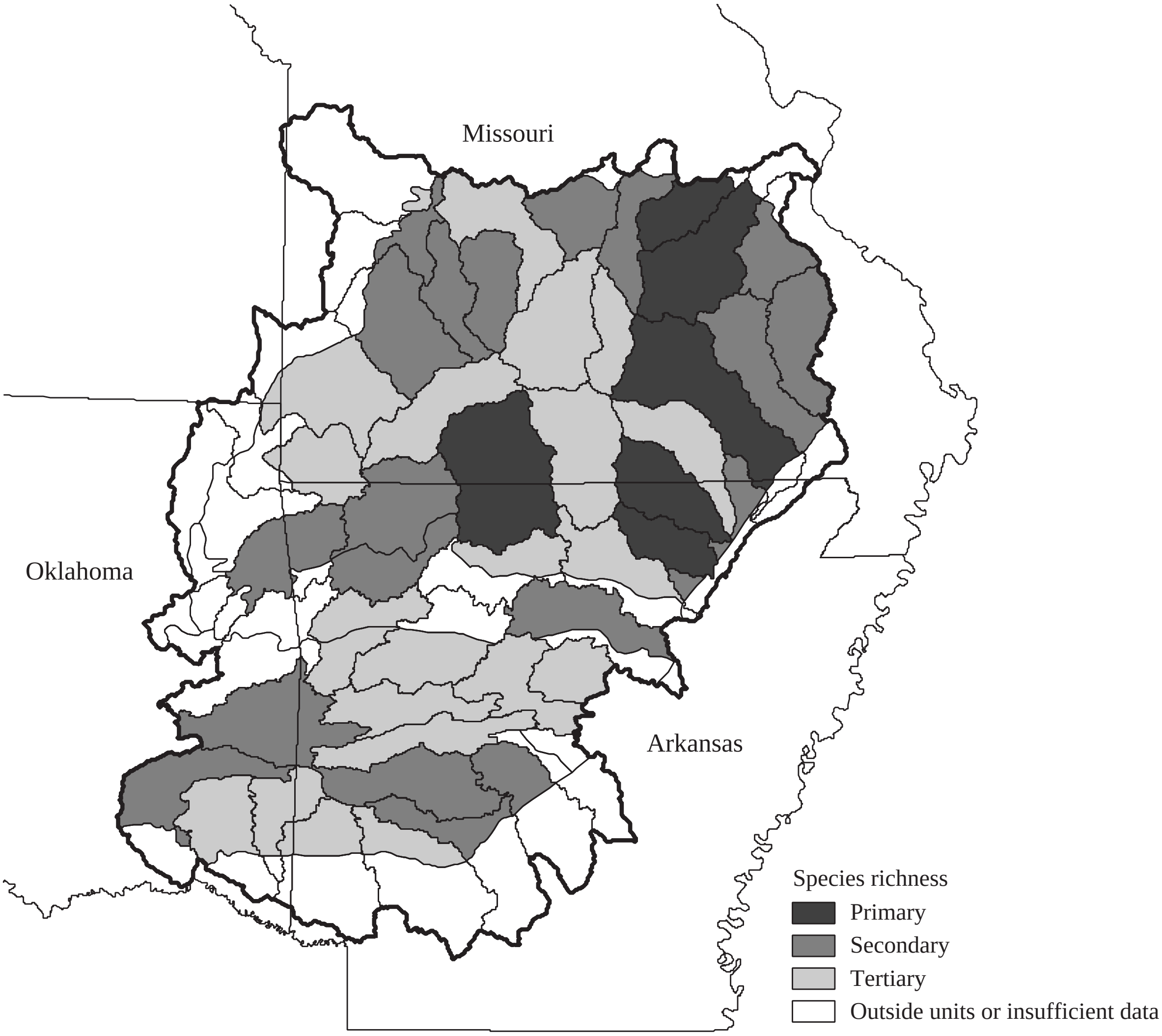


Figure 2.21—Levels of native freshwater mussel species richness by ecological-hydrologic unit.

levels for species richness are all in the Ozark Highlands ecological section. They include three Upper Black River Basin units—Spring River (OZ) (46 species), Current River (OZ) (42 species), and Strawberry River (OZ) (39 species)—the Upper White River Basin's Bull Shoals Lake (OZ) (35 species), and the Meramec River drainage units—Meramec River (OZ) (39 species) and Bourbeuse River (OZ) (37 species).

Ecological-hydrologic units of the Upper Black, St. Francis, Meramec, and Gasconade River Basins, located in the northeastern quarter of the Assessment area, form the major contiguous center for species richness. Ecological-hydrologic units of the Kiamichi-Little River and Ouachita-Saline River Basins draining southward from the Ouachita Mountains into the western Gulf Coastal Plain form a southern center of relatively high species richness. Four ecological-hydrologic units in the Neosho-Illinois and Upper White River Basins form an interior area of species richness that spans portions of the Ozark Highlands and Boston Mountains ecological sections. A third smaller center of relatively high species richness occurs in upstream tributaries to the Osage River Basin in the northwestern portion of the Assessment area.

Conservation-rank species richness values of ecological-hydrologic units—obtained by summing species conservation ranks (1 = currently stable, 2 = of special concern, 3 = threatened, 4 = endangered) for each species present—showed a pattern that is similar to the analysis just shown (fig. 2.22). These values ranged from 8 to 76 (table 2.15), with an average conservation

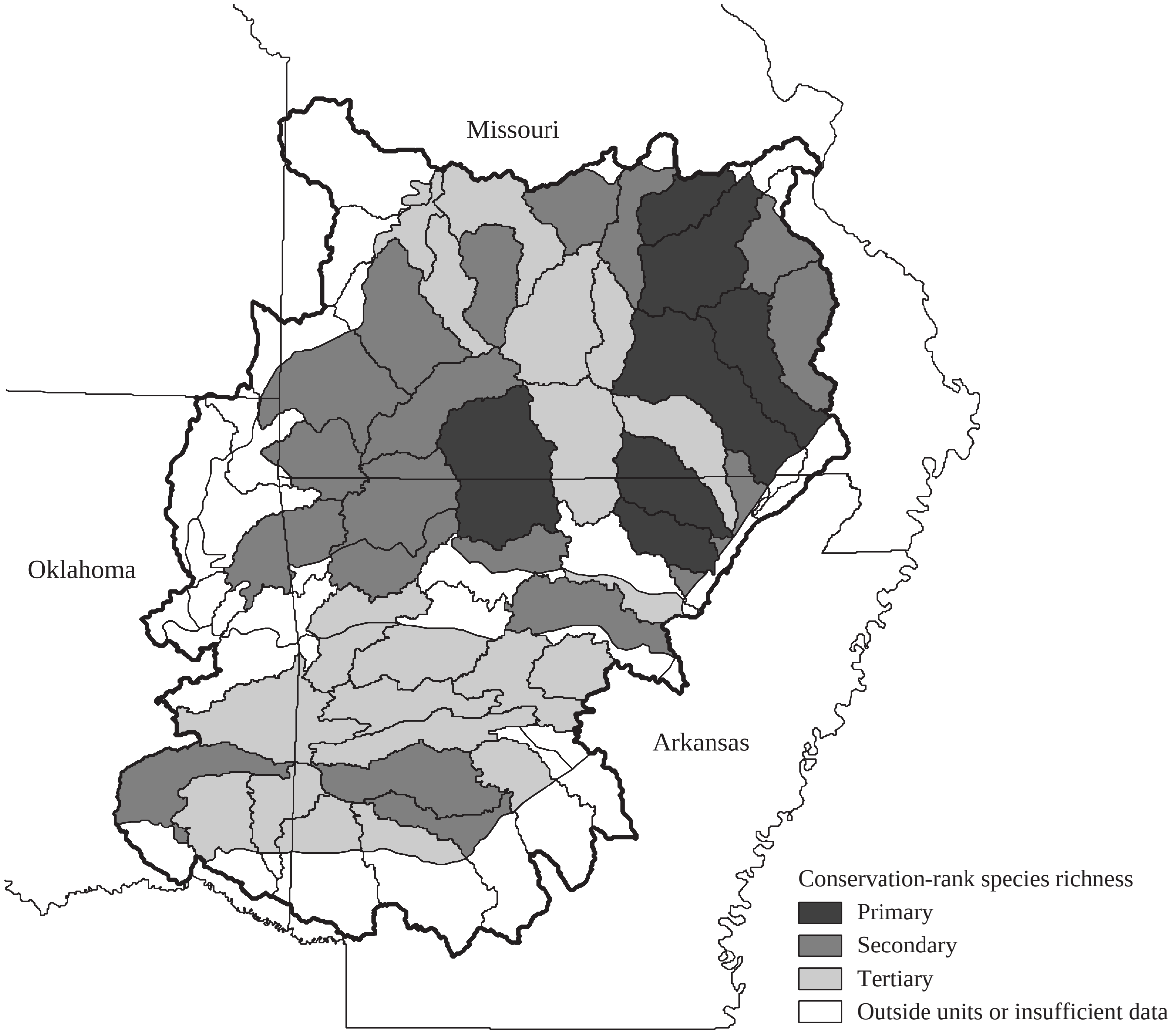


Figure 2.22—Levels of freshwater mussel conservation-rank species richness by ecological-hydrologic unit.

Table 2.15—Freshwater mussel species richness and density, conservation-rank values, and total endemics within the Assessment area by ecological-hydrologic unit

River basin Ecological-hydrologic unit name	Watershed code (HUC)	Area	Species richness	Species density	Conservation-rank species richness	Conservation-rank species density	Endemic species
		Mi^2		*Number per 100 mi^2*		*Number per 100 mi^2*	
Osage River Basin							
Harry S. Truman Reservoir-OZ	10290105	497	26	5.2	34	6.8	1
Harry S. Truman Reservoir-OA	10290105	714	22	3.1	26	3.6	1
Sac-OZ	10290106	1,716	27	1.6	41	2.4	3
Sac-OA	10290106	255	18	7.1	22	8.6	1
Pomme de Terre-OZ	10290107	848	25	3.0	34	4.0	3
South Grand-OZ	10290108	89	14	15.7	16	18.0	1
South Grand-OA	10290108	1,959	22	1.1	26	1.3	0
Lake of the Ozarks-OZ	10290109	1,385	19	1.4	21	1.5	0
Niangua-OZ	10290110	1,031	27	2.6	38	3.7	3
Lower Osage-OZ	10290111	952	33	3.5	46	4.8	2
Lower Osage-OA	10290111	124	22	17.7	29	23.4	0
Gasconade River Basin							
Upper Gasconade-OZ	10290201	1,788	22	1.2	30	1.7	1
Big Piney-OZ	10290202	756	12	1.6	17	2.2	2
Lower Gasconade-OZ	10290203	865	28	3.2	43	5.0	1
Lower Gasconade-OA	10290203	170	30	17.7	48	28.2	1
Meramec River Basin							
Meramec-OZ	07140102	1,815	39	2.2	63	3.5	3
Meramec-OA	07140102	345	41	11.9	62	18.0	2
Bourbeuse-OZ	07140103	785	37	4.7	55	7.0	2
Bourbeuse-OA	07140103	52	32	61.2	47	90.4	1
Big-OZ	07140104	806	27	3.4	40	5.0	3
Big-OA	07140104	156	28	18.0	40	25.6	1
Upper St. Francis River Basin							
Upper St. Francis-OZ	08020202	1,298	31	2.4	48	3.7	3
Neosho-Illinois River Basin							
Lake O' the Cherokees-OZ	11070206	586	—	—	—	—	—
Lake O' the Cherokees-OA	11070206	334	12	3.6	13	3.9	0
Spring-OZ	11070207	1,793	24	1.3	36	2.0	3
Spring-OA	11070207	785	20	2.5	26	3.3	1
Elk-OZ	11070208	1,031	23	2.2	39	3.8	5
Lower Neosho-OZ	11070209	1,028	—	—	—	—	—
Lower Neosho-BM	11070209	238	—	—	—	—	—
Lower Neosho-OA	11070209	944	—	—	—	—	—
Illinois-OZ	11110103	1,329	30	2.3	42	3.2	4
Illinois-BM	11110103	321	—	—	—	—	—
Arkansas River Basin							
Dirty-Greenleaf-BM	11110102	288	—	—	—	—	—
Dirty-Greenleaf-AV	11110102	229	—	—	—	—	—
Dirty-Greenleaf-OA	11110102	273	—	—	—	—	—
Robert S. Kerr Reservoir-BM	11110104	732	—	—	—	—	—
Robert S. Kerr Reservoir-AV	11110104	1,074	—	—	—	—	—
Poteau-OM	11110105	1,904	28	1.5	31	1.6	1
Frog-Mulberry-BM	11110201	719	20	2.8	28	3.9	0
Frog-Mulberry-AV	11110201	539	18	3.3	19	3.5	0
Dardanelle Reservoir-BM	11110202	668	—	—	—	—	—
Dardanelle Reservoir-AV	11110202	1,193	18	1.5	19	1.6	0
Lake Conway-Point Remove-AV	11110203	1,137	7	0.6	8	0.7	0
Petit Jean-AV	11110204	1,090	15	1.4	16	1.5	0

(continued)

Table 2.15—Freshwater mussel species richness and density, conservation-rank values, and total endemics within the Assessment area by ecological-hydrologic unit (continued)

River basin Ecological-hydrologic unit name	Watershed code (HUC)	Area	Species richness	Species density	Conservation-rank species richness	Conservation-rank species density	Endemic species
		Mi²		*Number per 100 mi²*		*Number per 100 mi²*	
Arkansas River Basin (continued)							
Cadron-AV	11110205	769	12	1.6	13	1.7	0
Fourche La Fave-OM	11110206	1,119	20	1.8	22	2.0	0
Lower Arkansas-Maumelle-AV	11110207	280	—	—	—	—	—
Lower Arkansas-Maumelle-OM	11110207	197	—	—	—	—	—
Lower Arkansas-Maumelle-OA	11110207	630	—	—	—	—	—
Kiamichi-Little River Basin							
Kiamichi-OM	11140105	1,316	33	2.5	49	3.7	3
Kiamichi-OA	11140105	506	27	5.3	39	7.7	2
Upper Little-OM	11140107	1,010	21	2.1	28	2.8	2
Upper Little-OA	11140107	399	29	7.3	39	9.8	3
Mountain Fork-OM	11140108	787	13	1.7	17	2.2	1
Mountain Fork-OA	11140108	69	24	35.0	31	44.9	1
Lower Little-OM	11140109	674	6	0.9	10	1.5	1
Lower Little-OA	11140109	1,301	36	2.8	54	4.2	3
Ouachita-Saline River Basin							
Ouachita Headwaters-OM	08040101	1,546	28	1.8	41	2.7	4
Upper Ouachita-OM	08040102	673	25	3.7	40	4.0	4
Upper Ouachita-OA	08040102	1,089	37	3.4	53	4.9	3
Little Missouri-OM	08040103	613	12	2.0	20	3.3	3
Little Missouri-OA	08040103	1,484	29	2.0	44	3.0	2
Upper Saline-OM	08040203	673	25	3.7	34	5.1	3
Upper Saline-OA	08040203	1,037	39	3.8	55	5.3	4
Upper White River Basin							
Beaver Reservoir-OZ	11010001	1,610	30	1.9	44	2.7	5
Beaver Reservoir-BM	11010001	946	29	3.1	43	4.5	5
James-OZ	11010002	1,448	23	1.6	36	2.5	4
Bull Shoals Lake-OZ	11010003	2,600	35	1.4	59	2.3	6
Middle White-OZ	11010004	1,034	—	—	—	—	—
Middle White-BM	11010004	407	11	2.7	13	3.2	0
Middle White-OA	11010004	34	17	50.5	23	67.6	0
Buffalo-OZ	11010005	653	22	3.4	37	5.7	5
Buffalo-BM	11010005	689	—	—	—	—	—
North Fork White-OZ	11010006	1,836	16	0.9	28	1.5	5
Little Red-BM	11010014	1,320	27	2.1	42	3.2	5
Little Red-AV	11010014	411	—	—	—	—	—
Little Red-OA	11010014	90	—	—	—	—	—
Upper Black River Basin							
Upper Black-OZ	11010007	1,439	32	2.2	52	3.6	6
Upper Black-OA	11010007	471	23	4.9	31	7.4	0
Current-OZ	11010008	2,453	42	1.7	62	2.5	6
Current-OA	11010008	172	14	8.2	16	9.3	0
Lower Black-OZ	11010009	490	33	6.7	46	9.4	1
Lower Black-OA	11010009	289	—	—	—	—	—
Spring-OZ	11010010	1,217	46	3.8	76	6.2	5
Eleven Point-OZ	11010011	1,202	22	1.8	32	2.7	5
Strawberry-OZ	11010012	789	39	4.9	61	7.9	5

HUC = hydrologic unit code; mi² = square mile; OZ = Ozark Highlands; BM = Boston Mountains; AV = Arkansas Valley; OM = Ouachita Mountains; OA = Outside the Highlands Assessment ecological sections; — = insufficient data.

rank of 35.5 per unit in the Assessment area (table 2.14). Conservation-rank species richness values in ecological-hydrologic units are as follows—primary (7 units with a range of 52 to 76), secondary (18 units with a range of 36 to 49), and tertiary (22 units with a range of 8 to 35). This distribution showed that the high richness area in the northeastern quarter of the Assessment area persisted, as did the smaller southern center of richness. The interior and upper Osage tributary areas of high species richness coalesced in the conservation-rank species richness analysis to form a broader western Ozark center of high conservation-rank species richness.

The five ecological-hydrologic units with the highest conservation-rank species richness in the Assessment area were the Spring (OZ) (76), Current (OZ) (62), and Strawberry (OZ) (61) units, of the Upper Black River Basin and the Meramec (OZ) (63) and the Bull Shoals (OZ) (59) units of the Upper White River Basin. (Of the 11 highest ranking ecological-hydrologic units, one was not in the Ozark Highlands—the Kiamichi in the Ouachita Mountains.) The freshwater mussel communities of the 11 highest ranking ecological-hydrologic units were characterized by high numbers of species (31 to 46), of which 5 to 7 species are considered threatened or endangered.

The density of freshwater mussel species varied among ecological-hydrologic units of the Assessment area. The average species density for 47 of the ecological-hydrologic units was 2.7 species per 100 mi^2 (table 2.14). The species density distribution of ecological-hydrologic units in the Assessment area shows northern and central centers of high species density (fig. 2.23). The primary level has 5 units with a range of 4.7 to 15.7 species per 100 mi^2; the secondary level has 11 units with a range of 2.8 to 3.8 species per 100 mi^2; and the tertiary level has 31 units with a range of 0.6 to 2.7 species per 100 mi^2. Ecological-hydrologic units with primary levels of species density had relatively small drainage areas (89 to 789 mi^2) and species richness values ranging from 14 to 39. Seven of the 10 smallest ecological-hydrologic had primary or secondary levels of species density. However, regression of species richness with drainage area was not statistically significant for ecological-hydrologic units.

Conservation-rank species density for ecological-hydrologic units inside the Assessment area ranged from 0.7 to 18.0 species per 100 mi^2 (table 2.15), with an average value of 3.8 species per 100 mi^2. The distribution of ecological-hydrologic units with primary (7 units with a range 5.7 to 18.0 species per 100 mi^2); secondary (15 units with a range of 3.5 to 5.1 species per 100 mi^2); and tertiary (25 units with a range of 0.7 to 3.3 species per 100 mi^2) levels of conservation-rank species density within the Assessment area illustrates a pattern similar to species density with distinct northern peripheral, central, and southern concentrations (not shown here).

Hydrologic units. The most species-rich hydrologic units were the Spring (Upper Black River Basin) with 46 species and the Meramec with 44 species, followed closely by the Current (Upper Black River Basin) and Upper Ouachita hydrologic units (43 and 42 species, respectively) (table 2.16). Four of the hydrologic units with relatively low species richness (North Fork White River, Dardanelle Reservoir, Lake of the Ozarks, and Middle White River) have been ecologically altered by major river channel reservoirs or adverse biological effects that affect aquatic habitats downstream of dams. (The “adverse biological effects” are associated with hypolimnetic releases—discharges from reservoirs of deeper, colder, less oxygenated water.) The average species richness was 28.7 per unit for 45 of the hydrologic units within the aquatic study area. The distribution of hydrologic units in terms of species richness was similar to that of ecological-hydrologic units: primary (4 watersheds with a range of 42 to 46 species), secondary (19 watersheds with a range of 29 to 39 species), and tertiary (22 watersheds with a range of 12 to 28 species). However, there was a more pronounced southern tier of species-rich units for southward draining Ouachita River and Red River system tributaries (fig. 2.24).

Nineteen of the 23 hydrologic units exhibiting primary or secondary levels of species richness were positioned at ecotones between uplands of the Ouachita Mountains or Ozark Highlands and lowlands of the West Gulf Coastal Plain or the Mississippi Alluvial Basin. These hydrologic units were enriched with species characteristically found in both tributaries and large rivers and thus exhibited higher species richness.

Conservation-rank species richness values ranged from 13 to 76 (mean = 41.4) for the 45 hydrologic units analyzed in the aquatic study area (table 2.16). The distribution of hydrologic units for conservation-rank species

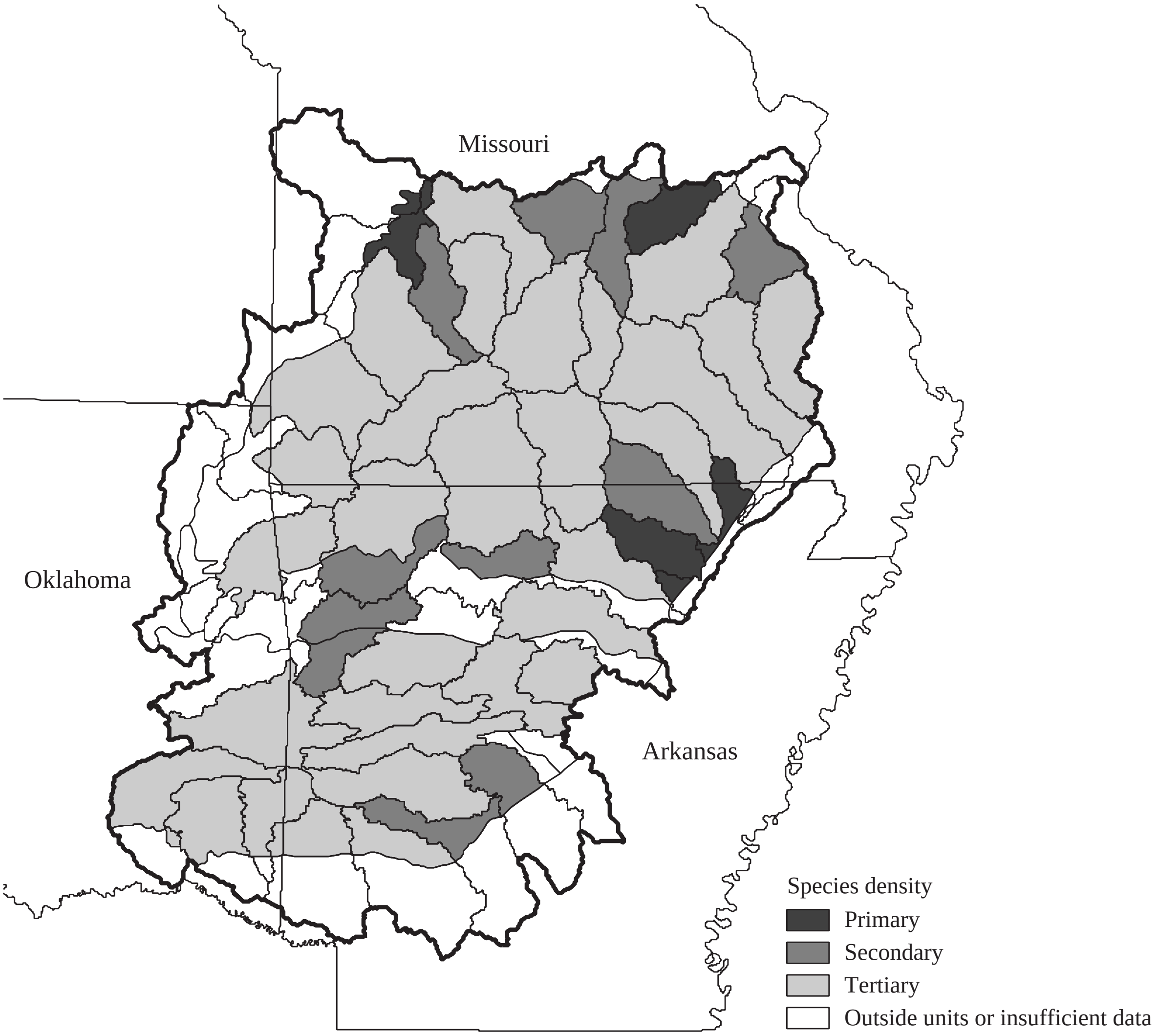


Figure 2.23—Levels of freshwater mussel species density by ecological-hydrologic unit.

richness—primary (11 watersheds with a range of 54 to 76), secondary (13 watersheds with a range of 41 to 50), and tertiary (21 watersheds with a range of 13 to 39)—was generally congruent with results for species richness. Two centers of conservation-rank species richness were evident among hydrologic units (fig. 2.25). The largest centers of conservation-rank species richness were located in the northeastern quarter and in the southernmost tier of hydrologic units of the Assessment area.

Freshwater mussel species density was highly variable among hydrologic units (table 2.16), ranging from 0.9 to 4.9; the average mussel species density was 2.1 species per 100 mi^2. Regression of species richness with unit area was significant ($P < 0.002$). The relationship log (species richness) = 0.425 + 0.312 log (unit area) accounted for only 20 percent of the species richness. Species density in a hydrologic unit was negatively correlated with unit area ($k = -0.686$, $P < 0.0001$). The distribution of hydrologic units in terms of species density—primary (6 watersheds with a range of 3.6 to 4.9 species per 100 mi^2), secondary (11 watersheds with a range of 2.2 to 3.3 species per 100 mi^2),

Table 2.16—Mussel species richness and density, conservation-rank richness and density, index of relative importance, and overall rank for watersheds within the aquatic study area

River basin Watershed name	Watershed code (HUC)	Species richness (rank order)		Species density (rank order)		Conservation-rank species richness (rank order)		Conservation-rank species density (rank order)		Index of relative importance (sum of rank orders)	Overall rank order[a]
				No. per 100 mi²				*No. per 100 mi²*			
Osage River Basin											
H.S. Truman Reservoir	10290105	28	(16)	2.3	(11)	36	(21)	3.0	(14)	62	22
Sac	10290106	29	(15)	1.5	(17)	43	(15)	2.2	(20)	67	24
Pomme de Terre	10290107	25	(18)	2.9	(8)	34	(23)	4.0	(8)	57	20
South Grand	10290108	24	(19)	1.2	(20)	30	(27)	1.5	(24)	90	30
Lake of the Ozarks	10290109	19	(23)	1.4	(18)	21	(30)	1.5	(24)	95	32
Niangua	10290110	27	(17)	2.6	(9)	38	(19)	3.7	(11)	56	19
Lower Osage	10290111	36	(8)	3.3	(6)	49	(11)	4.5	(6)	31	7
Gasconade River Basin											
Upper Gasconade	10290201	22	(21)	1.2	(20)	30	(27)	1.7	(22)	90	30
Big Piney	10290202	12	(27)	1.6	(16)	17	(32)	2.3	(19)	94	31
Lower Gasconade	10290203	32	(12)	3.1	(7)	50	(10)	4.9	(5)	34	9
Meramec River Basin											
Meramec	07140102	44	(2)	2.0	(13)	68	(2)	3.2	(13)	30	6
Bourbeuse	07140103	38	(6)	4.6	(2)	56	(7)	6.7	(2)	17	3
Big	07140104	37	(7)	3.8	(4)	57	(6)	5.9	(4)	21	4
Upper St. Francis River Basin											
Upper St. Francis	08020202	31	(13)	2.4	(10)	48	(12)	3.7	(11)	46	14
Neosho-Illinois River Basin											
Lake O' the Cherokees	11070206	15	(26)	1.6	(16)	16	(33)	1.7	(22)	97	33
Spring	11070207	32	(12)	2.6	(9)	47	(13)	3.9	(9)	43	12
Elk	11070208	23	(20)	2.2	(12)	39	(18)	3.8	(10)	60	21
Lower Neosho	11070209	—		—		—		—		—	—
Illinois	11110103	30	(14)	1.8	(15)	42	(16)	2.6	17)	62	22
Arkansas River Basin											
Dirty-Greenleaf	11110102	—		—		—		—		—	—
Robert S. Kerr Reservoir	11110104	—		—		—		—		—	—
Poteau	11110105	28	(16)	1.5	(17)	31	(26)	1.6	(23)	82	28
Frog-Mulberry	11110201	25	(18)	2.0	(13)	33	(24)	2.6	(17)	72	26
Dardanelle Reservoir	11110202	18	(24)	1.0	(21)	19	(31)	1.0	(25)	101	36
Conway- Pt. Remove	11110203	—		—		—		—		—	—
Petit Jean	11110204	15	(26)	1.4	(18)	16	(33)	1.5	(24)	101	36
Cadron	11110205	12	(27)	1.5	(17)	13	(34)	1.7	(22)	100	35
Fourche La Fave	11110206	21	(22)	1.9	(14)	27	(29)	2.4	(18)	83	29
Lower Ark-Maumelle	11110207	—		—		—		—		—	—
Kiamichi-Little River Basin											
Kiamichi	11140105	34	(10)	1.9	(14)	50	(10)	2.8	(15)	49	16
Upper Little	11140107	32	(12)	2.3	(11)	42	(9)	3.0	(14)	53	18
Mountain Fork	11140108	31	(13)	3.6	(5)	36	(21)	4.2	(7)	46	14
Lower Little	11140109	36	(8)	1.8	(15)	54	(9)	2.7	(16)	48	15
Ouachita-Saline River Basin											
Ouachita Headwaters	08040101	28	(16)	1.8	(15)	41	(17)	2.7	(16)	64	23
Upper Ouachita	08040102	42	(4)	2.4	(10)	64	(3)	3.6	(12)	29	5
Little Missouri	08040103	32	(12)	1.5	(17)	50	(10)	2.4	(18)	57	20
Upper Saline	08040203	39	(5)	2.3	(11)	55	(8)	3.2	(13)	37	10
Upper White River Basin											
Beaver Reservoir	11010001	33	(11)	1.3	(19)	47	(13)	1.8	(21)	64	23
James	11010002	23	(20)	1.6	(16)	35	(22)	2.4	(18)	76	26
Bull Shoals Lake	11010003	35	(9)	1.3	(19)	59	(5)	2.3	(19)	52	17
Middle White	11010004	21	(22)	1.4	(18)	27	(29)	1.8	(21)	90	30
Buffalo	11010005	22	(21)	1.6	(16)	37	(20)	2.8	(15)	72	26

(continued)

Table 2.16—Mussel species richness and density, conservation-rank richness and density, index of relative importance, and overall rank for watersheds within the aquatic study area (continued)

River basin Watershed naame	Watershed code (HUC)	Species richness (rank order)	Species density (rank order)	Conservation-rank species richness (rank order)	Conservation-rank species density (rank order)	Index of relative importance (sum of rank orders)	Overall rank order[a]
			No. per 100 mi^2		*No. per 100 mi^2*		
Upper White River Basin (continued)							
North Fork White	11010006	16 (25)	0.9 (22)	28 (28)	1.5 (24)	99	34
Little Red	11010014	27 (17)	1.5 (17)	42 (16)	2.3 (19)	69	25
Upper Black River Basin							
Upper Black	11010007	35 (9)	1.8 (15)	57 (6)	3.0 (14)	44	13
Current	11010008	43 (3)	1.6 (16)	64 (3)	2.4 (18)	40	11
Lower Black	11010009	33 (11)	4.2 (3)	46 (14)	5.9 (4)	32	8
Spring	11010010	46 (1)	3.8 (4)	76 (1)	6.2 (3)	9	1
Eleven Point	11010011	22 (21)	1.8 (15)	32 (25)	2.7 (16)	77	27
Strawberry	11010012	39 (5)	4.9 (1)	61 (4)	7.9 (1)	11	2

HUC = hydrologic unit code; mi^2 = square mile; — = insufficient data.

[a] Rank order identifies the order of importance with 1 being the highest, 34 the lowest.

Source: see "Data Sources and Methods of Analysis" of this section.

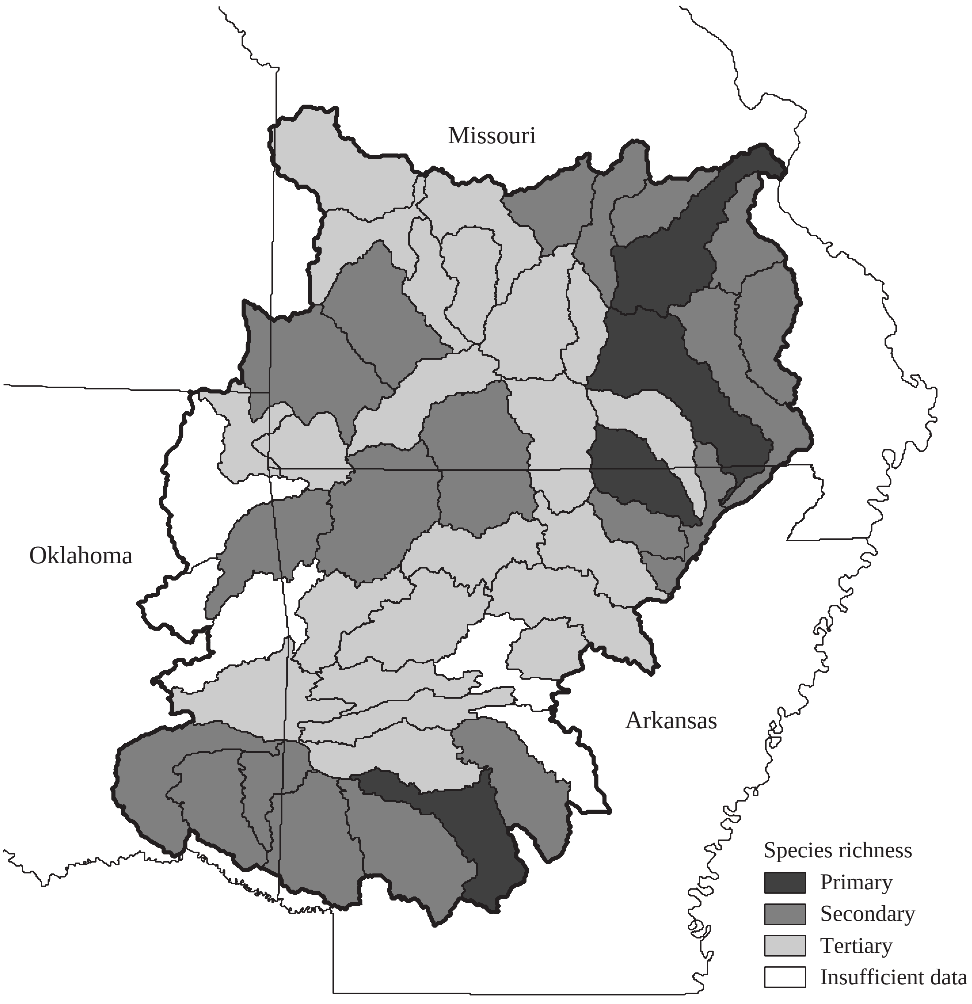


Figure 2.24—Levels of freshwater mussel species richness by watershed.

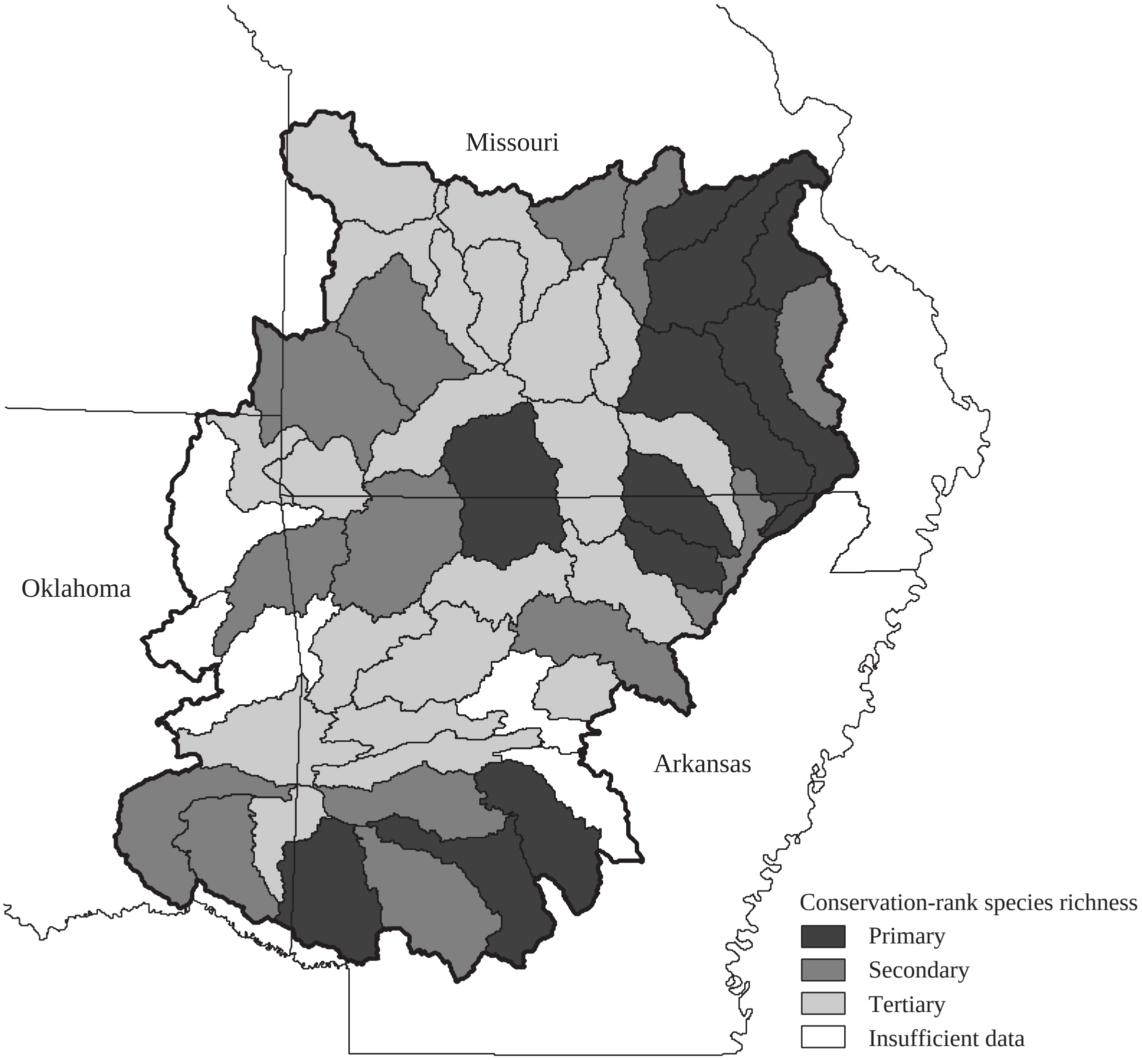


Figure 2.25—Levels of freshwater mussel conservation-rank species richness by watershed.

and tertiary (28 watersheds with a range of 0.9 to 2.0 species per 100 mi^2)—was generally congruent with that previously presented for ecological-hydrologic units, with the exception that the southern tier of hydrologic units increased in density level (fig. 2.26). These increases were due to the addition of species from ecological-hydrologic units outside of the Assessment area, and included several large river mussel species encountered in the ecotones between the Ouachita Mountains and the Gulf Coastal Plain.

Conservation-rank species density values ranged from 1.0 to 7.9 species per 100 mi^2 with an average of 3.1 (table 2.16). The hydrologic units exhibited primary (6 watersheds with a range of 4.9 to 7.9 species per 100 mi^2), secondary (13 watersheds with a range of 3.0 to 4.5 species per 100 mi^2), and tertiary (25 watersheds with a range of 1.0 to 2.8 per 100 mi^2) levels of conservation-rank density.

The Aquatic Team summed rank order values for each species richness and species density index to give an “index of relative importance” for each watershed (lower sums in this column on table 2.16 indicate greater richness and density). In the aquatic study area, this index ranked 10 watersheds as having the greatest

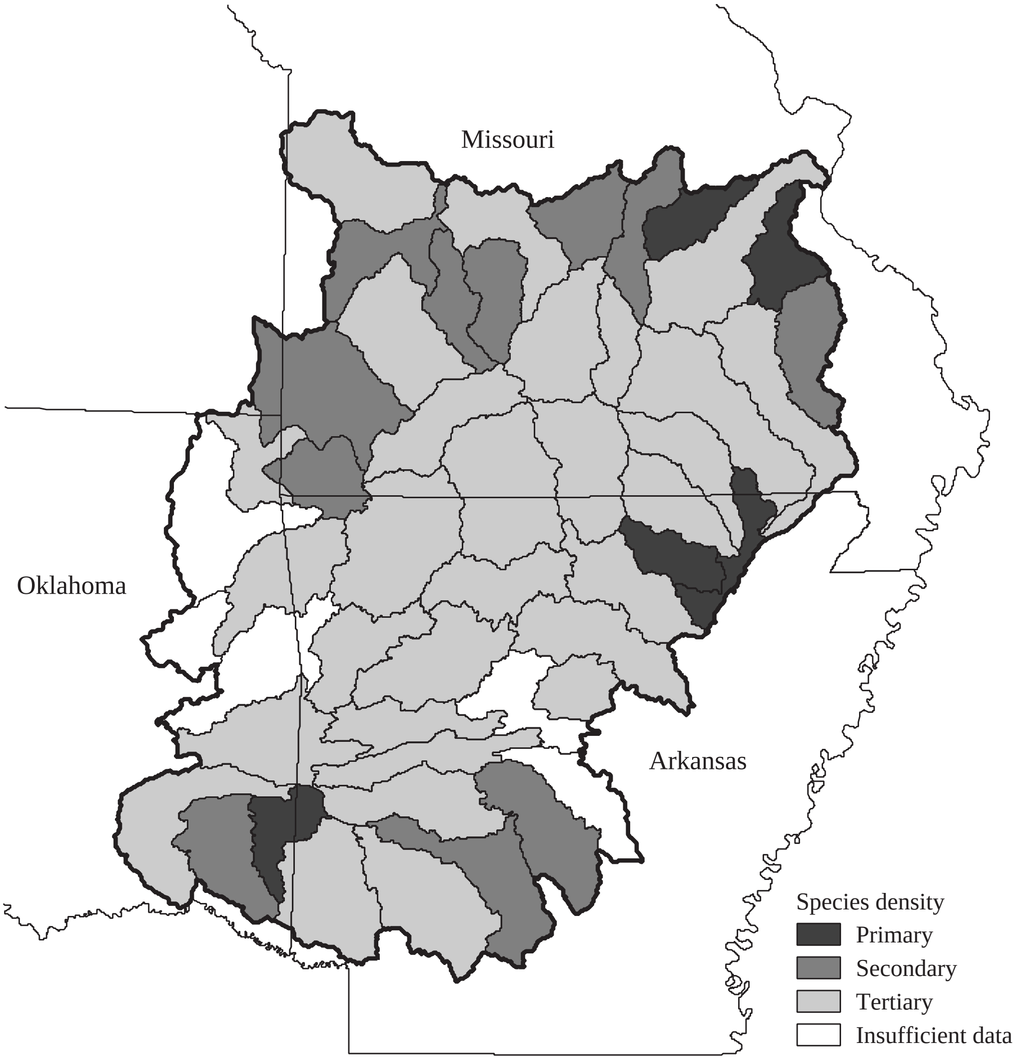


Figure 2.26—Levels of freshwater mussel species density by watershed.

richness and density: 3 each in the Upper Black River and Meramec River Basins, 2 in the Ouachita-Saline River Basin, and 1 each in the Osage River and Gasconade River Basins. The Spring and Strawberry Rivers (both in the Upper Black River Basin) received the number one and two "overall rank," respectively, for watersheds within the aquatic study area. Both ranked among the top five watersheds for each richness and density category. The Spring River ranked first in both species richness (46 species) and conservation-rank species richness (value = 76), and the Strawberry River ranked first in both species density (4.9 species per 100 mi^2) and conservation-rank density (7.9 per 100 mi^2). The Spring River mussel community included four threatened species, two endangered species, and five endemic species.

Endemic freshwater mussels. Johnson (1980) identified 10 species as being endemic to the Interior Highlands. In addition, Gordon (1980) and Gordon and Harris (1983) discussed the distributional patterns and zoogeography for Arkansas mussels and categorized seven species found within Arkansas as Interior Highlands endemic species.

Using current species concepts, 11 species (15.1 percent of the native mussels) are endemic to the Interior Highlands (table 2.13). Further inspection of these endemic species indicates three patterns of endemism that coincide with ecological sections: Ozark Highlands endemic species, Ouachita Mountains endemic species, and endemic species common to both ecological sections. Six species (Arkansas broken-ray, bleedingtooth mussel, Curtis pearlymussel, Neosho mucket, Ozark pigtoe, and speckled pocketbook) are restricted to the Ozark Highlands; three species (Arkansas fatmucket, Ouachita creekshell, and Ouachita rock-pocketbook) are found only in the Ouachita Mountains; and two species (Ouachita kidneyshell and western fanshell) occur in both the Ozark and Ouachita ecological sections.

At least one endemic mussel species was present in 38 of 47 ecological-hydrologic units in the Assessment area for which data were available. Endemicity averaged 2.6 endemic species per ecological-hydrologic unit. Primary levels of endemicity (11 units with a range of 5 to 6 species) were associated with ecological-hydrologic units in the Upper White and Upper Black River Basins (10 units) and the Neosho River Basin (number = 1 unit) of the Ozark Highlands. Secondary levels of endemicity (13 units with a range of 3 to 4 species) occurred in the Osage (2 units) and Meramec (2 units) Basins, the Upper White River Basin (2 units), the Upper St. Francis River Basin (1 unit), the Neosho-Illinois River Basin (1 unit), the Kiamichi River-Little Basin (1 unit), and all four ecological-hydrologic units of the Ouachita-Saline River Basin within the Highlands.

Implications and Opportunities

Freshwater mussels have been described as an imperiled fauna threatened by habitat destruction, overutilization (for commercial or other purposes), disease, predation, introduction of nonindigenous species, pollution, hybridization, and restricted range (Williams and others 1993). The single most important cause of decline in mussel diversity and abundance has been habitat destruction. Causes of this destruction have ranged from the obvious—dams, dredging, and channelization—to the subtler—siltation and contaminants. Erosion, caused in part by deforestation, poor agricultural practices, and destruction of riparian zones, has led to both increased silt loads and shifting, unstable stream bottoms. While habitat destruction continues, expansion of the distribution and numbers of nonindigenous mollusks such as the Asian clam and zebra mussel appears poised to destroy many remaining native mussel populations (Williams and others 1993).

Several hydrologic units with high "relative importance" indices are either on federally managed land or are within close proximity to such land. These include the Upper Ouachita and Upper Saline watersheds associated with the Ouachita National Forest and the Big River and Meramec River watersheds associated with the Mark Twain National Forest. Therefore, activities on federally managed lands can affect some of the best remaining populations of freshwater mussels within the Assessment area. Activities potentially harmful to freshwater mussels include timber management and road building and maintenance activities that may adversely affect water quality by increasing turbidity and sedimentation. A subtler—yet possibly lethal impact to mussels on Federal lands—would be the introduction of zebra mussels at recreational stream access sites by boaters.

Habitat protection and good conservation practices are essential to maintain existing freshwater mussel populations. Managers must implement best management practices (BMP's) when conducting timber harvests, road building and maintenance, and/or other construction activities near streams. Maintenance of riparian zones along streams is important to good water quality, nutrient levels, cover, and habitat—not only for freshwater mussels but also for the intimately associated fish and macroinvertebrate communities.

Managers and scientists interested in the recovery of freshwater mussel populations must understand community structure and function and then seek to reestablish key components that may have been eliminated or diminished by human activities. The first step to understanding community function is to understand the life cycle of each individual species. For freshwater mussels, this begins with acquiring knowledge concerning the fish host(s) required for successful reproduction; currently, the fish hosts of less than half of the mussel species in the Assessment area are known. Secondly, the interaction of physical and biological habitat variables in viable mussel communities is poorly understood. Additional research is needed to determine the combination of biological and physical-chemical attributes required to establish and maintain viable mussel communities. Partnerships among natural resource agencies, scientists and resource specialists, mussel researchers at academic institutions, and others may be the most effective way to sustain the needed research.

Preventing the introduction and spread of nuisance species to aquatic systems within the Assessment area is of increasing importance. A high priority is the education of users of Federal lands and waters regarding the catastrophic effects of introduced species. Partnerships among State and Federal resource agencies, academic institutions at all levels, and the media are critical to successfully stemming the tide of invaders such as the Asian clam and zebra mussel.

Diversity of Crayfishes

Question 2.6: What are the status and distribution of crayfishes within the Assessment area?

Decapod crustaceans in the families Astacidae, Cambaridae, and Parastacidae, commonly known as crayfishes or crawfishes, can be found nearly worldwide. Their highest diversity is in North America north of Mexico (Taylor and others 1996). The Southern United States harbors the most crayfish species, and within the Ozark-Ouachita Highlands, crayfishes are one of the most conspicuous and diverse components of the aquatic fauna (Bouchard and Robison 1980, Pflieger 1996). The Assessment area and immediately adjacent lowlands and prairies support about 17 percent (at least 57) of the crayfishes of the United States and Canada. Of the combined crayfish fauna of Arkansas, Missouri, and Oklahoma (Taylor and others 1996), 79 percent (about 72 taxa) occur within or immediately adjacent to the Assessment area. Many crayfishes in the Assessment area have extremely limited ranges (e.g., single springs or cave systems) or may occur widely in one basin and be absent from adjacent drainages. For example, within the relatively rich crayfish fauna of the Ozark Highlands, at least 16 species are unknown outside the area; many of these species are confined to single hydrologic units (Pflieger 1996).

Crayfishes, significant components of aquatic ecosystems, are large invertebrates often found in streams, rivers, and lakes. They facilitate important ecological processes, sustain recreational and commercial bait fisheries, and are a profitable and popular food (Taylor and others 1996, Pflieger 1996). Within the Assessment area, crayfishes often make up a large proportion of the biomass produced in aquatic systems (Rabeni 1992) and provide a critical food resource for stream fishes (Probst and others 1984). Nevertheless, knowledge of the basic biology and distribution of crayfishes in the Assessment area lags behind that of other aquatic organisms such as fishes and mussels. Recently, Pflieger (1996) published an excellent synthesis of information on the distribution and biology of the crayfishes of Missouri. That monograph along with the work of Bouchard and Robison (1980) and Hobbs (1989) formed the basis for this part of the Assessment. A comprehensive monograph on the biology and distribution of crayfishes of Arkansas is in preparation.

Crayfishes occupy many aquatic habitats in the Assessment area. Based on their usual or predominant habitat, crayfishes can be divided into four broad (but sometimes overlapping) categories: (1) stream dwellers; (2) swamp, marsh, and pond dwellers; (3) burrowers; or (4) cave dwellers (Pflieger 1996). Stream dwellers predominate the crayfish fauna of the Ozark-Ouachita Highlands, but species in all categories are represented. Several species usually associated with lowlands have penetrated the periphery of the Ozark-Ouachita Highlands, particularly along the Arkansas Valley (Bouchard and Robison 1980) and the interface of the Ozark Highlands and Mississippi Alluvial Basin (Pflieger 1996). The richness of crayfishes in the Assessment area is a result not only of varied aquatic habitats but also of the landscape and drainage patterns of its geologically ancient streams (Pflieger 1996).

Key Findings

1. Crayfish species representing 6 genera and 1 family (Cambaridae) are present in the Ozark-Ouachita Highlands Assessment area, and the genera *Orconectes* (24 species), *Procambarus* (13 species), and *Cambarus* (9 species) comprise 84 percent of the crayfish fauna in the 50 hydrologic units.
2. Crayfish species richness averaged 5.9 crayfish species per hydrologic unit with a range of from 2 to 14 species; however, most hydrologic units showed diverse crayfish faunas, with 29 of 50 units having crayfish richness values greater than 4 species.
3. The southeastern Ouachita Mountains and an area trending southwest to northeast from the western Boston Mountains to the eastern Ozark Plateaus showed primary or secondary levels of crayfish richness (6 to 14 species).
4. Crayfish density averaged 0.4 species per 100 mi^2 of a hydrologic unit and ranged from 0.1 to 0.9; 17 of 50 hydrologic units had densities equal to or exceeding 0.5 crayfish species per 100 mi^2.
5. Concentrations of hydrologic units with primary levels of crayfish density occurred along the northeastern edge of the Assessment area (Middle White unit, Upper St. Francis unit, and most units in the Black River and Meramec drainages) and in the southern part of the Assessment area (most units in the Ouachita-Saline drainage and the Lower Little unit of the Kiamichi-Little drainage).
6. The Ozark-Ouachita Highlands area supports at least 37 endemic crayfishes or 61 percent of the region's crayfish fauna; most of these endemic species are confined to the Ozark Plateaus and Boston Mountains (at least 22 endemic crayfishes), but endemicity is also relatively high in the Ouachita Mountains (at least 13 endemic crayfishes).

Data Sources and Methods of Analysis

To account for the distributions of crayfishes, the Aquatic Team subdivided each of 10 major drainages within the Assessment area according to hydrologic units or watersheds. River basins and watersheds are shown in figure 1.2. Fifty hydrologic units or watersheds were recognized within the aquatic study area. Half of these watersheds extend beyond the Assessment area and contain portions of other ecological sections (e.g., the Mississippi Alluvial Basin). Within a particular hydrologic unit, the team determined the presence or absence of a crayfish species or subspecies primarily from maps, distributional tables, and descriptions in Williams (1954), Reimer (1969), Bouchard and Robison (1980), Hobbs and Brown (1987), Hobbs and Robison (1985, 1988, 1989), Hobbs (1989), Pflieger (1996), Robison and Leeds (1996), and Taylor and others (1996). The team also used these sources for species regarded as endemic to the aquatic study area. With the exception of Missouri (Pflieger 1996), no recent distributional monographs for crayfishes are available for much of the study region; in particular, there are no current maps of crayfish distributions for Arkansas and Oklahoma. The status of a crayfish species reflects its known historical presence within a hydrologic unit but does not indicate its continued or present-day occurrence there. Available maps (e.g., Pflieger 1996) depicted distributions by discrete points of occurrence, allowing relatively unambiguous interpretation of crayfish distributions. In cases where the Aquatic Team could not interpret the location of data points or maps were not available, the team attempted to identify referenced site locations. In a limited number of cases, reference data were unavailable or not interpretable; the presence of a species in those hydrologic units was not included in the final data set. Because of the lack of detailed information on distribution, assignment to hydrologic units may have resulted in an underestimation of the range of some crayfish species, particularly those within Arkansas or Oklahoma. Likewise, some crayfish that occur predominantly in portions of hydrologic units extending outside the Assessment area were included in estimates of the species richness of those units. Scientific names are generally consistent with Taylor and others (1996); less than one-quarter of crayfish taxa have common names (Williams and others 1989a). Because of uncertainty regarding the distribution of subspecies, we treat *Orconectes palmeri palmeri* and *Orconectes palmeri longimanus* under the species name *Orconectes palmeri* (Penn 1957, Pflieger 1996).

The Aquatic Team analyzed diversity of crayfishes using species richness, species density, and numbers of endemic species. Species richness is the total number of crayfishes within each hydrologic unit. Hydrologic units vary in size, and richness often increases with an increase in stream size or area drained (areal additivity). To examine the effect of areal additivity, the team divided species richness by the number of square miles to produce species density values (times 100) for each unit. Species richness, species density, and number of endemic species were plotted on separate hydrologic unit maps. Three levels of relative species richness, density, and endemicity were recognized among hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 12 to 17 units (depending on tied scores) with highest values, secondary levels to the next highest 11 to 12 units, and tertiary values to the remaining units. Hence, primary levels approximate values in the fourth quartile; secondary levels, values in the third quartile; and tertiary levels, values in the first and second quartile.

Patterns and Trends

Composition of crayfish species. Crayfish faunal composition is distributed unevenly among genera. Present in the hydrologic units are 1 family (Cambaridae) and 57 species or subspecies representing 6 genera (table 2.17): *Cambarellus* (2 species); *Cambarus* (9 species); *Fallicambarus* (5 species); *Faxonella* (2 species); *Orconectes* (24 species, two of which are represented by 2 subspecies each); and *Procambarus* (13 species). The crayfish genera *Orconectes*, *Procambarus*, and *Cambarus* comprise 84 percent of the fauna in the 50 hydrologic units. The genus *Orconectes* predominates within the Ozark Highlands, Boston Mountains, and Ouachita Mountains. These ecological sections also support about 10 percent of the species and subspecies recognized in the entire genus *Cambarus*, the second most diverse genus in the family. Although several of the 13 representatives of the genus *Procambarus* are primarily lowland in distribution, others are completely adapted to upland habitats (e.g., *Procambarus tenuis*) or have penetrated the region from adjacent prairie regions or lowlands (Bouchard and Robison 1980, Pflieger 1996). Eight of the nine representatives of the genus *Cambarus* in the

Table 2.17—Crayfishes of the Ozark-Ouachita Highlands

Species	Common name	Endemic
Cambarellus puer	Cajun dwarf	
Cambarellus shufeldtii	Shufeldt's dwarf	
Cambarus aculabrum		X
Cambarus causeyi		X
Cambarus diogenes	Devil crayfish	
Cambarus hubbsi	Hubb's crayfish	X
Cambarus hubrichti	Salem Cave crayfish	X
Cambarus maculatus	Freckled crayfish	X
Cambarus setosus	Bristly Cave crayfish	X
Cambarus tartarus		X
Cambarus zophonastes		X
Fallicambarus caesius		X
Fallicambarus fodiens	Digger crayfish	
Fallicambarus harpi	Harp's crayfish	X
Fallicambarus jeanae		X
Fallicambarus strawni		X
Faxonella blairi		X
Faxonella clypeata	Shield crayfish	
Orconectes acares		X
Orconectes eupunctus	Coldwater crayfish	X
Orconectes harrisonii	Belted crayfish	X
Orconectes hylas	Woodland crayfish	X
Orconectes immunis	Papershell crayfish	
Orconectes leptogonopodus		X
Orconectes longidigitus	Longpincered crayfish	X
Orconectes luteus	Golden crayfish	
Orconectes macrus	Neosho midget crayfish	X
Orconectes marchandi	Mammoth Spring crayfish	X
Orconectes medius	Saddlebacked crayfish	X
Orconectes meeki brevis		X
Orconectes meeki meeki	Meek's crayfish	X
Orconectes menae		X
Orconectes nais		
Orconectes nana		X
Orconectes neglectus chaenodactylus		X
Orconectes neglectus neglectus	Ringed crayfish	
Orconectes ozarkae	Ozark crayfish	X
Orconectes palmeri		
Orconectes peruncus	Big Creek crayfish	X
Orconectes punctimanus	Spothanded crayfish	X
Orconectes quadruncus	St. Francis River crayfish	X
Orconectes saxatilis		X
Orconectes virilis	Northern crayfish	
Orconectes williamsi	William's crayfish	X
Procambarus acutus	White River crayfish	
Procambarus clarkii	Red swamp crayfish	
Procambarus curdi		
Procambarus gracilis	Grassland crayfish	
Procambarus liberorum		X
Procambarus ouachitae		X
Procambarus parasimulans		
Procambarus regalis		X
Procambarus reimeri		X
Procambarus simulans		
Procambarus tenuis		
Procambarus tulanei		
Procambarus viaeviridis	Vernal crayfish	

Source: see "Data Sources and Methods of Analysis" of this section.

aquatic study area are endemics and are either cave dwellers or are adapted to clear, spring-fed streams (Robison and Allen 1995, Pflieger 1996). The aquatic study area supports about 30 percent of all species known in the genus *Fallicambarus* and represents a significant center of diversity for this group of small, primarily burrowing crayfishes.

Crayfish richness and density. The number of crayfish species is not distributed evenly among the hydrologic units. Species richness averaged 5.9 crayfish species per hydrologic unit and ranged from 2 to 14 species (table 2.18). No crayfish were recorded as present in the Dirty-Greenleaf unit because of insufficient data for Oklahoma. Most units, however, showed diverse crayfish faunas; 29 of 50 units showed crayfish richness greater than 4 species.

Three geographic areas had primary levels of crayfish richness (8 to 14 species) (fig. 2.27): (1) the southeastern part of the Ouachita Mountains, (2) the central part of the Highlands in the Upper White River Basin, and (3) the northeastern corner of the Ozark Highlands. Hydrologic units of the southeastern Ouachita Mountains showing primary levels of crayfish richness included three of the four watersheds in the Ouachita-Saline drainage and the Lower Little watershed of the Kiamichi-Little drainage. The second group of hydrologic units with primary levels of crayfish richness includes (from southwest to northeast): Beaver Reservoir and Bull Shoals watersheds (Upper White River drainage); Spring, Current, and Upper Black watersheds (Upper Black River drainage); the Upper St. Francis watershed; and the Big and Meramec watersheds (Meramec River drainage). The highest values of crayfish species richness are in the Upper Black River drainage (Current watershed—14 crayfish species; Upper Black watershed—12 species) and the Kiamichi-Little River Basin (Lower Little watershed—13 species) (table 2.18).

Secondary levels of crayfish species richness (6 to 7 species) generally follow geographic patterns of units with primary levels of richness. For example, the Illinois, Lower Neosho, and Elk watersheds (Neosho-Illinois drainage); James unit (Upper White River drainage); and Robert S. Kerr and Frog-Mulberry watersheds (Arkansas River drainage) surround much of the central area with primary levels of diversity. Similarly, the Little

Table 2.18—Crayfish species richness, species density, and number of endemic species by watershed

River basin Watershed name	Watershed code (HUC)	Species richness	Species density	Endemic species
			No./100 mi²	
Osage River Basin				
H.S. Truman Reservoir	10290105	4	0.3	0
Sac	10290106	4	0.2	1
Pomme de Terre	10290107	2	0.2	0
South Grand	10290108	2	0.1	0
Lake of the Ozarks	10290109	2	0.1	0
Niangua	10290110	3	0.3	1
Lower Osage	10290111	3	0.3	0
Gasconade River Basin				
Upper Gasconade	10290201	4	0.2	2
Big Piney	10290202	3	0.4	2
Lower Gasconade	10290203	4	0.4	2
Meramec River Basin				
Meramec	07140102	9	0.4	6
Bourbeuse	07140103	4	0.5	1
Big	07140104	8	0.8	5
Upper St. Francis River Basin				
Upper St. Francis	08020202	10	0.8	6
Neosho-Illinois River Basin				
Lake O' the Cherokees	11070206	5	0.5	2
Spring	11070207	5	0.2	2
Elk	11070208	7	0.7	4
Lower Neosho	11070209	7	0.3	4
Illinois	11110103	6	0.4	4
Arkansas River Basin				
Dirty-Greenleaf	11110102	0	0.0	0
Robert S. Kerr Reservoir	11110104	6	0.3	3
Poteau	11110105	5	0.3	2
Frog-Mulberry	11110201	6	0.5	4
Dardanelle Reservoir	11110202	5	0.3	3
Conway-Pt. Remove	11110203	5	0.4	1
Petit Jean	11110204	3	0.3	0
Cadron	11110205	3	0.4	0
Fourche La Fave	11110206	4	0.4	1
Lower Ark-Maumelle	11110207	4	0.4	0
Kiamichi-Little River Basin				
Kiamichi	11140105	4	0.2	2
Upper Little	11140107	2	0.1	1
Mountain Fork	11140108	2	0.2	2
Lower Little	11140109	13	0.7	3
Ouachita-Saline River Basin				
Ouachita Headwaters	08040101	8	0.5	5
Upper Ouachita	08040102	11	0.6	5
Little Missouri	08040103	10	0.5	6
Upper Saline	08040203	7	0.4	1
Upper White River Basin				
Beaver Reservoir	11010001	11	0.4	7
James	11010002	7	0.5	5
Bull Shoals Lake	11010003	11	0.4	8
Middle White	11010004	7	0.5	5
Buffalo	11010005	3	0.2	2
North Fork White	11010006	6	0.3	4
Little Red	11010014	6	0.3	4
Upper Black River Basin				
Upper Black	11010007	12	0.6	2
Current	11010008	14	0.5	4
Lower Black	11010009	3	0.4	1
Spring	11010010	11	0.9	8
Eleven Point	11010011	7	0.6	5
Strawberry	11010012	6	0.8	3

HUC = hydrologic unit code; mi² = square mile.

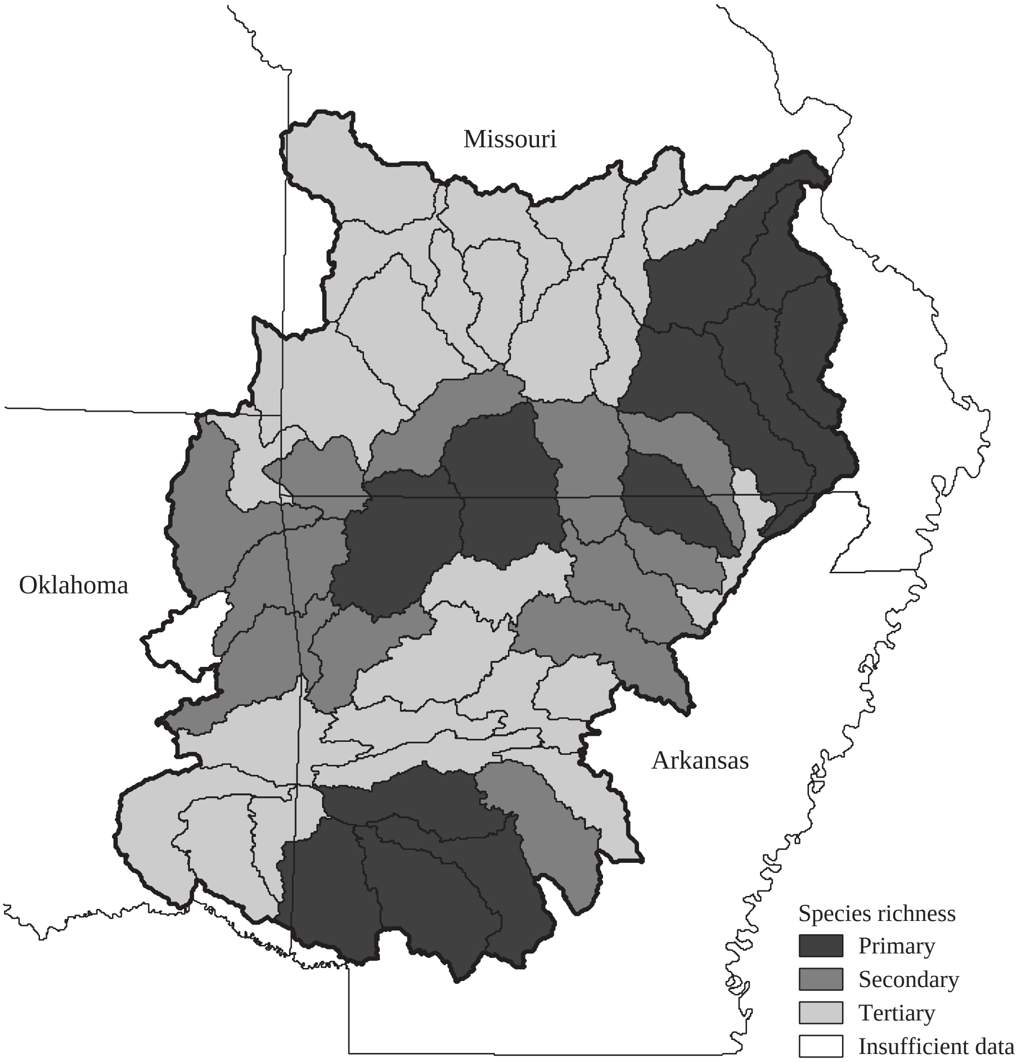


Figure 2.27—Levels of crayfish species richness by watershed.

Red, Middle White, and North Fork White (Upper White drainage), and the Strawberry and Eleven Point watersheds (Upper Black River drainage) are associated with the northeastern group of watersheds with primary levels of crayfish species richness.

Tertiary levels of crayfish species richness (fewer than six species) are concentrated primarily in hydrologic units in the northwestern one third of the Assessment area. All hydrologic units in the Osage and Gasconade River drainages show tertiary levels of crayfish richness as do the Spring and Lake O' the Cherokees watersheds (Neosho-Illinois drainage). Most watersheds in the Arkansas River and the Kiamichi-Little drainages also showed tertiary levels of crayfish richness.

The density of crayfish species is not distributed evenly among the hydrologic units (fig. 2.28). Crayfish density averaged 0.4 crayfish species per 100 mi^2 of a hydrologic unit and ranged from 0.1 to 0.9 (table 2.18). Seventeen of 50 hydrologic units had crayfish species densities of at least 0.5 species per 100 mi^2.

Two concentrations of primary levels of crayfish species density (0.5 to 0.9 species per 100 mi^2) are apparent (fig. 2.28). One concentration lies in the northeastern corner of the Assessment area and consists of the Middle White watershed and most

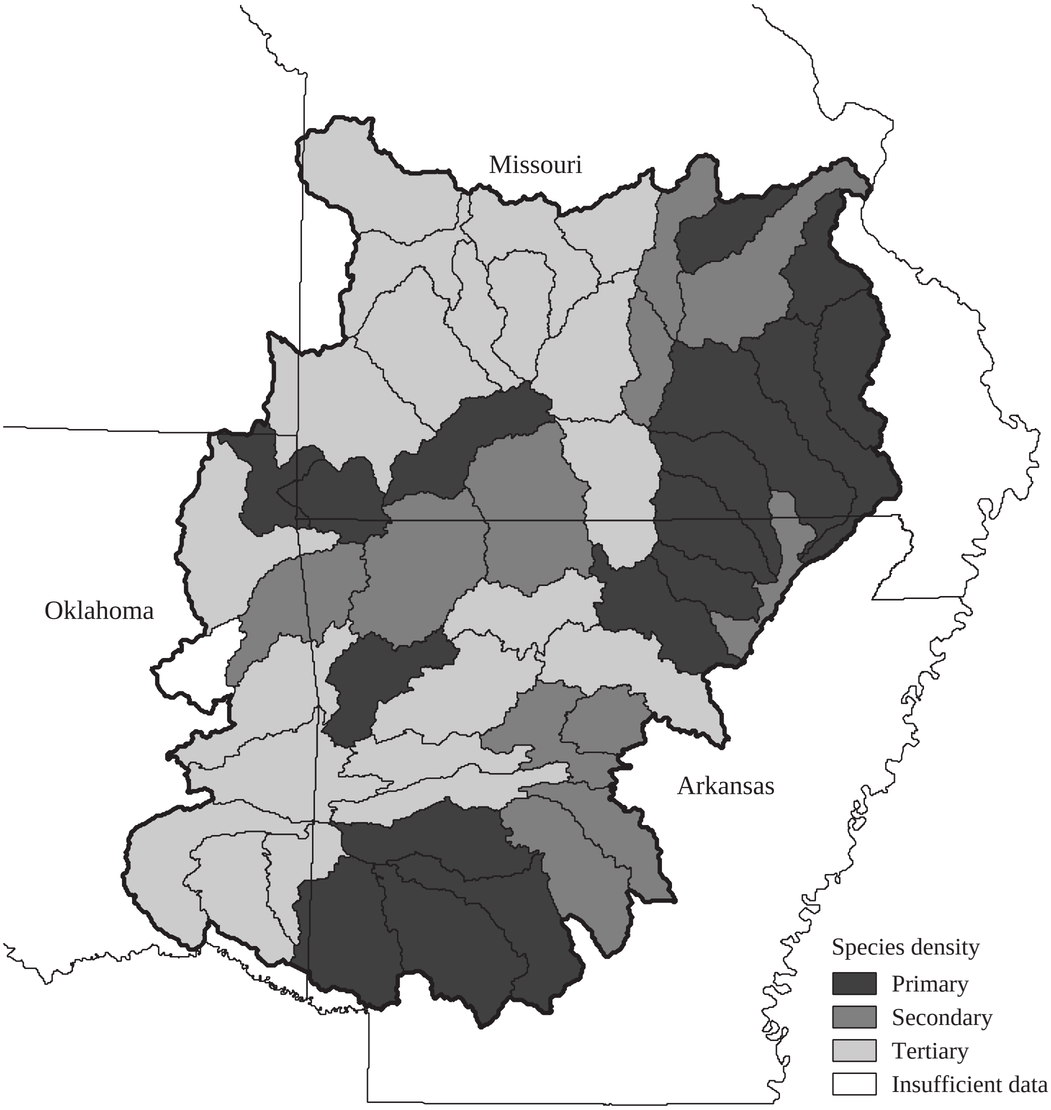


Figure 2.28—Levels of crayfish species density by watershed.

watersheds in the Upper Black River, Upper St. Francis, and Meramec drainages. A second group showing primary levels of crayfish species density consists of most watersheds in the Ouachita-Saline drainage and the Lower Little watershed (Kiamichi-Little drainages). In addition, two watersheds in the Neosho-Illinois drainage (Lake O' the Cherokees and Elk), and one each in the Upper White River drainage (James) and Arkansas River drainage (Frog-Mulberry) showed primary levels of crayfish density.

Secondary levels of crayfish species density (all those watersheds with 0.4 species per 100 mi^2) occurred in one notable concentration in the eastern Arkansas River Basin. Other watersheds showing secondary levels of crayfish density were scattered among the Neosho-Illinois, Upper White, Meramec, and Gasconade drainages (fig. 2.28). Most of these scattered watersheds were adjacent to watersheds showing primary levels of crayfish density.

Patterns of tertiary levels of crayfish density (0.1 to 0.3 species per 100 mi^2) were similar to patterns observed for tertiary levels of crayfish species richness. A distinct concentration of hydrologic units with tertiary levels of crayfish species density occupies the northern one-third of the Assessment area and includes watersheds of the Osage River; most watersheds in the Gasconade River drainage; the Spring watershed (Neosho-Illinois drainage), and the North Fork White watershed (Upper White drainage). Likewise, several watersheds in the Arkansas River drainage, Upper White drainage, and those along the western edge of the Assessment area show tertiary levels of crayfish species density.

Endemic crayfishes. The Ozark-Ouachita Highlands support at least 37 endemic crayfishes (table 2.17), which represent about 61 percent of the crayfish fauna known from the study area. Five of the six crayfish genera (*Orconectes*, *Cambarus*, *Fallicambarus*, *Faxonella*, and *Procambarus*) within the Assessment area are represented by endemic species. Most endemic species occur in waters of the Ozark Plateaus and Boston Mountains (at least 22 endemic crayfishes), but endemicity is also relatively high in the Ouachita Mountains (at least 13 endemic crayfishes).

At least one endemic crayfish species is represented in 41 of the 50 hydrologic units. Endemicity averaged 2.8 species per unit (two standard errors = 0.06) and ranged from 0 to 8 (table 2.18). Primary levels of endemicity (five to eight endemic crayfishes) were concentrated in the Ozark Highlands in watersheds of the Upper White, Upper Black, Upper St. Francis, and Meramec River Basins. Hydrologic units in the Ouachita-Saline drainage of the southeastern Ouachita Mountains also showed primary levels of endemicity (fig. 2.29). The number of endemic species was highest (7 to 8 species) in the Upper White River Basin (Beaver Reservoir and Bull Shoals Lake watersheds and the Upper Black River Basins' Spring watershed. Secondary levels of endemicity (3 to 4 species) include 11 watersheds located primarily in the Boston Mountains and southeastern Ozark Highlands (fig. 2.29).

Although a few endemic crayfishes enjoy a relatively wide distribution across several hydrologic units of the Ozark-Ouachita Highlands (e.g., *Cambarus hubbsi*); (Pflieger 1996), most are in one or few a hydrologic units. Many are known from very limited areas within a single hydrologic unit (e.g., *Cambarus zophonastes*, *Orconectes eupunctus*); (Robison and Allen 1995, Pflieger 1996). Within the crayfish genus *Orconectes*, at least 19 species or subspecies are endemic to the Assessment area, 14 of which are in the Ozark Plateaus and Boston Mountains. Within the northern half of the Assessment area, the Upper White and Upper Black drainages support at least six endemic species of the crayfish genus *Orconectes*; the Meramec and Upper St. Francis Rivers support two each. The Ouachita Mountains area supports five endemic crayfishes of the genus *Orconectes*.

Nearly all members of the crayfish genus *Cambarus* within the Assessment area are endemic species; similar to the genus *Orconectes,* the highest number occurred on the Ozark Highlands and Boston Mountains. Most of the narrowly distributed *Cambarus* endemic species are highly adapted for life in caves or springs and show very restricted distributions (Robison and Allen 1995, Pflieger 1996). Five species are primarily cave dwellers or nearly so: *Cambarus aculabrum*, an Ozark endemic; *Cambarus hubrichti*, a widespread cave dweller of the Ozark Highlands; *Cambarus setosus*, confined to three spring systems in the Salem Plateau; *Cambarus tartarus*, known from one Oklahoma cave; and *Cambarus zophonastes*, a White River Basin endemic (Bouchard and Robison 1980, Hobbs 1989, Robison and Allen 1995, Pflieger 1996). Of these, *Cambarus aculabrum*, *C. tartarus*, and *C. zophonastes* are known only from one or two cave systems each. *Cambarus hubbsi* and *C. maculatus* (the latter a Meramec River endemic) are adapted to life in streams (Robison and Allen 1995, Pflieger 1996). Within the crayfish genera *Fallicambarus*, *Faxonella*, and *Procambarus*, eight species are endemic to the southern portion of the Ouachita Mountains (Robison and Allen 1995).

Implications and Opportunities

Crayfishes are found in almost every type of aquatic habitat, where they facilitate many important ecological processes. However, compared to other aquatic organisms such as fish and mussels, there is limited

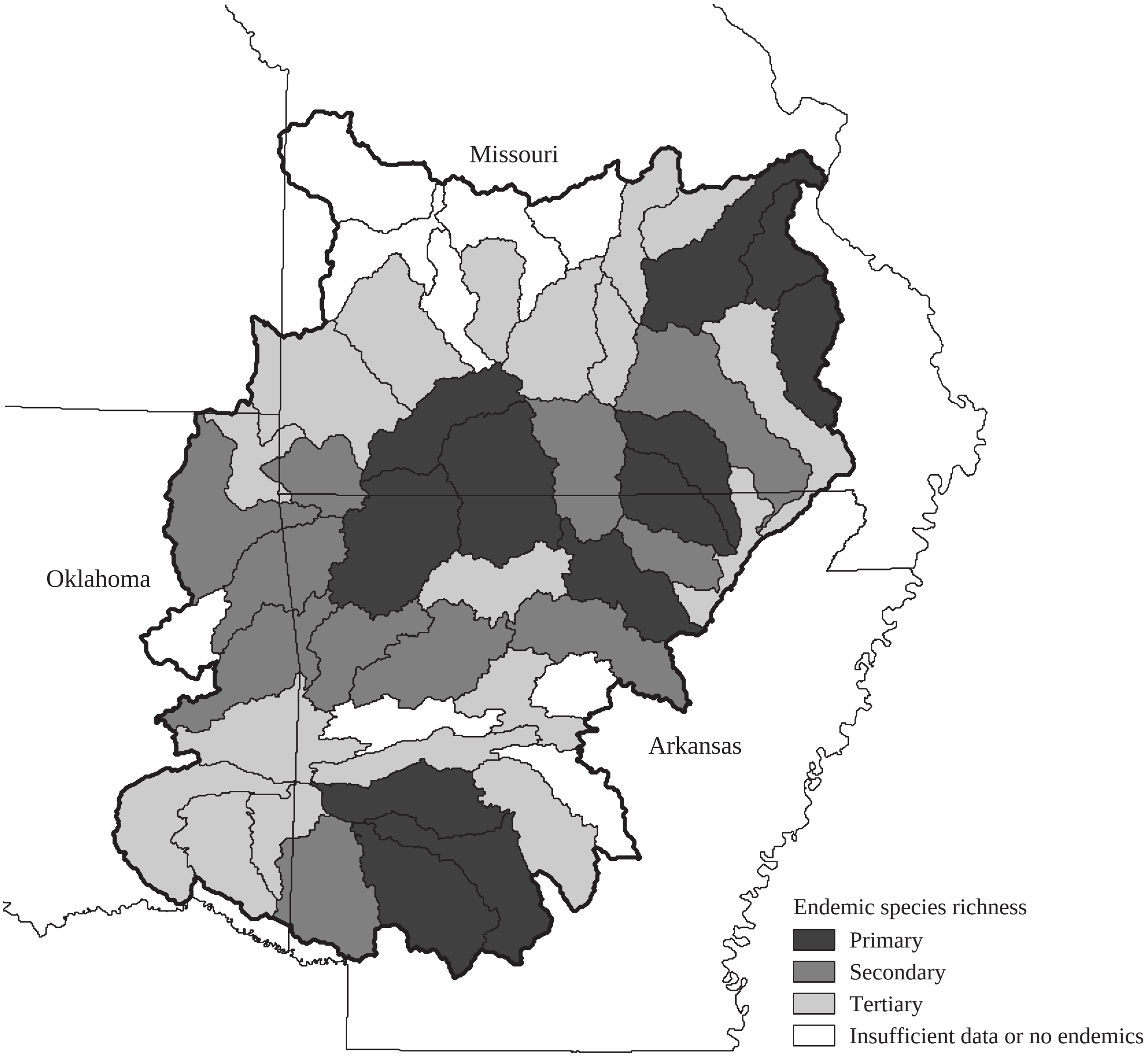


Figure 2.29—Levels of endemic crayfish species richness by watershed.

knowledge about basic crayfish biology, distribution, and ecological importance. The Aquatic Team synthesized the known information on crayfishes and discovered that there are distinct information voids.

Species richness, densities, and endemism were unevenly distributed within the Assessment area. The high numbers of endemic species (61 percent of the crayfish in the Assessment area)—many with extremely limited range—suggest opportunities for academic research. Incorporation of crayfish study and monitoring into routine State and Federal management and monitoring plans will provide valuable information for stream quality and greatly augment knowledge of this diverse resource. A lack of historical information results in an even greater urgency to establish a baseline of information to accurately examine crayfish populations.

Diversity of Aquatic Insects

Question 2.7: What are the status and distribution of aquatic insects within the Assessment area?

The Aquatic Team focused its assessment of aquatic insects on two orders—the caddisflies (order Trichoptera) and stoneflies (order Plecoptera)—because comprehensive distributional monographs are available on them for the Interior Highlands (Poulton and Stewart 1991, Moulton and Stewart 1996). Members of both orders are used routinely in biological monitoring due to their sensitivity to changes in water quality (Platts and others 1983, Rohm and others 1987, Plafkin and others 1989, U.S. EPA 1989b, Clingenpeel and Cochran 1992).

The caddisfly fauna of the Assessment area is allied most closely with counterparts in the Eastern (e.g., Appalachian Mountains) and Southeastern United States. For example, the number of shared caddisfly species in the Assessment area, the eastern Highlands (Appalachians), and the southeastern Gulf Coastal Plain is so high and the intermixing so thorough that clear differences among the three regions' caddisfly assemblages are difficult to distinguish (Hamilton and Morse 1990).

Caddisfly richness is lower in the Highlands than in other mountainous areas of North America. According to Ross (1965) and Rafferty (1985), this lower richness may be due to (1) the size of the Highlands and (2) the area being the most arid, low-level mountainous part of North America. No known caddisfly lineages appear to have originated in the Highlands. The relatively low caddisfly richness indicates that the fauna is relatively recent in its origin in the Highlands (Moulton and Stewart 1996).

The mountainous topography, high-gradient streams, varying levels of flow permanence (i.e., the influence of storms and drought on streamflow seasonality), temperature regimes, and generally mild climate of the Highlands account in large part for the unique stonefly and caddisfly faunas of the Assessment area (Poulton and Stewart 1991, Moulton and Stewart 1996). Three patterns of primary species distribution describe the observed richness of the stonefly and caddisfly faunas of the Assessment area: (1) endemic species; (2) widespread species with continuous distributions or open dispersal routes (i.e., regional populations can disperse across the Illinois Ozarks corridor); and (3) species with discontinuous distributions (i.e., regional populations that are geographically separated from their main ranges) (Poulton and Stewart 1991, Moulton and Stewart 1996).

Key Findings

1. Streams and rivers of the Ozark-Ouachita Highlands harbor a richness of species representing about 15 percent and 17 percent of all stoneflies and caddisflies, respectively, known from North America. Eight families including 23 stonefly genera and 82 species and 17 families including 57 caddisfly genera and 206 species are known to occur in the Ozark-Ouachita Highlands Assessment area.
2. The Ouachita Mountains support the greatest richness of stoneflies and caddisflies (195 species) in the Assessment area. Nineteen of the regionally endemic stonefly species occur in the Ouachita Mountains; six of these occur in no other subregion. Three of the 13 endemic caddisfly species (*Cheumatopsyche robisoni*, *Ochrotrichia robisoni*, and *Ochrotrichia weddleae*) found in the Ouachita Mountains are not known elsewhere.

Data Sources and Methods of Analysis

To analyze distributions of stoneflies and caddisflies, the Aquatic Team subdivided each of 10 major drainages within the Assessment area according to hydrologic units or watersheds. River basins and watersheds are shown in figure 1.2. Fifty hydrologic units or watersheds were recognized within the aquatic study area. Half of these watersheds extend beyond the Assessment area and contain portions of other ecological sections (e.g., the Mississippi Alluvial Basin). Within a particular hydrologic unit, the team determined the presence or absence of a stonefly or caddisfly species as well as endemicity. This was done primarily from maps and distributional tables in Poulton and Stewart (1991) and Moulton and Stewart (1996), respectively.

Poulton and Stewart (1991) and Moulton and Stewart (1996) independently undertook analyses of faunal composition of stoneflies and caddisflies. Both studies used smaller drainage units and more finely divided ecological regions than were used in this Assessment report. Each study also included several variables to classify or predict the presence of stonefly or caddisfly species (e.g., stream size, flow permanence, and vegetational types for stoneflies; and latitude, longitude, physiography, geology, springs, and vegetational type for caddisflies). A summary and synthesis of the primary results of the two studies are presented here; for details, the reader is referred to the original studies.

Poulton and Stewart (1991) collected specimens from more than 1,200 sites. These researchers included monthly collections of stoneflies from 693 stream sites across 123 watersheds between November 1983 and May 1988. They found stoneflies at 523 sites and subsequently made repeat collections at 191 of these. For caddisflies, Moulton and Stewart (1996) collected from over 500 different locations between March 1990 and March 1994. Limited collecting occurred after November 1992. These researchers augmented their field collection records by examining and including museum material. In both of these substantial and unprecedented studies, most collection localities were within the Assessment area.

The Aquatic Team used species richness, species density, and number of regionally endemic species to analyze diversity of stoneflies and caddisflies. Species richness is the number of stoneflies and caddisflies within each hydrologic unit. Hydrologic units vary in size, and aquatic species richness often increases with an increase in stream size or area drained (areal additivity). To examine the effect of areal additivity, the Aquatic Team divided species richness by the number of square miles to produce species density values (expressed as density per 100 mi^2) for each unit. In addition, the team examined the regression of the log of stonefly and caddisfly species richness with the log of square miles in hydrologic units.

The Aquatic Team plotted species richness, species density, and regional endemicity on separate hydrologic unit maps of the Assessment area. The team recognized three levels of relative species richness, density, and endemicity among hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 15 to 17 units, depending on tied scores, with highest values; secondary levels to the next highest 15 to 21 units; and tertiary values to the remaining units. Hence, primary levels approximate values in the fourth quartile (or top 25 percent); secondary levels, values in the third quartile (or second 25 percent); and tertiary levels, values in the first and second quartiles (or bottom 50 percent).

Patterns and Trends

Stonefly and caddisfly species composition. Richness is divided unevenly among stoneflies and caddisflies in the aquatic study area. For the stoneflies, 8 families, 23 genera, and 82 species are represented (Poulton and Stewart 1991). Three stonefly families, Perlidae (26 species), Capniidae (15 species), and Perlodidae (14 species) represent 67 percent of the stonefly fauna of the study area. Caddisflies are represented by 206 species distributed among 57 genera and 17 families. The families Hydroptilidae (59 species), Leptoceridae (42 species), and Hydropsychidae (31 species) account for 64 percent of the study area's caddisfly fauna (Moulton and Stewart 1996).

Analyses of similarity of stonefly assemblages among study area watersheds showed a primary split between upland and lowland stonefly species similar to that described for freshwater fishes (Pflieger 1971, 1975; Mayden 1985; Matthews and Robison 1988; Poulton and Stewart 1991; Moulton and Stewart 1996). Watersheds with primarily lowland stonefly species included those bordering the Assessment area in the Mississippi Alluvial Basin, Missouri River border, and Illinois Ozarks.

Most of the Assessment area is dominated by upland stonefly species, where distinct groupings of stoneflies occur within the Assessment area. One faunal region for stoneflies, which is at least in part analogous to the Ozark Fish Faunal Region, includes most of the watersheds of the Ozark Plateaus, excluding the Black River drainage. The Black River and several immediately adjacent and connecting watersheds in the Gasconade and Meramec Rivers have a distinctive assemblage of stoneflies associated primarily with the presence of high-volume springs. Watersheds in the Ouachita Mountains, Arkansas Valley, and parts of the Boston Mountains comprise another distinct grouping of stoneflies—one that possesses the highest numbers of endemic species (Poulton and Stewart 1991).

Although some species have strong affinities for particular geographic areas, the presence or absence of many uncommon species reflects historical (often influenced by the glacial era) distributions as well as ecological or geographic isolation. For example, 23 species were common in intermittent or dry streams, and an additional 28 were restricted to permanently flowing streams or spring-fed streams. Poulton and Stewart (1991) concluded that the best predictors of stonefly occurrence were stream thermal regime and flow permanence—variables related strongly to life-cycle requirements of different stonefly species.

Caddisflies showed fewer distinct faunal groupings than either stoneflies or fishes (Moulton and Stewart 1996). The Ozark Highlands are distinguished clearly as a faunal region, but caddisfly assemblages do not vary among the watersheds of the Mississippi Alluvial Plain, West Gulf Coastal Plain, or most of the Ouachita Mountains. Interwatershed dispersals of caddisflies tend to minimize regional differences. Because of this homogeneity of caddisfly assemblages among watersheds, physiographic subregion served as the best predictor of the presence of endemic caddisflies (Moulton and Stewart 1996).

Stonefly and caddisfly combined species richness and density. Numbers of stonefly and caddisfly species were not evenly distributed among the watersheds (table 2.19), nor were their distributions oriented to a simple geographical axis or direction. Combined species richness averaged 66.4 species per watershed and ranged from 9 to 123 species. Most watersheds, however, showed diverse, rich faunas: 35 of the 50 hydrologic units showed stonefly and caddisfly species richness of 50 or more species.

Three geographic centers of primary levels of stonefly and caddisfly species richness (85 to 123 species) were apparent within the aquatic study area (fig. 2.30): (1) a north central center in the Ozark Highlands, (2) a western center in the Arkansas and Neosho-Illinois River Basins, and (3) a southern center in southward draining rivers of the Ouachita Mountains. The northern center included the Upper and Lower Gasconade watersheds in the Gasconade River Basin; North Fork White, Middle White, and Bull Shoals watersheds in the Upper White drainage; and the Current watershed in the Upper Black River Basin. The western center comprised watersheds within the Neosho-Illinois drainage (Illinois watershed) and Arkansas River drainage (Robert S. Kerr Reservoir, Dardanelle Reservoir, Frog-Mulberry, and Poteau watersheds). The southern center comprised watersheds in the Kiamichi-Little drainage (Kiamichi, Mountain Fork, and Lower Little watersheds) and the Ouachita-Saline drainage (Little Missouri, Ouachita Headwaters, and Upper Ouachita watersheds).

Secondary levels of stonefly and caddisfly species richness (49 to 84 species) generally were located in the northern two thirds of the Assessment area (fig. 2.30). Most watersheds with secondary levels of species richness (57 percent) occurred as tributaries to the Neosho-Illinois (Spring and Elk watersheds), Upper White (James, Beaver, Buffalo, Little Red watersheds), and Upper Black River Basins (Spring, Eleven Point, Strawberry, and Upper and Lower Black watersheds). Other areas with secondary levels of species richness are scattered throughout the Assessment area (fig. 2.30).

Stonefly and caddisfly combined species density was highly variable among hydrologic units of the Assessment area (table 2.19). The average species density was 4.7 species per 100 mi^2, and the range in density was 0.6 to 10.4 species per 100 mi^2. Regression of the log of stonefly and caddisfly species richness with the log of square miles in units was significant ($P < 0.0007$). However, the relationship accounted for only 18 percent of the variation in species richness (where log species richness = 1.98 + 0.193 log (unit area) and $r^2 = 0.18$). The density of stonefly and caddisfly species was correlated negatively with watershed area ($r = -0.71$, $P < 0.0001$). This indicates that the smaller watersheds tended to have greater species density.

Watersheds with primary density levels (5.6 to 10.4 stonefly and caddisfly species per 100 mi^2) were found in four clusters, the western portion of the Arkansas Valley, the Ouachita Mountains, and both the lower eastern and the north central areas of the Ozark Highlands (fig. 2.31). Of these watersheds, nine also had primary and seven had secondary levels of species richness. Watersheds in the species-rich Arkansas River drainage (Frog-Mulberry and Robert S. Kerr watersheds); Neosho-Illinois drainage (Illinois watershed); Ouachita-Saline River drainage (Ouachita Headwaters and Upper Ouachita watersheds); and

Table 2.19—Stoneflies (Plecoptera), caddisflies (Tricoptera), and combined species richness and density within watersheds of the aquatic study area

River basin Watershed name	Watershed code (HUC)	Area	Tricoptera species	Plecoptera species	Tricoptera and Plecoptera combined species richness	Tricoptera and Plecoptera combined species density
		100 mi^2	*- - - - - - - - Number - - - - - - - -*			*Number per 100 mi^2*
Osage River Basin						
H.S. Truman Reservoir	10290105	12.1	4	13	17	1.4
Sac	10290106	19.7	48	24	72	3.6
Pomme de Terre	10290107	8.5	33	22	55	6.5
South Grand	10290108	20.6	4	9	13	0.6
Lake of the Ozarks	10290109	13.8	13	26	39	2.8
Niangua	10290110	10.4	54	27	81	7.8
Lower Osage	10290111	10.8	10	28	38	3.5
Gasconade River Basin						
Upper Gasconade	10290201	17.9	83	30	113	6.3
Big Piney	10290202	7.5	15	19	34	4.5
Lower Gasconade	10290203	10.3	52	35	87	8.4
Meramec River Basin						
Meramec	07140102	21.5	22	37	59	2.7
Bourbeuse	07140103	8.3	7	23	30	3.6
Big	07140104	9.7	11	22	33	3.4
Upper St. Francis River Basin						
Upper St. Francis	08020202	13.0	28	36	64	4.9
Neosho-Illinois River Basin						
Lake O' the Cherokees	1107020146	9.2	6	11	17	1.9
Spring	11070207	25.7	34	28	62	2.4
Elk	11070208	10.4	35	28	63	6.1
Lower Neosho	11070209	22.1	6	21	27	1.2
Illinois	11110103	16.4	74	37	111	6.8
Arkansas River Basin						
Dirty-Greenleaf	11110102	7.9	9	24	33	4.2
Robert S. Kerr Reservoir	11110104	18.1	57	46	103	5.7
Poteau	11110105	18.9	75	26	101	5.3
Frog-Mulberry	11110201	12.7	48	37	85	6.7
Dardanelle Reservoir	11110202	18.6	64	33	97	5.2
Conway- Pt. Remove	11110203	11.4	18	21	39	3.4
Petit Jean	11110204	10.9	2	31	33	3.0
Cadron	11110205	7.8	16	22	38	4.9
Fourche La Fave	11110206	11.2	32	42	74	6.6
Lower Ark-Maumelle	11110207	11.1	0	9	9	0.8
Kiamichi-Little River Basin						
Kiamichi	11140105	18.2	75	24	99	5.4
Upper Little	11140107	14.0	29	20	49	3.5
Mountain Fork	11140108	8.6	66	24	90	10.4
Lower Little	11140109	19.7	66	38	104	5.3
Ouachita-Saline River Basin						
Ouachita Headwaters	08040101	15.4	66	36	102	6.6
Upper Ouachita	08040102	17.7	79	35	114	6.5
Little Missouri	08040103	21.0	72	39	111	5.3
Upper Saline	08040203	17.1	23	31	54	3.1
Upper White River Basin						
Beaver Reservoir	11010001	25.6	34	40	74	2.9
James	11010002	14.4	25	27	52	3.6
Bull Shoals Lake	11010003	26.0	59	37	96	3.7

(continued)

Table 2.19—Stoneflies (Plecoptera), caddisflies (Tricoptera), and combined species richness and density within watersheds of the aquatic study area (continued)

River basin Watershed name	Watershed code (HUC)	Area	Tricoptera species	Plecoptera species	Tricoptera and Plecoptera combined species richness	Tricoptera and Plecoptera combined species density
		100 mi²	*Number*			*Number per 100 mi²*
Upper White River Basin (cont.)						
Middle White	11010004	15.0	65	36	101	6.7
Buffalo	11010005	13.4	29	35	64	4.8
North Fork White	11010006	18.3	59	28	87	4.8
Little Red	11010014	17.9	29	31	60	3.3
Upper Black River Basin						
Upper Black	11010007	19.1	46	36	82	4.3
Current	11010008	26.3	85	38	123	4.7
Lower Black	11010009	7.8	27	32	59	7.6
Spring	11010010	12.2	34	34	68	5.6
Eleven Point	11010011	12.1	33	22	55	4.6
Strawberry	11010012	7.7	18	32	50	6.5

HUC = hydrologic unit code; mi² = square mile.

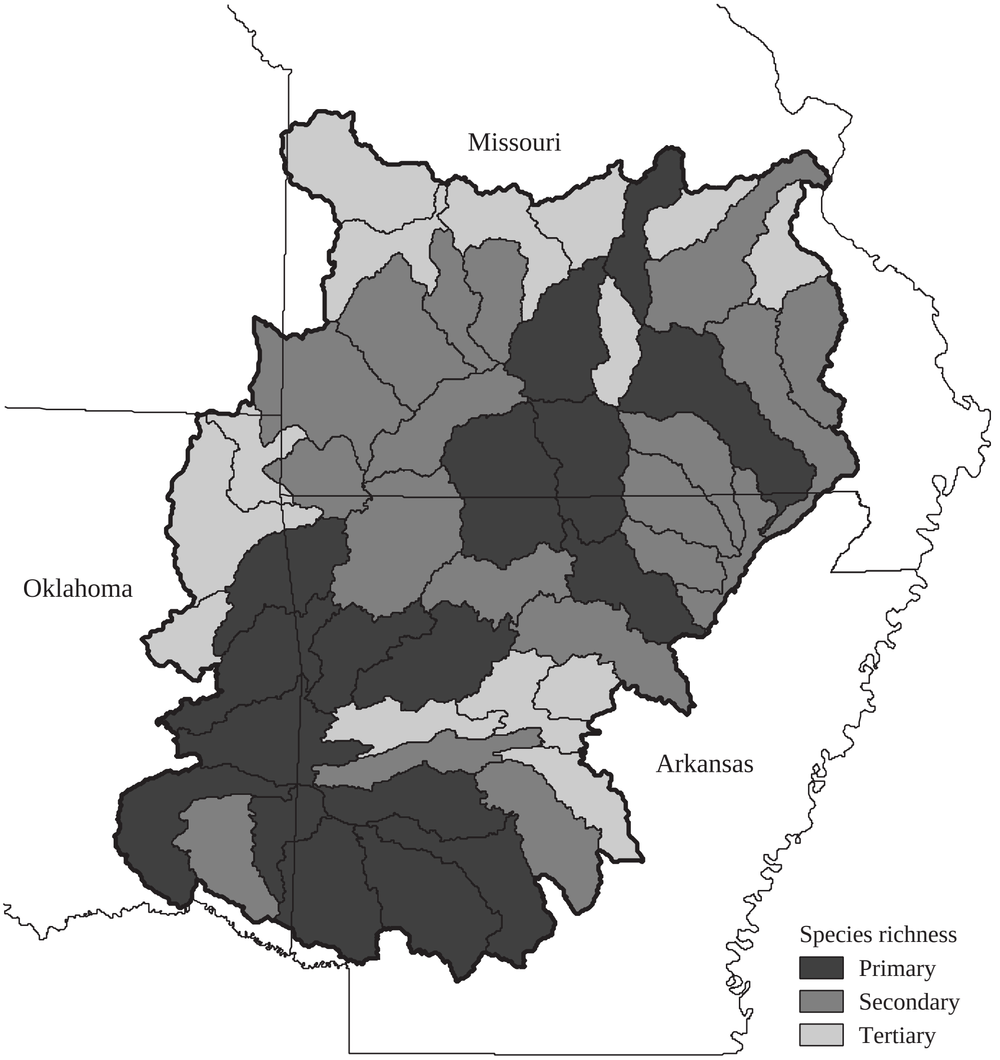


Figure 2.30—Levels of stonefly and caddisfly species richness (combined) by watershed.

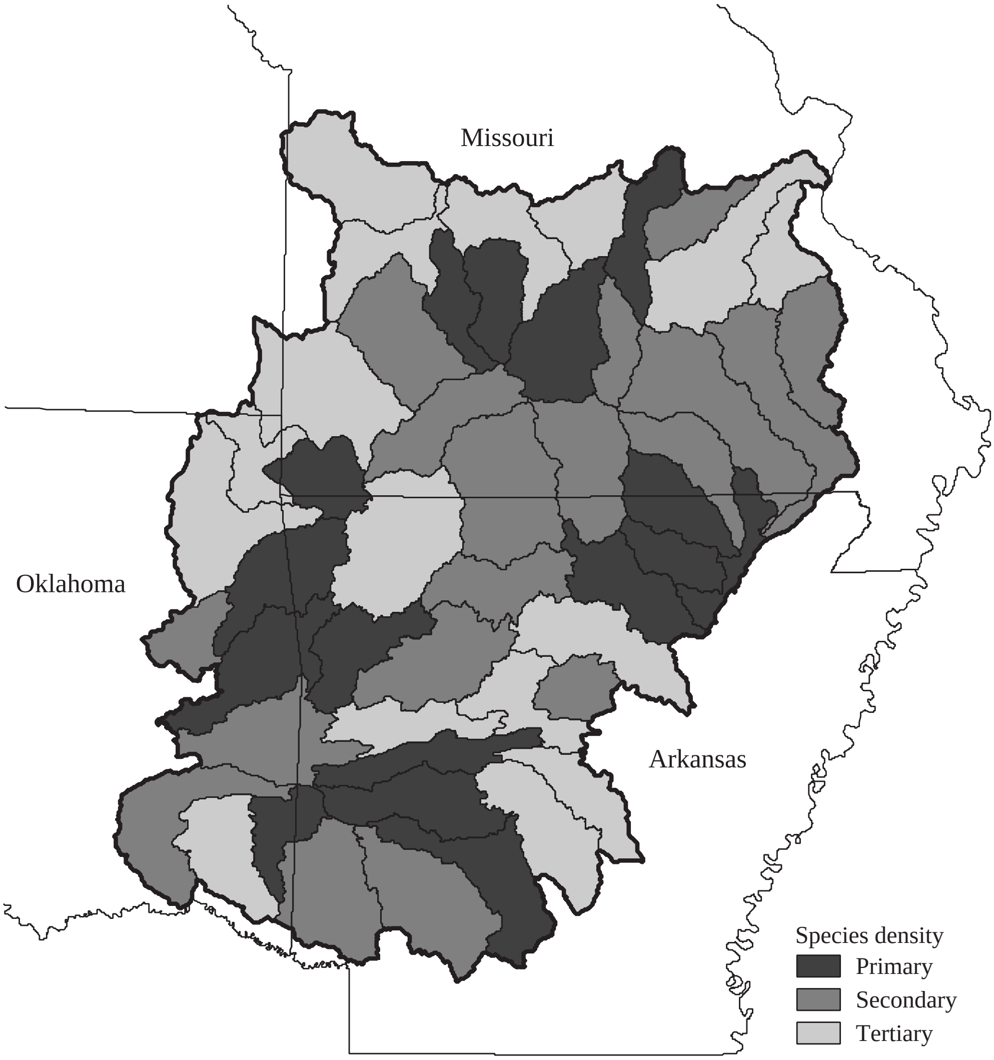


Figure 2.31—Levels of stonefly and caddisfly species density (combined) by watershed.

Gasconade River drainage (Upper and Lower Gasconade watersheds) also showed primary levels of stonefly and caddisfly species density, as did the Mountain Fork (Kiamichi-Little drainage) and Middle White (Upper White River drainage) watersheds. The Spring, Strawberry, and Lower Black (Upper Black River drainage); Fourche La Fave (Arkansas River drainage); Elk (Neosho-Illinois drainage); and the Pomme de Terre and Niangua (Osage River drainage) watersheds all had primary levels of species density but secondary levels of species richness.

Areas with secondary levels of species density (3.6 to 5.4 caddisfly and stonefly species per 100 mi^2) traverse the study area from southwest to northeast (fig. 2.31). Fourteen of 18 watersheds showing secondary levels of species density also had primary or secondary levels of species richness. Seven hydrologic units within the Upper White and Upper Black River drainages showed secondary density levels (the James, Bull Shoals, Buffalo, North Fork White, Eleven Point, Current, and the Upper Black watersheds). All of these watersheds also showed either primary or secondary levels of species richness. Other watersheds that showed secondary levels of density and either primary or secondary levels of species richness included: the Kiamichi and Lower Little (Kiamichi-Little drainage); Dardenelle and Poteau (Arkansas River drainage); Upper St. Francis drainage; Little Missouri (Ouachita drainage); and the Sac (Osage drainage). Finally, four watersheds showed secondary levels of species density and only tertiary levels of species richness: the Bourbeuse (Meramec River drainage), Dirty Greenleaf and Cadron (Arkansas River drainage), and Big Piney (Gasconade drainage) watersheds. Watersheds with primary or secondary levels of both species richness and density may be considered exceptional areas of insect diversity within the study area.

Endemic caddisflies and stoneflies. Fifty-one (16 percent) of the 316 stonefly and caddisfly species represented in the Highlands are considered endemic species, including 24 species (25 percent) of stoneflies and 27 species (11 percent) of caddisflies (table 2.20). Eleven of 17 caddisfly families have at least 1 endemic species in the study area. The families Hydroptilidae, Leptoceridae, and Glossosomatidae have seven, four, and three endemic species, respectively, in the area. The families Hydropsychidae and Lepidostomatidae have two endemic species in the study area, and the families Brachycentridae, Helicopsychidae, Limnephilidae, Odontoceridae, Philopotamidae, and Rhyacophilidae each have one (Moulton and Stewart 1996). Six of the eight stonefly families are represented by multiple endemic species—eight from Perlidae, seven from Capniidae, three from Leuctridae, two from Taeniopterygidae, two from Chloroperlidae, and two from Perlodidae (Poulton and Stewart 1991).

According to Poulton and Stewart (1991) and Moulton and Stewart (1996), this estimate of the number of endemic stonefly and caddisfly species is conservative. Ongoing systematic studies of stoneflies and caddisflies of the Assessment area indicate that several currently recognized species may be two or more distinct species or that further phylogenetic analyses are needed (Moulton and Stewart 1996). For example, the fieldwork of Poulton and Stewart (1991) and Moulton and Stewart (1996) revealed four species new to science and provided the first descriptions of the immature stages of several species.

The number of endemic stonefly and caddisfly species averaged 8.46 endemic species per watershed and ranged from 0 to 22 species. Primary levels of endemic species (11 to 22 species) were aggregated in the Upper White and Upper Black (35 percent of the primary level endemic watersheds); Arkansas (35 percent); Kiamichi-Little (15 percent); and Ouachita-Saline (15 percent) drainages to form an almost contiguous grouping in the southern half of the study area (fig. 2.32). Twelve percent of the hydrologic units showed primary levels of endemic species as well as primary levels of species richness and density (Illinois, Robert S. Kerr, Frog-Mulberry, Mountain Fork, Ouachita Headwaters, Upper Ouachita, and Middle White watersheds). All of the other watersheds with primary levels of endemicity showed either primary or secondary levels for species richness and density except for the Beaver and Petit Jean watersheds, which had a tertiary level of species density. The Current River watershed had the highest endemicity (22 species) and species richness (123 species) in the Highlands.

All watersheds with secondary levels of endemic species (6 to 10 endemic species) occurred adjacent to watersheds with primary levels of endemic species. Nine (56 percent) of the 16 secondary-level watersheds also had primary and/or secondary levels of species richness and density. The Cadron watershed (Arkansas River) showed a secondary level of endemic species, but only a tertiary (one to five endemic species per watershed) level of species richness and density.

Recently described, undescribed, and rare endemic caddisfly species may occur in one or only a few hydrologic units. For example, *Protoptila* species *A* occurred only in the Current River watershed; *Neotrichia kitae*, only in the Bull Shoals watershed; *Ceraclea maccalmonti*, only in Bennett Springs (Niangua watershed); and *Marilia* species *A*, only in the Spring River and Upper Illinois watersheds. *Glyphopsyche missouri*, although restricted to Meremec Spring, was a dominant component of the benthic community. *Agapetus artesus* was restricted to a few cold, high-volume Ozark springs in Missouri, and *Agapetus medicus* occurred only in perennial or ephemeral headwater streams in the Ozark and Ouachita Mountains. *Cheumatopsyche robisoni* and *Cheumatopsyche rossi*, two closely related endemic species, were restricted primarily to free-flowing spring habitats in the Ouachita Mountains and Ozark Highlands, respectively. *Ochrotrichia contorta* was found only in the high-volume spring habitat of the Eleven Point River drainage; *Ochrotrichia robisoni* was restricted to small to medium-sized streams in the Ouachita and Boston Mountains physiographic regions; and *Ochrotrichia weddleae* occurred only in second and third order streams of the Kiamichi River (Moulton and Stewart

Table 2.20—Aquatic insects by order, family, and species found within the Assessment area

Order	Family	Species	Ouachita Mtns	Arkansas Valley	Boston Mtns	Ozark Highlands
Plecoptera	Capniidae	*Allocapnia granulata*	X	X	X	X
Plecoptera	Capniidae	*Allocapnia jeanae*[a]	X	X	X	X
Plecoptera	Capniidae	*Allocapnia malverna*	X			X
Plecoptera	Capniidae	*Allocapnia mohri*[a]	X	X	X	X
Plecoptera	Capniidae	*Allocapnia mystic*[a]	X			X
Plecoptera	Capniidae	*Allocapnia oribata*[a]			X	
Plecoptera	Capniidae	*Allocapnia ozarkana*[a]			X	X
Plecoptera	Capniidae	*Allocapnia peltoides*[a]	X	X		
Plecoptera	Capniidae	*Allocapnia pygmaea*				X
Plecoptera	Capniidae	*Allocapnia rickeri*	X	X	X	X
Plecoptera	Capniidae	*Allocapnia sandersoni*[a]		X	X	X
Plecoptera	Capniidae	*Allocapnia vivipara*				X
Plecoptera	Capniidae	*Allocapnia warreni*[a]				X
Plecoptera	Capniidae	*Nemocapnia carolina*	X			
Plecoptera	Capniidae	*Paracapnia angulata*	X		X	X
Plecoptera	Chloroperlidae	*Alloperla caddo*[a]	X			
Plecoptera	Chloroperlidae	*Alloperla caudata*	X	X	X	X
Plecoptera	Chloroperlidae	*Alloperla hamata*	X		X	X
Plecoptera	Chloroperlidae	*Alloperla leonarda*				X
Plecoptera	Chloroperlidae	*Alloperla ouachita*[a]	X			
Plecoptera	Chloroperlidae	*Haploperla brevis*	X	X	X	X
Plecoptera	Leuctridae	*Leuctra tenuis*	X		X	X
Plecoptera	Leuctridae	*Zealeuctra cherokee*[a]	X	X	X	X
Plecoptera	Leuctridae	*Zealeuctra claasseni*	X	X	X	X
Plecoptera	Leuctridae	*Zealeuctra narfi*	X	X	X	X
Plecoptera	Leuctridae	*Zealeuctra wachita*[a]	X			
Plecoptera	Leuctridae	*Zealeuctra warreni*[a]	X	X	X	X
Plecoptera	Nemouridae	*Amphinemura delosa*	X	X	X	X
Plecoptera	Nemouridae	*Amphinemura nigritta*				X
Plecoptera	Nemouridae	*Prostoia completa*	X	X	X	X
Plecoptera	Nemouridae	*Prostoia similis*				X
Plecoptera	Nemouridae	*Shipsa rotunda*	X			
Plecoptera	Perlidae	*Acroneuria evoluta*	X	X	X	X
Plecoptera	Perlidae	*Acroneuria filicis*	X	X	X	X
Plecoptera	Perlidae	*Acroneuria internata*				
Plecoptera	Perlidae	*Acroneuria mela*	X	X	X	X
Plecoptera	Perlidae	*Acroneuria ozarkensis*[a]				X
Plecoptera	Perlidae	*Acroneuria perplexa*	X	X	X	X
Plecoptera	Perlidae	*Agnetina capitata*				X
Plecoptera	Perlidae	*Agnetina flavescens*	X	X	X	X
Plecoptera	Perlidae	*Attaneuria ruralis*				X
Plecoptera	Perlidae	*Neoperla carlsoni*	X	X	X	X
Plecoptera	Perlidae	*Neoperla catharae*	X		X	X
Plecoptera	Perlidae	*Neoperla choctaw*	X	X		X
Plecoptera	Perlidae	*Neoperla falayah*[a]	X	X	X	X
Plecoptera	Perlidae	*Neoperla harpi*[a]	X	X	X	X
Plecoptera	Perlidae	*Neoperla osage*[a]	X	X	X	X
Plecoptera	Perlidae	*Neoperla robisoni*[a]	X		X	X
Plecoptera	Perlidae	*Paragnetina kansensis*	X			X
Plecoptera	Perlidae	*Paragnetina media*				X
Plecoptera	Perlidae	*Perlesta baumanni*[a]	X	X		
Plecoptera	Perlidae	*Perlesta browni*[a]	X	X		X
Plecoptera	Perlidae	*Perlesta cinctipes*	X	X	X	X

(continued)

Table 2.20—Aquatic insects by order, family, and species found within the Assessment area (continued)

Order	Family	Species	Ouachita Mtns	Arkansas Valley	Boston Mtns	Ozark Highlands
Plecoptera	Perlidae	*Perlesta decipiens*	X	X	X	X
Plecoptera	Perlidae	*Perlesta fusca*[a]	X	X	X	X
Plecoptera	Perlidae	*Perlesta shubuta*				X
Plecoptera	Perlidae	*Perlinella drymo*	X	X	X	X
Plecoptera	Perlidae	*Perlinella ephyre*	X	X	X	X
Plecoptera	Perlodidae	*Clioperla clio*	X	X	X	X
Plecoptera	Perlodidae	*Helopicus nalatus*	X	X	X	X
Plecoptera	Perlodidae	*Hydroperla crosbyi*	X	X	X	X
Plecoptera	Perlodidae	*Hydroperla fugitans*				X
Plecoptera	Perlodidae	*Isoperla bilineata*				X
Plecoptera	Perlodidae	*Isoperla burksi*	X	X	X	X
Plecoptera	Perlodidae	*Isoperla coushatta*	X	X		X
Plecoptera	Perlodidae	*Isoperla decepta*				X
Plecoptera	Perlodidae	*Isoperla dicala*			X	X
Plecoptera	Perlodidae	*Isoperla mohri*	X	X	X	X
Plecoptera	Perlodidae	*Isoperla namata*	X	X	X	X
Plecoptera	Perlodidae	*Isoperla ouachita*[a]	X	X	X	X
Plecoptera	Perlodidae	*Isoperla signata*			X	X
Plecoptera	Perlodidae	*Isoperla szczytkoi*[a]		X		
Plecoptera	Pteronarcyidae	*Pteronarcys pictetii*				X
Plecoptera	Taeniopterygidae	*Strophopteryx arkansae*[a]	X	X	X	X
Plecoptera	Taeniopterygidae	*Strophopteryx cucullata*[a]	X	X	X	X
Plecoptera	Taeniopterygidae	*Strophopteryx fasciata*	X	X	X	X
Plecoptera	Taeniopterygidae	*Taeniopteryx burksi*	X	X	X	X
Plecoptera	Taeniopterygidae	*Taeniopteryx lita*	X	X		
Plecoptera	Taeniopterygidae	*Taeniopteryx lonicera*	X			
Plecoptera	Taeniopterygidae	*Taeniopteryx maura*	X	X		
Plecoptera	Taeniopterygidae	*Taeniopteryx metequi*	X	X	X	X
Plecoptera	Taeniopterygidae	*Taeniopteryx parvula*	X			X
Trichoptera	Brachycentridae	*Brachycentrus numerosus*				X
Trichoptera	Brachycentridae	*Bracycentrus lateralis*				X
Trichoptera	Brachycentridae	*Micrasema ozarkana*[a]				X
Trichoptera	Brachycentridae	*Micrasema rusticum*	X	X	X	X
Trichoptera	Brachycentridae	*Micrasema wataga*				X
Trichoptera	Dipseudopsidae	*Phylocentropus placidus*	X	X		
Trichoptera	Glossosomatidae	*Agapetus artesus*[a]				X
Trichoptera	Glossosomatidae	*Agapetus illini*	X	X	X	X
Trichoptera	Glossosomatidae	*Agapetus medicus*[a]	X			
Trichoptera	Glossosomatidae	*Glossosoma intermedium*				X
Trichoptera	Glossosomatidae	*Proptoptila species A*[a]				X
Trichoptera	Glossosomatidae	*Protoptila lega*	X			X
Trichoptera	Glossosomatidae	*Protoptila maculata*	X		X	X
Trichoptera	Glossosomatidae	*Protoptila tenebrosa*				X
Trichoptera	Helicopsychidae	*Helicopsyche borealis*	X	X	X	X
Trichoptera	Helicopsychidae	*Helicopsyche limnella*[a]	X	X	X	X
Trichoptera	Helicopsychidae	*Helicopsyche piroa*	X			X
Trichoptera	Hydropsychidae	*Ceratopsyche bronta*			X	X
Trichoptera	Hydropsychidae	*Ceratopsyche morosa*			X	X
Trichoptera	Hydropsychidae	*Ceratopsyche piatrix*[a]			X	X
Trichoptera	Hydropsychidae	*Ceratopsyche slossonae*			X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche aphanta*	X	X	X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche burksi*	X	X	X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche campyla*	X	X	X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche gracilis*	X			X
Trichoptera	Hydropsychidae	*Cheumatopsyche harwoodi enigma*				X

(continued)

Table 2.20—Aquatic insects by order, family, and species found within the Assessment area (continued)

Order	Family	Species	Ouachita Mtns	Arkansas Valley	Boston Mtns	Ozark Highlands
Trichoptera	Hydropsychidae	*Cheumatopsyche lasia*	X			X
Trichoptera	Hydropsychidae	*Cheumatopsyche miniscula*	X	X	X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche oxa*	X		X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche pasella*	X			X
Trichoptera	Hydropsychidae	*Cheumatopsyche pettiti*	X	X	X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche robisoni*[a]	X			
Trichoptera	Hydropsychidae	*Cheumatopsyche rossi*[a]	X	X		X
Trichoptera	Hydropsychidae	*Cheumatopsyche sordida*			X	X
Trichoptera	Hydropsychidae	*Cheumatopsyche speciosa*			X	X
Trichoptera	Hydropsychidae	*Diplectrona metaqui*				X
Trichoptera	Hydropsychidae	*Diplectrona modesta*	X	X	X	X
Trichoptera	Hydropsychidae	*Homoplectra doringa*		X	X	X
Trichoptera	Hydropsychidae	*Hydropsyche alvata*		X		X
Trichoptera	Hydropsychidae	*Hydropsyche arinale*	X	X	X	X
Trichoptera	Hydropsychidae	*Hydropsyche betteni*	X	X	X	X
Trichoptera	Hydropsychidae	*Hydropsyche bidens*	X			X
Trichoptera	Hydropsychidae	*Hydropsyche orris*	X	X	X	X
Trichoptera	Hydropsychidae	*Hydropsyche rossi*	X	X	X	X
Trichoptera	Hydropsychidae	*Hydropsyche scalaris*	X		X	X
Trichoptera	Hydropsychidae	*Hydropsyche simulans*	X		X	X
Trichoptera	Hydropsychidae	*Macrostemum carolina*	X	X		X
Trichoptera	Hydropsychidae	*Potamyia flava*	X	X	X	X
Trichoptera	Hydroptilidae	*Dibusa angata*	X		X	X
Trichoptera	Hydroptilidae	*Hydroptila ajax*				X
Trichoptera	Hydroptilidae	*Hydroptila albicornis*				X
Trichoptera	Hydroptilidae	*Hydroptila amoena*	X		X	X
Trichoptera	Hydroptilidae	*Hydroptila angusta*			X	X
Trichoptera	Hydroptilidae	*Hydroptila armata*	X	X	X	X
Trichoptera	Hydroptilidae	*Hydroptila artesa*[a]				X
Trichoptera	Hydroptilidae	*Hydroptila berneri*	X			
Trichoptera	Hydroptilidae	*Hydroptila broweri*				X
Trichoptera	Hydroptilidae	*Hydroptila consimilis*			X	X
Trichoptera	Hydroptilidae	*Hydroptila delineata*	X			
Trichoptera	Hydroptilidae	*Hydroptila grandiosa*	X	X	X	X
Trichoptera	Hydroptilidae	*Hydroptila hamata*	X	X	X	X
Trichoptera	Hydroptilidae	*Hydroptila oneili*	X			
Trichoptera	Hydroptilidae	*Hydroptila perdita*	X	X	X	X
Trichoptera	Hydroptilidae	*Hydroptila quinola*	X		X	
Trichoptera	Hydroptilidae	*Hydroptila remita*	X			
Trichoptera	Hydroptilidae	*Hydroptila sandersoni*	X	X	X	X
Trichoptera	Hydroptilidae	*Hydroptila spatulata*	X			X
Trichoptera	Hydroptilidae	*Hydroptila strepha*				X
Trichoptera	Hydroptilidae	*Hydroptila tusculum*				X
Trichoptera	Hydroptilidae	*Hydroptila vala*		X	X	X
Trichoptera	Hydroptilidae	*Hydroptila virgata*	X	X	X	X
Trichoptera	Hydroptilidae	*Hydroptila waubesiana*	X	X	X	X
Trichoptera	Hydroptilidae	*Ithytrichia clavata*		X		X
Trichoptera	Hydroptilidae	*Ithytrichia mazon*		X		
Trichoptera	Hydroptilidae	*Leucotrichia pictipes*				X
Trichoptera	Hydroptilidae	*Mayatrichia ayama*	X			
Trichoptera	Hydroptilidae	*Neotrichia arkansasensis*[a]	X	X	X	X
Trichoptera	Hydroptilidae	*Neotrichia kitae*[a]				X
Trichoptera	Hydroptilidae	*Neotrichia minutisimella*				X
Trichoptera	Hydroptilidae	*Neotrichia okopa*		X	X	X
Trichoptera	Hydroptilidae	*Neotrichia riegeli*	X			X
Trichoptera	Hydroptilidae	*Neotrichia vibrans*	X		X	X
Trichoptera	Hydroptilidae	*Ochrotrichia anisca*	X	X	X	X

(continued)

Table 2.20—Aquatic insects by order, family, and species found within the Assessment area (continued)

Order	Family	Species	Ouachita Mtns	Arkansas Valley	Boston Mtns	Ozark Highlands
Trichoptera	Hydroptilidae	*Ochrotrichia arva*			X	X
Trichoptera	Hydroptilidae	*Ochrotrichia contorta*[a]				X
Trichoptera	Hydroptilidae	*Ochrotrichia eliaga*				X
Trichoptera	Hydroptilidae	*Ochrotrichia riesi*			X	X
Trichoptera	Hydroptilidae	*Ochrotrichia robisoni*[a]	X		X	
Trichoptera	Hydroptilidae	*Ochrotrichia spinosa*	X		X	X
Trichoptera	Hydroptilidae	*Ochrotrichia tarsalis*	X		X	X
Trichoptera	Hydroptilidae	*Ochrotrichia unio*				X
Trichoptera	Hydroptilidae	*Ochrotrichia weddleae*[a]	X			
Trichoptera	Hydroptilidae	*Ochrotrichia xena*				X
Trichoptera	Hydroptilidae	*Orthotrichia aegerfasciella*	X	X	X	X
Trichoptera	Hydroptilidae	*Orthotrichia cristata*				X
Trichoptera	Hydroptilidae	*Orthotrichia instabilis*	X			
Trichoptera	Hydroptilidae	*Oxyethira coercens*	X			X
Trichoptera	Hydroptilidae	*Oxyethira dualis*			X	X
Trichoptera	Hydroptilidae	*Oxyethira forcipata*				X
Trichoptera	Hydroptilidae	*Oxyethira janella*	X			
Trichoptera	Hydroptilidae	*Oxyethira novasota*	X		X	
Trichoptera	Hydroptilidae	*Oxyethira pallida*	X	X	X	X
Trichoptera	Hydroptilidae	*Oxyethira rivicola*	X	X		
Trichoptera	Hydroptilidae	*Oxyethira zeronia*	X	X		X
Trichoptera	Hydroptilidae	*Paucicalcaria ozarkensis*[a]	X		X	
Trichoptera	Hydroptilidae	*Stactobiella delira*	X		X	X
Trichoptera	Hydroptilidae	*Stactobiella palmata*		X	X	X
Trichoptera	Lepidostomatidae	*Lepidostoma carrolli*	X			
Trichoptera	Lepidostomatidae	*Lepidostoma griseum*			X	X
Trichoptera	Lepidostomatidae	*Lepidostoma lescheni*[a]	X	X		
Trichoptera	Lepidostomatidae	*Lepidostoma libum*			X	X
Trichoptera	Lepidostomatidae	*Lepidostoma ozarkense*[a]			X	X
Trichoptera	Lepidostomatidae	*Lepidostoma togatum*	X	X		X
Trichoptera	Leptoceridae	*Ceraclea ancylus*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea cancellata*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea flava*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea maccalmonti*[a]				X
Trichoptera	Leptoceridae	*Ceraclea maculata*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea nepha*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea ophioderus*	X			X
Trichoptera	Leptoceridae	*Ceraclea protonepha*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea punctata*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea resurgens*	X			
Trichoptera	Leptoceridae	*Ceraclea tarsipunctata*	X	X	X	X
Trichoptera	Leptoceridae	*Ceraclea transversa*	X	X	X	X
Trichoptera	Leptoceridae	*Leptocerus americanus*	X	X		X
Trichoptera	Leptoceridae	*Mystacides sepulchralis*	X		X	X
Trichoptera	Leptoceridae	*Nectopsyche candida*	X	X	X	X
Trichoptera	Leptoceridae	*Nectopsyche diarina*				X
Trichoptera	Leptoceridae	*Nectopsyche exquisita*	X	X	X	X
Trichoptera	Leptoceridae	*Nectopsyche pavida*	X	X	X	X
Trichoptera	Leptoceridae	*Nectopsyche spiloma*			X	X
Trichoptera	Leptoceridae	*Oecetis avara*	X	X	X	X
Trichoptera	Leptoceridae	*Oecetis cinerascens*	X	X		X
Trichoptera	Leptoceridae	*Oecetis ditissa*	X	X	X	X
Trichoptera	Leptoceridae	*Oecetis eddlestoni*	X	X	X	
Trichoptera	Leptoceridae	*Oecetis inconspicua*	X	X	X	X
Trichoptera	Leptoceridae	*Oecetis nocturna*	X	X	X	X
Trichoptera	Leptoceridae	*Oecetis osteni*	X			

(continued)

Table 2.20—Aquatic insects by order, family, and species found within the Assessment area (continued)

Order	Family	Species	Ouachita Mtns	Arkansas Valley	Boston Mtns	Ozark Highlands
Trichoptera	Leptoceridae	*Oecetis ouachita*[a]	X			
Trichoptera	Leptoceridae	*Oecetis ozarkensis*[a]				X
Trichoptera	Leptoceridae	*Oecetis persimilis*	X	X	X	X
Trichoptera	Leptoceridae	*Setodes oxapius*[a]		X		X
Trichoptera	Leptoceridae	*Triaenodes aba*				X
Trichoptera	Leptoceridae	*Triaenodes cumberlandensis*	X			
Trichoptera	Leptoceridae	*Triaenodes dipsius*	X	X	X	X
Trichoptera	Leptoceridae	*Triaenodes flavescens*				X
Trichoptera	Leptoceridae	*Triaenodes ignitus*	X	X		X
Trichoptera	Leptoceridae	*Triaenodes injustus*	X	X		X
Trichoptera	Leptoceridae	*Triaenodes marginatus*	X	X	X	X
Trichoptera	Leptoceridae	*Triaenodes melacus*				X
Trichoptera	Leptoceridae	*Triaenodes nox*				X
Trichoptera	Leptoceridae	*Triaenodes perna*	X			X
Trichoptera	Leptoceridae	*Triaenodes tardus*	X	X		X
Trichoptera	Leptoceridae	*Triaenodes tridontus*	X			
Trichoptera	Limnephilidae	*Frenesia missa*				X
Trichoptera	Limnephilidae	*Glyphopsyche missouri*[a]				X
Trichoptera	Limnephilidae	*Ironoquia punctatissima*	X	X	X	X
Trichoptera	Limnephilidae	*Limnephilus submonilifer*			X	X
Trichoptera	Limnephilidae	*Platycentropus radiatus*	X			
Trichoptera	Limnephilidae	*Pseudostenophylax uniformis*				X
Trichoptera	Limnephilidae	*Pycnopsyche guttifer*				X
Trichoptera	Limnephilidae	*Pycnopsyche indiana*	X	X		X
Trichoptera	Limnephilidae	*Pycnopsyche lepida*	X	X	X	X
Trichoptera	Limnephilidae	*Pycnopsyche rossi*	X		X	X
Trichoptera	Limnephilidae	*Pycnopsyche subfasciata*	X	X	X	X
Trichoptera	Molannidae	*Molanna blenda*	X		X	X
Trichoptera	Molannidae	*Molanna ulmerina*	X		X	X
Trichoptera	Molannidae	*Molanna uniophila*	X		X	X
Trichoptera	Odontoceridae	*Marilia flexuosa*			X	X
Trichoptera	Odontoceridae	*Marilia species A*[a]				X
Trichoptera	Philopotamidae	*Chimarra aterrima*		X	X	X
Trichoptera	Philopotamidae	*Chimarra feria*	X	X	X	X
Trichoptera	Philopotamidae	*Chimarra obscura*	X	X	X	X
Trichoptera	Philopotamidae	*Chimarra parasocia*	X			X
Trichoptera	Philopotamidae	*Chimarra socia*	X			X
Trichoptera	Philopotamidae	*Wormaldia moesta*	X	X	X	X
Trichoptera	Philopotamidae	*Wormaldia shawnee*				X
Trichoptera	Philopotamidae	*Wormaldia strota*[a]	X	X	X	X
Trichoptera	Phryganeidae	*Agrypnia vestita*	X	X		X
Trichoptera	Phryganeidae	*Phryganea sayi*				X
Trichoptera	Phryganeidae	*Ptilostomis ocellifera*	X	X	X	X
Trichoptera	Phryganeidae	*Ptilostomis postica*	X	X		X
Trichoptera	Polycentropodidae	*Cernotina calcea*	X	X	X	X
Trichoptera	Polycentropodidae	*Cernotina spicata*	X			
Trichoptera	Polycentropodidae	*Cyrnellus fraternus*	X	X	X	X
Trichoptera	Polycentropodidae	*Neureclipsis crepuscularis*	X	X	X	X
Trichoptera	Polycentropodidae	*Paranyctiophylax affinis*	X	X	X	X
Trichoptera	Polycentropodidae	*Paranyctiophylax serratus*	X	X		X
Trichoptera	Polycentropodidae	*Polycentropus centralis*	X	X	X	X
Trichoptera	Polycentropodidae	*Polycentropus chelatus*				X
Trichoptera	Polycentropodidae	*Polycentropus cinereus*	X	X	X	X
Trichoptera	Polycentropodidae	*Polycentropus confusus*				X
Trichoptera	Polycentropodidae	*Polycentropus crassicornis*	X	X	X	X
Trichoptera	Polycentropodidae	*Polycentropus harpi*	X	X	X	X

(continued)

Table 2.20—Aquatic insects by order, family, and species found within the Assessment area (continued)

Order	Family	Species	Ouachita Mtns	Arkansas Valley	Boston Mtns	Ozark Highlands
Trichoptera	Polycentropodidae	*Polycentropus stephani*[a]			X	X
Trichoptera	Psychomyiidae	*Lype diversa*	X	X		X
Trichoptera	Psychomyiidae	*Paduniella nearctica*[a]		X	X	X
Trichoptera	Psychomyiidae	*Psychomyia flavida*	X	X	X	X
Trichoptera	Rhyacophilidae	*Rhyacophila banksi*				X
Trichoptera	Rhyacophilidae	*Rhyacophila fenestra*				X
Trichoptera	Rhyacophilidae	*Rhyacophila glaberrima*	X			X
Trichoptera	Rhyacophilidae	*Rhyacophila kiamichi*[a]	X	X	X	X
Trichoptera	Rhyacophilidae	*Rhyacophila lobifera*	X			X
Trichoptera	Uenoidae	*Neophylax concinnus*	X		X	X
Trichoptera	Uenoidae	*Neophylax fuscus*				X

[a] Endemic species.

Source: Poulton and Stewart (1991), Moulton and Stewart (1996).

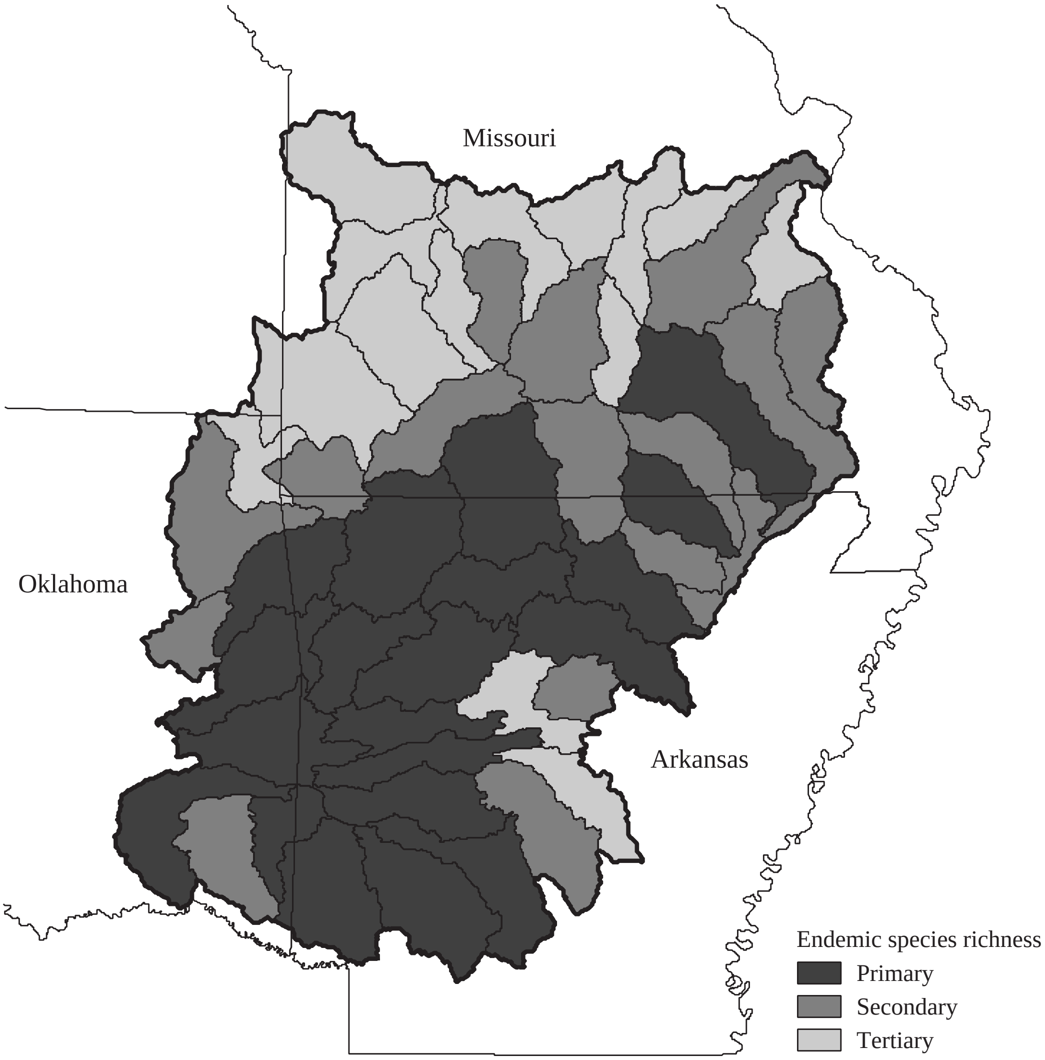


Figure 2.32—Levels of endemic stonefly and caddisfly species richness (combined) by watershed.

1996). *Lepidostoma lescheni* originally was found only on Magazine Mountain (Petit Jean watershed) but has since been collected in seeps and springs in the Little Missouri watershed. Other endemic caddisflies were locally abundant or evenly distributed throughout the Highlands: *Wormaldia strota* (occurred in 20 percent of the hydrologic units), *Setodes oxapius* (16 percent), *Neotrichia arkansasensis* (16 percent), *Helicopsyche limnella* (16 percent), *Rhyacophila kiamichi* (15 percent), and the newly described *Paduniella nearctica* (8 percent).

Recently described endemic stonefly species also have been found in one or only a few of the hydrologic units. *Isoperla szczytkoi* occurred only in the Petit Jean watershed; *Alloperla caddo* only in the Upper Saline and Fourche La Fave watersheds; *Alloperia ouachita* only in small, clear, rapid rocky streams in the Little Missouri watershed; *Acroneuria ozarkensis* only in the Buffalo and Lower Gasconade watersheds; *Zealeuctra wachita* only in intermittent streams in the Upper Ouachita watershed; *Allocapnia oribata* only in perennial streams in the Little Red watershed; and *Allocapnia warreni* only in the Illinois watershed (Poulton and Stewart 1991). Endemic stonefly species that occurred more abundantly and/or were more evenly distributed within the Highlands were *Isoperla ouachita* (occurs in 100 percent of the watersheds); *Allocapnia mohri* (80 percent); *Neoperla harpi* (77 percent); *Neoperla osage* (75 percent); *Strophopteryx cucullata* (56 percent); *Strophopteryx arkansae* (44 percent); *Zealeuctra warreni* (34 percent); and *Neoperla falayah* (34 percent).

Implications and Opportunities

The levels of species richness, density, and numbers of endemic stoneflies and caddisflies in the study area, particularly the Ozark Highlands and Ouachita Mountains, indicate that habitat diversity for these aquatic insects is high. Typical of mountainous areas, the Highlands have extensive headwater streams, seeps, and springs. These aquatic habitats are particularly rich in aquatic insects and, in turn, are sensitive to detrimental effects from human activities.

The Aquatic Team examined and compared the population distributions, species richness, species density, and endemic distributions of Plecoptera and Trichoptera, but much more could be added to achieve as accurate a picture as possible. While studies by Poulton and Stewart (1991) and Moulton and Stewart (1996) offer unprecedented documentation of stoneflies and caddisflies in the Assessment area, these insects represent only a small part of the total aquatic invertebrate community. Plecoptera and Trichoptera are only 2 of the 12 aquatic insect orders listed in Merritt and Cummins (1996). A more comprehensive list of aquatic insects and other aquatic invertebrates would help natural resource managers to better understand, monitor, and support the health of aquatic systems.

Endangered, Threatened, and Other Aquatic Species of Special Concern

Question 2.8: What are the status and distribution of endangered, threatened, and other aquatic species of special concern within the Assessment area?

As is true elsewhere, conservation of aquatic biodiversity in the Assessment area is a battle against extinction (Minckley and Deacon 1991) and ultimately, a battle for ecological integrity at landscape scales (Angermeier and Karr 1994). The loss of and decline in populations of aquatic species are attributed primarily to alteration of habitats, chemical pollution, overexploitation, and/or the introduction of competitive nonindigenous organisms (Allan and Flecker 1993, Williams and others 1993, Warren and Burr 1994). The process of extinction often can be related to landscape-scale phenomena that decrease habitat area or quality and increase isolation of populations (Angermeier 1995). However, loss of diversity via extinction is not usually observable or cataclysmic. Rather, the process is gradual, with total extinction preceded by local or regional annihilations (Angermeier 1995). Understanding (and ultimately preventing) human-caused imperilment and extinction of aquatic organisms is likely to require far greater focus on landscape-level patterns and processes than traditional approaches to maintaining diverse aquatic communities have used in the past.

One of the most important lines of defense against extinction of aquatic and other organisms in the United

States is the Endangered Species Act (ESA) of 1973, as amended. However, the Clean Water Act (CWA) of 1972, as amended, is another potentially powerful statutory vanguard for habitat and species conservation that can prevent human-caused endangerment of aquatic species and communities (Angermeier and Karr 1994). The ESA established a process whereby Federal legal protections are available to protect animal and plant species in jeopardy of extinction. Under the ESA, the term "species" includes species, subspecies, and certain distinctive populations (Littell 1992). Endangered, threatened, proposed endangered, and proposed threatened animals and plants are provided protection under the ESA and are listed under these categories by the USDI Fish and Wildlife Service (1997a, b). Candidate species are those for which the Fish and Wildlife Service has sufficient information to initiate listing under the ESA (USDI FWS 1997a, b).

Other organizations and agencies, both public and private, are playing increasing roles in the early recognition and long-term monitoring of species that are potentially at risk of extinction or population declines. Using protocols developed by The Nature Conservancy, the States in the Assessment area track the distributions and populations of species with Federal ESA status. States also monitor those that are considered globally imperiled through globally rare (i.e., ranked as G1, G2, or G3 by The Nature Conservancy), and those with State distributions (S1 through S5 as ranked by State heritage programs). For a complete explanation of these ranks, see the "Glossary of Terms" at the end of this report.

In addition, the American Fisheries Society, using panels of professional biologists, has provided independent rankings of conservation status for fishes (Williams and others 1989b), mussels (Williams and others 1993), and crayfishes (Taylor and others 1996). In this report, the Aquatic Team discusses species recognized by State heritage programs and the American Fisheries Society as "of special concern" species. The information provided by these groups can serve as a primary source from which future candidates for Federal status may be drawn (USDI FWS 1996) and as important planning and prioritizing tools for recovery efforts, status surveys, and research on aquatic organisms.

Key Findings

1. A total of 125 aquatic taxa have 1 or more of the following designations: Federal status (14 species), globally imperiled through globally rare (78 taxa have G1, G2, or G3 ranks), and State critically imperiled (68 taxa have S1 ranks). Included are 7 insects; 37 mollusks, 35 of which are freshwater mussels; 23 crustaceans, 15 of which are crayfish; 55 fishes; and 3 herptiles (amphibians or reptiles).
2. Of the 14 aquatic taxa with Federal status, 6 are mollusks, 2 are crustaceans, and 6 are fishes.
3. In the Assessment area, about 32, 50, and 26 percent of fishes, mussels, and crayfishes, respectively, have Federal status, globally rare ranks, and/or S1 State ranks.
4. Sixty percent of the hydrologic units recorded at least one species with a Federal status on Element Occurrence Records (EOR's); the pattern of distribution (i.e., 0 to 4 species per unit out of 14 possible species) suggests that the presence of such species differs dramatically across units.
5. Hydrologic units with three or four species with Federal status were located in the southern Ouachita Mountains (Upper Little, Lower Little, and Upper Ouachita units), in the Neosho-Illinois drainage (Lake O' the Cherokees, Illinois, Elk, and Spring units), and in the Sac unit (Osage River drainage). Units with one to two species with Federal status were scattered widely across the Assessment area.
6. Two concentrations of hydrologic units showed primary levels of endangered, threatened, and other species of special concern (10 to 30 species with Federal status, global ranks, or State ranks): (1) along the southern edge of the Assessment area in the Ouachita Mountains and (2) along the northeastern edge of the Assessment area in the Upper Black River and Upper St. Francis drainages. Secondary levels of endangered, threatened, and other species of special concern (seven to nine species per watershed) tended to be associated with hydrologic units adjacent to those with primary levels.

Data Sources and Methods of Analysis

The Aquatic Team synthesized information on endangered, threatened, and other aquatic organisms of special concern, including aquatic insects, mollusks, crayfishes, totally aquatic herptiles, and fishes. To analyze and display the distribution of these aquatic species, each of 10 major drainages within the aquatic study area was subdivided, yielding 50 hydrologic units or watersheds (fig. 2.17).

The team noted each endangered, threatened, and other species of special concern that was present or absent within each hydrologic unit. Some species with occurrences in portions of hydrologic units extending outside the Assessment area were included in the analysis. The team included species with Federal status (i.e., endangered, proposed endangered, threatened, and proposed threatened under the ESA); those ranked globally as G1, G2, or G3 by The Nature Conservancy; and those ranked as S1, S2, or S3 by the State heritage programs. The team referred to these three conservation rankings as "Federal status," "global ranks," and "State ranks," respectively. The team presented separately the conservation status rankings of the American Fisheries Society (see the "Management Indicator Species" section later in this chapter).

The team determined distributions of endangered, threatened, and other aquatic species of special concern within a particular hydrologic unit from Element Occurrence Records (EOR's) received from heritage programs in Arkansas, Oklahoma, and Missouri (USDA FS 1997a, b). The EOR data sets were based on information updated by the States in 1997.

The team used the temporal coverage, spatial coverage, and quality of information on State EOR's to determine the occurrence of each species within hydrologic units. The presence of an endangered, threatened, or other aquatic species of special concern reflects known historical presence within a unit but does not necessarily indicate the continued occurrence of a species in that watershed. Recent verification of the continued presence of species documented in historical EOR's (i.e., those 10 or 20 years old) may be limited by constraints on funding, personnel, and expertise in State heritage programs. Further, the collection of EOR data tends to be weighted toward surveys or environmental assessments associated with State or Federally regulated projects or lands. The team compared lists of species compiled from EOR data with lists of endangered, threatened, proposed endangered, and proposed threatened species of the USDI Fish and Wildlife Service (1997a, b), and corrected inconsistencies. They also augmented and corrected information from the States by using information for fishes from Pflieger (1975) and Robison and Buchanan (1988) and for crayfishes from Pflieger (1996).

The Aquatic Team analyzed endangered, threatened, and other aquatic organisms of special concern by major groups of organisms (insects, mollusks, crustaceans, fishes, and herptiles) and by geographic distribution. The number of endangered and threatened species accounted for by EOR's was tallied for each hydrologic unit, and the results were mapped across hydrologic units in four categories: no Federal status species or insufficient data; one to two Federal status species; three Federal status species; and four Federal status species. The Aquatic Team added the number of other species of special concern (i.e., those with global and State ranks) to the Federal status tally for each hydrologic unit and mapped the results to show total imperilment for each unit. Three levels of total imperilment were recognized among hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 13 units with highest values, secondary levels to the next highest 14 units, and tertiary values to the remaining units. Hence, primary levels approximate values in the fourth quartile (top 25 percent), secondary levels (second 25 percent), values in the third quartile, and tertiary levels, values in the first and second quartiles (bottom 50 percent).

Patterns and Trends

Composition of Federal status and other aquatic species of special concern. Representation of endangered, threatened, and other species of special concern was uneven across major groups of aquatic organisms (i.e., fish, mollusks, crayfishes, insects, and herptiles) within the Assessment area. The 125 taxa included 7 insects, 37 mollusks (35 of which are freshwater mussels), 23 crustaceans (15 of which are crayfish), 55 fishes, and 3 herptiles (table 2.21). Fourteen (including two candidate species) of these have Federal status (six

Table 2.21—Endangered, threatened, and other species of special concern in the aquatic study area

Group	Species	Common name	Global[a]	Federal[b]	MO[c]	AR[c]	OK[c]
Insect	*Allocapnia jeanae*	Winter stonefly	G1?			S1?	
Insect	*Allocapnia ozarkana*	Winter stonefly	G1?			S1?	
Insect	*Dannella provonshai*	Mayfly	G1?				
Insect	*Glyphopsyche missouri*	Missouri glyphopsyche caddisfly	G1G3		S1S3		
Insect	*Gomphus ozarkensis*	Ozark clubtail dragonfly	G4			S2	
Insect	*Ophiogomphus westfalli*	Arkansas snaketail dragonfly	G2		S?		
Insect	*Paduniella nearctica*	Nearctic paduniellan caddisfly	G1?			S1?	
Mollusk	*Alasmidonta marginata*	Elktoe	G5				S1
Mollusk	*Amnicola cora*	Foushee cavesnail	G1			S1	
Mollusk	*Anodonta grandis corpulenta*	Giant floater	G5T3Q		S2		
Mollusk	*Anodonta suborbiculata*	Flat floater	G4			S1?	
Mollusk	*Antrobia culveri*	Tumbling creek cave snail	G1	C	S1		
Mollusk	*Arcidens confragosus*	Rock pocketbook	G3		S1		
Mollusk	*Arkansia wheeleri*	Ouachita rock pocketbook	G1	E		S1	S1
Mollusk	*Cumberlandia monodonta*	Spectaclecase	G2G3		S2		
Mollusk	*Cyprogenia aberti*	Western fanshell	G2		S1	S2	
Mollusk	*Ellipsaria lineolata*	Butterfly	G4				S2
Mollusk	*Elliptio dilatata*	Spike	G5				S1
Mollusk	*Epioblasma curtisi*	Curtis pearlymussel	G1T1	E	S1	S1?	
Mollusk	*Epioblasma triquetra*	Snuffbox	G3		S1	S1	
Mollusk	*Fusconaia ebena*	Ebonyshell	G4				S1
Mollusk	*Glebula rotundata*	Round pearlshell	G3G4				S1
Mollusk	*Lampsilis abrupta*	Pink mucket	G2	E	S2	S2	
Mollusk	*Lampsilis hydiana*	Louisiana fatmucket	G2				S1
Mollusk	*Lampsilis ornata*	Southern pocketbook	G5			S1?	
Mollusk	*Lampsilis powellii*	Arkansas fatmucket	G1G2	T		S2?	
Mollusk	*Lampsilis rafinesqueana*	Neosho mucket	G2		S1	S1	S1
Mollusk	*Lampsilis streckeri*	Speckled pocketbook	G1Q	E		S1	
Mollusk	*Lasmigona costata*	Fluted shell	G5				S1
Mollusk	*Leptodea leptodon*	Scaleshell	G2G3		S1	S?	S1
Mollusk	*Ligumia recta*	Black sandshell	G5				S1
Mollusk	*Obovaria jacksoniana*	Southern hickorynut	G1G2				S2
Mollusk	*Plectomerus dombeyanus*	Bankclimber	G4				S2
Mollusk	*Plethobasus cyphyus*	Sheepnose	G3		S2		
Mollusk	*Pleurobema cordatum*	Ohio River pigtoe	G3				S2
Mollusk	*Ptychobranchus occidentalis*	Ouachita kidneyshell	G3G4		S?		S2
Mollusk	*Quadrula cylindrica*	Rabbitsfoot	G4T2T3		S1	S?	S1
Mollusk	*Quadrula metanevra*	Monkeyface	G3				S1
Mollusk	*Simpsonaias ambigua*	Salamander mussel	G2			S1?	
Mollusk	*Toxolasma lividus*	Purple lilliput	G1G2Q		S1		
Mollusk	*Toxolasma texasensis*	Texas lilliput	G4				S1
Mollusk	*Villosa arkansasensis*	Ouachita creekshell	G2				S1S2
Mollusk	*Villosa iris*	Rainbow	G4				S1
Mollusk	*Villosa lienosa*	Little spectacle case	G5				S2
Crustacean	*Allocrangonyx hubrichti*	Central Missouri cave amphipod	G1G3		S1S3		
Crustacean	*Caecidotea dimorpha*	Isopod	G1		S3		
Crustacean	*Caecidotea macropoda*	Bat cave isopod	G1G3				SU
Crustacean	*Caecidotea steevesi*	Isopod	G1			S1	
Crustacean	*Caecidotea stiladactyla*	Isopod	G1			S1	
Crustacean	*Cambarus aculabrum*	Crayfish	G1	E		S?	
Crustacean	*Cambarus causeyi*	Crayfish	G1			S1	
Crustacean	*Cambarus hubrichti*	Salem Cave crayfish	G3		S2		
Crustacean	*Cambarus setosus*	Bristly Cave crayfish	G2		S2		
Crustacean	*Cambarus zophonastes*	Cave crayfish	G1	E		S1	
Crustacean	*Fallicambarus harpi*	Harp's crayfish	G1			S1	
Crustacean	*Fallicambarus jeanae*	Crayfish	G1			S?	
Crustacean	*Fallicambarus strawni*	Crayfish	G1G2			S1?	
Crustacean	*Faxonella blairi*	Crayfish	G2				S1S2
Crustacean	*Orconectes eupunctus*	Coldwater crayfish	G3		S3		

(continued)

Table 2.21—Endangered, threatened, and other species of special concern in the aquatic study area (continued)

Group	Species	Common name	Global[a]	Federal[b]	MO[c]	AR[c]	OK[c]
Crustacean	*Orconectes marchandi*	Mammoth Spring crayfish	G3		S3		
Crustacean	*Orconectes peruncus*	Big Creek crayfish	G2		S3		
Crustacean	*Orconectes williamsi*	Williams' crayfish	G1		S?		
Crustacean	*Procambarus parasimulans*	Crayfish	G3			S?	
Crustacean	*Procambarus reimeri*	Crayfish	G3			S1?	
Crustacean	*Stygobromus montanus*	Mountain cave amphipod	G1			S1	
Crustacean	*Stygobromus onondagaensis*	Onondaga cave amphipod	G1G3		S1S3		
Crustacean	*Stygobromus ozarkensis*	Ozark cave amphipod	G?		S1	S1	
Fish	*Acipenser fulvescens*	Lake sturgeon	G3			S1	
Fish	*Amblyopsis rosae*	Ozark cavefish	G2	T	S1	S1	S1
Fish	*Ammocrypta clara*	Western sand darter	G3G4			S2?	S3
Fish	*Ammocrypta vivax*	Scaly sand darter	G5				S1S2
Fish	*Atractosteus spatula*	Alligator gar	G5			S2	S1
Fish	*Crystallaria asprella*	Crystal darter	G3		S1	S2?	
Fish	*Cycleptus elongatus*	Blue sucker	G3		S3		
Fish	*Cyprinella spiloptera*	Spotfin shiner	G5			S1	
Fish	*Esox niger*	Chain pickerel	G5				S1SX
Fish	*Etheostoma fragi (E. spectabile fragi)*	Strawberry (River) darter	G5T1			S1	
Fish	*Etheostoma cragini*	Arkansas darter	G3GT	C	S2	S1	S2
Fish	*Etheostoma fusiforme*	Swamp darter	G5			S2	
Fish	*Etheostoma microperca*	Least darter	G5			S1	
Fish	*Etheostoma moorei*	Yellowcheek darter	G1			S1	
Fish	*Etheostoma nianguae*	Niangua darter	G2	T	S2		
Fish	*Etheostoma pallididorsum*	Paleback darter	G2			S2	
Fish	*Etheostoma parvipinne*	Goldstripe darter	G4G5				S2
Fish	*Fundulus blairae*	Blair's starhead topminnow	G3G4Q				S2
Fish	*Fundulus sciadicus*	Plains topminnow	G4				S1
Fish	*Hiodon alosoides*	Goldeye	G5			S2	
Fish	*Ictalurus nebulosus*	Brown bullhead	G5				S1SH
Fish	*Lampetra aepyptera*	Least brook lamprey	G5			S2?	
Fish	*Lampetra appendix*	American brook lamprey	G5			S2?	
Fish	*Lythrurus snelsoni*	Ouachita Mountain shiner	G2			S?	S2
Fish	*Macrhybopsis aestivalis tetranemus*	Arkansas River speckled chub	G5T5				S?
Fish	*Moxostoma anisurum*	Silver redhorse	G5			S1?	
Fish	*Moxostoma macrolepidotum*	Shorthead redhorse	G5			S2?	
Fish	*Mugil cephalus*	Striped mullet	G5			S1?	
Fish	*Nocomis asper*	Redspot chub	G4			S2?	
Fish	*Notropis amnis*	Pallid shiner	G4				S1S2
Fish	*Notropis atrocaudalis*	Blackspot shiner	G4				S1
Fish	*Notropis bairdi*	Red River shiner	G3				S3
Fish	*Notropis chalybaeus*	Ironcolor shiner	G5				S1
Fish	*Notropis girardi*	Arkansas River shiner	G2G3	PE		SX	S1
Fish	*Notropis hubbsi*	Bluehead shiner	G3			S3	S1
Fish	*Notropis maculatus*	Taillight shiner	G5				S1
Fish	*Notropis ortenburgeri*	Kiamichi shiner	G3			S2	S3
Fish	*Notropis ozarcanus*	Ozark shiner	G3		S3		
Fish	*Notropis perpallidus*	Peppered shiner	G3			S2	S2S3
Fish	*Notropis sabinae*	Sabine shiner	G4			S2?	
Fish	*Noturus eleutherus*	Mountain madtom	G5				S2
Fish	*Noturus lachneri*	Ouachita madtom	G2			S2	
Fish	*Noturus placidus*	Neosho madtom	G2	T	S1		S1
Fish	*Noturus taylori*	Caddo madtom	G1			S1	
Fish	*Percina cymatotaenia*	Bluestripe darter	G2		S3		
Fish	*Percina maculata*	Blackside darter	G5				S2
Fish	*Percina nasuta*	Longnose darter	G3		S1		S1
Fish	*Percina pantherina*	Leopard darter	G1	T		S1	S1
Fish	*Percina phoxocephala*	Slenderhead darter	G5			S2	

(continued)

Table 2.21—Endangered, threatened, and other species of special concern in the aquatic study area (continued)

Group	Species	Common name	Global[a]	Federal[b]	MO[c]	AR[c]	OK[c]
Fish	*Percina shumardi*	River darter	G5				S2
Fish	*Percina uranidea*	Stargazing darter	G3				S2
Fish	*Phenacobius mirabilis*	Suckermouth minnow	G5			S1	
Fish	*Polyodon spathula*	Paddlefish	G4			S2?	
Fish	*Scaphirhynchus platorynchus*	Shovelnose sturgeon	G4				S1
Fish	*Typhlichthys subterraneus*	Southern cavefish	G3		S3	S1	
Herptile	*Cryptobranchus alleganiensis bishopi*	Ozark hellbender	G4T3		S3		
Herptile	*Macroclemys temminckii*	Alligator snapping turtle	G3G4		S1		
Herptile	*Sternotherus carinatus*	Razorback musk turtle	G5			S1	

[a] Global ranks: see “Glossary of Terms” for definitions.
[b] Federal ranks: C = candidate; T = threatened; E = endangered; PE = potentially endangered.
[c] State ranks: Denoted by S and a number (1–5) or letter code.
Source: see “Data Sources and Methods of Analysis” of this section.

mollusks, two crustaceans, and six fishes). Taxa with G1 to G3 global ranks (excluding Federal status taxa) include 6 aquatic insects, 15 mollusks, 20 crustaceans, 19 fishes, and 1 herptile. The remaining 50 taxa are State ranked and include: 1 insect, 16 mollusks, 1 crustacean, 30 fishes, and 2 herptiles. In the Assessment area, about 32, 50, and 26 percent of fishes, mussels, and crayfishes, respectively, have Federal status, global ranks, and/or State ranks (see previous analyses of richness and density of these groups).

The degree of imperilment of aquatic organisms in the study area as estimated by numbers of species with Federal status may be conservative. For example, 18 species of freshwater mussels within the aquatic study area are regarded as endangered or threatened by the American Fisheries Society (Williams and others 1993), and 14 received global ranks from The Nature Conservancy. However, only 6 species of freshwater mussels have Federal status. Similarly, only 2 crayfishes in the Assessment area have Federal status, but the American Fisheries Society (Taylor and others 1996) recognized 13 as endangered or threatened, and The Nature Conservancy considers 13 as globally rare. The scant representation of aquatic insects on the lists of imperiled fauna reflects the relatively incomplete documentation of their distribution and status and is not unique to the Assessment area (Murphy 1991). For other groups of aquatic organisms, the discrepancy between Federal status lists and other sources may be attributed, in part, to the backlog in the listing process that is ongoing under the Endangered Species Act (Reffalt 1991, Warren and Burr 1994).

Federal status and other aquatic species of special concern among hydrologic units. Endangered and threatened aquatic species were not distributed evenly among the hydrologic units (fig. 2.33), but 60 percent of the hydrologic units had at least one Federal status aquatic species recorded on EOR’s. The total number of Federal status species for the Assessment area is 14, but the number of Federal status species ranged from 0 to 4 across watersheds (table 2.22). Hydrologic units with three or four Federal status species were located in the southern Ouachita Mountains (Upper Little, Lower Little, and Upper Ouachita watersheds), the Neosho-Illinois River Basin (Spring, Lake O’ the Cherokees, Elk, and Illinois watersheds), and the Sac watershed (Osage River drainage). Hydrologic units with one or two Federal status species were scattered widely across the Assessment area.

The number of Federal status and other special concern species recorded on EOR’s is not distributed evenly among the hydrologic units (fig. 2.34). Total numbers of Federal status, global rank, and State rank aquatic species averaged 7.4 (two standard errors = 1.79) per hydrologic unit and ranged from 0 to 30 species. Seven hydrologic units had no Federal status or other imperiled species, but 30 hydrologic units had EOR’s for 6 or more imperiled species.

Two concentrations of hydrologic units showed primary levels of total imperilment (10 to 30 species per

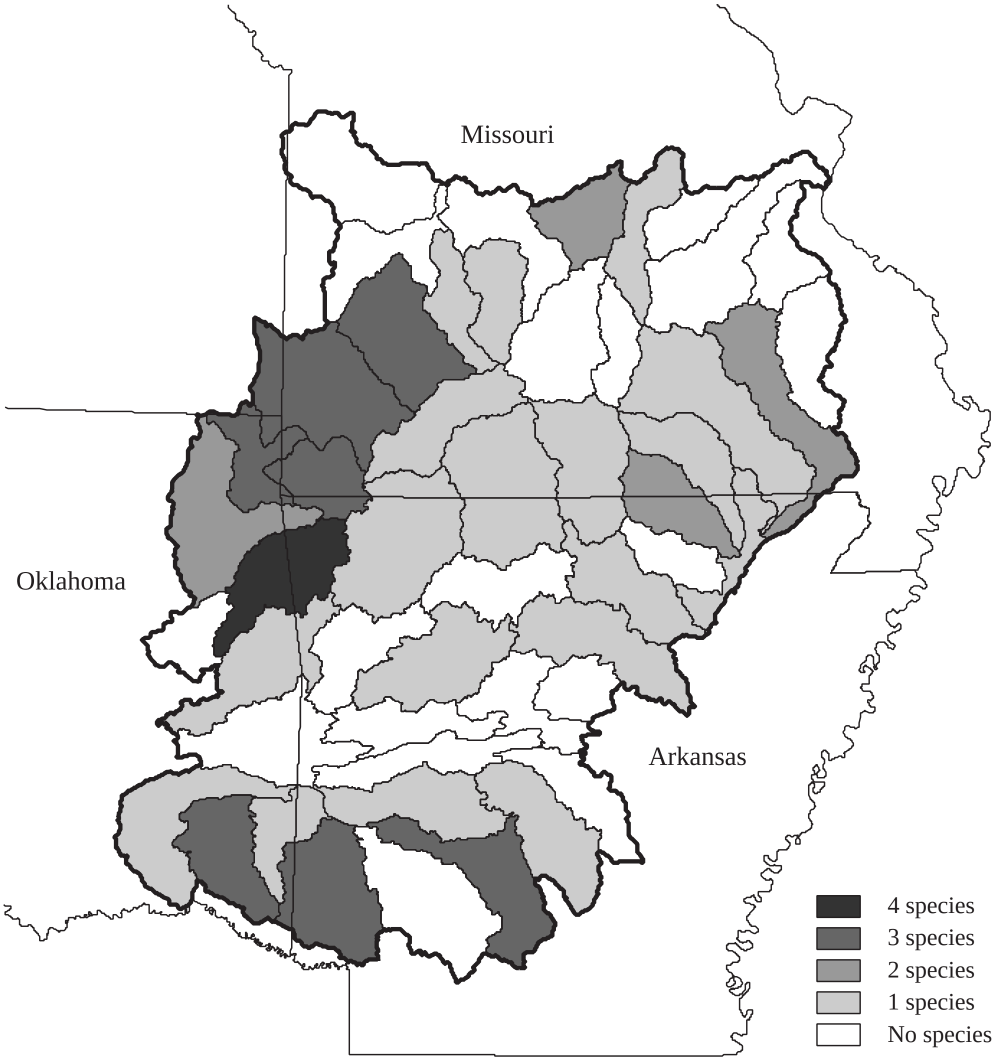


Figure 2.33—Number of endangered and threatened aquatic species by watershed.

hydrologic unit) (fig. 2.34). One group is along the southern edge of the Assessment area in the Ouachita Mountains, and another is along the northeastern edge of the Assessment area in the Upper Black River and Upper St. Francis drainages and to a lesser extent the Upper White River drainage. Hydrologic units of the southern Ouachita Mountains with primary levels of total imperilment included the Upper Little (30 imperiled species), Mountain Fork (21 species), Lower Little (22 species), and Kiamichi (14 species) watersheds (Kiamichi-Little drainage) and to the east, the Upper Ouachita watershed (17 species; Ouachita-Saline drainage). Hydrologic units within the Kiamichi-Little drainage showed the highest levels of total imperilment in the Assessment area. For perspective, the Upper Little, Lower Little, and Mountain Fork watersheds showed EOR's comprising 24, 18, and 17 percent, respectively, of Federal status and other special concern aquatic species in the Assessment area. The second concentration of watersheds with primary levels of total imperilment includes: the Middle White watershed (Upper White River drainage); the Spring, Current, and Eleven Point watersheds (Black River drainage); and the Upper St. Francis watershed. Of these, the Current and Spring watersheds showed EOR's representing 12 and 15 percent, respectively, of Federal status and other

Table 2.22—Number of aquatic species with Federal status or special concern status that are found in the aquatic study area[a]

River basin Watershed name	Watershed code (HUC)	Federal status	Special status
Osage River Basin			
H.S. Truman Reservoir	10290105	0	0
Sac	10290106	3	7
Pomme de Terre	10290107	1	1
South Grand	10290108	0	0
Lake of the Ozarks	10290109	0	1
Niangua	10290110	1	3
Lower Osage	10290111	2	6
Gasconade River Basin			
Upper Gasconade	10290201	0	5
Big Piney	10290202	0	4
Lower Gasconade	10290203	1	5
Meramec River Basin			
Meramec	07140102	0	9
Bourbeuse	07140103	0	1
Big	07140104	0	0
Upper St. Francis River Basin			
Upper St. Francis	08020202	0	11
Neosho-Illinois River Basin			
Lake O' the Cherokees	11070206	3	6
Spring	11070207	3	10
Elk	11070208	3	7
Lower Neosho	11070209	2	9
Illinois	11110103	4	11
Arkansas River Basin			
Dirty-Greenleaf	11110102	0	0
Robert S. Kerr Reservoir	11110104	1	10
Poteau	11110105	0	8
Frog-Mulberry	11110201	0	6
Dardanelle Reservoir	11110202	1	7
Conway- Pt. Remove	11110203	0	0
Petit Jean	11110204	0	1
Cadron	11110205	0	0
Fourche La Fave	11110206	0	0
Lower Ark-Maumelle	11110207	0	2
Kiamichi-Little River Basin			
Kiamichi	11140105	1	14
Upper Little	11140107	3	30
Mountain Fork	11140108	1	21
Lower Little	11140109	3	22
Ouachita-Saline River Basin			
Ouachita Headwaters	08040101	1	8
Upper Ouachita	08040102	3	17
Little Missouri	08040103	0	7
Upper Saline	08040203	1	5
Upper White River Basin			
Beaver Reservoir	11010001	1	9
James	11010002	1	5
Bull Shoals Lake	11010003	1	8
Middle White	11010004	1	11
Buffalo	11010005	0	4
North Fork White	11010006	1	5
Little Red	11010014	1	7
Upper Black River Basin			
Upper Black	11010007	2	9
Current	11010008	1	15
Lower Black	11010009	1	9
Spring	11010010	2	19
Eleven Point	11010011	1	10
Strawberry	11010012	0	7

HUC = hydrologic unit code.

[a] Data derived from State heritage program records; see text for definitions.

imperiled species within the Assessment area. In the western part of the Assessment area, one watershed in the Arkansas River drainage (Robert S. Kerr Reservoir watershed) and two in the Neosho-Illinois drainage (Illinois and Spring watersheds) also showed primary levels of total imperilment.

Secondary levels of total imperilment (seven to nine species per hydrologic unit) tended to be associated with hydrologic units adjacent to those with primary levels of total imperilment (fig. 2.34). In the Ouachita Mountains, for example, the Little Missouri and Ouachita Headwaters watersheds (Ouachita-Saline drainage), both with secondary levels of total imperilment, complemented watersheds in this province with primary levels of total imperilment. Likewise, the Meramec watershed (Meramec River drainage), Upper Black, Lower Black, and Strawberry watersheds (Black River drainage), and Little Red watershed (Upper White River drainage) lie adjacent to watersheds with primary levels of total imperilment in the northeastern portion of the Assessment area. The Sac watershed (Osage River drainage), the Lower Neosho and Elk watersheds (Neosho-Illinois drainage), Poteau and Dardanelle watersheds (Arkansas River drainage), and Bull Shoals Lake and Beaver Reservoir watersheds (Upper White River drainage) also showed secondary levels of total imperilment.

Tertiary levels of total imperilment (1 to 6 species per hydrologic unit) were concentrated primarily in the Osage and Gasconade River drainages as well as the Arkansas River drainage (fig. 2.34). All hydrologic units in the Gasconade River drainage and all but the Sac watershed in the Osage River drainage show tertiary levels of total imperilment. Likewise, all watersheds in the Arkansas River drainage with the exception of the Poteau, Dardanelle Reservoir, and Robert S. Kerr Reservoir watersheds show tertiary levels of total imperilment. The team emphasizes, however, that 16 of 23 watersheds with tertiary levels of total imperilment had 1 to 6 imperiled species.

No consistent pattern was revealed for Federal status or other species of special concern being associated with watersheds having high percentages of national forest ownership. Some basins and watersheds that have national forest lands have relatively high numbers of Federal status and/or other species of special concern (Kiamichi-Little, Upper Black, and portions of the Ouachita-Saline and Upper White River

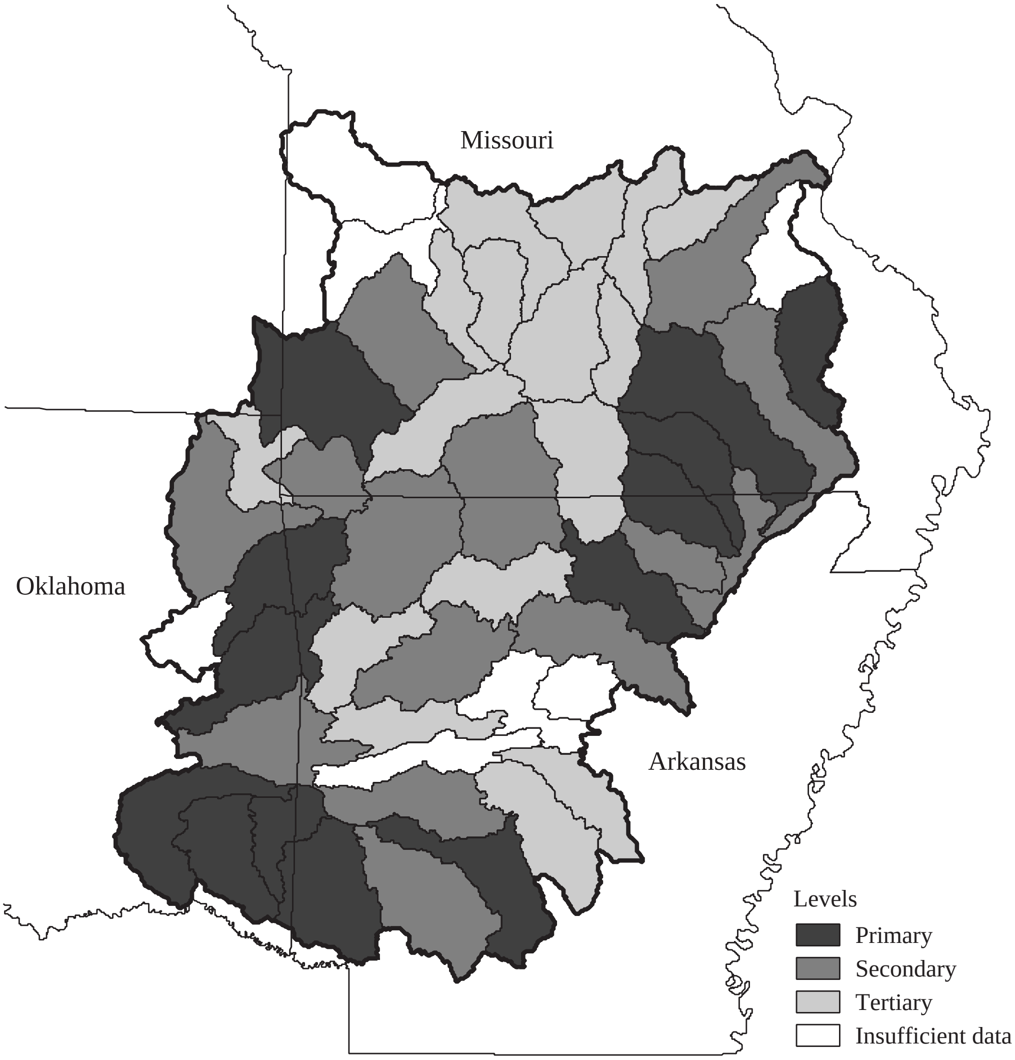


Figure 2.34—Levels of endangered, threatened, and special concern aquatic species by watershed.

Basins). Other basins have relatively low numbers of both, notably those watersheds in the Arkansas River and Gasconade River Basins.

Implications and Opportunities

Increased and coordinated efforts to inventory and monitor aquatic species are needed within the Assessment area. The current information for the true status (population sizes, trends, and threats) of many species is so fragmentary that some species that are now considered imperiled may be undeserving of consideration whereas other species may be in jeopardy of extinction but go unrecognized (Williams and Neves 1992). It is apparent from recent work documenting the distribution and status of aquatic species (e.g., Pflieger 1996) that comprehensive inventory efforts in some States are given higher priority and greater support than in others. The ability of natural resource managers to recognize species threatened with extinction or experiencing population declines depends primarily on the timeliness and comprehensiveness of inventory information available to them. The data base assembled by the team for the report provides a basis for increased interstate and Federal-State coordination of efforts to provide up-to-date status information on aquatic species in the Ozark-Ouachita Highlands.

Commercially and Recreationally Important Species

Question 2.9: What is the status of commercial and recreational aquatic species within the Assessment area?

In 1996, 35.2 million people 16 years of age and older engaged in recreational fishing in the United States (USDI FWS 1997c). Within the Assessment area, fishing is one of the more popular outdoor activities (see "Recreation," Chapter 5 of the *Ozark-Ouachita Highlands Assessment: Social and Economic Conditions* (USDA FS 1999a)). The Assessment area is home to world-class fishing; popular fishing resorts; thriving fishing guide services; major fishing boat and fishing tackle manufacturers, wholesalers, and retailers; and major professional fishing tournaments and champions. These aspects of recreational fishing are highly visible and generate considerable cash flow for the economies of the Assessment area.

Further evidence of the public's interest in recreational fishing occurred when Missouri and Arkansas voters approved special sales taxes that include funding for improved management of recreational fisheries. This increased funding, in part, finances land acquisition, new or improved fishing access, and additional staff to improve management of aquatic species. These new taxes were not aimed solely at improving recreational fishing; hunting, State park facilities, and other similar outdoor activities and resources also were funded. Few other States have had similar boosts in funding to bolster budgets of fish and wildlife agencies.

The high level of recreational fishing, of course, would not have developed had the fishery resources not been available. While the early inhabitants of the Highlands found plentiful stream and river fishery resources, these environments have been significantly altered by construction of dams, locks, levees, reservoirs, lakes, and ponds (see Chapter 1 of this report) and by increasing demands on and harvest of fish.

Fishery managers respond to the challenge of altered habitats by trying to manage for sustainable yield (through natural fish reproduction) where possible. When necessary, managers supplement and replenish stocks with fish from hatcheries. The subsequent yields are determined by sport and commercial angling pressure tempered by (1) the capability of the habitat to sustain aquatic species, (2) the effectiveness of fishing regulations to prohibit excessive and/or illegal take, and (3) the ability of the fish and wildlife agency to direct resources to improve habitat or increase fish stocking. Managers meet changes in angling pressure and/or harvest with changes that often include revised angling regulations. Supplemented yield implies at least some part of the harvest cannot be naturally sustained and must be artificially boosted by supplemental stocking of fishes. Yield is also tempered by the aquatic resources available, hatchery capability, and funding support for hatchery operations. Natural, sustainable yield is the relative equilibrium that exists in many bass, bluegill, and crappie fisheries where no stocking occurs. Examples of supplemented yield are stocked trout fisheries where anglers' license fees finance the hatchery stockings that allow harvest levels to remain at desired levels.

It is not possible in this report to define past, present, and projected levels of game fish and commercial fish species in other than general terms because the data are not specific enough for the Assessment area. The data are either State totals that include data outside the Assessment area or are solely from selected commercial fisheries within the Assessment area.

In this section, the Aquatic Team discusses available harvest information for commercial species of fishes and mussels as well as trend analysis when the team had more than 1 year of data. The team identifies differences in legal definitions of game fish, commercial fish, and mussel species among Assessment area States. They also present information on the stocking of non-native fish populations and the supplemental stocking of selected native game fish species by State and river drainages within the Assessment area.

Key Findings

1. Commercial fish harvesting within the Assessment area is limited to Arkansas waters. The only legal commercial fishing in Oklahoma occurs within the Eufaula Reservoir just west of the Assessment area, where one individual has a commercial license.
2. Commercial fish harvests and the number of commercial fishers are somewhat stable.
3. Mussel harvesting regulations in Arkansas govern whether an area is open, closed, or set aside as a refugium (protected area) within an open area.
4. Oklahoma had only one licensed shell (mussel) buyer in 1997. The majority of the buying is of shells from backwater areas of lakes in northeast Oklahoma; the few species in this area with thick, large shells and little surface erosion are in demand commercially.
5. Demand for shells is driven by the market for pearl blanks (a round piece of shell inserted in commercial pearl oysters to stimulate pearl formation). Actual harvest levels are lower than harvest limits because of the pearl industry's requirements for a specific color and size.
6. Legally designated species of game and commercial fish vary by State, although sought-after species differ little among States. Designating a species as a game fish generally regulates its harvest more closely than harvests of other recreational species.
7. Significant efforts have been made—mostly introductions of non-native fish species—to manage open-water habitats of large reservoirs within the Assessment area and to utilize adequately cool and cold water habitats within and downstream from these reservoirs.
8. State and Federal fisheries-management agencies protect native stocks of smallmouth bass, walleye, and sauger by foregoing some stocking opportunities that might contaminate these native stocks genetically. Where supplemental stocking is needed in habitats containing protected native species, hatcheries are using spawners of the same genetic stock as the protected native species found in the receiving water bodies.

Data Sources and Methods of Analysis

Arkansas, Missouri, and Oklahoma agencies that license such activities furnished the most recent commercial fishing and mussel harvesting information. Because of both personnel constraints and fairly consistent trends in harvests (Armstrong 1997), Arkansas stopped collecting data on commercial fishing in 1992 except for a few selected lakes. The Arkansas Game and Fish Commission provided data about mussel harvests from 1992 through 1996 and commercial fish harvests in the Nimrod and Blue Mountain Reservoirs from 1995 through 1997.

The Oklahoma Department of Wildlife Conservation provided data about commercial fishing harvests for 1995 and mussel harvests for 1986 through 1995. Similarly, the Missouri Department of Conservation provided data for commercial fish harvests from 1945 to 1994 and for shell harvests from 1992 through 1996.

The Aquatic Team derived lists of species of legal game and commercial fish from the Wildlife Codes (hunting and fishing regulations) of each State. The team found that, in many cases, fish family groups were listed as game and/or commercial species when, in fact, a particular species in a group does not grow large enough to have angling or commercial value. Therefore, the team attempted to identify only the species within the fish family that might have commercial or angling value. Thus, channel catfish are shown as a game and commercial species whereas small "madtom" catfish are not. The Oklahoma buyer furnished the list of commercial species of mussels bought there. The team combined an in-house update of Arkansas commercial mussels species with a list found in "Arkansas Mussels" (Harris and Gordon, n.d.). Similarly, they used the list of commercial species from "Missouri Naiades" (Oesch 1984). These last two publications were written before a rise in demand for shells for the pearl trade and reflect a wider range of species than is currently most in demand (Downing 1997, Harris 1997a). The team examined State regulations for shell harvesting to determine what is and is not legal. They found commercial harvest records are somewhat ambiguous because different species are sometimes grouped together.

The team obtained stocking records, generally from 1994 into 1997, from each Assessment State. They used information about major species of game fish not native to the receiving waters and, in several cases, species that are non-reproducing hybrid game fish. Because the team knew that largemouth bass, bluegill and other panfish, and channel catfish are stocked extensively across the Assessment area, they felt it likely that most Assessment area waters contain these fish (with the exception of some of the trout waters). Therefore, the Aquatic Team did not attempt to examine bass, panfish, and catfish stocking records.

Patterns and Trends

Mussel harvest. The Arkansas Game and Fish Commission, Missouri Department of Conservation, and Oklahoma Department of Wildlife Conservation regulate freshwater shell harvesting in their respective States. Shell buyers are not only required to have a license but must also report purchases annually or quarterly.

Waters open for commercial shell harvesting in Missouri are restricted to the Missouri River (which represents the northern border of the aquatic study area) and the Mississippi and lower St. Francis Rivers (which are just outside the eastern border) (MO DC 1997).

All waters from Pulaski County, AR, northeast to Randolph County, AR—the most eastern Arkansas counties in the Assessment area—are open for mussel harvesting year round. The remainder of the State in the Assessment area is closed to commercial mussel harvesting except for (1) the Arkansas River from the Oklahoma State line to Pulaski County; (2) the lower Petit Jean River; (3) the lower Fourche La Fave River; (4) sections of Cadron, North Cadron, and Point Remove Creeks; and (5) the White and Strawberry Rivers. Portions of the lower White, Black, Spring, and St. Francis Rivers have areas designated as refugia (protected areas) (AR GFC 1995a).

All Oklahoma waters are open for commercial mussel harvesting with the exception of Tenkiller Lake, the Kiamichi and Illinois Rivers, and mussel sanctuaries that include the first 2 mi of rivers entering the State and the first 2 mi below impoundments (OK DWC 1996b). However, according to the licensed shell buyer (Downing 1997), the demand is only for the thicker shells of a few species with little shell-surface erosion. These preferences restrict harvesting to a few backwater areas of reservoirs within or west of the Assessment area.

Although these three States restrict species and minimum size allowed for harvest, the regulations allow more species to be harvested than are currently of commercial interest. Table 2.23 lists species currently harvested or deemed to have had commercial value since the 1980's. The 1996 harvest of mussels in Missouri apparently was concentrated in Pools 11, 17, 18, and 19 of the Mississippi River and consisted of washboard, threeridge, and mapleleaf mussels (Buchanan 1997). In Arkansas, the 1996 harvest consisted of 42 percent washboard, 34 percent threeridge, 8 percent ebonyshell, 5 percent mapleleaf, 3 percent mucket, and 8 percent a mix of species (Burnley 1996, 1997). The Oklahoma harvest was predominantly mapleleaf and threeridge mussels (Wallace 1996).

The Aquatic Team collected data on the mussels bought in Missouri from 1989 through 1996. The least productive year was 1992 when harvesters collected only 8,808 pounds of mussels worth $10,814. The peak year was 1995, when 642,757 pounds were collected worth an estimated $941,189. In 1989, harvesters collected 399,086 pounds for $199,086, and 1996 yielded a harvest of 109,688 pounds worth $155,798. Though these data are not from the Assessment area, they are relevant due to the proximity of the harvested area to the Assessment area (Koch 1993, Buchanan 1997).

The Arkansas harvest of mussels ranged from 452,892 pounds valued at $256,759 in 1992 to 1,250,958 pounds in 1996 with an estimated value of $1,388,661 (Todd 1993, 1994, 1995; Burnley 1996, 1997). As with Missouri, the peak Arkansas harvest was in 1995, with 2,191,198 pounds valued at $2,589,782. For 1996, the St. Francis River supported 30 percent of the total reported harvest, the White River 21 percent, the Black River 10 percent, the Arkansas River about 9 percent, and the Ouachita River less than 0.1 percent. In 1996, the Fourche La Fave River produced about 11 percent of that year's harvest (the only year of the 5 years of record showing a harvest from this river). These reports are not sufficiently detailed to be able to determine what percent of Arkansas' harvest of mussels was from the Assessment area (Todd 1993, 1994, 1995; Burnley 1996, 1997).

Oklahoma's harvest ranged from 459,669 pounds purchased for $242,464 in 1986 to a peak of 992,947 pounds purchased for $1,327,597 in 1990; 338,277

Table 2.23—Commercial mussel species in the aquatic study area, by State

Species	Common name	Arkansas	Missouri	Oklahoma
Actinonaias ligamentina	Mucket	X	X	
Amblema plicata	Threeridge	X		X
Cyclonaisa tuberculate	Purple wartyback	X		
Cyprogenia aberti	Western fanshell	X		
Ellipsaria lineolata	Butterfly	X	X	
Elliptio dilatata	Spike	X	X	
Fusconaia ebena	Ebonyshell	X	X	X
Fusconaia flava	Wabash pigtoe	X	X	
Lampsilis cardium	Plain pocketbook		X	
Lampsilis siliquoidea	Fatmucket		X	
Lampsilis teres	Yellow sandshell	X	X	
Ligumia recta	Black sandshell	X		
Megalonaias nervosa	Washboard	X	X	X
Obliquaria reflexa	Threehorn wartyback	X	X	X
Obovaria olivaria	Hickorynut	X		
Plectomerus dombeyanus	Bankclimber	X	X	
Pleurobema coccineum	Round pigtoe	X	X	
Potamilus purpuratus	Bleufer	X	X	
Ptychobranchus occidentalis	Ouachita kidneyshell	X		
Quadrula metanevra	Monkeyface	X	X	X
Quadrula nodulata	Wartyback	X	X	
Quadrula pustulosa	Pimpleback	X	X	X
Quadrula quadrula	Mapleleaf	X	X	X
Tritogonia verrucosa	Pistolgrip	X	X	
Total		22	18	7

Source: Harris (1997a), Oesch (1984), Downing (1997).

pounds were purchased for $609,850 in 1995. From 1986 to 1995, the lowest harvest was in 1992 when 161,834 pounds were purchased for $162,625 (Wallace 1996). The Oklahoma report did not specify locations of harvests.

For 1995, the peak harvest year, the total for the three States was 3,172,232 pounds of shells harvested and purchased from the pickers for an estimated value of $4,140,821. (Note that this dollar value does not reflect what the buyers ultimately received for the shells.) Arkansas accounted for 69 percent of this harvest; Missouri, 20 percent; and Oklahoma, 11 percent. The Aquatic Team estimated that from 5 to 15 percent of this harvest was from within the Assessment area in Arkansas and Oklahoma.

Mussel harvesting appears to be driven by the market for shells used in the cultured pearl industry. Also playing a role are depletion of mussel beds and regulation of harvests through minimum size limits, area closures, and season limits (Koch 1993). In 1996, Arkansas raised license fees but found that when prices are high and shells are abundant, higher license fees are no deterrent to shell pickers and buyers (Burnley 1996, 1997).

Experts anticipate that shell harvest will decline because the market for pearl blanks has decreased due to decimation of eastern pearl oysters from disease. As soon as the problems with eastern pearl culture are solved, market demand for shells is likely to increase again.

Commercial fish harvest. Species legally available for harvest in Arkansas, Missouri, and Oklahoma are presented in table 2.24 minus those that (1) do not reach minimum size requirements, (2) are quite rare, or (3) are present in areas either not open to commercial harvest or that are open but unlikely to be commercially fished.

Oklahoma considered all non-game fish species available for commercial harvest; however, only three fish families—sucker, gar, and minnow—are harvested. These three families contain up to nine potentially harvestable species. The three States present the commercial harvest information by fish family only, so

Table 2.24—Game and commercial fish species of the Assessment area, by State

Species	Common name	Arkansas		Missouri		Oklahoma	
		Game	Commercial	Game	Commercial	Game	Commercial
Acipenser fulvescens	Lake sturgeon		X				
Ambloplites ariommus	Shadow bass	X		X			
Ambloplites constellatus	Ozark bass	X		X			
Ambloplites rupestris	Rock bass	X		X			
Ameiurus catus	White catfish	X	X	X			
Ameiurus melas	Black bullhead	X			X		
Ameiurus natalis	Yellow bullhead	X			X		
Ameiurus nebulosus	Brown bullhead	X			X		
Amia calva	Bowfin		X		X		
Aplodinotus grunniens	Freshwater drum		X		X		
Atractosteus spatula	Alligator gar	X	X		X		X
Carpiodes carpio	River carpsucker		X		X		
Carpiodes cyprinus	Quillback		X		X		
Carpiodes velifer	Highfin carpsucker		X		X		
Catostomus commersoni	White sucker	X	X		X		
Centrarchus macropterus	Flier	X					
Ctenopharyngodon idella	Grass carp		X		X		
Cycleptus elongatus	Blue sucker	X	X		X		
Cyprinus carpio	Common carp		X		X		X
Esox lucius	Northern pike	X		X		X	
Esox masquinongy	Muskellunge	X		X			
Esox masquinongy x lucius	Tiger muskellunge	X		X			
Esox niger	Chain pickerel	X		X			
Hypentelium nigricans	Northern hogsucker	X					
Hypophthalmichthys molitrix	Silver carp		X		X		X
Hypophthalmichthys nobilis	Bighead carp		X		X		X
Ictalurus furcatus	Blue catfish	X	X	X	X	X	
Ictalurus punctatus	Channel catfish	X	X	X	X	X	
Ictiobus bubalus	Smallmouth buffalo		X		X		X
Ictiobus cyprinellus	Bigmouth buffalo		X		X		X
Ictiobus niger	Black buffalo		X		X		X
Lepisosteus osseus	Longnose gar		X		X		X
Lepisosteus platostomus	Shortnose gar		X		X		X
Lepomis cyanellus	Green sunfish	X					
Lepomis gibbosus	Pumpkinseed	X					
Lepomis gulosus	Warmouth	X		X			
Lepomis macrochirus	Bluegill	X					
Lepomis megalotis	Longear sunfish	X					
Lepomis microlophus	Redear sunfish	X					
Lepomis miniatus	Redspotted sunfish	X					
Micropterus dolomieu	Smallmouth bass	X		X		X	
Micropterus punctulatus	Spotted bass	X		X		X	
Micropterus salmoides	Largemouth bass	X		X		X	
Minytrema melanops	Spotted sucker	X	X		X		
Morone chrysops	White bass	X		X		X	
Morone mississippiensis	Yellow bass	X		X			
Morone saxatilis	Striped bass	X		X		X	
Monore saxatilis x chrysops	Hybrid striped bass	X		X			
Moxostoma anisurum	Silver redhorse	X	X		X		
Moxostoma carinatum	River redhorse	X	X		X		
Moxostoma duquesnei	Black redhorse	X	X		X		
Moxostoma erythrurum	Golden redhorse	X	X		X		
Moxostoma macrolepidotum	Shorthead redhorse	X	X		X		
Moxostoma poecilurum	Blacktail redhorse	X					
Oncorhynchus clarki	Cutthroat trout	X					

(continued)

Table 2.24—Game and commercial fish species of the Assessment area, by State (continued)

Species	Common name	Arkansas		Missouri		Oklahoma	
		Game	Commercial	Game	Commercial	Game	Commercial
Oncorhynchus mykiss	Rainbow trout	X		X		X	
Polyodon spathula	Paddlefish	X	X	X	X		
Pomoxis annularis	White crappie	X		X		X	
Pomoxis nigromaculatus	Black crappie	X		X		X	
Pylodictis olivaris	Flathead catfish	X	X	X			
Salmo trutta	Brown trout	X		X		X	
Salvelinus fontinalis	Brook trout	X		X		X	
Salvelinus namaycush	Lake trout	X					
Scaphirhynchus platorynchus	Shovelnose sturgeon		X		X		
Stizostedion canadense	Sauger	X		X		X	
Stizostedion canadense x vitreum	Saugeye	X					
Stizostedion vitreum	Walleye	X		X		X	
Total		51	30	27	30	15	9

Source: see "Data Sources and Methods of Analysis" of this section.

further breakdown by species is not possible from their reports.

Arkansas waters open to commercial fishing (AR GFC 1996) within the Assessment area consisted of (1) the lower Fourche La Fave River, (2) the entire Arkansas River, (3) the lower Petit Jean River, (4) portions of the lower White River, and (5) the Black River. No commercial fish harvest is occurring in Arkansas lakes and reservoirs within the Ozarks (Oliver 1997). Commercial fish harvest is occurring in the Arkansas River, Nimrod Lake on the Fourche La Fave River, and Blue Mountain Lake on the Petit Jean River. With the exception of the two lakes, no efforts have been made since 1992 to compile data about commercial harvests for Arkansas (Armstrong 1997). From July 1, 1987, through June 30, 1988—the last year of record for the entire State of Arkansas—22,955,319 pounds of fish were commercially harvested worth an estimated $8,598,055 (Farwick 1997). Of that figure, 5,023,626 pounds were harvested from the whole Arkansas River system, worth an estimated $2,166,122. Fishers harvested over 2 million pounds each of buffalo and catfish from the Arkansas River.

For the 1996 through 1997 and 1995 through 1996 commercial fishing seasons, four commercial fishers harvested at Nimrod Lake and three at Blue Mountain Lake, according to Arkansas Game and Fish Commission reports (Limbird and Ahlert 1993, 1996, 1997). During the 1994 through 1995 season, there was one commercial fisher at Nimrod Lake and four at Blue Mountain Lake. For the above three seasons, commercial harvests at Blue Mountain Lake were 9,362, 14,173, and 40,432 pounds of fish, respectively. Buffalo and carp made up 46 and 32 percent, 44 and 45 percent, and 45 and 43 percent, respectively, of the harvest for the three seasons at Blue Mountain Lake. The harvests at Nimrod Lake were 42,480, 57,764, and 17,638 pounds for the years 1996 to 1997, 1995 to 1996, and 1994 to 1995, respectively. For these times, the percent catch by weight of buffalo and carp was 90 and 2 percent, 92 and 1 percent, and 93 and 2 percent, respectively, for the three seasons at Nimrod Lake. Flathead catfish made up 11 percent of the harvest by weight at Blue Mountain Lake during 1996 to 1997, 5 percent of the harvest by weight the preceding year, and 2 percent in 1994 to 1995. Numbers harvested for the same periods were 127, 108, and 88 flatheads. For Nimrod Lake, the flathead catfish harvest by weight (percentages) and numbers harvested were 2 percent and 115 flatheads during 1996 to 1997, 0.8 percent and 51 flatheads during 1995 to 1996, and 2.5 percent and 33 flatheads in 1994 to 1995. Gar harvests for the 3 seasons ranged from 33 to 637 gar from Blue Mountain. From 0 to 230 gar were caught over the 3 seasons at Nimrod. Combined netted species of game fish amounted to 1.5 percent or less of the harvest (by weight per year per lake) and represented an insignificant loss. The game fish losses are minimized by fishing gear being restricted to gill and trammel nets of 3½-inch bar mesh and larger. Statewide commercial fishing efforts appear to be consistent as measured by sales of commercial fishing licenses. It is also believed that anglers are using commercial harvests for personal use, with a decline in what is sold (Armstrong 1997). In addition, some drops or shifts in license sales and fishing efforts have occurred, likely the result of Arkansas fish consumption advisories and commercial harvest closures in response to elevated mercury levels in fish in some locales. These drops occurred on a localized basis in the lower Ouachita River Basin, south of the Assessment area.

The report "Missouri Commercial Fish Harvest, 1993" (Robinson 1995) had the most recent information on Missouri fish harvests available at the time of this Assessment; 1994 and 1995 tables were compiled later (Robinson 1998). Waters open to commercial fishing in Missouri all lie to the north and east of the Assessment area. As is true for mussel harvests, only the Missouri, Mississippi, and lower St. Francis Rivers are open to commercial fishing (MO DC 1997). From 1993 through 1995, the number of licensed commercial fishers with gear was 340, 319, and 395, respectively. A commercial fishing license is also required of mussel harvesters, but their nets and other fishing gear are not regulated. Most commercial fishers (94 percent) have reported harvesting fewer than 5,000 pounds of fish annually since the 1988 license period. This level of harvesting strongly suggests that few anglers make much money from commercial fishing (Robinson 1995).

Removal of all catfish species from the commercial fish list on the Missouri River (which became effective July 1, 1992) is also considered to have caused a drop in the number of commercial fishers (Robinson 1995). The reported 1993 Missouri commercial fish harvest was 566,000 pounds with common carp and all buffalo contributing 47 percent of the total harvest by weight. The 1994 harvest was 668,000 pounds, with 49.5 percent buffalo and common carp by weight. The 1995 harvest was 541,000 pounds, with 57 percent buffalo and common carp by weight. The grass carp harvest has grown from 8,787 pounds in 1993 to 15,330 pounds in 1994 and 21,366 pounds in 1995. The grass carp harvest was only 4 pounds in the St. Francis River in 1993, with none reported harvested in the St. Francis the last 2 years of record (1994 and 1995). In 1994, approximately 53 percent of the grass carp harvest was from the Missouri River, and 63 percent was harvested from the Mississippi River in 1995. Since 1945, an average of 23 commercial anglers per year have fished the St. Francis River fairly constantly. Both the Mississippi and Missouri Rivers have seen drops in numbers of commercial fishers since the early 1980's, when peaks of nearly 700 anglers on the Mississippi and over 1,000 anglers on the Missouri occurred. The 1995 totals for the 2 rivers indicate the presence of an estimated 194 and 124 commercial fishers, respectively. The Mississippi River's estimated number of commercial fishers has remained fairly level since 1988, but the precipitous drop in commercial fishers on the Missouri River bottomed out in 1994 at 110. Commercial fishing is anticipated to remain fairly constant on these waters unless (1) license fees increase significantly, (2) consumption advisories are imposed, (3) further restrictions on the harvest of catfish are imposed, or (4) the market for fresh fish changes dramatically. As previously noted, few commercial fishers make their living solely from commercial fishing.

In 1995, Oklahoma issued one commercial fishing license that restricted the fisherman to one area in Lake Eufaula (Wallace 1996). This lake is just to the west of the Assessment area. From 1994 to 1995, the number of commercial fishers dropped from two to one for the same area. Commercial fish harvests in Lake Eufaula decreased from 11,725 pounds in 1994 to 10,991 pounds in 1995. The commercial fish harvest from Lake Eufaula during 1995 comprised 9,166 pounds of buffalo, 870 pounds of common carp, and 955 pounds of gar.

Turtles can be harvested with a fishing license in Missouri, Arkansas, and Oklahoma. Oklahoma opened commercial turtle harvesting in 1994 and requires either a buyer's or a harvester's license (OK DWC 1996a). Arkansas and Missouri commercial fishing licenses allow the turtles to be harvested for commercial sales. Alligator snapping turtles are not allowed to be taken or harvested in Arkansas or Missouri; this prohibition shut down a growing industry in Arkansas (Armstrong 1997). Missouri commercial fishing records (Robinson 1995, 1998) do not include turtle harvests, so turtle harvesting is either not occurring or is not being reported in Missouri. Arkansas commercial turtle harvest records have not been compiled. For 1995, Oklahoma (Wallace 1996) reported the harvest of 18,946 turtles of 11 species. Red-eared turtles comprised nearly 45.5 percent of the turtles purchased; common snapping turtles, smooth soft-shell turtles, and spiny soft-shell turtles were the next most common species harvested. In 1995, buyers paid turtle harvesters over $28,000. Origins of these harvested turtles were not given in the Oklahoma report.

Recreational fisheries. Designated species of game fish are listed in table 2.24. These listed species reflect named species of game fish or members of families of game fish sought by anglers. While Arkansas includes the members of the sunfish family as game fish, Oklahoma does not; Missouri lists only rock bass and warmouth as game fish within this fish family grouping (AR GFC 1996, MO DC 1997, and OK DWC 1996a). The paddlefish, the recreational harvest of which is regulated by the three States, is not listed as a game species by Oklahoma. Of the three States, Arkansas is the only one that includes bullhead catfish as a game species (because of its inclusion in the catfish family); however, no State limit is set for their harvest. Arkansas imposes a 50-fish limit on sunfish. Missouri also has a 50-fish limit on sunfish by virtue of having a 50-fish limit for all non-game fish species. Missouri has a 15-fish limit on rock bass and warmouth. Oklahoma does not impose a limit on the number of sunfish that can be harvested. While Oklahoma does not list hybrid striped bass as a game fish, it does regulate harvest with creel limits (the number of fish that can be harvested). The full suite of game fish listed for the three States reflects what recreational fishers seek. In addition, many—if not most—of the commercial species are also caught and harvested. While the three States may have different lists of game fish, in practice, similar species are being managed through the imposition of statewide creel limits.

Arkansas is stocking eight additional species of game fish in waters within the Arkansas portion of the Assessment area besides the standard bass, bluegill, and other sunfish and channel catfish stockings (table 2.25) (Armstrong 1997). The stockings are conducted to: (1) develop self-sustaining fisheries; (2) provide unique sport-fishing opportunities; and (3) encourage non-reproducing species to take advantage of unique habitats (e.g., reservoirs and their tail water fisheries) and/or underutilized forage fish. Trout are stocked in many of the large reservoirs (at least seasonally, when and where water temperature and oxygen levels will support the trout). They are also stocked in the cool to cold tailwaters downstream from the reservoirs with deep releases of cold water. Striped bass and hybrid striped bass (a hybrid of striped bass and white bass) are stocked in many of the large reservoirs to prey upon shad in the open water environment, particularly the larger-sized shad. Hybrid striped bass and saugeye (a hybrid of walleye and sauger) are stocked in some smaller waters to reduce the numbers of forage species, including underutilized sunfish. Walleye are stocked in several reservoirs in Arkansas to supplement natural reproduction of established walleye populations.

Table 2.25—Additional game fish species[a] stocked in study area water bodies, by State and river basin

	State			River basin									
Species	AR	MO	OK	Arkansas	Upper Black	Gasconade	Kiamichi-Little	Meramec	Neosho-Illinois	Osage	Ouachita-Saline	Upper St. Francis	Upper White
Striped bass	X	X		X			X			X	X		X
Hybrid striped bass	X	X	X	X			X		X	X	X		X
Saugeye	X		X	X	X		X						
Walleye	X	X	X	X	X		X		X	X	X	X	X
Muskellunge		X								X			
Rainbow trout	X	X	X	X	X	X	X	X	X	X	X		X
Cutthroat trout	X				X								X
Brook trout	X				X								X
Brown trout	X	X	X		X	X	X	X	X	X			X
Flathead catfish		X							X	X			

[a] Game fish species in addition to largemouth bass, sunfish, and catfish, which are stocked in each of the three States and all of the river basins.

Source: see "Data Sources and Methods of Analysis" of this section.

Missouri implements an ongoing stocking program very similar to that of Arkansas with the addition of trout stocking in cold water springs such as the immensely popular Bennett Springs State Park and several other put-and-take trout stream fisheries (Wulff 1997). Missouri also has a number of self-sustaining rainbow trout fisheries in cold water streams and springs within the Assessment area (MO DC, n.d.). Oklahoma is stocking five additional game fish species in similar reservoir and tailwaters situations (Smith 1997, Harper 1997).

The Assessment States are taking care not to tamper with the genetic stock of the region's fishes. All three States are avoiding stocking sauger and saugeye in several drainages that could genetically contaminate native populations of sauger. To protect native walleye populations, Missouri is raising six different strains to ensure the genetic integrity of different native river runs of walleye (Wulff 1997). Genetic research on smallmouth bass from eastern Oklahoma and throughout its range has identified Neosho and Ouachita forms of smallmouth bass as being distinct from Upper Mississippi River and Ohio River drainage forms (Stark and others 1995). The Neosho form of smallmouth bass is found in the Arkansas River tributaries draining the southern and western Ozark Highlands; the Ouachita form is found within the Ouachita Mountains in southeastern Oklahoma and southwestern Arkansas (which includes the Little and Ouachita Rivers and their tributaries). With such recent findings, all three States are exercising care in managing smallmouth bass stocks to ensure the genetic integrity of this species.

Implications and Opportunities

The era of major introductions of new species into the Assessment area is probably over because it is fairly likely there will not be any new reservoirs or major changes made in management of existing reservoirs and their water releases. It is possible that some species manipulation could still occur. For instance, if Arkansas experiences a great deal of success with brook trout and/or cutthroat trout, the Missouri Department of Conservation and/or the Oklahoma Department of Wildlife Conservation may add one of both of these species to their trout stocking programs. Lake trout stocked in Greers Ferry Lake from 1986 through 1989 apparently spawned at least once—a few offspring of the stocked trout have shown up in recent harvests (Perrin 1997). Whether this one-time reproduction from the original stockings will also fade out as did the original stocked fish or whether reproduction of the lake trout will continue to grow, resulting in a major new fishery, is presently unknown.

It is anticipated that fisheries management throughout the Assessment area will increasingly focus on maintaining or restoring significant warm-water and cool-water stream fisheries and improving game-fish populations and angling in progressively smaller water bodies as time goes on. Emphasis on managing trout and reservoir game fish is not likely to diminish. While public management efforts for trout and reservoir fisheries are quite visible, considerable technical assistance is still available to the landowner for management of private waters. Bass, bluegill, crappie, and catfish are still the "species of choice" of recreationists in the Assessment area.

Commercial mussel harvesting is driven by the overseas demand for shell blanks for the cultured pearl industry. Mussel harvesting needs to be monitored to ensure sustainability of the harvested species as well as other species that may be indirectly affected by harvest activities. Uniformity of harvest regulations (including minimum shell sizes, season dates, and time of day open for harvest) and uniformity of reporting would support management of harvests within the Assessment area and beyond. Knowledge of the source of shells—both in-State and out-of-State—seems necessary to efficiently monitor and protect the resource.

Commercial fish harvesting within the Assessment area is restricted to Arkansas waters at this time. Lack of analysis of required commercial fishers reports and lack of close monitoring of the fishing (at other than Blue Mountain and Nimrod Lakes) is seen as a handicap for efficient fisheries management. State fish and game agencies in the Highlands may wish to remind the general public periodically that commercial fishing is harvesting a renewable resource, and as such, can be incorporated into a management scheme to improve recreational fishing. Commercial fishing is a lifestyle of some and in most cases is compatible with management objectives of the State agencies and the public they serve. Commercial turtle harvesting may need closer scrutiny to determine the sustainability of the Assessment area's resources in this regard.

Management of recreational fish species is an evolving science. Great strides in improving habitat and populations have been made and will continue to be made. Working with landowners on the myriad of small lakes and ponds throughout the Assessment area provides continued opportunities to meet demand for quality recreational fishing. Conserving the native genetic stocks of game fish is imperative. Further analysis of the genetics of smallmouth bass, walleye, rock bass, warmouth, and other sought-after species is possibly warranted to ensure the integrity of existing populations. Continuing research on expectations of recreational anglers is important in focusing management to improve the anglers' experiences on these waters. Citizen involvement in conservation and restoration programs such as Missouri and Arkansas Stream Teams will continue to mobilize resources to restore and protect the fishing quality of Assessment area waters. Professional biologists and conservation agencies need to work diligently with users of aquatic resources and serve as support for grass-roots efforts like the Stream Teams to restore, protect, and enhance the plentiful aquatic resources of the Assessment area.

Management Indicator Species

Question 2.10: What management indicator species are located within the Assessment area, and what is their potential role for the aquatic resources?

The National Forest Management Act calls for the selection and use of "management indicator species" (MIS) as a means to evaluate and monitor species and their habitats during project or forest planning and through project or forest plan implementation and follow-up. Implementing regulations in the Code of Federal Regulations (CFR) state:

> In order to estimate the effects of each planning or project alternative on fish and wildlife populations, certain vertebrate and/or invertebrate species present in the area shall be identified and selected as management indicator species and the reasons for their selection will be stated. These species shall be selected because their population changes are believed to indicate the effects of management activities. In the selection of management indicator species, the following categories shall be represented where appropriate: endangered and threatened plant and animal species identified on State and Federal lists for the planning area; species with special habitat needs that may be influenced significantly by planned management programs; species commonly hunted, fished, or trapped; non-game species of special interest; and additional plant or animal species selected because their population changes are believed to indicate the effects of management activities on other species of selected major biological communities or on water quality (36 CFR, 1995).

This selection process is identified in 36 CFR Chapter II (7-1-95 edition) and will be followed in the revision of national forest plans unless superseded by new or additional direction. The base lists of aquatic species from which to choose MIS are contained in this section and the "Endangered, Threatened, and Other Aquatic Species of Special Concern" section of this chapter. Planners are not restricted solely to these lists of MIS candidates, but these lists represent a starting point for further analysis and consultations.

Key Findings

1. Lists of fish, mussels, crayfish, and aquatic insects gathered during this Assessment include data about their special status as reported and ranked by Federal and State agencies, The Nature Conservancy, and the American Fisheries Society; such rankings can form the basis for the selection of management indicator species for forest plan revision.
2. The American Fisheries Society identified 19 fish, 76 mussel, and 59 crayfish species that occur in the Highlands as endangered, threatened, of special concern, or currently stable.

Data Sources and Methods of Analysis

Source tables for different MIS candidates were developed, as discussed in the respective subsections concerning fish, crayfish and mussels. Three articles in *Fisheries*, a journal of the American Fisheries Society, provided the rankings for this section (Williams and others 1989b, 1993; Taylor and others 1996).

Patterns and Trends

Patterns and trends for MIS species are covered in preceding sections of this report. The American Fisheries Society rankings are given in tables 2.26 through 2.28. The ranking categories are as follows: (1) endangered—a species or subspecies in danger of extinction throughout all or a significant portion of its range; (2) threatened—a species or subspecies likely to become endangered throughout all or a significant portion of its range; (3) special concern—a species or subspecies that may become endangered or threatened by relatively minor disturbances to its habitat and deserves careful monitoring of its abundance and distribution; (4) currently stable—a species or subspecies the distribution of which is widespread and stable and is not in need of immediate conservation management actions (Williams and others 1993). The fish species list (table 2.26) predates the mussel and crayfish lists and was not developed with the "currently stable" category. American Fisheries Society rankings do not convey official status under the Endangered Species Act (ESA) even though they contain categories of threatened and endangered species; Federal rankings under the ESA supersede State and AFS rankings. Federal rankings can be found in the "Endangered, Threatened, and Other Aquatic Species of Special Concern" section in this chapter and in table 2.21.

Implications and Opportunities

Lists of species for the aquatic environments of the Assessment area are presented in preceding sections of this chapter. These lists can serve to begin the refinement process in selecting MIS for the aquatic environments in the Highlands. While identification and use of MIS is mandated by regulations governing national forest planning, any agency can find MIS useful at any decision or project level.

Table 2.26—Fish species in the aquatic study area ranked as endangered, threatened, or of special concern by the American Fisheries Society[a]

Species	Common name	Endangered	Threatened	Special concern
Acipenser fulvescens	Lake sturgeon		X	
Amblyopsis rosae	Ozark cavefish		X	
Crystallaria asprella	Crystal darter			X
Cycleptus elongatus	Blue sucker			X
Etheostoma cragini	Arkansas darter			X
Etheostoma moorei	Yellowcheek darter		X	
Etheostoma nianguae	Niangua darter		X	
Etheostoma pallididorsum	Paleback darter		X	
Lythrurus snelsoni	Ouachita Mountain shiner			X
Macrhybopsis meeki[b]	Sicklefin chub		X	
Notropis perpallidus	Peppered shiner			X
Noturus lachneri	Ouachita madtom		X	
Noturus placidus	Neosho madtom		X	
Noturus taylori	Caddo madtom		X	
Percina cymatotaenia	Bluestripe shiner			X
Percina nasuta	Longnose darter		X	
Percina pantherina	Leopard darter		X	
Percina uranidea	Stargazing darter			X
Polyodon spathula	Paddlefish			X
Total		0	11	8

[a] Rankings may differ from those assigned by the USDI Fish and Wildlife Service.
[b] Species within the aquatic study area but outside the Assessment area.
Source: Williams and others (1989b).

Table 2.27—Mussel species in the aquatic study area ranked as endangered, threatened, of special concern, or currently stable by the American Fisheries Society[a]

Species	Common name	Endangered	Threatened	Special concern	Currently stable
Actinonaias ligamentina	Mucket				X
Alasmidonta marginata	Elktoe			X	
Alasmidonta viridis	Slippershell			X	
Amblema plicata	Threeridge				X
Anodonta suborbiculata	Flat floater				X
Anodontoides ferussacianus	Cylindrical papershell				X
Arcidens confragosus	Rock-pocketbook				X
Arkansia wheeleri	Ouachita rock-pocketbook	X			
Cumberlandia monodonta	Spectaclecase		X		
Cyclonaias tuberculata	Purple wartyback			X	
Cyprogenia aberti	Western fanshell		X		
Ellipsaria lineolata	Butterfly			X	
Elliptio crassidens	Elephant-ear				X
Elliptio dilatata	Spike				X
Epioblasma curtisi	Curtis pearlymussel	X			
Epioblasma triquetra	Snuffbox		X		
Epioblasma turgidula	Turgid blossom	X			
Fusconaia ebena	Ebonyshell				X
Fusconaia flava	Wabash pigtoe				X
Fusconaia ozarkensis	Ozark pigtoe			X	
Fusconaia subrotunda	Long-solid			X	
Lampsilis abrupta	Pink mucket	X			
Lampsilis cardium	Pocketbook			X	
Lampsilis hydiana	Louisiana fatmucket				X
Lampsilis ornata	Southern pocketbook			X	
Lampsilis powelli	Arkansas fatmucket		X		
Lampsilis rafinesqueana	Neosho mucket		X		
Lampsilis reeveiana	Arkansas broken-ray		X	X	
Lampsilis satura	Sandbank pocketbook			X	
Lampsilis siliquoidea	Fatmucket				X
Lampsilis streckeri	Speckled pocketbook	X			
Lampsilis teres	Yellow sandshell				X
Lasmigona complanata	White heelsplitter				X
Lasmigona costata	Fluted-shell				X
Leptodea fragilis	Fragile heelsplitter				X
Leptodea leptodon	Scaleshell	X			
Ligumia recta	Black sandshell			X	
Ligumia subrostrata	Pondmussel				X
Megalonaias nervosa	Washboard				X
Obliquaria reflexa	Threehorn wartyback				X
Obovaria jacksoniana	Southern hickorynut			X	
Obovaria olivaria	Hickorynut				X
Plectomerus dombeyanus	Bankclimber				X
Plethobasus cyphyus	Sheepnose		X		
Pleurobema coccineum	Round pigtoe				X
Pleurobema pyramidatum	Pyramid pigtoe		X		
Potamilus alatus	Pink heelsplitter				X
Potamilus capax	Fat pocketbook	X			
Potamilus ohiensis	Pink papershell				X
Potamilus purpuratus	Bleufer				X
Ptychobranchus occidentalis	Ouachita kidneyshell		X		
Pyganodon grandis	Giant floater				X
Quadrula apiculata	Southern mapleleaf				X
Quadrula cylindrica	Rabbitsfoot		X		
Quadrula fragosa	Winged mapleleaf	X			
Quadrula metanevra	Monkeyface				X
Quadrula nodulata	Wartyback				X

(continued)

Table 2.27—Mussel species in the aquatic study area ranked as endangered, threatened, of special concern, or currently stable by the American Fisheries Society[a] (continued)

Species	Common name	Endangered	Threatened	Special concern	Currently stable
Quadrula pustulosa	Pimpleback				X
Quadrula quadrula	Mapleleaf				X
Simpsonaias ambigua	Salamander mussel			X	
Strophitus undulatus	Squawfoot				X
Toxolasma lividus	Purple lilliput			X	
Toxolasma parvus	Lilliput				X
Toxolasma texasensis	Texas lilliput				X
Tritogonia verrucosa	Pistolgrip				X
Truncilla donaciformis	Fawnsfoot				X
Truncilla truncata	Deertoe				X
Uniomerus declivus	Tapered pondhorn				X
Uniomerus tetralasmus	Pondhorn				X
Utterbackia imbecillis	Paper pondshell				X
Venustaconcha ellipsiformis	Ellipse			X	
Venustaconcha pleasi	Bleedingtooth mussel			X	
Villosa arkansasensis	Ouachita creekshell			X	
Villosa iris	Rainbow				X
Villosa lienosa	Little spectaclecase				X
Total		8	10	17	41

[a] Rankings may differ from those assigned by the USDI Fish and Wildlife Service.

Source: Williams and others (1989a).

Table 2.28—Crayfish species in the aquatic study area ranked by the American Fisheries Society as endangered, threatened, of special concern, or currently stable[a]

Species	Common name	Endangered	Threatened	Special concern	Currently stable
Cambarellus puer	Cajun dwarf				X
Cambarellus shufeldtii	Shufeldt's dwarf				X
Cambarus aculabrum		X			
Cambarus causeyi				X	
Cambarus diogenes	Devil crayfish				X
Cambarus hubbsi	Hubb's crayfish				X
Cambarus hubrichti	Salem Cave crayfish				X
Cambarus maculatus	Freckled crayfish				X
Cambarus setosus	Bristly Cave crayfish			X	
Cambarus subterraneus		X			
Cambarus tartarus		X			
Cambarus zophonastes		X			
Fallicambarus caesius					X
Fallicambarus fodiens	Digger crayfish				X
Fallicambarus harpi	Harp's crayfish	X			
Fallicambarus jeanae				X	
Fallicambarus strawni			X		
Faxonella blairi					X
Faxonella clypeata	Shield crayfish				X
Orconectes acares					X
Orconectes eupunctus	Coldwater crayfish			X	
Orconectes harrisonii	Belted crayfish			X	
Orconectes hylas	Woodland crayfish				X
Orconectes immunis	Papershell crayfish				X
Orconectes leptogonopodus					X
Orconectes longidigitus	Longpincered crayfish				X
Orconectes luteus	Golden crayfish				X
Orconectes macrus	Neosho midget crayfish				X
Orconectes marchandi	Mammoth Spring crayfish	X			
Orconectes medius	Saddlebacked crayfish				X
Orconectes meeki brevis			X		
Orconectes meeki meeki	Meek's crayfish				X
Orconectes menae			X		
Orconectes nais					X
Orconectes nana				X	
Orconectes neglectus chaenodactylus				X	
Orconectes neglectus neglectus	Ringed crayfish				X
Orconectes ozarkae	Ozark crayfish				X
Orconectes palmeri longimanus					X
Orconectes palmeri palmeri	Grey-speckled crayfish				X
Orconectes peruncus	Big Creek crayfish		X		
Orconectes punctimanus	Spothanded crayfish				X
Orconectes quadruncus	St. Francis River crayfish		X		
Orconectes saxatilis		X			
Orconectes virilis	Northern crayfish				X
Orconectes williamsi	William's crayfish			X	
Procambarus acutus	White River crayfish				X
Procambarus clarkii	Red swamp crayfish				X
Procambarus curdi					X
Procambarus gracilis	Grassland crayfish				X
Procambarus liberorum					X
Procambarus ouachitae					X
Procambarus parasimulans					X
Procambarus regalis				X	
Procambarus reimeri		X			
Procambarus simulans					X
Procambarus tenuis				X	
Procambarus tulanei					X
Procambarus viaeviridis	Vernal crayfish				X
Total		8	5	10	36

[a] Rankings may differ from those assigned by the USDI Fish and Wildlife Service; common names provided if known.

Source: Taylor and others (1996).

Aquatic Habitats

Question 2.11: What is the status of the aquatic habitats within the Assessment area?

The presence and abundance of aquatic organisms (e.g., fish and aquatic invertebrates) and features of the physical habitat (e.g., stream size) are primary tools to assess the quality of aquatic habitats (Karr and others 1986, Plafkin and others 1989, Dolloff and others 1993). To examine the status of aquatic habitats, a series of measurements and samples usually is taken at a specific site or series of sites within a stream or river. Such specific information is unavailable for large portions of the Assessment area.

Investigations of habitat quality are usually limited by both the area investigated and the length of the study and may differ in primary objectives (e.g., water pollution detection versus suitability of habitat for a fishery). Recently initiated efforts by the Geological Survey's NAWQA program are designed to provide a consistent description of the features of physical habitats as part of an evaluation of water quality. The focus of the NAWQA program within the Assessment area to date has been the Ozark Plateaus, but that study was released after writing ceased for this report and is not included here (Femmer 1997). Large-scale analyses in Arkansas have linked water quality and other physical variables to overall patterns of fish distribution (Rohm and others 1987, Matthews and Robison 1988, Matthews and others 1992). In previous sections of this chapter, the Aquatic Team evaluated the diversity of selected groups of aquatic organisms (i.e., fishes, mussels, crayfishes, stoneflies, and caddisflies) across the study area. However, no comparable information base exists that can be used to directly examine the status of aquatic habitats across the Ozark-Ouachita Highlands (see "Surface Water Quality (Streams)" and "Surface Water Quality (Lakes)" in this chapter, "Outstanding Resource Waters" in Chapter 4, and other studies referenced above).

The Aquatic Team used the number of stream types within hydrologic units to examine the large-scale patterns of diversity of aquatic habitats across the Assessment area. Each "stream type" is a unique combination of three landscape-scale attributes: (1) hydrologic unit, (2) ecological section, and (3) stream size. Each of these attributes may include habitat conditions that influence the number and kinds of aquatic organisms found across the Assessment area. For example, endemic and other native aquatic species are associated with specific drainage systems or, as termed in this report, hydrologic units. Likewise, sections within hydrologic units often have different stream water chemistry and geomorphologies (i.e., differing conditions that arise from the distinctive geological evolution of each section's landscape, riparian zones, and water bodies). Consequently, streams show differences in the makeup of their aquatic communities. Finally, different stream sizes within different ecological sections within a hydrologic unit generally support different numbers of aquatic species. When combined, these three attributes—hydrologic unit, ecological section, and stream size—provide a description of large-scale differences among running-water habitats within and among hydrologic units. For example, a first-order stream (i.e., smallest headwater) in the Ozark Highlands of the Upper White River hydrologic unit represents a distinctly different stream type than a first-order stream in the West Gulf Coastal Plain section of the Upper Ouachita River hydrologic unit. Likewise, a small stream is expected to differ in physical habitat and faunal composition from a medium-sized river within the same province and hydrologic unit.

Key Findings

1. Over half of the hydrologic units in the Assessment area have 10 or more stream types per hydrologic unit (average = 8.7 stream types per hydrologic unit; range of 5 to 15 per hydrologic unit), and no hydrologic unit has fewer than 5 stream types.
2. Primary levels of stream type diversity (11 to 15 stream types per hydrologic unit) are located mostly in the southern half of the Assessment area; secondary levels (10 stream types per hydrologic unit) are located in hydrologic units along the periphery of the Assessment area.
3. Native fish species richness is associated significantly and positively with the number of different stream types in hydrologic units.

4. Numbers of endemic fish species and stream types are not associated among hydrologic units.
5. Hydrologic units with primary and secondary levels of stream type diversity and native fish species richness may be considered of particular significance in maintaining present and future aquatic biodiversity within the Ozark-Ouachita Highlands.
6. Available analyses indicate that strong associations exist between environmental variables (e.g., water quality, geology, substrate) and the distribution of fishes over much of the Assessment area, and any pervasive alteration of existing habitat conditions likely would affect the composition and distribution of the fish fauna.

Data Sources and Methods of Analysis

The Aquatic Team calculated stream type diversity by summing the combinations of stream orders and ecological sections for each hydrologic unit within the Assessment area, following Warren and others (1997). The team recognized 50 hydrologic units (watersheds) as occurring partly or wholly within the Assessment area. As reported in the "Diversity of Fishes" subsection of this chapter, the team further subdivided 32 of these watersheds by digitally overlaying ecological sections (Keys and others 1995) onto each hydrologic unit to form two or more ecological-hydrologic units (fig. 2.17).

Twenty-five hydrologic units include lands and waters outside the Assessment area. For these units, stream type diversity includes stream types not necessarily within the Highlands. The team used the EPA's River File version 3 (RF3), to determine stream size. The Aquatic Team recognized stream sizes as ranging from first order (smallest streams) to seventh order (largest streams), where order was determined following Strahler (1964). The team then delineated three levels of stream type diversity among hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 13 units with highest values; secondary levels were assigned to the next highest 13 units; and tertiary levels, to the remaining 24 units. Hence, primary levels approximate values in the fourth quartile (top 25 percent); secondary levels (second 25 percent), values in the third quartile; and tertiary levels, values in the first and second quartiles (bottom 50 percent).

The Aquatic Team used two approaches to examine the association of stream type diversity with elements of the aquatic fauna. First, using data synthesized for this report, the team examined stream type diversity for association with richness of native fish species and richness of endemic fish species in hydrologic units. Second, the team summarized the work of Matthews and Robison (1988) and Matthews and others (1992) on large-scale physical habitat attributes and distribution of fishes.

Fish species richness is the total number of native fishes recorded as present in a hydrologic unit; richness of endemic fish species is the number of fishes that are endemic to the Assessment area and occur exclusively in a particular hydrologic unit (see "Diversity of Fishes" in this chapter). The Aquatic Team used a rank correlation procedure (known in statistics as Kendall's tau beta coefficient) to test the association between stream type diversity, richness of native fish species, and richness of endemic species among hydrologic units.

In this report, stream type diversity accounts only for flowing surface waters and the presence of a unique combination of ecological section and stream size within a hydrologic unit. Some hydrologic units certainly contain other unique habitat types such as springs, caves, wetlands, or natural lakes that are not accounted for by stream type diversity. Hydrologic units also may have impoundments (e.g., reservoirs) that have altered the habitats available to aquatic organisms. The gains or losses of habitat diversity in these inundated areas are not reflected in this report as contributing to or lessening the number of stream types within a hydrologic unit. Likewise, the measure of stream type diversity in this report does not account for the spatial extent of a particular stream type within a hydrologic unit. The Aquatic Team accounted only for the presence of certain stream types within a unit.

Patterns and Trends

Stream type diversity is not evenly distributed across the Assessment area (table 2.29). The average stream type diversity was 8.7 stream types per hydrologic unit (two standard errors = 0.86), and the range was 5 to 15 different stream types per hydrologic unit. Thirty-eight of 50 hydrologic units had at least 6 stream types; no hydrologic unit had fewer than 5 stream types. Half of

Table 2.29—Stream type diversity and numbers of native and endemic fish species in the aquatic study area watersheds

River basin Watershed name	Watershed code (HUC)	Stream type diversity[a]	Native fish species	Endemic fish species
Osage River Basin				
H.S. Truman Reservoir	10290105	10	63	2
Sac	10290106	10	62	7
Pomme de Terre	10290107	5	61	3
South Grand	10290108	10	40	0
Lake of the Ozarks	10290109	6	65	4
Niangua	10290110	5	67	7
Lower Osage	10290111	11	85	6
Gasconade River Basin				
Upper Gasconade	10290201	6	61	6
Big Piney	10290202	5	61	6
Lower Gasconade	10290203	10	86	6
Meramec River Basin				
Meramec	07140102	9	96	4
Bourbeuse	07140103	10	65	3
Big	07140104	11	66	4
Upper St. Francis River Basin				
Upper St. Francis	08020202	5	94	6
Neosho-Illinois River Basin				
Lake O' the Cherokees	11070206	10	90	3
Spring	11070207	10	88	2
Elk	11070208	6	57	4
Lower Neosho	11070209	15	98	3
Illinois	11110103	9	106	4
Arkansas River Basin				
Dirty-Greenleaf	11110102	15	100	3
Robert S. Kerr Reservoir	11110104	11	112	5
Poteau	11110105	6	95	2
Frog-Mulberry	11110201	11	95	3
Dardanelle Reservoir	11110202	11	92	3
Conway- Pt. Remove	11110203	5	77	0
Petit Jean	11110204	5	73	1
Cadron	11110205	5	67	1
Fourche La Fave	11110206	5	69	3
Lower Ark-Maumelle	11110207	12	90	0
Kiamichi-Little River Basin				
Kiamichi	11140105	10	87	2
Upper Little	11140107	8	103	4
Mountain Fork	11140108	9	101	5
Lower Little	11140109	11	118	5
Ouachita-Saline River Basin				
Ouachita Hdwaters	08040101	5	75	6
Upper Ouachita	08040102	10	113	5
Little Missouri	08040103	10	94	4
Upper Saline	08040203	10	96	2
Upper White River Basin				
Beaver Reservoir	11010001	11	82	13
James	11010002	6	63	12
Bull Shoals Lake	11010003	6	79	11
Middle White	11010004	15	112	11
Buffalo	11010005	9	54	10
North Fork White	11010006	6	74	11
Little Red	11010014	15	90	8
Upper Black River Basin				
Upper Black	11010007	10	111	5
Current	11010008	10	116	9
Lower Black	11010009	8	98	5
Spring	11010010	5	114	8
Eleven Point	11010011	5	71	7
Strawberry	11010012	5	89	4

HUC = hydrologic unit code.

[a] Stream type diversity is the sum of the stream order occurence for each ecological section present in the watershed.

Source: see "Data Sources and Methods of Analysis" of this section.

the hydrologic units had stream type diversity values of 10 or more.

Primary levels of stream type diversity (11 to 15 stream types) were located mostly in the middle of the aquatic study area (fig. 2.35). Hydrologic units straddling two ecological sections tended to show primary levels of stream type diversity. For example, most hydrologic units containing parts of both the Arkansas Valley and Boston Mountains or Ozark Highlands and Boston Mountains showed primary levels (i.e., Lower Neosho, Dirty-Greenleaf, Robert S. Kerr Reservoir, Beaver Reservoir, Frog-Mulberry, Dardanelle Reservoir, Little Red, and Middle White units). Several other units along the periphery of the Assessment area also showed primary levels of stream type diversity: the Lower Little, Lower Arkansas-Maumelle, and Upper Black units. In the north, the Lower Osage (Osage River drainage) and the Big (Meramec River drainage) units also showed primary levels.

Secondary levels of stream type diversity (10 stream types per hydrologic unit) occur particularly along the periphery of the Assessment area (fig. 2.35). This pattern was most apparent along the northwestern, western, and southern borders of the aquatic study area, where almost all units showed at least secondary levels of stream type diversity.

Tertiary levels of stream type diversity (fewer than 10 stream types per hydrologic unit) were concentrated

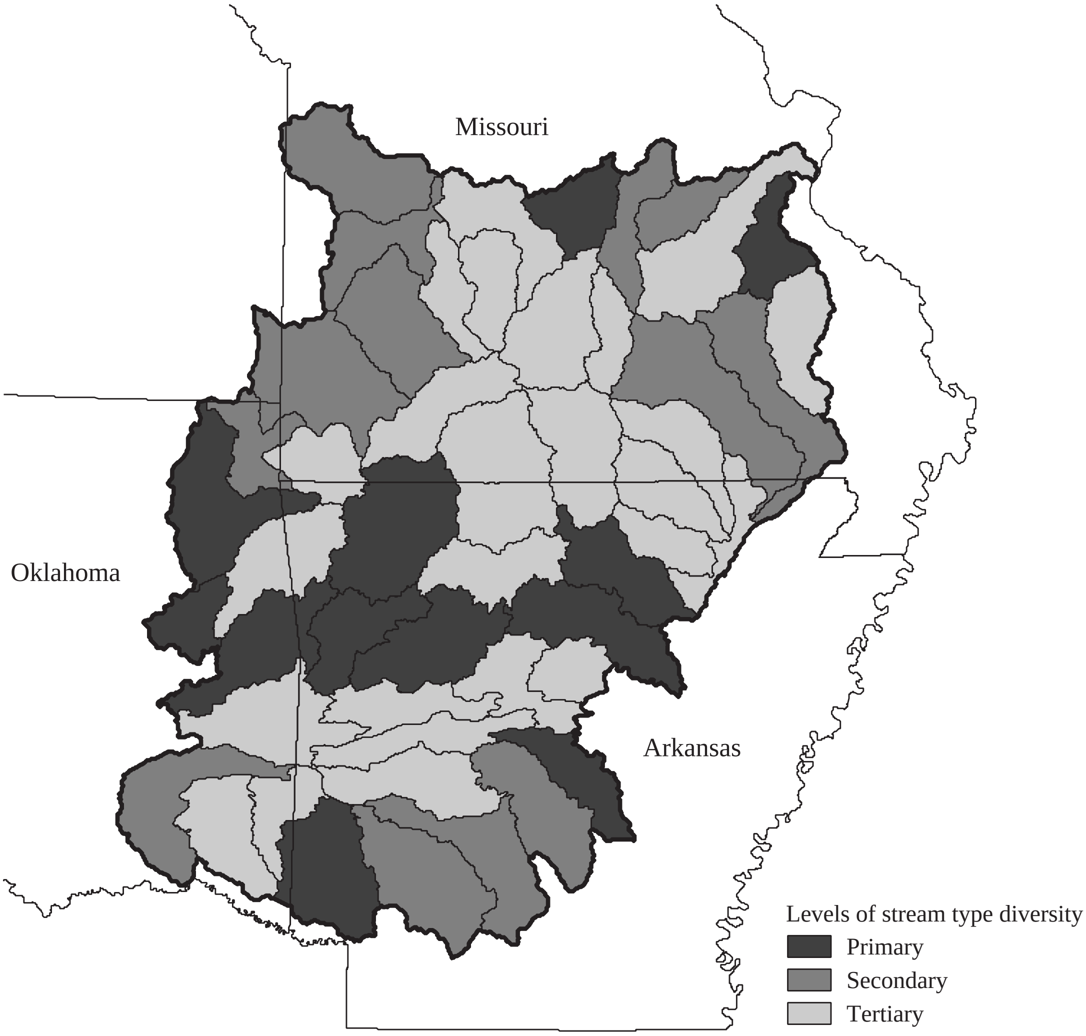


Figure 2.35—Stream type diversity by watershed.

in hydrologic units primarily in the Ozark Highlands and in those units draining into the Arkansas River (fig. 2.35). These hydrologic units typically had values of five or six stream types.

Native fish species richness was associated with the number of stream types in hydrologic units. The correlation of the rank of native fish species richness and stream types of hydrologic units was significant and positive (Kendall's tau beta coefficient = 0.29, $P < 0.0066$). The rank of endemic fish species richness and stream types within hydrologic units was not correlated (Kendall's tau beta coefficient = -0.01, $P < 0.9474$).

The association of native fish species richness with stream type diversity is not unexpected. Increasing heterogeneity of habitats from small to large spatial scales often is associated with increasing levels of faunal diversity (Schluter and Ricklefs 1993). Those hydrologic units with primary and secondary levels of stream type diversity and native fish species richness may be considered of particular significance in maintaining present and future aquatic biodiversity within the Ozark-Ouachita Highlands.

In their analyses, Matthews and Robison (1988) and Matthews and others (1992) included the portion of the Assessment area within the State of Arkansas. Matthews and Robison (1988) examined the association of fish distribution in 101 drainage units of Arkansas by focusing on three groups of environmental variables: (1) geographical (elevation, longitude, latitude); (2) meteorological (annual precipitation, frost-free days, mean January temperature, mean July temperature); and (3) local or site-specific (turbidity, substrate, width, geology). In an extension of that work, Matthews and others (1992) also examined the association of fish distribution in Arkansas by using 11-year averages of Arkansas Department of Pollution Control and Ecology and Geological Survey water quality data (Petersen 1988) for 70 of the original 101 drainage units in Arkansas. These water quality data included oxygen, pH, conductivity, alkalinity, total hardness, magnesium, sulfate, chloride, total dissolved solids, total phosphorus, nitrate, ammonia, turbidity, and biochemical oxygen demand. Hence, their work and this summary of their work are directly applicable only to that portion of the Assessment area in Arkansas.

Matthews and Robison (1988) found that values for 10 of 11 geographic, meteorological, and local variables were associated with the presence or absence of fish species in upland (highland habitats within the Arkansas Assessment area) versus lowland habitats in Arkansas. In constructing predictive models, they reported that a variety of combinations of these variables provided a good basis for predicting the presence or absence of fishes associated with specific drainage units. In particular, local factors (turbidity, substrate, width, and geology) and one strongly defining meteorological factor (mean January temperature) were most predictive of the presence or absence of a fish species.

Matthews and others (1992) found significant associations between fish distributions and general water quality patterns. They reported specific associations between water quality variables and fishes of the Southern Ozark and Ouachita Mountain Fish Faunal and Ozark Upland Fish Faunal Regions (which together encompass most of the Assessment area in Arkansas). Fishes characteristics of the Assessment area were associated with lower total dissolved solids, hardness, chloride, conductivity, ammonia, and biochemical oxygen demand, and with higher dissolved oxygen, pH, alkalinity, and magnesium. Matthews and others (1992) emphasized that environmental variables such as water quality parameters are likely to operate in concert with each other and not as isolated single variables. They further emphasized that evidence of a high degree of association between fishes and environmental variables in the Assessment area should be considered carefully before projects are undertaken that may instigate pervasive alteration of existing aquatic habitat conditions.

Implications and Opportunities

The method of addressing aquatic habitats presented here provides only a small portion of the information necessary to understand aquatic ecosystems. However, combining watersheds, size classes, and ecological units is a promising method for classifying aquatic habitats.

Riparian Areas

Question 2.12: What are the extent and vegetative composition of riparian areas within the Assessment area?

A riparian area is a zone immediately adjacent to a river, stream, lake, or pond. A healthy stream riparian area, one with stable stream banks with little or no erosion, sustains many ecological functions (Gregory and others 1991). Healthy riparian areas will withstand seasonal flooding and support the aquatic system by contributing organic matter (e.g., fallen trees, leaves) for the food chain. Such areas also provide structures for habitats (e.g., undercut banks, large woody debris, and rootwads). In addition, riparian areas provide essential shade and stream temperature regulation as well as cover and travel corridors for wildlife. Finally, they serve as filters to reduce erosion and sediment inputs from upland erosion that may occur outside the riparian area (Barling and Moore 1994). All streams need well-established riparian areas of natural vegetation to attain and maintain their biological integrity.

Land uses within riparian areas provide insight into the condition of the riparian and aquatic systems. Watersheds or river basins with large percentages of forested or undisturbed riparian areas tend to be more stable in terms of overall water quality and biological integrity. Agricultural, urban, and residential riparian areas are at a greater risk of incurring adverse effects from human activities. Assessments of riparian areas covering large areas are generally not available. With the advent of remote sensing and Geographic Information System (GIS) technologies, it is now possible to develop inventories of riparian area conditions over large geographical areas (Hunsaker and Levine 1995, Steedman 1988) such as the Highlands.

Key Findings

1. Of the almost 3 million acres of riparian areas identified within the Assessment area, approximately 57 percent are forested, 37 percent are agricultural, 2 percent are urban, and 4 percent are classified as "other."
2. The Upper Saline watershed has the greatest percentage (87.4 percent) and the South Grand watershed has the lowest percentage (14.9 percent) of forested riparian areas in the study area.
3. National forests generally have highly forested riparian areas (86 to 93 percent).

Data Sources and Methods of Analysis

Two GIS data layers were required for this section. The stream GIS layer is from the EPA's RF3 data base, and the land cover GIS layer is from the Geological Survey's Geographic Information Retrieval and Analysis System (GIRAS). The RF3 data layer was derived from 1:100,000 maps. This data layer has not been released by the EPA for general public use and does contain some mapping errors. The GIRAS data were at the 1:250,000 scale. Unfortunately, the GIRAS data set was developed in the late 1970's and early 1980's. While probably not representative of the latest land cover in the Assessment area, it is the best data base currently available.

The Aquatic Team identified riparian areas by buffering 100 ft on each side of the streams in the RF3 data base. The team then intersected this buffered area with the land use data base and executed queries about the resulting data set by watershed and national forest ownership layers. Empty values resulting from the intersecting process were ignored.

Patterns and Trends

The Aquatic Team identified 2,966,192 acres of riparian areas within the Assessment area; approximately 57 percent of the acres are forested, 37 percent are agricultural, 2 percent was urban, and 4 percent are classified as "other" (table 2.30).

Table 2.30—Acres in riparian areas and predominant land uses within riparian zones of Assessment area watersheds

River basin Watershed name	Watershed code (HUC)	Riparian area	Forest		Agriculture		Urban		Other	
		Acres	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*
Osage River Basin										
H.S. Truman Reservoir[a]	10290105	42,950	17,779	41.4	24,038	56.0	190	0.4	943	2.2
Sac[a]	10290106	67,173	20,345	30.3	43,316	64.5	1,053	1.6	2,459	3.7
Pomme de Terre	10290107	33,759	13,443	39.8	18,893	56.0	735	2.2	688	2.0
South Grand	10290108	81,843	12,176	14.9	66,662	81.5	699	0.9	2,307	2.8
Lake of the Ozarks	10290109	67,697	41,932	61.9	17,772	26.3	1,261	1.9	6,732	9.9
Niangua	10290110	45,317	26,099	57.6	17,884	39.5	369	0.8	964	2.1
Lower Osage	10290111	38,762	17,343	44.7	19,001	49.0	141	0.4	2,276	5.9
Gasconade River Basin										
Upper Gasconade	10290201	74,499	37,876	50.8	35,670	47.9	907	1.2	46	0.1
Big Piney	10290202	31,490	18,708	59.4	12,174	38.7	576	1.8	32	0.1
Lower Gasconade	10290203	44,191	25,913	58.6	17,857	40.4	237	0.5	183	0.4
Meramec River Basin										
Meramec	07140102	89,491	55,196	61.7	29,990	33.5	2,462	2.8	1,843	2.1
Bourbeuse	07140103	32,450	14,469	44.6	17,301	53.3	284	0.9	396	1.2
Big	07140104	41,441	24,095	58.1	14,693	35.5	909	2.2	1,743	4.2
Upper St. Francis River Basin										
Upper St. Francis	08020202	54,052	30,688	56.8	20,823	38.5	297	0.5	2,244	4.2
Neosho-Illinois River Basin										
Lake O' the Cherokees[a]	11070206	25,258	7,782	30.8	13,612	53.9	1,059	4.2	2,806	11.1
Spring[a]	11070207	59,363	10,939	18.4	45,168	76.1	1,229	2.1	2,028	3.4
Elk[a]	11070208	23,718	10,058	42.4	12,358	52.1	794	3.3	509	2.1
Lower Neosho[a]	11070209	65,775	24,777	37.7	34,386	52.3	897	1.4	5,716	8.7
Illinois	11110103	62,643	27,856	44.5	31,138	49.7	2,289	3.7	1,360	2.2
Arkansas River Basin										
Dirty-Greenleaf	11110102	32,767	10,531	32.1	18,711	57.1	980	3.0	2,545	7.8
Robert S. Kerr Reservoir	11110104	74,885	34,335	45.8	30,537	40.8	1,711	2.3	8,303	11.1
Poteau	11110105	93,900	53,927	57.4	36,472	38.8	1,082	1.2	2,419	2.6
Frog-Mulberry	11110201	48,495	29,998	61.9	14,667	30.2	982	2.0	2,847	5.9
Dardanelle Reservoir	11110202	76,594	47,879	62.5	22,782	29.7	1,109	1.4	4,824	6.3
Conway- Pt. Remove	11110203	50,867	24,512	48.2	19,878	39.1	977	1.9	5,499	10.8
Petit Jean	11110204	41,429	23,608	57.0	16,608	40.1	279	0.7	934	2.3
Cadron	11110205	37,256	20,324	54.6	16,379	44.0	218	0.6	335	0.9
Fourche La Fave	11110206	51,225	38,911	76.0	10,895	21.3	113	0.2	1,307	2.6
Lower Ark-Maumelle	11110207	55,560	27,281	49.1	17,468	31.4	3,612	6.5	7,199	13.0
Kiamichi-Little River River Basin										
Kiamichi	11140105	71,546	48,960	68.4	19,629	27.4	594	0.8	2,363	3.3
Upper Little[a]	11140107	42,871	34,795	81.2	6,471	15.1	368	0.9	1,238	2.9
Mountain Fork[a]	11140108	32,296	26,777	82.9	3,154	9.8	223	0.7	2,142	6.6
Lower Little[a]	11140109	73,601	54,667	74.3	15,017	20.4	709	1.0	3,208	4.4
Ouachita-Saline River Basin										
Ouachita Headwaters	08040101	66,307	48,287	72.8	10,159	15.3	1,740	2.6	6,121	9.2
Upper Ouachita	08040102	88,334	70,565	79.9	13,446	15.2	1,253	1.4	3,070	3.5
Little Missouri	08040103	91,523	61,959	67.7	20,500	22.4	6,955	7.6	2,108	2.3
Upper Saline	08040203	86,278	75,390	87.4	7,836	9.1	1,150	1.3	1,902	2.2
Upper White River Basin										
Beaver Reservoir	11010001	84,621	48,970	57.9	25,467	30.1	1,911	2.3	8,272	9.8
James	11010002	52,889	19,143	36.2	31,802	60.1	1,303	2.5	642	1.2
Bull Shoals Lake	11010003	115,836	69,459	60.0	32,143	27.7	1,606	1.4	12,628	10.9
Middle White	11010004	59,994	38,409	64.0	17,186	28.6	465	0.8	3,935	6.6
Buffalo	11010005	50,547	40,049	79.2	10,004	19.8	74	0.1	420	0.8
North Fork White	11010006	74,760	47,014	62.9	23,061	30.8	247	0.3	4,437	5.9
Little Red	11010014	79,921	52,446	65.6	19,275	24.1	1,189	1.5	7,011	8.8
Upper Black River Basin										
Upper Black	11010007	80,174	48,414	60.4	30,176	37.6	900	1.1	683	0.9
Current	11010008	106,619	75,859	71.1	30,328	28.4	334	0.3	98	0.1
Lower Black	11010009	38,438	11,363	29.6	26,351	68.6	193	0.5	530	1.4
Spring	11010010	47,600	26,262	55.2	20,296	42.6	730	1.5	312	0.7
Eleven Point	11010011	46,996	28,565	60.8	18,274	38.9	107	0.2	49	0.1
Strawberry	11010012	30,191	15,154	50.2	14,617	48.4	186	0.6	234	0.8
Total		2,966,192	1,691,287	57.0	1,092,325	37.0	49,688	2.0	132,890	4.0

HUC = hydrologic unit code.

[a] Streams and corresponding riparian areas were mapped at a lower density in the River File 3 data base for portions of these watersheds.

Figure 2.36 displays the percent of forested riparian area for the watersheds within the aquatic study area. Riparian forest cover was separated into three catego

Figure 2.36 displays the percent of forested riparian area for the watersheds within the aquatic study area. Riparian forest cover was separated into three categories: ries: less than 32 percent, 33 to 68 percent, and greater than 68 percent. Of the nine watersheds with the highest percent of forested riparian area, seven are located in the Ouachita Mountains. The Upper Saline watershed has the greatest percentage of forested riparian area (87.4 percent).

Of the six watersheds with the lowest percentage of forested riparian area, all are located on the outlying watersheds. Most are in the northwestern portion of the Assessment area where there is a strong influence of prairie. The South Grand watershed (with only 14.9 percent) has the lowest percentage of forested riparian cover.

The riparian areas of the Ozark-St. Francis, Ouachita, and Mark Twain National Forests are 93, 92, and 86 percent forested, respectively (table 2.31).

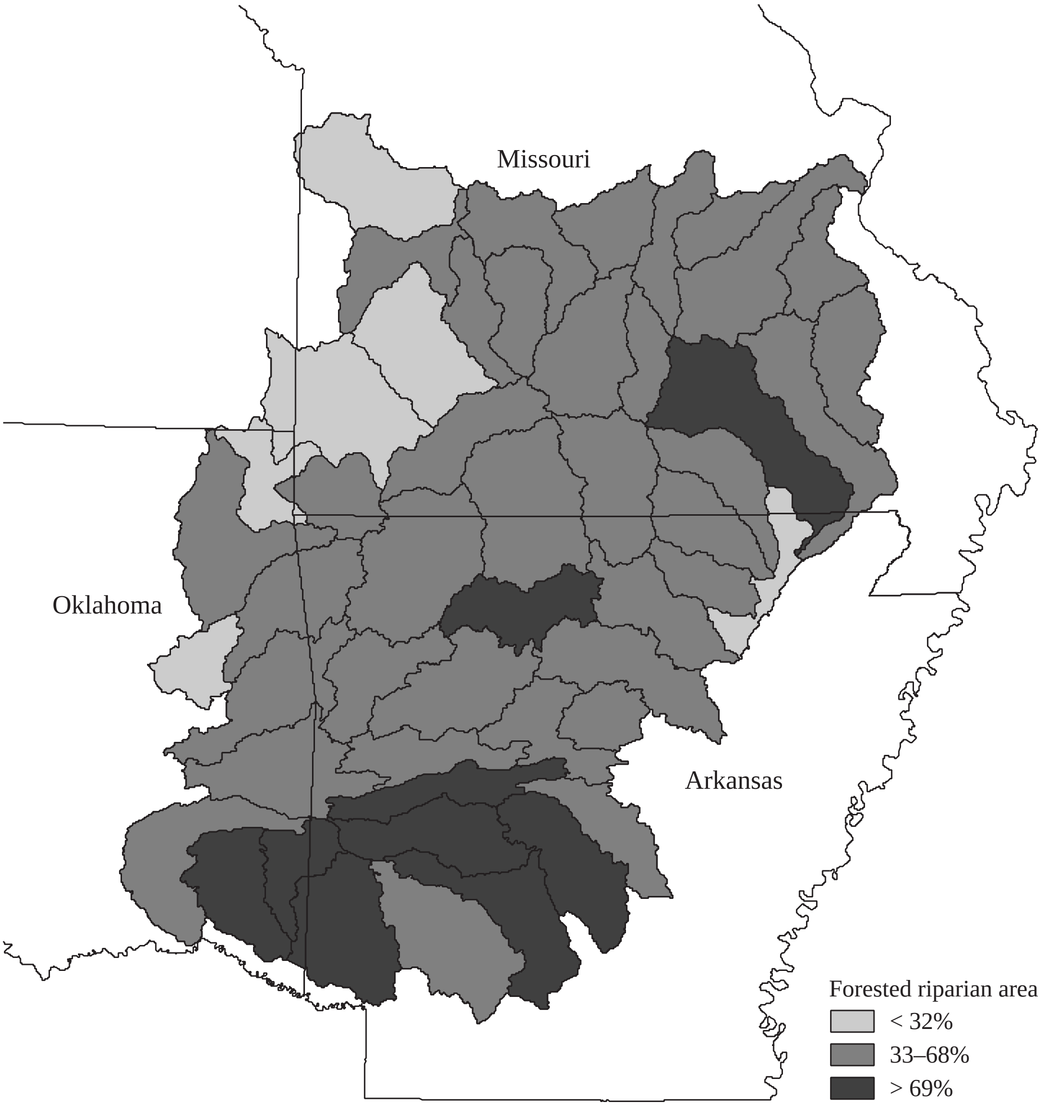


Figure 2.36—Percent of forested riparian areas by Assessment area watershed.

Table 2.31—Acres in riparian areas and the predominant land uses within those riparian areas, by national forest

National forest	Forest		Agriculture		Urban		Other	
	Acres	*%*	*Acres*	*%*	*Acres*	*%*	*Acres*	*%*
Ozark	75,453	93	3,765	5	0	0	1,828	2
Ouachita	117,906	92	7,582	6	58	<1	2,596	2
Mark Twain	127,386	86	19,380	13	100	<1	738	2

Generally, land uses in riparian areas parallel land uses within their respective watersheds. The outlying watersheds typically have greater percentages of agricultural and "other" use categories. Watersheds within the mountainous areas typically have greater percentages of forested riparian area.

Implications and Opportunities

As better data bases about land uses become available, this type of analysis will become more meaningful. However, it is clear that some watersheds in the Assessment area have very low percentages of forest cover in riparian areas, which may signal higher potential for problems associated with unhealthy riparian areas if forest is the primary indigenous vegetation.

The national forests within the Assessment area conserve large areas of forested riparian areas. The opportunity exists for the Forest Service (and other public land management agencies) to continue sound management of these areas and to promote the restoration, wise use, and continued protection of riparian areas.

Wetlands

Question 2.13: What are the extent and composition of wetlands within the Assessment area?

There are several definitions for wetlands, and most of them share similar meanings. In most definitions, a wetland area is required to (1) be periodically flooded, (2) have plants that are adapted to growing in wet conditions, and (3) have soils that developed under wet conditions. Despite these similarities, no single conclusive definition exists for wetlands. Following are examples of some of the current definitions for wetlands:

- "Wetlands are those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (EPA, 40 CFR 230.3, December 24, 1980; and CE, 33 CFR 328.3, November 13, 1986).
- The Food Security Act of 1985 (as amended) contains a similar definition of wetlands that also emphasizes hydrology, the presence of plants that are adapted for life in water-saturated soils, and saturated soil conditions.
- The Fish and Wildlife Service's definition of wetlands includes both vegetated and nonvegetated wetlands, recognizing that some types of wetlands lack vegetation (for example, mud flats, sand flats, rocky shores, gravel beaches, and sand bars).

Wetlands are important because they store floodwaters, reduce flood peaks, filter sediments and nutrients from runoff, and provide habitats for wetlands-dependent plants and animals. The Assessment area has a variety of wetlands including (1) bottomland hardwood wetlands, (2) swamps, (3) fens (wet alkaline areas with peaty or other organic rooting medium), (4) wet prairies, and (5) freshwater marshes. Bottom land hardwood wetlands are seasonally flooded areas near streams and rivers where pin oak, silver maple, cottonwood, black willow, and river birch are the dominant vegetation; flooding is frequent; and the soils are poorly drained. Swamps consist of depressions, oxbow ponds, and backwater sloughs along stream and river floodplains where bald cypress and/or tupelo gum are the dominant trees; flooding is frequent; and the soils are very poorly drained. Fens occur on side slopes of hills in narrow are areas along floodplains of larger streams and rivers where tall grasses and sedges are the dominant vegetation, flooding is frequent, and the soils are poorly drained. Freshwater marshes are depressions along rivers where cattails, bulrushes, and sedges are the dominant forms of vegetation; flooding is frequent during winter and spring; and the soils are very poorly drained (Nelson 1987).

Key Findings

1. Since the 1780's, wetland losses in Assessment area States have ranged from 50 to greater than 75 percent (Dahl 1990).
2. Most of the State Soil Geographic data base soil-map units that include hydric soils (soils that are saturated, flooded, or ponded long enough during the growing season to deplete the oxygen in the upper part of the soil) are found along the Grand, Sac, Black, White, Arkansas, Ouachita, and Little Rivers. These areas are potential wetlands because they have saturated soils, one of the essential components of the designation "wetlands."
3. According to the State 305(b) inventory reports of water quality, most of the wetlands in Arkansas, Missouri, and Oklahoma have been converted to agricultural production during historic times.
4. Camden and Taney Counties, MO, and Pulaski County, AR, had the most Clean Water Act 404 permits issued from 1988 through 1996. If the number of permits issued indicates activity in wetlands and other water bodies, the Osage, Upper White, and Arkansas River Basins had the most activity from 1988 through 1996.

Data Sources and Methods of Analysis

The State Soil Geographic (STATSGO) data base for Arkansas, Missouri, and Oklahoma provided the data needed to locate potential wetland areas in the study area. Dahl's (1990) study of wetland losses provided an estimate of the amount of wetlands lost in the Assessment area up to 1990. The State 305(b) water quality reports for Arkansas, Missouri, and Oklahoma provided information on the reasons for wetlands loss. The Aquatic Team used data compiled by the Environmental Working Group (1997) on the numbers of nationwide 404 permits issued by the U.S. Army Corps of Engineers to determine where most of the activities have occurred in wetlands in the Assessment area. Nelson (1987) provided locations and descriptions of some of the important wetlands in the Ozark Highlands section. The Fish and Wildlife Service's *Regional Wetlands Concept Plan* (1992) provided information on wetlands in Arkansas.

Patterns and Trends

Most of the STATSGO map units that include hydric soils (soils that are saturated, flooded, or ponded long enough during the growing season to deplete the oxygen in the upper part of the soil) are found within the Osage, Upper Black, Meramec, Gasconade, and Ouachita-Saline River Basins and the following noncontiguous units: Spring (Neosho-Illinois River Basin), Little Red, Lower Arkansas-Maumelle, and Lower Little (fig. 2.37). Table 2.32 lists some of the important wetlands in the Assessment counties (many are just outside the Highlands per se).

The U.S. Army Corps of Engineers issues permits for activities that require dredging and any filling of material into the waters of the United States. The permits are issued under section 404 of the Clean Water Act (see Chapter 3 of this report). The term "waters of the United States" includes rivers, lakes, streams, intermittent streams, mudflats, and wetlands (33 CFR 328.3, 1995). General permits are issued at a national or regional level and are designed to regulate activities that have minimal effects on water resources. Larger and more complex projects often require individual permits that entail more oversight by the Corps of Engineers. The number of permits issued can be used to get a general indication of the activity that is occurring in wetlands and other water bodies. Camden and Taney Counties, MO, and Pulaski County, AR, had the most permits issued from 1988 through 1996 in Assessment area counties. Assuming that the number of permits issued indicates activity in wetlands and other water bodies, then the Osage, Upper White, and Arkansas River Basins had the most activity. Table 2.33 shows the numbers of 404 permits denied, issued, and withdrawn by the Corps of Engineers in Assessment area counties from 1988 through 1996.

Figure 2.37—Areas of hydric soils in and adjacent to the Ozark-Ouachita Highlands.

Wetland losses from the 1780's to the 1980's range from 50 to greater than 75 percent in present-day States of the Assessment area (Dahl 1990). According to the Arkansas Statewide Comprehensive Outdoor Recreat*ion Plan for 1995* (Turner 1995), Arkansas continues to experience significant wetland loss. Turner (1995) cites (1) drainage and flood protection; (2) dredging and stream channelization; (3) conversion from forested wetlands to scrub-scrub, emergent, or open-water wetlands; (4) alteration of drainage patterns; (5) construction of dikes and levees; and (6) discharge of pollutants as threats to the remaining forested wetlands of Arkansas. Most of the wetlands lost in Arkansas have been converted to agriculture. Johnston (1994) cites a Fish and Wildlife Service study that estimates that 54 percent of the wetlands lost between the 1950's and 1970's were forested wetlands. From the mid-1970's to the 1980's, 95 percent of all wetlands lost were forested wetlands. According to the Fish and Wildlife Service, Arkansas was one of the States with the largest losses of forested wetlands.

Conversion to agricultural production, clearing of hardwood forests, railroad construction, federally encouraged draining and filling of wetlands, river and stream channelization projects, extensive Federal and private levee development, and dams for flood control

Table 2.32—Some important wetlands in Assessment area counties

Wetland	County and State
Mingo National Wildlife Refuge[a]	Wayne and Stoddard, MO
Fiddler Pond, Irish Wilderness	Oregon, MO
Peck Ranch Sinkhole Pond Natural Area	Carter, MO
Tupelo Gum Pond Natural Area	Carter, MO
Sunklands Natural Area	Shannon, MO
Burr Oak Basin Natural Area	Shannon, MO
Sand Ponds State Forest	Butler, MO
Coonville Creek Natural Area	St. Francois, MO
Hussman Fen Natural Area	Shannon, MO
Sutton Creek Fen	Shannon, MO
Medley Hollow Fen	Shannon, MO
Coakley Hollow Fen Natural Area	Camden, MO
Bennett Spring Hanging Fen Natural Area	Dallas and Laclede, MO
Ruble Meadow	Reynolds, MO
Grasshopper Hollow Natural Area	Reynolds, MO
Raised Fen	Reynolds, MO
Wash Creek Alder Bog	Bollinger, MO
Big Buffalo Creek Marsh Natural Area	Benton, MO
Mint Spring Natural Area	Gasconade, MO
Cupola Pond Natural Area	Ripley, MO
Allred Lake Natural Area	Butler, MO
Lily Pond Natural Area	Reynolds, MO
Garrison Fen	Fulton, AR
Rock Creek Seep Fen	Sharp, AR
Arnold Cemetery Road Pondberry[a]	Jackson, AR
Centerville Pondberry[a]	Jackson, AR
Otter Lake[a]	Jackson, AR
Swifton Sand Ponds[a]	Jackson, AR
Bald Knob	White, AR
Bayou Des Arc[a]	White and Prairie, AR
Raft Creek Bottoms	White and Prairie, AR
Wingmead Farms[a]	Prairie, AR
Seaton Dumpa	Lonoke, AR
White Rivera	Prairie, AR
Bayou Metoa	Arkansas, Prairie, and Lonoke, AR
Fourche Bottomsa	Pulaski, AR
Big Lake/Lorance Creeka	Pulaski and Saline, AR
Pond Creek Bottomsa	Sevier, AR
Buttermilk Spring	Montgomery, AR
Meyer's Creek Seep	Garland, AR
Holla Bend National Wildlife Refuge	Yell and Pope, AR
Dave Donaldson Black River Wildlife Management Area	Clay and Randolph, AR
Cossatot National Wildlife Refuge[a]	Sevier, AR
Little River National Wildlife Refuge[a]	McCurtain, OK

[a] Outside the Highlands but within the aquatic study area.
Source: Nelson (1987), USDI FWS (1992).

Table 2.33—Permits denied, general and individual permits issued, and permits withdrawn under Section 404 of the Clean Water Act in Assessment area counties (1988–1996)

County	Permits denied	General permits issued	Individual permits issued	Permits withdrawn
Missouri				
Barry	0	54	9	0
Barton	0	9	1	0
Benton	9	66	26	9
Bollinger	0	9	11	0
Boone	0	66	3	2
Butler	1	77	20	3
Camden	21	274	198	31
Carter	0	15	3	1
Cedar	1	7	2	3
Christian	0	31	7	3
Cole	1	75	16	3
Crawford	0	43	10	3
Dade	0	15	1	0
Dallas	2	37	9	6
Dent	0	17	6	2
Douglas	2	13	9	2
Franklin	1	89	14	3
Gasconade	2	52	15	7
Greene	2	91	8	3
Henry	0	115	33	6
Hickory	0	33	2	2
Howell	0	19	0	0
Iron	0	40	7	0
Jasper	1	90	3	1
Jefferson	1	116	12	7
Laclede	0	16	5	1
Lawrence	0	41	4	6
McDonald	1	24	4	1
Madison	0	12	0	0
Maries	4	16	4	3
Miller	2	69	35	6
Morgan	13	109	69	8
Newton	0	41	1	0
Oregon	0	1	3	0
Osage	5	34	10	1
Ozark	0	30	7	0
Phelps	1	68	9	1
Polk	1	23	3	3
Pulaski	0	24	7	4
Reynolds	0	15	6	2
Ripley	0	84	16	1
Shannon	1	4	4	3
St. Clair	0	15	18	0
St. Francois	0	14	1	0
Ste. Genevieve	0	20	5	3
Stone	2	81	11	3
Taney	2	135	54	6
Texas	1	81	6	8
Washington	1	30	5	2
Wayne	1	80	9	4
Webster	0	16	4	2
Wright	1	11	3	0
Arkansas				
Baxter	1	88	26	4
Benton	3	132	5	3
Arkansas (continued)				
Boone	0	24	3	1
Carroll	0	31	11	0
Clark	0	26	0	1
Cleburne	0	54	6	1
Conway	1	26	13	4
Crawford	0	70	13	3
Faulkner	1	53	10	4
Franklin	1	57	12	4
Fulton	0	25	2	0
Garland	0	53	7	1
Hot Springs	0	18	1	0
Howard	0	24	3	1
Independence	0	21	11	2
Izard	0	32	11	2
Jackson	5	35	15	2
Johnson	1	55	10	2
Lawrence	3	30	8	3
Logan	0	62	12	0
Lonoke	0	30	17	8
Madison	5	14	1	1
Marion	1	37	14	1
Montgomery	0	12	2	0
Newton	0	8	3	0
Perry	0	21	2	1
Pike	0	11	1	0
Polk	0	9	1	0
Pope	1	87	27	4
Pulaski	7	174	122	17
Randolph	1	71	8	1
Saline	0	20	2	4
Scott	0	10	2	0
Searcy	0	8	1	1
Sebastian	4	85	20	6
Sevier	0	12	4	0
Sharp	1	10	2	1
Stone	1	13	12	0
Van Buren	0	14	1	0
Washington	0	74	2	1
White	3	38	15	2
Yell	0	53	12	2
Oklahoma				
Adair	0	11	4	0
Atoka	0	30	3	0
Cherokee	0	44	12	3
Delaware	0	18	24	3
Haskell	0	41	2	0
Latimer	0	35	5	1
LeFlore	0	78	6	2
Mayes	0	14	5	0
McCurtain	0	75	2	4
Muskogee	0	46	7	0
Ottawa	0	19	4	0
Pittsburg	0	55	3	0
Pushmataha	0	26	0	0
Sequoyah	0	17	6	3

Source: Environmental Working Group (1997).

contributed to wetland loss in Missouri (MO DNR 1994).

The Fish and Wildlife Service and the Natural Resources Conservation Service estimate that historical wetland loss ranges from 50 to 67 percent in Oklahoma. Agriculture, including conversion to cropland and pastureland, is responsible for approximately 80 percent of the total wetlands lost in Oklahoma. The loss of adjacent buffers (contiguous areas that support wetlands) threatens the State's remaining wetlands. Statewide, the loss of wetlands has contributed to (1) decreased quality of surface and ground water supplies, (2) increased flooding, and (3) reduced ability of wetlands to absorb and cycle sediments and nutrients (USDI FWS 1992). Unfortunately, information does not exist that is specific to the Assessment area.

Educating the public about critical functions of wetlands will be a key to their conservation and restoration. A telephone survey conducted for the Arkansas Department of Parks and Tourism (Turner 1995) found that 65 percent of the respondents didn't think that destruction of wetlands was an environmental problem in Arkansas or did not know if it was a problem. Another survey conducted by the Arkansas Multi-Agency Wetland Planning Team reports the following:

- Arkansas respondents do not know a great deal about wetlands, but many think wetlands are declining.
- Respondents support protection of wetlands for wildlife habitats both as vital components of the ecosystem and for future generations.
- A few Arkansas respondents oppose wetland conservation because they fear government regulation or consider wetlands "just swamps."
- Many more consider wetland conservation important and think that State government and landowners should be responsible for protecting them.
- Some respondents support incentives for landowners to restore and protect wetlands and endorse partnerships between the government and the private sector to conserve wetlands.

Implications and Opportunities

The surveys mentioned suggest there is a need for more education about wetlands. Some support already exists for wetland conservation and restoration.

Voluntary (incentive based) wetland conservation and restoration programs for private landowners will increase in importance. Most of the Nation's wetland ecosystems (nearly 74 percent) are privately owned. Federal or State agencies manage 25 percent, and local governments manage 2 percent (USDA FS 1994). Less than 5 percent of Arkansas' original wetlands are currently protected in State parks, wildlife management areas, natural areas, and national wildlife refuges (AR M-AWPT 1997).

Conflicts over land use will have to be resolved if wetland conservation efforts are to succeed. The Natural Resources Conservation Service's 1992 National Resources Inventory (NRI) indicated that wetland losses due to agriculture will continue, but at a much slower rate. Commercial and residential development, drainage and filling, road building, water development projects, ground water withdrawals, loss of instream flows, water pollution, and vegetation removal continue to threaten wetlands (USDI FWS 1992).

Wetland losses will likely continue to decrease and may approach the national policy of "no net loss" in the Ozark-Ouachita Highlands in the future. The level of public support that is generated for wetland conservation and restoration programs will determine whether or not the wetlands in the Assessment area approach or attain this "no net loss" status.

Chapter 3: The Clean Water Act and Aquatic Restoration Programs

Question 3.1: What laws, policies, and programs for the protection of water quality, streams, wetlands, and riparian areas are in place?

Federal and State laws and policies concerning aquatic resources provide a legal mandate to ensure that human activities are conducted with consideration for the protection, preservation, and restoration of our Nation's water resources.

This chapter discusses and summarizes many of the laws and policies that are in effect and reviews the success of these regulations to date. Topics specifically addressed include: section 404 of the Clean Water Act (CWA); the National Pollutant Discharge Elimination System (NPDES); total maximum daily loads (TMDL's); and the control of nonpoint source pollution, which includes best management practices (BMP's). Table 3.1 summarizes a number of statutes that have been enacted and linked to the protection of water quality.

In addition to laws, many federally funded programs exist to protect, restore, or improve aquatic resources. This chapter also discusses and summarizes many of these programs in the context of the Assessment area. Portions of this chapter draw heavily upon SAMAB (1996).

Key Findings

1. There have been significant changes in regulations that affect water resources, particularly regulations concerning nonpoint source problems such as sedimentation and nutrient loading.
2. Nonpoint source pollution is one of the major water quality issues to contend with in the future.
3. There are several U.S. Department of Agriculture (USDA) incentive programs that focus on the restoration of riparian areas and wetlands, including the Wetlands Reserve Program (WRP) and Environmental Quality Incentive Program (EQIP).

The Clean Water Act (CWA)

The protection of aquatic resources is governed by the Federal Water Pollution Control Act (FWPCA), which dates back to 1948. This law was passed after a half century of debate over the responsibility of the Federal Government for resolving water pollution problems. The FWPCA incorporated principles from State and Federal cooperative program development, limited Federal enforcement authority, and limited financial assistance. Now known as the Clean Water Act (CWA), the FWPCA was largely shaped by the comprehensive 1972 amendments, which are often viewed as the starting point for modern water pollution control laws. The 1972 amendments established a regulatory system for point sources of pollution (e.g., pipes that carry industrial effluent or sewage). They also extended water quality standards to intra-State waters and provided for implementation of water quality standards through discharge permits that require monitoring the frequency, amounts, source, and nature of effluents. The CWA has been amended several times; the most recent changes occurred with the passage of the Water Quality Act of 1987.

The objective of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (CWA 101(a)). The CWA of 1987 explicitly reaffirmed the national goal to eliminate discharges of pollutants into navigable waters of the United States and, wherever attainable, to achieve water quality that provides for the protection and propagation of fish, shellfish, and wildlife. Providing for propagation means protecting or improving the full range of aquatic habitats necessary to support reproducing populations of all native forms of aquatic life (U.S. EPA 1990). The CWA of 1987 further states as a national goal that programs be developed and implemented for the control of nonpoint source pollution. (Nonpoint source pollution originates from diffuse sources such as runoff from construction activities.) The primary mechanism for controlling nonpoint source pollution is the adoption and implementation of BMP's.

Table 3.1—A summary of statutes related to water quality[a]

Popular name; general citation	Specific citation; topic	Purpose
Federal Insecticide, Fungicide, and Rodenticide Act [7 U.S.C. 136]	[7 U.S.C. 5506] Water policy with respect to agrichemicals	To develop programs for users and dealers of agrichemicals to insure that they and the general public understand the implications of their actions and the potential effects on water.
Clean Air Act [42 U.S.C. 7401]	[42 U.S.C. 7403] Research, investigation, training, and other activities	To improve the understanding of the long- and short-term causes, effects, and trends of ecosystem damage from air pollutants, including their effects on water quality.
Federal Water Pollution Control Act [33 U.S.C. 1251]	[33 U.S.C. 1251] Congressional declaration of goals and policy	To restore and maintain the chemical, physical, and biological integrity of the Nation's water.
Safe Drinking Water Act [42 U.S.C. 300f]	Safety of public water systems: definitions	To maintain the quality of the Nation's drinking water by setting water quality standards.
Soil and Water Resources Conservation Act [16 U.S.C. 2001]	[16 U.S.C. 2003] Congressional policy and declaration of purpose	To appraise on a continuing basis the soil, water, and related resources of the Nation and develop and update periodically a program for furthering the conservation, protection, and enhancement of the soil, water, and related resources of the Nation consistent with the roles and program responsibilities of other Federal agencies and State and local governments.
Surface Mining Control and Reclamation Act [30 U.S.C. 1201]	[30 U.S.C. 1202] Statement of purpose	To establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations.
Coastal Zone Management Act [16 U.S.C. 1451]	[16 U.S.C. 1452] Congressional declaration of policy	To protect natural resources including wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitats within the coastal zone.
Wild and Scenic Rivers Act [16 U.S.C. 1271]	[16 U.S.C. 1271] Congressional declaration of policy	To preserve in a free-flowing condition certain select rivers of the Nation that possess outstanding scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values.
National Forest Management Act of 1976 [16 U.S.C. 1600]	[16 U.S.C. 1604] National forest system land and resource management plans	To protect water bodies during timber harvest operations to prevent adverse effects on water quality or fish habitats.
Marine Protection, Research, and Sanctuaries Act, sec. 2 [33 U.S.C. 1401]	[33 U.S.C. 1401] Congressional finding, policy, and declaration of purpose	To regulate the dumping of materials into the ocean that would adversely affect human health or welfare, the marine environment, ecological systems, or economic potentials.
Solid Waste Disposal Act [42 U.S.C. 6901]	[42 U.S.C. 6902(10)] Objectives and national policy	To promote the demonstration, construction, and application of solid waste management, resource recovery, and resource conservation systems that preserve and enhance the quality of air, water, and soil resources.
Executive Orders (E.O.) for Floodplain and Wetland Management 11988 and 11990	E.O. 11988 and 11990	Insures that wetlands and floodplain functions and values are considered and potential effects are evaluated during the planning and implementation of all Federal actions. Alternatives will be considered to avoid adverse impacts; if no practical alternative is available, mitigation measures will be implemented to minimize impacts.

(continued)

Table 3.1—A summary of statutes related to water quality[a] (continued)

Popular name; general citation	Specific citation; topic	Purpose
National Environmental Policy Act (NEPA) [42 U.S.C. 4371-4375]	[42 U.S.C. 4321] Congressional declaration of purpose	Declares a national policy to promote efforts that will prevent or eliminate damage to the environment.
Endangered Species Act (ESA) [16 U.S.C. 1531]	[16 U.S.C. 1531] Congressional findings and declaration of purposes and policy	The ESA requires the Secretary of the Interior, through the Fish and Wildlife Service and the Department of Commerce's National Marine Fisheries Service, to identify endangered and threatened species and to develop recovery plans for such species. It requires that all Federal agencies cooperate with State and local agencies to resolve water resource issues in concert with the conservation of endangered and threatened species. The ESA also provides Federal assistance to States to implement conservation activities for species likely to become endangered or threatened.

[a] For more details and/or recent changes in these and other laws, see the following Web sites: <http://www4.law.cornell.edu/uscode/> and <http://www.epa.gov/epahome/rules.html>.

Considerable debate and concern continue over the implications of making changes in current water resource legislation. When opposing interest groups advocate fewer or greater environmental controls, water pollution issues often become polarized.

Clean Water Act (CWA) Sections

Sections of the CWA that are pertinent to natural resource management in the Assessment area are summarized here, and several are then discussed in more detail.

Section 301 prohibits the discharge of any pollutant into waters of the United States without a permit and allows issuance of permits under section 404.

Section 303 requires that water quality standards contain two components: (1) designated use and (2) water quality criteria. This section also requires that projects be consistent with both components. Accordingly, a project that does not comply with a designated use of the water does not comply with the applicable water quality standard. Section 303(d) and the EPA's Water Quality Planning and Management Regulations (40 CFR 130) established a process to implement State water quality standards.

Section 308 gives the EPA the authority to obtain information that is necessary to carry out enforcement responsibilities under the CWA.

Section 309(a) requires the EPA to take appropriate enforcement action to assure compliance with sections 301, 308, 401, and 404 of the CWA.

Section 309(g), as amended in 1987, authorizes the EPA to assess administrative penalties for, among other things, discharges resulting from dredge and fill activities not authorized by sections 301, 308, 401, and 404 of the CWA.

Section 319 authorizes the EPA to issue grants to States to implement management programs approved by the EPA. Under section 319, States assess causes of nonpoint source pollution within their boundaries, adopt management programs to control this pollution, and implement watershed management programs.

Section 401—Water Quality Certification—requires an applicant for a Federal license or permit to conduct any activity that "may result in any discharge into the navigable waters to obtain a State water quality certification so that the discharge will comply with the applicable provisions of sections 1311, 1312, 1313, 1316, and 1317 of this title." Section 401(d) further provides that "any certification . . . shall set forth any effluent limitations and other limitations, and monitoring requirements necessary to ensure that any applicant . . . will comply with any applicable effluent limitations and other limitations, under sections 1311 and 1312 of this title . . . and with any other appropriate requirement of State law set forth under such certification" (33 U.S.C. 401).

Section 402(p)—Stormwater Discharges—requires the EPA to address stormwater discharges associated with industrial activities. The EPA's definition of such an industrial discharge is found in 40 CFR 122.26(b)(14): "the discharge from any conveyance which is used for collecting and conveying stormwater and which is directly related to manufacturing, processing, or raw materials storage areas at an industrial plant." These regulations are targeted at the control of stormwater runoff from construction sites where disturbed areas will be 5 acres or larger, including a collection and delivery system that discharges the runoff through a point source.

Section 404 of the CWA (33 U.S.C. 1344) directs the U. S. Army Corps of Engineers to regulate the "discharge of dredged and fill material into all waters of the United States, including wetlands." The intent of the law is to protect the Nation's waters from the indiscriminate discharge of material capable of causing pollution.

Wetlands—Section 404

Established under the FWPCA of 1972, the section 404 regulatory program makes it unlawful to discharge dredged or fill material into "waters of the United States" without first receiving a permit from the Corps of Engineers. The term "waters of the United States" includes traditionally navigable waters, interstate waters and wetlands, all impoundments of jurisdictional waters, all tributaries of waters of the United States, the territorial seas, and wetlands adjacent to any of these waters (33 CFR 328.3(a); 40 CFR 230.3(s), 232.2).

A discharge of fill material involves the physical placement of soil, sand, gravel, dredged material, or other material into these waters. Exemptions were added to section 404 in 1977 to exclude normal farming, ranching, and forestry activities that have been active and ongoing (33 CFR 323.4). For example, if farmers plow, plant, and harvest in wetlands, they can continue to do so without a section 404 permit as long as they do not convert wetlands to dry land. Activities that convert a wetland that has not been used for farming or forestry or that is not part of an ongoing program are not exempt from section 404 permit requirements. The conversion of a bottomland hardwood wetland to a pine plantation or for crop production, for example, would not be exempt. Activities that do not involve discharge of dredged or fill material into U.S. waters never require a permit. However, excavation of materials may require a permit.

Debate continues on the definition of wetlands and activities that fall under the section 404 exemptions. Currently, jurisdictional wetlands are defined by the Corps of Engineers as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support and that under normal circumstances do support a prevalence of vegetation typically adapted for life in saturated soils." Identification methods for wetlands are outlined in the *Wetlands Delineation Manual* (U.S. ACE 1987).

Nationwide and Section 404 Permits

Nationwide permits (NWP's) are a general type of permit authorized by the Corps of Engineers for activities that are not specifically restricted (33 CFR 330.2(b)). NWP's are designed to efficiently regulate 40 types of activities that have minimal impact on water resources. For example, a specific permit is not required to stabilize a stream bank that affects less than 500 ft of stream and does not exceed an average of 1 cubic yard of material per running foot of bank. Minor road crossings, deposition of fill material, and minor discharges are also permitted under the provisions of the NWP system (33 CFR app. (b)). Activities that are not specifically authorized under the NWP system may require an individual permit, regional general permit, or a dredge-and-fill permit under section 404 of the CWA. A water quality certification under section 401 of the CWA or a waiver from the appropriate State water quality agency may be required for those NWP's that result in a discharge into waters of the United States.

Activities Not Requiring a Section 404 Permit

Most silvicultural activities are exempt from section 404 permit requirements provided they meet 15 road BMP's or baseline provisions for road construction. Specific requirements for BMP application are outlined in 33 CFR 323.4. For example, "the design, construction, and maintenance of a road crossing shall not disrupt the migration or other movement of those species of aquatic life inhabiting the water body" (33 CFR 323.4(6)(vii)).

Mechanical site preparation in seasonally, intermittently, or temporarily flooded wetlands or saturated wetlands does not require a permit if the BMP's listed below are implemented. "Saturated wetlands" are characterized by subsoil saturated to the land surface for extended periods during the growing season or by surface water that is seldom visible and include pine flatwoods and wet flats (e.g., certain pine-hardwood forests). To exempt activities from section 404 permit requirements, managers of forested wetlands must follow these BMP's:

- Position shear blades or rakes at or near the soil surface and windrow, pile, and otherwise move logs and logging debris by methods that minimize dragging or pushing through the soil to minimize soil disturbance associated with shearing, raking, and moving trees, stumps, brush, and other unwanted vegetation;
- Conduct activities in such a manner as to avoid excessive soil compaction and maintain soil tilth;
- Arrange windrows in such a manner as to limit erosion, overland flow, and runoff;
- Prevent disposal or storage of logs and logging debris in streamside management zones (defined as areas adjacent to streams, lakes, and other water bodies) to protect water quality;
- Maintain the natural contour of the site, and ensure that activities do not immediately or gradually convert the wetland to a nonwetland; and
- Conduct activities with appropriate water management mechanisms to minimize off-site water quality impacts.

Exemption of Farm and Forest Roads

Section 404(f)(1) exempts farm and forest roads from 404 permit requirements (33 CFR 323.4(a)(6) and April 4, 1996, Regulatory Guidance Letter—EPA Headquarters to Region X). Determination of whether a road is a forest road under section 404(f)(1)(e) is not based solely on its use for timber hauling. A forest road may also provide access for planting, fire control, or other silvicultural support, but it cannot serve purposes unrelated to forest management. For example, a road to a gravel pit used to transport gravel for purposes other than forest road construction cannot be exempt as a forest road. Similarly, if a road through a national forest principally serves people visiting a recreational site—not the actual business of silviculture—it is not a forest road. Because farm roads are covered by the same law and regulation, similar guidance applies to farm roads. To qualify for a section 404(f) exemption, a forest or farm road must comply with the requirements of 33 CFR 323.4(a)(6), 33 CFR 323.4(b), and 33 CFR 323.4(c) (implementing section 404(f)(2)). The forest or farm road must be part of an ongoing silvicultural, farming, or ranching operation that complies with the BMP's of 33 CFR 323.4(a)(6).

National Pollutant Discharge Elimination System (NPDES)

At the heart of the Clean Water Act is the NPDES, which regulates both direct and indirect discharges of pollutants into surface waters. The act makes unlawful the discharge of any pollutant from a point source into surface waters without a permit. Thus, no one has the right to add pollutants to water unless expressly permitted to do so.

Under the CWA, two types of regulation control the discharge of pollutants—those that are "water quality based" and those that are "technology based." Requirements that are water quality based limit permissible amounts of pollutants allowed in a defined water body or segment of a water body. The amount of allowable pollution is based on the capacity of the receiving water to accept or absorb a pollutant and varies according to the beneficial use of the water. A beneficial use is defined as a use for recreation, industrial, or public drinking water (CWA section 303(c)). The ability of a receiving water to accept pollution is a function of the size and flow of a stream, existing water quality conditions, the type of pollutant, and other site specific factors.

Standards that are technology based tend to dominate the CWA regulatory system. These standards focus on the treatment of a pollutant before it is discharged into a stream and define a level of effluent quality that is achievable using the best available pollution control technology. All dischargers must meet minimum treatment requirements. Additionally, toxics—a special class of harmful pollutants—are singled out for special treatment by the CWA.

Water quality standards (designated beneficial uses and the criteria to protect those uses) are implemented and enforced through compliance with the NPDES as administered by the EPA. Under section 402 of the CWA, a discharger must obtain an NPDES permit from the EPA or from a State that has an EPA-certified program (CWA section c 402(b)). Water quality standards (both water quality based and technology based) are written into permits according to the particular situation that exists at a given site. The standards consider the type of pollutant and the condition and beneficial use of the receiving waters. NPDES permits are issued for 5 years and may include requirements for monitoring and reporting of discharge effluents. Discharging pollution without a permit or violation of the terms or standards of an issued permit may result in civil and criminal penalties.

Compliance with the terms of an NPDES permit meets almost all of the CWA's regulatory provisions and may be achieved under State authority. A delegated State program is bound by many of the same statutory requirements applicable to the Federal program. The EPA's goal is to give States the authority to administer and enforce the NPDES program in its entirety. All of the States within the Assessment area have NPDES permitting authority.

Specific requirements for the issuance of an NPDES permit are described in CWA 402(a)(1). The NPDES permit system is an effective means of controlling discharge wastes from discrete point sources that are easily identifiable (e.g., industrial facilities, municipal water treatment plants, and combined sewers).

Silvicultural activities, excluded from NPDES permitting requirements per 40 CFR 122.3(3), July 1, 1990, include "Any introduction of pollutants from nonpoint source agricultural and silvicultural activities including storm water runoff from . . . range lands and forest lands . . . but not discharges from silvicultural point sources as defined in section 122.7" (section 122.3(e)). Section 122.7 defines a silvicultural point source as ". . . any discernible, confined, and discreet conveyance related to rock crushing, gravel washing, log sorting, or log storage facilities" that is operated in connection with silvicultural activities and from which pollutants are discharged into the waters of the United States. (Log sorting and storage facilities are those facilities of a relatively permanent nature found at mills and major reloading facilities. Landings authorized under a timber sale contract are part of the harvesting activities and do not fall into this category.) Section 122.7 does not address nonpoint source silvicultural activities such as "nursery operations, site preparation, reforestation and subsequent cultural treatment, thinning, prescribed burning, pest and fire control, harvesting operations, surface drainage, or road construction and maintenance from which there is natural runoff."

While the requirements for use designations and water quality criteria result in fairly uniform water quality standards among States, actual implementation of standards varies considerably due to provisions in some State standards for mixing zones to dilute pollution. These provisions can also result in variability in NPDES permit limit requirements.

Total Maximum Daily Loads (TMDL's), Section 303(d)

Section 303(d) of the Clean Water Act requires States to prepare a list of impaired surface waters and to develop a priority ranking for the determination of total maximum daily loads (TMDL's). The TMDL's guide implementation of State water quality standards. A TMDL is the sum of (1) a waste load allocation (WLA), or that portion of a surface water's loading capacity that is allocated to an existing or future point source discharge; (2) a load allocation (LA), or that portion of the surface water's loading capacity that is due to either existing or future nonpoint source pollution or to natural background sources; and (3) a margin of safety (MS), or that portion of a surface water's loading capacity that is allocated to uncertainty. The relationship is represented by TMDL = WLA + LA + MS. States are required to identify and list water bodies where water quality standards are not met following the application of technology-based controls and to establish TMDL's for these water quality limited waters. The EPA is required to approve or disapprove State lists and TMDL's and to develop lists and TMDL's when States fail to do so.

Antidegradation Policy

Even though the CWA recognizes that States have the authority to set their own water quality standards, the EPA reviews the State's standards and has the authority to supersede those that do not meet minimum Federal requirements. For example, a State must designate "beneficial uses" for its waters such as "fishable" or "swimmable" that are consistent with criteria established in the CWA. Furthermore, State water quality criteria must be shown to protect the designated uses, and the criteria must be at least as stringent as Federal guidelines.

The EPA requires that State water quality standards include "a statewide antidegradation policy" to ensure that existing instream water uses and the level of water quality necessary to protect the existing uses be maintained. This policy requires that State standards be sufficient to maintain existing beneficial uses of navigable waters and prevent their further degradation. The policy sets a three-tiered approach for water quality protection. Tier I maintains and protects existing uses and the water quality necessary to protect these uses. Tier II protects the water quality where it is better than that necessary to protect fishable or swimmable uses. Tier III prohibits a lowering of existing water quality standards.

States are allowed to designate Outstanding Resource Waters (ORW's), which are given the highest level of protection—Tier III—under the Antidegradation Policy (40 CFR 131).

Nonpoint Source Pollution Control

Nonpoint source pollution is defined as diffuse sources of pollution not regulated as point sources (U.S. EPA 1987). Nonpoint sources of pollution include atmospheric deposition (e.g., acid rain); contaminated sedimentation (untraceable pollutants found in streambed sediment); and many widely distributed activities that disturb land and may generate polluted runoff (e.g., agricultural activities, logging operations, and onsite sewage disposal). The control of nonpoint source pollution is somewhat more difficult than point sources regulated under the NPDES. Nonpoint source pollution is less visible, less traceable, and thus more difficult to control through applying pre-established criteria.

Siltation and nutrients are most often associated with nonpoint source impacts to water resources. In 1992, the EPA reported that nonpoint sources of pollution are more widespread than point sources and introduce vast quantities of pollutants into our Nation's waters (U.S. EPA 1992c). Agricultural activities accounted for 72 percent of the Nation's impaired rivers. Reporting States pointed out that siltation and nutrients affected 45 and 35 percent of all impaired stream miles, respectively. Nationally, silviculture (forestry) accounted for approximately 8 percent of the impaired river miles.

Such a national survey may not capture regional differences and variability in land use. For example, a region that is predominantly industrial and urban would produce a much different type of nonpoint source pollution than one dominated by agricultural or forestry activities. Furthermore, because it is impractical for States to report on the quality of all streams, only 18 percent of the Nation's 3.5 million miles of rivers were assessed in the summary document. Notwithstanding the limitations of such a survey, the scientific community and regulatory agencies generally recognize that nonpoint source pollution is one of the major water quality issues to contend with in the future (U.S. EPA 1989a).

Section 319

As early as 1972, Congress recognized the need to establish a nationwide program to control nonpoint sources (section 208—FWPCA). In 1987, it enacted section 319 of the CWA. The following language was added to CWA section 101(a)(7): "It is the national policy that programs for the control of nonpoint sources be developed and implemented in an expeditious manner so as to enable the goals of this Act to be met through the control of both point and nonpoint sources of pollution."

Section 319 requires States to assess their waters and to develop management programs to control and reduce specific nonpoint source pollution. The section further authorizes Federal loan and grant funds to assist States, units of local government, conservation districts, individuals, farmers, and foresters in managing nonpoint source pollution. Consistent with section 319, States are completing their assessments and management programs that, after review by the EPA, will serve as the cornerstone for the national nonpoint source pollution program (U.S. EPA 1989a). All States within the Assessment area have implemented or are designing programs to implement water quality BMP's to control nonpoint source pollution.

The primary mechanism for regulating nonpoint source pollution is the adoption and implementation of BMP's. The EPA describes BMP's as: "Methods, measures, or practices selected by an agency to meet its nonpoint control needs. BMP's include but are not limited to structural and nonstructural controls and operation and maintenance procedures. BMP's can be applied before, during, and after pollution producing activities to reduce or eliminate the introduction of pollutants into receiving waters." Specific examples of BMP's include stabilization and treatment of disturbed ground during road construction or the proper placement of waterbars on skid trails during timber harvesting operations.

State water quality agencies may certify BMP's for Federal agencies conducting activities that disturb land. This certification delegates responsibility to Federal agencies to protect and restore those waters under their jurisdiction. The USDA Forest Service has memoranda of understanding or letters of certification with Arkansas and Oklahoma that confirm that Forest Service BMP's meet current requirements of respective State BMP's. Forest Service standards and guidelines for management activities are designed to meet or exceed all State BMP's.

In a 1994 study of regional BMP's for the South, investigators concluded that, as a whole, forestry represents a relatively minor source of nonpoint source pollution compared to sources such as agriculture, urban development, hydrologic alterations such as dams, and mining activities (NCASI 1994). However, forestry activities can become a significant source of nonpoint source pollution if BMP's are not properly implemented. Two examples of effective BMP compliance programs are Virginia and South Carolina. A study of BMP effectiveness in South Carolina found that during 1990 and 1991, silvicultural BMP's were implemented on 84.7 percent of the harvesting operations (Adams and Hook 1993). A survey of BMP implementation in Virginia during 1994 indicated that BMP implementation averaged 91 to 96 percent for related timber harvest activities (Austin 1994). Both studies concluded that improper implementation of BMP's or a lack of awareness of sensitive areas were the major problems with poor implementation and outcomes of the BMP programs. A recent study of BMP effectiveness monitoring showed no significant impacts to benthic invertebrate communities or water quality when BMP's are followed for forestry activities with proper streamside management (FL DEP 1997).

It has been shown that BMP's can curtail nonpoint source pollution. For example, Swift (1988) found that proper design of forest roads could reduce sediment washing into streams by more than 90 percent. Swift pointed out that guidelines for road design are available to minimize the impacts on water quality from both road construction and use. It is important that such improved technology is transferred from researchers to those involved in forest management as well as to those in industrial, urban, and rural development (Hackney and others 1992).

Implications and Opportunities

In the last 10 years, the Nation has witnessed a significant turning point in water resource legislation and water pollution control. With the passage of the 1987 Water Quality Act, Congress acknowledged the need to strengthen existing laws and create new programs to protect our Nation's waters. Programs specifically designed to deal with such problems as nonpoint source pollution, toxic pollutants, other point source pollution, and the protection of national treasures, such as the Mississippi River and Gulf of Mexico, are examples of this newfound emphasis.

The water pollution regulatory program administered by the EPA has been largely successful in reducing pollution and destruction of the Nation's aquatic resources. Many streams and lakes have gradually recovered from years of abuse and now support abundant aquatic life and provide for swimming and other kinds of recreation. However, recent evidence shows that much work remains to be done to protect and enhance aquatic resources for the future.

Ultimately, the responsibility for meeting the mandates of the CWA falls on society as a whole. Private businesses, citizens, and Federal, State, and local governments all share in this important effort.

Aquatic Restoration Programs

Some federally funded programs to protect, restore, or improve the Nation's aquatic resources have a long history of application in the Assessment area; others are still in the planning stages. A variety of departments and agencies are involved, including U.S. Department of Agriculture agencies (the Forest Service, Natural Resources Conservation Service, and Farm Service Agency), U.S. Department of the Interior agencies (National Park Service, Bureau of Land Management, and Fish and Wildlife Service), U.S. EPA, and the Department of the Army, Corps of Engineers.

Each program is unique and is oriented toward improving specific aspects of the aquatic resource. Some involve specific non-Federal partners and State cooperators; others are open to participation by the general public. All are nonregulatory. A brief synopsis of these programs follows. More detailed information is available from sources listed as points of contact and from individual national forests and State headquarters of the respective agencies.

Bring Back the Natives

This 50/50 challenge cost-share program targets the restoration of native fish habitats. National forests match cooperators (such as Trout Unlimited) to improve conditions for the restoration of native fish populations in streams. The National Fish and Wildlife Foundation receives Federal appropriations; it shares such funds with public and private partners for the same purpose. For additional information, contact the nearest Forest Service national forest supervisor's office (the agency's home page is <http://www.fs.fed.us/>), Trout Unlimited chapter (Web site is <http://www.tu.org/index.html>), or the National Fish and Wildlife Foundation (Web site is <http://www.nfwf.org/bbn/bbn.htm>).

Challenge 21

Challenge 21 is a new Army Corps of Engineers program to expand the use of nonstructural flood reduction measures and allow for more effective coordination of Federal programs on a watershed basis. The program was developed under the reauthorization of the Water Resources Development Act. The Corps' Web site is <http://cw71.cw-wc.usace.army.mil/>.

Clean Water Action Plan

A new initiative, the Clean Water Action Plan, focuses on partnerships between Federal agencies, State agencies, and public and private cooperators to solve water quality related problems on a watershed basis. The initiative will also target riparian restoration, grazing allotment strategies, forest road management, and other stewardship activities on Federal lands. More information can be obtained at the following USDA and EPA Web sites: <http://www.nhq.nrcs.usda.gov/cleanwater/index.html> or <http://www.epa.gov/cleanwater/action/overview.html>.

Conservation Reserve Program (CRP)

Administered by the Farm Service Agency, the Conservation Reserve Program (CRP) reduces soil erosion, reduces sedimentation in streams and lakes, improves water quality, establishes wildlife habitat, and enhances forest and wetland resources. The program encourages farmers to convert highly erodible cropland or other environmentally sensitive acreage to vegetative cover such as tame or native grasses, wildlife plantings, trees, filterstrips, or riparian buffers. Farmers receive an annual rental payment for the term of the multiyear contract. Cost sharing is provided to establish the vegetative cover practices. The Conservation Reserve Enhancement Program is a new subprogram of the CRP that focuses on riparian restoration and protection and sets criteria for enrolling land based on location, watershed characteristics, and conservation practices that can be demonstrated to be of unusually high environmental value. State agencies submit the plans. The primary benefit of such a program is that landowners who meet these criteria can enroll in CRP automatically without participating in the bidding process. For additional information, contact a local Farm Service Agency office or the agency's Web site at <http://www. fsa.usda.gov/>.

Conservation Technical Assistance (CTA) Program

The Natural Resources Conservation Service offers technical assistance through conservation district offices to private agricultural landowners under the Conservation Technical Assistance program. Farm plans are prepared with recommended conservation operations such as erosion control, stream channel improvement, stream crossings, and riparian area protection. The Natural Resources Conservation Service identifies cost-share options and other programs that the landowner may wish to pursue to implement the plan. Contact any Natural Resources Conservation Service district conservationist for additional information and/or the agency's home page on the Web at <http://www.nrcs.usda.gov/>.

Emergency Watershed Protection (EWP) Program

The Natural Resources Conservation Service, in conjunction with other agencies, manages the Emergency Watershed Protection (EWP) program to restore stream channels, remove blockages, stabilize landslides, and solve flooding problems caused by catastrophic natural events. Restoration of watershed conditions following hurricanes, tornadoes, fires, and other storm events is provided for both private and public lands, depending on the source of problems. Costs on these improvements can be shared or a project can be fully funded, depending on the immediacy of the need for treatment. Contact a State conservationist for additional information or the EWP "Fact Sheet" at <http://www.nhq.nrcs.usda.gov/CCS/ewpFs.html>.

Environmental Quality Incentives Program (EQIP)

The Natural Resources Conservation Service administers the new Environmental Quality Incentives Program (EQIP) that combines the functions of the Agricultural Conservation Program, Water Quality Incentives Program, Great Plains Conservation Program, and the Colorado River Basin Salinity Control Program. The EQIP establishes conservation priority areas where significant water, soil, and other natural resource problems exist and establishes 5- to 10-year technical assistance contracts and up to 75 percent cost share for manure management, pest management, and erosion control. Information on other incentive programs such as the Wildlife Habitat Incentives Program funded under the 1996 Farm Bill can be found at the following Web site: <http://www.nhq.nrcs.usda.gov/>. Contact any Natural Resources Conservation Service area office for additional information.

Fisheries Across America

This USDI Fish and Wildlife Service's cost-share program provides for aquatic habitat improvement, with emphasis on information and education. Contact the Regional Fish and Wildlife Service office in Atlanta, GA (for Arkansas), Albuquerque, NM (for Oklahoma), or Minneapolis, MN (for Missouri) for additional information and/or the agency's Web site <http://www.nwi.fws.gov/>.

Forestry Incentives Program (FIP)

The Forestry Incentives Program (FIP), administered by the Natural Resources Conservation Service, supports forestry BMP's on privately owned, nonindustrial forest lands nationwide. FIP is designed to benefit the environment while meeting future demands for wood products. Eligible practices are tree planting, timber stand improvement, site preparation for natural regeneration, and other related activities. FIP is available in counties designated by a Forest Service survey of eligible private timber acreage. Contact a State or regional office of the Natural Resources Conservation Service for more information on FIP and/or the agency's home page at <http://www.nrcs.usda.gov/>.

Partners for Wildlife

Partners for Wildlife offers technical and financial assistance to private landowners of degraded wetlands or other wildlife habitat. The Fish and Wildlife Service provides the funds for restoration work administered under a cooperative agreement with the landowner. Lands received by easement or fee title transfer by the Farm Services Administration are also eligible for habitat restoration using these funds. Contact the Regional Fish and Wildlife Service office in Atlanta, GA (for Arkansas), Albuquerque, NM (for Oklahoma), or Minneapolis, MN (for Missouri) for additional information and/or the agency's Web site at <http://www.nwi.fws.gov/>.

Rivers, Trails, and Conservation Assistance Program

The National Park Service's Rivers, Trails, and Conservation Assistance Program is oriented toward local and State governmental agencies. It helps carry out statewide river assessments, wild and scenic river studies, and river conservation strategies. Contact the Midwest Regional Office in Omaha, NB, for additional information or the agency's Web site at <http://www.nps.gov/rtca/>.

Section 319 Nonpoint Source Program

This EPA program provides grants to State water quality agencies to carry out nonpoint source pollution planning and management activities. Approximately half of the grant is used to implement and manage the overall nonpoint source program; the remainder is intended to demonstrate BMP's on the ground. While the EPA provides grants primarily to States, cooperators and subgrantees can include public agencies, watershed associations, universities, and private landowners. Practices must be oriented to nonpoint pollution prevention or abatement, and projects must include public education and technology transfer components. Contact the State water quality management agency for additional information or visit this agency's Web site at <http://www.epa.gov/>.

Section 1135 Program

The section 1135 program, aimed at cost sharing with local sponsors to improve degraded fish and wildlife habitat, is associated with such Corps of Engineers water projects as impoundments and channel maintenance activities. For example, 1135 funds helped on a cost-share basis to reconnect former oxbows and construct fish ladders to facilitate migration around dams. Contact any district office of the Corps of Engineers for additional information. The agency's Web site is <http://cw71.cw-wc.usace.army.mil/>.

Small Watershed Program and Flood Prevention Program

This program authorizes the Natural Resources Conservation Service to initiate cooperative watershed studies in which both on- and off-site soil and water resource impacts are analyzed and corrective actions recommended. Programs occur only in some watersheds (with 250,000 or fewer acres) having clearly identified needs and a local sponsoring organization. The Forest Service provides technical assistance to the Natural Resources Conservation Service for forestry analysis.

Typically the lands involved are private, but public lands may be either treated or utilized to help solve problems originating on private land. Flood control structures are an example of a measure taken, often on public land and for public benefit, to solve problems generated by upstream activities on private land. If the Natural Resources Conservation Service determines that recommended improvement measures are cost effective and funding is secured, cost sharing becomes available. Contact a local Natural Resources Conservation Service district conservationist for additional information and/or the following Web page: <http://www.nrcs.usda.gov/NRCSProg.html#Anchor-Watersheds>.

State and Private Forestry, Cooperative Forestry

Administered by the Forest Service, Cooperative Forestry programs offer landowner assistance, natural resource conservation education, urban and community forestry, and economic action programs. Further information is available on the Internet at this Web site: <http://willow.ncfes.umn.edu/coop/coop.htm>.

Stewardship Incentives Program (SIP)

The Stewardship Incentives Program (SIP), administered by the Forest Service but delivered at the State level by State forestry agencies, provides funds for the development of stewardship plans for private, non-industrial landowners. These plans provide for such activities as timber and wildlife management, recreational use, and water quality improvement. Landowners agree to carry out practices compatible with the plan and can receive cost-share assistance for approved practices. State forestry agencies establish most of the terms of the approved practices (e.g., wildlife habitat improvement, reforestation, and erosion control). An interagency stewardship committee guides the program statewide. Eligible landowners must have an approved Forest Stewardship Plan and own 1,000 or fewer acres of qualifying land. Authorizations may be obtained for exceptions of up to 5,000 acres. Contact the nearest Forest Service office (home page <http://www.fs.fed.us/>) or the local county forester for additional information.

Watershed and River Basin Planning and Installation (Public Law 566)

This Department of Agriculture program, coordinated by the Natural Resources Conservation Service, provides technical and financial assistance (in cooperation with local sponsoring organizations, State, and other public agencies) to plan and install watershed-based projects on private lands to create and restore wetlands. Some of the purposes for watershed projects are flood prevention; soil erosion reduction; protection of rural, municipal, and industrial water supplies; sedimentation control; and fish and wildlife habitat enhancement. Contact a State conservationist for additional information and/or the following Web site: <http://www.ftw.nrcs.usda.gov/pl566/pl566.html>.

Wetlands Reserve Program (WRP)

The Wetlands Reserve Program (WRP), administered by the Natural Resources Conservation Service, funds the purchase of easements on private wetlands and follows up on wetland restoration and revegetation efforts. Eligible lands include altered but restorable wetlands and adjacent, critical nonwetlands. The Natural Resources Conservation Service and Fish and Wildlife Service develop management plans with which landowners agree. Landowners then become responsible for 25 percent of the restoration cost and maintenance. Land use is restricted to activities compatible with maintaining wetland functions. All 50 States are eligible for the program.

The revised WRP required that, beginning on October 1, 1996, one third of the total program acres be enrolled in permanent easements, one third in 30-year easements, and one third in cost-share agreements for restoration only. Individuals may choose the category for their eligible land when they apply. Contact any Natural Resources Conservation Service area office for additional information and/or the agency's home page at <http://www.nrcs.usda.gov/>.

Implications and Opportunities

To fulfill the goals of the Clean Water Act and related watershed improvement incentive programs, State and Federal agencies administer laws, policies, and programs for aquatic resource protection. Water quality and riparian problems still persist in some watersheds of the Assessment area, but cooperative approaches for restoration and protection have improved and protected conditions of some aquatic ecosystems. Although USDA and other Federal agencies have had local successes with various restoration and stewardship programs and regulatory agencies have had similar successes with water quality enforcement and nonpoint source grant programs, results have not been quantified or evaluated in the Assessment area. No conclusion, therefore, can currently be drawn about the effectiveness of laws, policies, and programs on improving aquatic conditions in the Assessment area. Such an evaluation might prove very valuable in identifying and implementing future laws, policies, and voluntary programs for aquatic resources.

In the future, States, Federal agencies, and local partners will reprioritize actions to restore watersheds and aquatic resources. These efforts will need to be at a large enough scale to include all watershed components such as aquatic ecosystems, terrestrial components, air, and socioeconomic conditions. Finally, the sharing of natural resource information and spatial data among State, Federal, private, and local partners can help achieve goals of both the CWA and forest stewardship. This Assessment is an attempt to encourage such sharing in the future.

Chapter 4: Effects of Human Activities

State and Federal Classifications of Water Quality

This first section of Chapter 4 discusses some State and Federal classifications of waters within the Assessment area. The Aquatic Team focused on three areas for this discussion: "Outstanding Resource Waters," "Impaired Waters," and "Index of Watershed Indicators." In addition, under the direction of the EPA, each State is currently completing a Unified Watershed Assessment. Because of time constraints, this information was not included in this report. However, information concerning the Unified Watershed Assessment can be found at the following Web site: <http://www.epa.gov/cleanwater/uwafinal/>. Final reports can be found at <http://www.deq.state.ok.us/Water1/home/index.html> for Oklahoma, at <http://www.cares.missouri.edu/mowiap/> for Missouri, and at <http://www.ar.nrcs.usda.gov/uwa/index.htm> for Arkansas.

Outstanding Resource Waters (ORW's)

Question 4.1: Which streams and rivers have been designated as Oustanding Resource Waters by pollution control agencies in Missouri, Oklahoma, and Arkansas?

Outstanding Resource Waters (ORW's) serve as "baselines" against which other waters within the same ecoregion may be compared. These waters include extraordinary (State determined), ecologically sensitive (State determined), and legislatively designated (State or Federally designated) streams and lakes. Extraordinary waters are those recognized by the States as having exceptional combinations of physical, chemical, and biological characteristics that sustain healthy aquatic habitats. Ecologically sensitive waters provide habitat for threatened, endangered, or endemic aquatic or semi-aquatic species. Legislatively designated waters in the Assessment area include the National Wild and Scenic River System and State scenic river systems.

Within the framework of the Clean Water Act (CWA), each State designates its own ORW's and develops an antidegradation policy that stipulates that designated uses of a water body (e.g., public water supply and recreation) cannot be impaired to allow greater discharge of pollutants into that water body. The CWA prohibits any lowering of existing water quality in ORW's. For further discussion of the CWA, see Chapter 3 of this report. See Chapter 5 of the *Ozark-Ouachita Highlands Assessment: Social and Economic Conditions* (USDA FS 1999a) for a further discussion of legislatively designated waters and their associated recreational activities.

Key Findings

1. There are 4,113 stream miles of extraordinary, ecologically sensitive, and legislatively designated waters within the Assessment area. A single body of water may fall within more than one of these categories.
2. Of those miles, 17 percent occur on or adjacent to national forest lands.

Data Sources and Methods of Analysis

The Aquatic Team used maps and descriptions from each State's water quality regulations (AR DPCE 1991, MO DNR 1996a, OK WRB 1996) to include extraordinary, ecologically sensitive, and legislatively designated waters on the EPA's River File version 3 (RF3) data layer. While the Aquatic Team made every effort to accurately depict the characteristics of these waters of the Assessment area, errors are present because of the difficulty of locating stream segments (many stretches of extraordinary waters were simply based on stream names). Because of this difficulty and occasional differences in stream densities mapped on the RF3 layer, the Aquatic Team analyzed and displayed the identified extraordinary waters using the EPA's River File version 2 (RF2) data layer. Unfortunately, this data base identifies a stream as an ORW only and does not identify mapped stream segments as extraordinary, ecologically sensitive, or legislatively designated. The Aquatic Team identified streams within national forest lands by intersecting stream segments with each forest's ownership layer. All stream mileages were taken from the RF2 data.

Patterns and Trends

State agencies are responsible for monitoring extraordinary, ecologically sensitive, and legislatively designated waters. As of late 1997, 4,113 stream mi in the Assessment area fit within one or more of these categories (table 4.1 and fig. 4.1).

National forests occupy only about 9 percent of the Assessment area, but 17 percent of all extraordinary, ecologically sensitive, and legislatively designated waters occur on or near national forest lands. A significant percentage of ORW's exist on lands managed by the National Park Service as well, but the team did not develop quantitative estimates for them. The U.S. Army Corps of Engineers and various State agencies are responsible for smaller percentages of the region's ORW's.

Table 4.1—Miles of Assessment area streams classified as Outstanding Resource Waters (ORW's) (by State and national forest), portion of these ORW's in the States and national forests, and portion of the Assessment area occupied by each national forest

State, national forest	Length of ORW's	Portion of ORW stream miles	NF lands as portion of Assessment area
	Miles	------- *Percent* -------	
Oklahoma	563	14	
Arkansas	3,089	75	
Missouri	461	11	
Total	4,113	100	
Ouachita NF	364	9	3
Ozark NF	226	5	2
Mark Twain NF	111	3	3
Total	701	17	9[a]

ORW's = Outstanding Resource Waters; NF = national forest.

[a] Difference in total is a result of rounding.

The 1996 land exchange between the Ouachita National Forest and Weyerhaeuser Corporation increased the percentage of extraordinary and ecologically sensitive waters within the Ouachita National Forest, particularly in Oklahoma. With the possible exception of Crooked Creek in Arkansas, which has been proposed as an extraordinary stream, no other additions or removals of streams from the network of ORW's in the Highlands are likely in the near future. See Chapter 5 of this Assessment's *Social and Economic Conditions* (USDA FS 1999a) for a list of streams that might be considered for special Federal or State designations over the next 5 to 10 years.

Implications and Opportunities

Some of the richest and highest quality streams in the Highlands are located on national forests and national rivers, where their careful stewardship is a high priority. Application of appropriate best management practices (BMP'S) in watersheds feeding into these streams is critical to their long-term health.

The precise locations of ORW's are not available in digital format, hampering computer analysis. An opportunity exists for the national forests and State agencies to work together to develop an accurate, complete data base of ORW's of the Highlands.

Impaired Waters

Question 4.2: Which waters have pollution control agencies in Missouri, Oklahoma, and Arkansas determined to be impaired or threatened, and what are the suspected sources of impairment?

As a result of the CWA, each State is responsible for identifying impaired or threatened waters. Impairment occurs when a water body is not fully supporting its designated beneficial uses (e.g., as a domestic water supply, swimming area, or fishery). Impairment may result from a point source (such as untreated sewage flowing out of a pipe directly into a water body or one of its tributaries) or a nonpoint source (such as erosion moving from a field into a stream). After a State

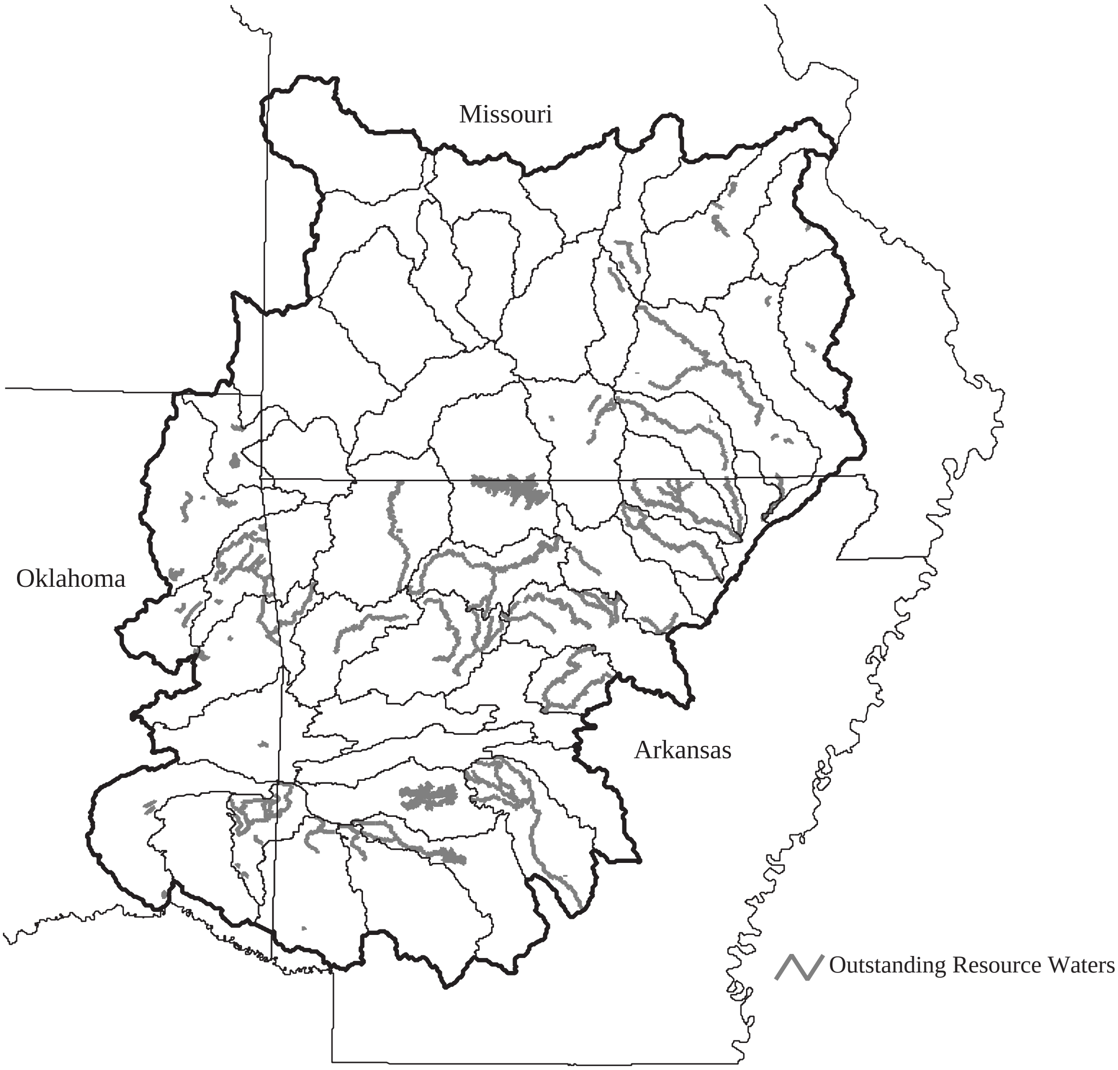


Figure 4.1—Locations of Outstanding Resource Waters (ORW's) within the Assessment area.

pollution control agency monitors and evaluates streams and lakes to see if their beneficial uses are being protected, the State designates contaminated waters as impaired or threatened. At a minimum, each State must list the contaminant(s) and probable source(s) of contaminants affecting each impaired or threatened water body. (For this report, a contaminant is defined as an unwholesome or undesirable element that causes water to be unfit for use, e.g., raw sewage in a lake used for fishing and swimming. A contaminant source (or source of impairment) is the origin of the undesirable element, e.g., a factory could be a primary source and a dairy farm could be a secondary source of bacteria that impairs a stream.)

Each State formally reports the results of its monitoring efforts to the EPA, including impaired water bodies as is required under section 303(d) of the CWA. These lists were taken from the State 305(b) reports to Congress (AR DPCE 1996, MO DNR 1994, OK DEQ 1996). While these reports are rich in information, the Aquatic Team listed impaired streams by contaminants and sources of contaminants only to allow for a common discussion of impaired waters within the Assessment area among the three States.

Key Findings

1. The State 305(b) lists identify 5,588 mi of impaired streams within the Assessment area.
2. The predominant sources of impairment of water quality (primary and secondary sources combined) within the Assessment area are agriculture (36.1 percent), unknown (10.9 percent), and mining (10.2 percent).
3. Of the 5,588 mi of impaired streams, 133 are associated with national forest lands.
4. Major sources of impairment for stream segments within national forest lands include agriculture, road construction, and silviculture.

Data Sources and Methods of Analysis

The Aquatic Team took the lists of threatened or impaired waters from the 1996 305(b) reports from Oklahoma and Arkansas and from the 1994 Missouri 305(b) report (AR DPCE 1996, MO DNR 1994, OK DEQ 1996). The team then linked these reported impaired streams with the EPA's RF3 data base. To simplify data, the team analyzed the results in EPA's River File version 1 (RF1) data layer and then categorized the data by the source of contamination. Stream mileages were taken from the EPA's RF1 data layer.

The team sorted the data for stream segments having their centers within national forest lands. The original data from Oklahoma and Missouri were not linked to a Geographic Information System (GIS) layer or data base; therefore, the team entered these data based on maps or narratives. As a result, all stream mileages are based on the developed GIS layers and will not necessarily match published values. Because each State uses different criteria for monitoring and reporting, the Aquatic Team identified impaired waters only rather than all waters monitored by the States.

Patterns and Trends

Within the Assessment area, the State 305(b) reports identify 5,588 mi of stream as not fully supporting or only partially supporting beneficial uses (table 4.2). Figure 4.2 displays the locations of those impaired streams. The majority of impaired streams occur in

Table 4.2—Stream miles within the Assessment area identified as impaired in State 305(b) reports by primary and (where known) secondary source(s) of contamination

Source of contamination (primary, secondary)	Miles[a]	
Acid deposition	320	
Agriculture	1,022	
Agriculture, acid deposition	2	
Agriculture, flow modification	73	
Agriculture, industry	53	
Agriculture, mining	362	
Agriculture, municipal	283	
Agriculture, natural	369	
Agriculture, riparian modification	41	
Agriculture, road construction	280	
Agriculture, silviculture	328	
Agriculture, urban	74	Flow
regulation	1	Flow
regulation, unknown	19	
Industry	42	
Industry, municipal	18	
Mining	269	
Mining, municipal	43	
Mining, natural	158	
Mining, unknown	9	
Municipal	143	
Municipal, agriculture	24	
Municipal, industry	24	
Municipal, road construction	40	
Municipal, unknown	21	
Natural	9	
Road construction	21	
Road construction, agriculture	39	
Road construction, municipal	48	
Road construction, silviculture	110	
Silviculture, acid deposition	193	
Unidentified	274	
Unknown	838	
Unknown, agriculture	10	
Urban, agricultural	19	
Urban, natural	11	
Total	5,588	

[a] Rounded to nearest whole number.

Source: AR DPCE (1996), MO DNR (1994), OK DEQ (1996).

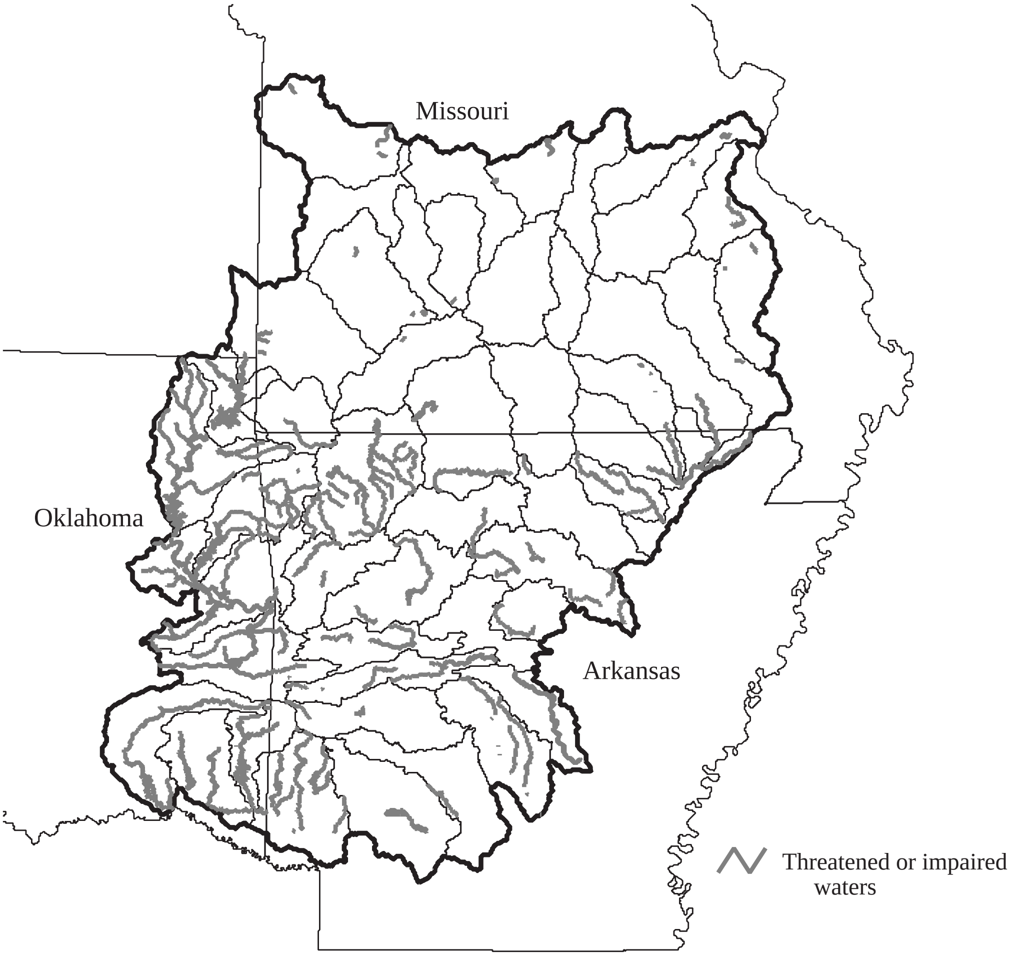


Figure 4.2—Locations of impaired streams within the Assessment area as identified in the Oklahoma, Missouri, and Arkansas 305(b) reports.

Oklahoma and Arkansas. However, this is a result of each State's reporting process and is not necessarily indicative of a negative trend in water quality.

By combining the primary and secondary sources of impairment and expressing the associate stream mileages as a percent, the team found that agriculture (as either a primary or secondary source) is the major source (36.1 percent) of impairment to water quality across the Assessment area (table 4.3). The "unknown" source on table 4.3 is primarily linked to bacteria, alterations of pH, and suspended solids and is the second greatest "source" of contamination, representing 10.9 percent of the impaired streams. Mining, the third greatest source of impairment, contaminates 10.2 percent of all affected streams.

Of the 5,588 mi of impaired streams within the Assessment area, 133 are associated with national forest lands (table 4.4). The Aquatic Team arrived at this figure by summing the lengths of stream segments that had their centers within national forest land. This exercise determined whether the impaired stream segments are on national forest lands, not whether the source of impairment is on national forest lands or other lands upstream (i.e., although a stream segment within national forest boundaries may be impaired, the source of the impairment may have come from sources upstream, outside the national forest boundaries). The team found that major sources of impairment on stream segments within national forest boundaries include agriculture, road construction, and silviculture.

Table 4.3—Sources (primary or secondary) and types of contaminants and their relative contributions to stream impairment in the Assessment area[a]

Contaminant source	Contaminant(s)	Portion of impaired stream miles
		Percent
Acid deposition	Altered pH	6.2
Agriculture	Bacteria, nutrients, organics, pesticides, and siltation	36.1
Flow regulation	Flow alteration, nutrients, organics, and siltation	1.1
Industry	Bacteria, minerals, and nutrients	1.7
Mining	Metals, minerals, nutrients, organics, altered pH, unknown toxic, and siltation	10.2
Municipal	Bacteria, minerals, nutrients, and organics	7.8
Natural	Metals, altered pH, and unknown toxic	6.6
Riparian modification	Habitat alterations	0.5
Road construction	Siltation	6.5
Silviculture	Pesticides and nutrients	7.7
Unidentified	Nutrients	3.3
Unknown	Bacteria, mercury, noxious plants, nutrients, organics, pesticides, altered pH, siltation, suspended solids, and unknown toxic	10.9
Urban	Nutrients, organics, and pesticides	1.3

[a] Total is less than 100 percent due to rounding; see "Glossary of Terms" for definitions of impairment, contaminant source, and contaminant.
Source: AR DPCE (1996), MO DNR (1994), OK DEQ (1996).

Table 4.4—Stream miles within national forests affected by contaminants, as identified in State 305(b) reports showing primary and (where listed) secondary sources and associated contaminants

National forest	Stream miles	Contaminant source(s)	Contaminant(s)
Mark Twain	5.11	Agriculture	Siltation
Total	5.11		
Ouachita	8.79	Acid deposition	Altered pH
	24.71	Agriculture	Siltation and bacteria
	2.90	Agriculture, industry	Siltation and bacteria
	24.72	Road construction, silviculture	Siltation
	3.92	Unknown	Bacteria, pesticides, and altered pH
Total	65.04		
Ozark	1.74	Agriculture, mining	Siltation and nutrients
	2.16	Agriculture, road construction	Siltation
	35.76	Agriculture, silviculture	Siltation
	8.20	Municipal	Bacteria
	15.10	Road construction, municipal	Siltation and bacteria
Total	62.96		
Grand total	133.11		

Source: AR DPCE (1996), MO DNR (1994), OK DEQ (1996).

Implications and Opportunities

The Forest Service needs to work closely with appropriate State agencies to share data and resources related to monitoring and evaluating waters in and near national forest lands. Where monitoring identifies problems on public lands, joint State and Federal remedies can be sought. Where impaired streams cross multiple ownerships, opportunities exist for cooperative watershed improvement efforts among willing landowners, local organizations, the Forest Service, and other agencies.

EPA Index of Watershed Indicators (IWI)

Question 4.3: How does the condition of Assessment area watersheds compare with the rest of the United States?

The Index of Watershed Indicators (IWI) is an EPA program designed to describe broadly the condition and vulnerability (sensitivity) of aquatic systems in each of the 2,111 watersheds of the continental United States. This index establishes baseline conditions and allows scientists and others to monitor progress toward achieving clean water goals at the watershed scale. The IWI uses watersheds (hydrologic units with an eight-digit code) as its basic units. Fifty of these watersheds occur within the Assessment area.

Key Findings

1. Of the 50 watersheds within the Assessment area, 24 (48 percent) are designated as having "better water quality and low vulnerability to stressors" (pollutants that could further strain the aquatic resource). Nationwide, EPA gave this rating to only 9 percent of watersheds.
2. Within the Assessment area, only the Spring watershed in the Neosho-Illinois River Basin has a rating of "more serious water quality problems and high vulnerability to stressors." The South Grand and Fourche La Fave watersheds are in the following class: "more serious water quality problems and low vulnerability to stressors."

Data Sources and Methods of Analysis

The EPA compiled the data base using individual State 305(b) reports for information about (1) rivers that meet designated uses set in State and tribal water quality standards, (2) indicators of source water conditions for drinking water systems, and (3) contaminated sediments. States also provided consumption advisories concerning potential problems involved with eating fish and wildlife found in the Assessment area. Indicators of source water conditions for drinking water systems and water quality data for pollutants came from the EPA's data STOrage and RETrieval system (STORET). (For more information on this water quality data base, see the Web site at <http://www.epa.gov/owow/STORET>.) Wetlands loss was determined using the USDA, Natural Resources Conservation Service, National Resource Inventory (NRI) data base. (For more information about the NRI, see <http://www.nhq.nrcs.usda.gov/NRI/intro.html>.)

Vulnerability scores of pollutant loads above permitted discharge limits are taken from the National Pollutant Discharge Elimination System (NPDES) permits. A watershed with low vulnerability suggests pollutants or other stressors are low, and, therefore there exists a lower potential for future declines in aquatic health. Actions to prevent declines in aquatic conditions in these watersheds are appropriate but at a lower priority than in watersheds with higher vulnerability. The index of agricultural runoff potential is taken from the NRI data base. Population change is taken from USDC Bureau of the Census data. Hydrologic modification caused by dams is taken from the National Inventory of Dams data base. Urban runoff potential is derived from the EPA's Urban Runoff Potential Measure and Bureau of the Census data. Information about aquatic and wetlands species at risk is taken from the Natural Heritage Data Center in each State. The estuarine pollution susceptibility index is derived from Coastal and Estuarine and Marine Eutrophication Vulnerability data.

Watershed condition scores. The EPA assigns a "condition score" to each river within each watershed. The "condition score" is based on the following criteria: (1) whether it meets some or all designated uses set for State and tribal water quality standards, (2) fish and wildlife consumption advisories, (3) indicators of source water condition for drinking water systems, (4) contaminated sediments, (5) ambient water quality data (four toxic pollutants and four conventional pollutants), (6) and wetlands loss index. Condition scores are then categorized as follows:

- Better water quality,
- Water quality with less serious problems, or
- Water quality with more serious problems.

Watershed vulnerability scores. The EPA assigns a vulnerability rating of high or low to watersheds by scoring them according to the following criteria:

- Aquatic and wetlands species at risk,
- Amount of toxic and conventional pollutants discharged above permitted limits,
- Urban runoff potential,
- Index of agricultural runoff potential,
- Population change,
- Hydrologic modification caused by dams, and
- Estuarine pollution susceptibility index (not applicable to the Assessment area).

Condition and vulnerability. These two sets of indicators (condition and vulnerability) are then combined to create the following ratings:

- Better water quality and low vulnerability to stressors,
- Better water quality and high vulnerability to stressors,
- Less serious water quality problems and low vulnerability to stressors,
- Less serious water quality problems and high vulnerability to stressors,
- More serious water quality problems and low vulnerability to stressors,
- More serious water quality problems and high vulnerability to stressors, and
- Insufficient data exists to make an assertion of condition or vulnerability.

Access to more detailed information about IWI is available at: <ftp.epa.gov/pub/iwi/surf/> and through the search engine "Surf Your Watershed" at: <http://www.epa.gov/surf2/>.

To rate "condition," individual data layers received scores of 0—no effect or no information, 1—moderate effect, or 2—the worst case. Assessed rivers meeting all designated uses were weighted with a possible score of 0, 6, 12, or 18. Scores were summed for each watershed. When scores for condition exceed 18, the watershed is considered to have serious water quality problems. Watersheds with combined scores between 8 and 17 are classified as having less serious water quality problems. Scores below 8 are associated with watersheds that have better water quality (once they have been determined to have sufficient data for classification).

The eight stressors for the vulnerability index were summed. Values less than 8 were scored as low vulnerability and values greater than 8 were scored as high vulnerability (U.S. EPA 1997a).

Patterns and Trends

Data for this analysis were accessed in June of 1997. Of the 50 watersheds within the Assessment area, 24 (48 percent) score as having better water quality with a low vulnerability to activities that could further stress the aquatic resource (fig. 4.3). Nationwide, only 9 percent score this high. Compared to the rest of the continental United States, watersheds within the Assessment area generally have a higher water quality and are not readily susceptible to stressors. No watersheds were identified as having better water quality and high vulnerability to stressors. Sixteen watersheds were classified as less serious water quality problems and low vulnerability to stressors, and one watershed (the Lower Neosho watershed in the Neosho-Illinois River Basin) was rated as "less serious water quality problems and high vulnerability to stressors." To simplify figure 4.3, the watersheds with less serious water quality problems and those with high and low vulnerability were combined. Six watersheds had insufficient data to determine condition or vulnerability.

Within the Assessment area, only the Spring watershed in the Neosho-Illinois River Basin scored as having more serious water quality problems with a high vulnerability. This watershed lies in a karst area (a landscape high in limestone and marked by numerous caves and springs) near the intersections of the Arkansas, Missouri, and Oklahoma State lines. Animal wastes and other agriculture-related runoff are the major sources of the water quality problems there. Two other watersheds—South Grand and Fourche La Fave—were classed as having "more serious water quality problems and low vulnerability to stressors." Neither watershed is fully supporting its beneficial uses.

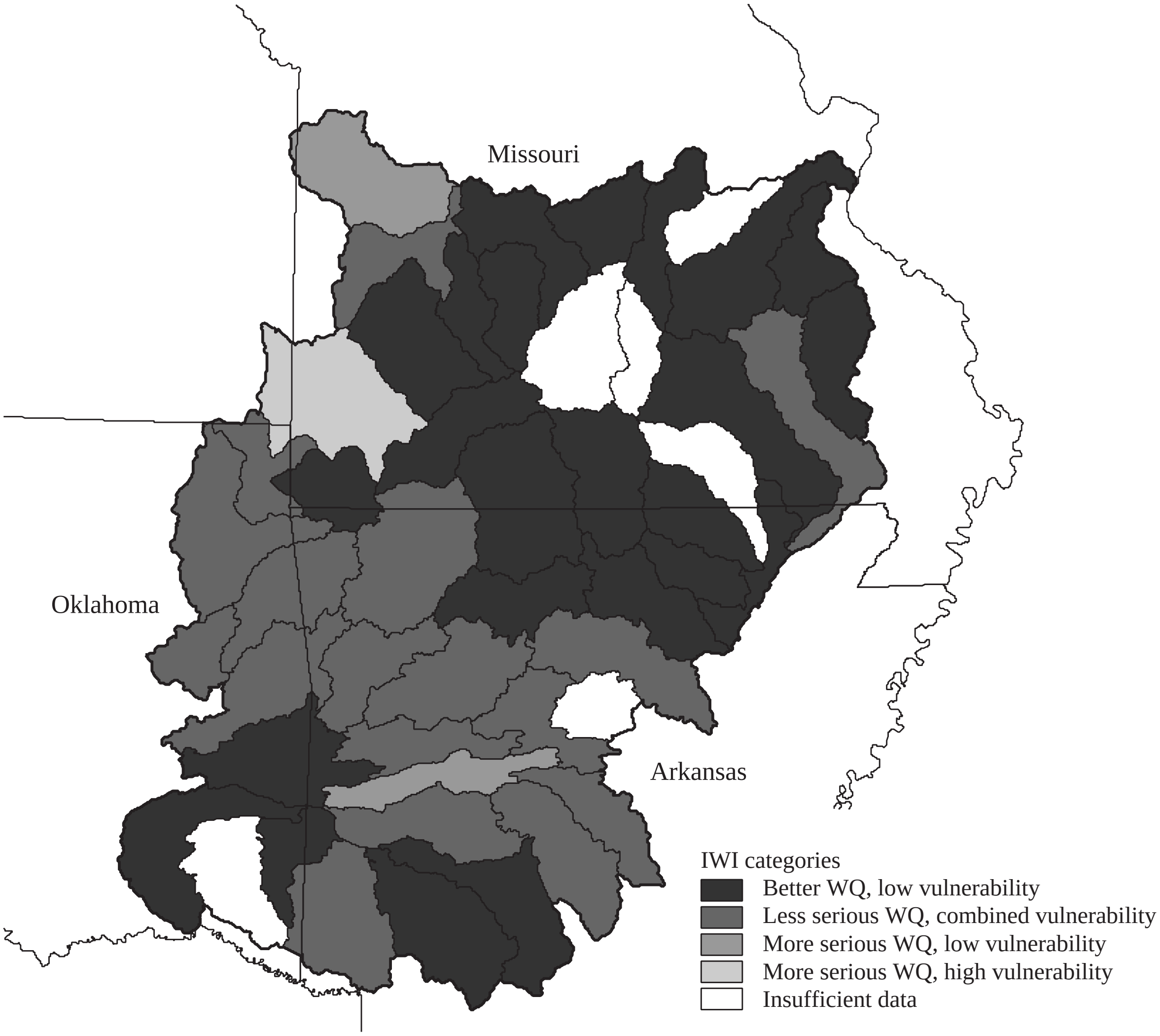


Figure 4.3—Water quality (WQ) categories of Assessment area watersheds as determined by the Index of Watershed Indicators (IWI).

Implications and Opportunities

The IWI, which permits comparisons within and between regions, is a useful index of watershed conditions across the Nation. Regular updating of the IWI would provide measures of progress toward meeting goals for water quality and watershed conditions.

The only watershed with serious water quality problems and an appreciable amount of national forest land is the Fourche La Fave.

Point Sources

Point sources of water pollution are single conveyances from which contaminants enter a stream; they often originate from municipal and industrial processes. Examples of point sources include wastewater discharge pipes, stormwater drains, mine pits, industrial facilities, smokestacks, and ditches.

Unlike nonpoint pollution, water pollution from point sources enters streams or lakes at identifiable locations and can be easily monitored. The 1972 amendments to the CWA prohibit the discharge of any pollutant to navigable waters from a point source unless the discharge is authorized by an NPDES permit. Efforts to improve water quality under the NPDES have traditionally focused on reducing pollutants in discharges of industrial process wastewater and municipal sewage. At the onset of the program in 1972, many sources of industrial process wastewater and municipal sewage were not adequately controlled, thus they represented pressing environmental problems. In addition, discharges from sewer pipes and industrial processes were easily identified as responsible for poor, often drastically degraded water quality conditions. Since enactment of the 1972 amendments to the CWA, significant progress has been made in cleaning up industrial process wastewater and municipal sewage.

The EPA stores information on wastewater dischargers in the Permits Compliance System (PCS). The PCS updates information about dischargers, including locations, permitted volumes and concentrations of discharges, monitoring requirements, and information on permit violations. In addition to the PCS, an EPA data base integrates data from three other major EPA program systems: the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), Toxic Release Inventory System (TRIS), and Resource Conservation and Recovery Information System (RCRIS).

CERCLA and Superfund Sites

Question 4.4: What are the current status and potential effects of hazardous waste sites on aquatic resources within the Assessment area?

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) was enacted in 1980 and amended by the Superfund Amendments and Reauthorization Act of 1986. These acts establish broad authority for the Federal Government to respond to problems posed by the release, or threat of release, of hazardous substances, pollutants, or contaminants. The CERCLA also imposes liability on those responsible for releases and provides the authority for the Government to undertake enforcement and abatement action against responsible parties. The EPA's data base CERCLIS contains information on hazardous waste sites, site inspections, preliminary assessments, and remedial status. Customers have several ways of obtaining access to CERCLIS information. For background on the Superfund, the National Priorities List (which contains hazardous waste sites eligible for long-term cleanup), CERCLA, and CERCLIS, consult the following Web site: <http://www.epa.gov/superfund/>.

Key Findings

1. Within the Assessment area, there are 798 sites in CERCLIS.
2. Of the 798 sites, 15 are Superfund sites on the National Priorities List (NPL).

Data Sources and Methods of Analysis

Data were retrieved from the EPA's CERCLIS and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) data bases (U.S. EPA 1996a, b) and the Right-To-Know Network (1997). A CERCLIS query allows the user to locate and learn about the status of Superfund facilities. The number of sites was normalized by dividing the number of sites by the area of the watershed. This value is then expressed as the number of sites per 1,000 square miles (mi^2).

Patterns and Trends

The CERCLIS data base identified 798 sites within the Assessment area. Watersheds that have the highest number of CERCLIS sites (including Superfund sites) are the Meramec, Spring (Neosho-Illinois River Basin), and Lower Arkansas-Maumelle with 162, 81, and 49 sites, respectively. The Meramec, Lower Arkansas-Maumelle, and Dirty-Greenleaf watersheds have the highest densities of CERCLIS sites with 75, 44.26 and 31.69 sites per 1,000 mi^2, respectively. Currently, the rate of identification of new CERCLIS sites is low. Furthermore, CERCLIS sites are not usually significant sources of the types of pollution that are causing widespread impacts in the Assessment area. Many

CERCLIS sites do not require immediate action, and most have a low priority for future remedial action.

There are 15 Superfund sites in the Highlands: 4 in Arkansas, 1 each in Kansas and Oklahoma (in very close proximity to each other along their shared boundaries), and 9 in Missouri (fig. 4.4). These sites are eligible for extensive, long-term cleanup under the Superfund program. Types of facilities include industrial landfills and mining and wood products facilities. The Superfund sites in the Assessment area generally are found in developed areas such as the Meramec, Sac, and Spring (Neosho-Illinois River Basin) watersheds, which together have 10 of the 15 sites (table 4.5).

Implications and Opportunities

As a whole, the Assessment area does not experience widespread impacts due to CERCLIS sites. However, these contaminated sites can have significant localized impacts on the environment and human health. To address watershed- and landscape-scale impacts, States should assess CERCLIS sites and sanitary landfills that contribute contamination that may be linked to fish advisories or violations of water quality standards in nearby surface and ground water. If current Federal and State hazardous waste management regulations and practices are maintained, the number of CERCLIS sites should decrease over time.

Figure 4.4—Locations of Superfund sites in the Assessment area as reported by Oklahoma, Arkansas, Kansas, and Missouri to the EPA (U.S. EPA 1996a, b). (See table 4.5 for names of watersheds with Superfund sites.)

Table 4.5—Superfund (NPL) and CERCLIS sites within the aquatic study area, by watershed

River basin Watershed name	Watershed code (HUC)	Area	Superfund sites	CERCLIS sites	NPL site density	Density, all sites
		Mi^2			*- - -Sites per 1,000 mi^2*	*- - -*
Osage River Basin						
H.S. Truman Reservoir	10290105	1,211		2	0	1.65
Sac	10290106	1,971	3	28	1.52	14.21
Pomme de Terre	10290107	848		2	0	2.36
South Grand	10290108	2,048		18	0	8.79
Lake of the Ozarks	10290109	1,385		8	0	5.78
Niangua	10290110	1,031		5	0	4.85
Lower Osage	10290111	1,077		7	0	6.50
Gasconade River Basin						
Upper Gasconade	10290201	1,788		4	0	2.24
Big Piney	10290202	756		2	0	2.65
Lower Gasconade	10290203	1,035		8	0	7.73
Meramec River Basin						
Meramec	07140102	2,160	4	162	1.85	75.00
Bourbeuse	07140103	837		19	0	22.70
Big	07140104	962		29	0	30.15
Upper St. Francis River Basin						
Upper St. Francis	08020202	1,298		13	0	10.02
Neosho-Illinois River Basin						
Lake O' the Cherokees	11070206	920	1	15	1.09	16.30
Spring	11070207	2,578	3	81	0	31.42
Elk	11070208	1,031		3	0	2.91
Lower Neosho	11070209	2,210		37	0	16.74
Illinois	11110103	1,651		34	0	20.59
Arkansas River Basin						
Dirty-Greenleaf	11110102	789		25	0	31.69
Robert S. Kerr Reservoir	11110104	1,807		34	0	18.82
Poteau	11110105	1,904		9	0	4.73
Frog-Mulberry	11110201	1,259	1	4	0.79	3.18
Dardanelle Reservoir	11110202	1,861		9	0	4.84
Conway-Point Remove	11110203	1,137		6	0	5.28
Petit Jean	11110204	1,090	1	5	0.92	4.59
Cadron	11110205	769		1	0	1.30
Fourche La Fave	11110206	1,119		2	0	1.79
Lower Arkansas-Maumelle	11110207	1,107		49	0	44.26
Kiamichi-Little River Basin						
Kiamichi	11140105	1,821		2	0	1.10
Upper Little	11140107	1,409		8	0	5.68
Mountain Fork	11140108	856	1	2	1.17	2.34
Lower Little	11140109	1,975		6	0	3.04
Ouachita-Saline River Basin						
Ouachita Headwaters	08040101	1,546		14	0	9.06
Upper Ouachita	08040102	1,762		24	0	13.62
Little Missouri	08040103	2,097		13	0	6.20
Upper Saline	08040203	1,709		11	0	6.44
Upper White River Basin						
Beaver Reservoir	11010001	2,556	1	2	0.39	0.78
James	11010002	1,448		29	0	20.03
Bull Shoals Lake	11010003	2,600		9	0	3.46
Middle White	11010004	1,474		11	0	7.46
Buffalo	11010005	1,342		0	0	0.00
North Fork White	11010006	1,836		1	0	0.54
Little Red	11010014	1,821		9	0	4.94

(continued)

Table 4.5—Superfund (NPL) and CERCLIS sites within the aquatic study area, by watershed (continued)

River basin Watershed name	Watershed code (HUC)	Area	Superfund sites	CERCLIS sites	NPL site density	Density, all sites
	Mi²		- - - - - - *Number*- - - - - -		- - -*Sites per1,000 mi²* - - -	
Upper Black River Basin						
Upper Black	11010007	1,910		19	0	9.95
Current	11010008	2,625		4	0	1.52
Lower Black	11010009	780		4	0	5.13
Spring	11010010	1,217	.	3	2.47	2.47
Eleven Point	11010011	1,202		4	0	3.33
Strawberry	11010012	789		2	0	2.53

NPL = National Priorities List; CERCLIS = Comprehensive Environmental Response, Compensation, and Liability Information System; HUC = hydrologic unit code.
Source: U.S. EPA (1996a, b).

National Pollutant Discharge Elimination System (NPDES) Sites

Question 4.5: What are the current status and potential effects of permitted discharges on aquatic resources?

All facilities in the United States that release point source discharges—including wastewater treatment plants—are required to have a permit under the NPDES. Such a permit specifies (1) limits for mass (or concentration) of specific pollutants, (2) monitoring requirements, and (3) other provisions such as spill prevention plans. All three specifications can be used to assess pollution loading and risks.

Data Sources and Methods of Analysis

As mentioned previously, the PCS stores information on permitted wastewater dischargers—including location, allowed flows, limits for each allowable pollutant, monitoring requirements, monitoring reports, and permit violations. The PCS data base contains location data for more than 85 percent of the point sources in the Assessment area; precise locations are not available for some of the other smaller sources. The Aquatic Team obtained data from the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) CD-ROM (Version 1.0) provided by the EPA (U.S. EPA 1996a, b).

Key Findings

1. About 136 point sources currently discharge treated wastewater into surface waters of the Assessment area. Many of these sources with NPDES permits are considered major facilities based on volume of discharge and pollutant loadings (concentrations of pollutants in discharged effluent).
2. The majority of the permit sources with discharges greater than 1 million gallons per day (gal/d) are municipal treatment facilities.
3. Approximately 200 sewage treatment plants that serve populations ranging from 1,000 to 132,000 discharge treated water into surface waters of the Ozark-Ouachita Highlands. Average facility flows range from 1,000 to 2 million gal/d. Larger municipal sewage treatment plants include those of Springfield, MO, and Little Rock, AR.
4. Four industries constitute most of the point source dischargers: sewage treatment plants, pulp mills, lead and zinc ore operations, and electrical services.
5. Of the four types of NPDES facilities that are ranked as major, the largest number are found in the Lower Neosho, Upper Black, and James River watersheds.
6. Bull Shoals Lake watershed in the Upper White River Basin has the most NPDES sites in the Assessment area.

Discharge sources were divided into municipal and industrial categories and further classified by size. Major point sources are defined as (1) any municipal facility that has a design flow of at least 1 million gallons per day (gal/d), a service population of 10,000 persons or more, or a significant impact on water quality; or (2) any industrial facility that receives a high score in a rating procedure that is based on flow, pollutant loadings, potential health impacts, and water quality factors. All other sources are considered "minor."

Patterns and Trends

Table 4.6 shows NPDES sites by (1) major watersheds, (2) watershed size, (3) number of NPDES sites, and (4) site density/mi^2. The average site density was 0.024 sites/mi^2. More than 498 facilities currently discharge effluents into surface waters within the Assessment area (fig. 4.5). Pollutant loading for a watershed is not necessarily related to the number of facilities because a single large facility can make a greater impact than many small ones. However, discharges from small facilities into small streams can also cause significant detrimental impacts. Pollutant loads from permitted discharges were compiled on a countywide basis to adjust for the incomplete data that are associated with some individual discharges. Smaller facilities are not required to report flow data, so their loading could not be calculated. The countywide estimates represent primarily the loads from facilities with complete data sets. These estimates should adequately represent the distribution of point source loads on a regional basis.

About 136 point sources currently discharge treated wastewater into surface waters of the Assessment area. Many of these sources with NPDES permits are considered major facilities based on volume of discharge and pollutant loading (concentrations of pollutants in discharged effluent). The majority of the permit sources with discharges greater than 1 million gal/d are municipal treatment facilities. Approximately 200 sewage treatment plants that serve populations ranging from 1,000 to 132,000 discharge treated water into surface waters of the Ozark-Ouachita Highlands. Average facility flows range from 1,000 to 2 million gal/d. Larger municipal sewage treatment plants include those of Springfield, MO, and Little Rock, AR.

Four industries constitute most of the point sources: sewage treatment plants, pulp mills, lead and zinc ore operations, and electrical services. Of the four types of NPDES facilities that are ranked as major, the largest number are found in the Lower Neosho, Upper Black, and James River watersheds.

Bull Shoals Lake watershed in the Upper White River Basin had the most NPDES sites in the Assessment area. Watersheds having the greatest density of discharge sites per square mile include the Lower Arkansas-Maumelle River, Lake O' the Cherokees, Big River, Meramec River, James River, Bull Shoals Lake, and Spring Creek (Neosho-Illinois River Basin). Watersheds with the lowest density of NPDES sites include the Fourche La Fave, Kiamichi, Upper Little, and Eleven Point Rivers (table 4.6 and fig. 4.6).

Implications and Opportunities

The Assessment area is expected to continue to experience growth in industrial, commercial, and residential developments, each of which requires sewage treatment plants and often other waste treatment facilities. Population growth and urbanization will result in proportional increases in point source pollutant loads. The lack of complete information for all point sources complicates assessment and planning efforts.

As a whole, the Assessment area does not experience widespread impacts due to NPDES permitted effluents. Localized impacts on the environment may occur where there are high amounts of outfalls. Procedures to evaluate all permits within a watershed or river basin will help identify cumulative impacts from all point and nonpoint sources.

Table 4.6—NPDES sites and site density within the aquatic study area

River basin Watershed name	Watershed code (HUC)	Area	NPDES sites	Site density
		Mi^2		*No./mi*^{2}
Osage River Basin				
H.S. Truman Reservoir	10290105	1,211	15	0.012
Sac	10290106	1,971	20	0.010
Pomme de Terre	10290107	848	15	0.018
South Grand	10290108	2,048	42	0.021
Lake of the Ozarks	10290109	1,385	51	0.037
Niangua	10290110	1,031	29	0.028
Lower Osage	10290111	1,077	35	
Gasconade River Basin				
Upper Gasconade	10290201	1,788	16	0.009
Big Piney	10290202	756	11	0.015
Lower Gasconade	10290203	1,035	12	0.012
Meramec River Basin				
Meramec	07140102	2,160	122	0.056
Bourbeuse	07140103	837	41	0.049
Big	07140104	962	61	0.063
Upper St. Francis River Basin				
Upper St. Francis	08020202	1,298	54	0.042
Neosho-Illinois River Basin				
Lake O' the Cherokees	11070206	920	58	0.063
Spring	11070207	2,578	132	0.051
Elk	11070208	1,031	34	0.033
Lower Neosho	11070209	2,210	72	0.033
Illinois	11110103	1,651	15	0.009
Arkansas River Basin				
Dirty-Greenleaf	11110102	789	13	0.016
Robert S. Kerr Reservoir	11110104	1,807	35	0.019
Poteau	11110105	1,904	35	0.018
Frog-Mulberry	11110201	1,259	18	0.014
Dardanelle Reservoir	11110202	1,861	24	0.013
Conway-Point Remove	11110203	1,137	20	0.018
Petit Jean	11110204	1,090	13	0.012
Cadron	11110205	769	7	0.009
Fourche La Fave	11110206	1,119	2	0.002
Lower Arkansas-Maumelle	11110207	1,107	86	0.078
Kiamichi-Little River Basin				
Kiamichi	11140105	1,821	6	0.003
Upper Little	11140107	1,409	7	0.005
Mountain Fork	11140108	856	8	0.009
Lower Little	11140109	1,975	21	0.011
Ouachita-Saline River Basin				
Ouachita Headwaters	08040101	1,546	37	0.024
Upper Ouachita	08040102	1,762	29	0.016
Little Missouri	08040103	2,097	28	0.013
Upper Saline	08040203	1,709	35	0.020
Upper White River Basin				
Beaver Reservoir	11010001	2,556	90	0.035
James	11010002	1,448	87	0.060
Bull Shoals Lake	11010003	2,600	138	0.053
Middle White	11010004	1,474	46	0.031
Buffalo	11010005	1,342	12	0.009
North Fork White	11010006	1,836	24	0.013
Little Red	11010014	1,821	44	0.024

(continued)

Table 4.6—NPDES sites and site density within the aquatic study area (continued)

River basin Watershed name	Watershed code (HUC)	Area	NPDES sites	Site density
		Mi²		*No./mi²*
Upper Black River Basin				
Upper Black	11010007	1,910	79	0.041
Current	11010008	2,625	26	0.010
Lower Black	11010009	780	12	0.015
Spring	11010010	1,217	28	0.023
Eleven Point	11010011	1,202	6	0.005
Strawberry	11010012	789	8	0.010

NPDES = National Pollution Discharge Elimination System; HUC = hydrologic unit code; mi² = square mile.
Source: U.S. EPA (1996a, b).

Figure 4.5—Facilities discharging effluents into surface waters of the Assessment area that have National Pollutant Discharge Elimination System (NPDES) permits (U.S. EPA 1996a, b).

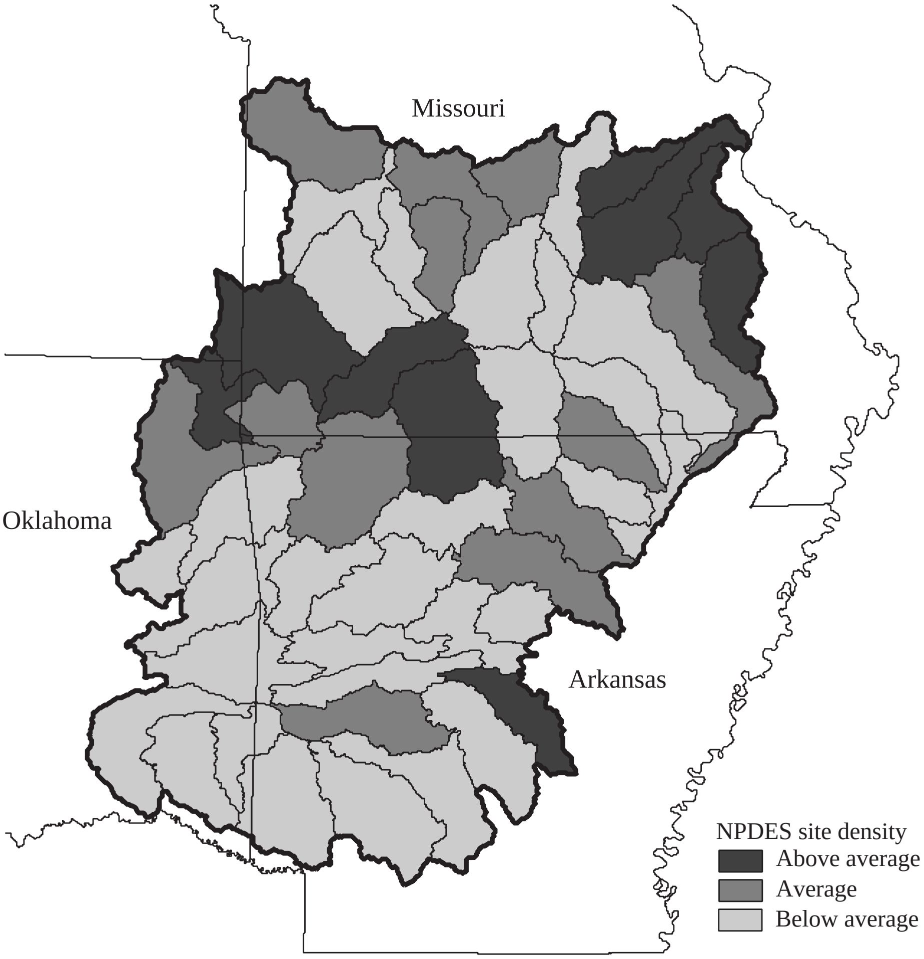


Figure 4.6—Density of National Pollutant Discharge Elimination System (NPDES) permits in the Assessment area (U.S. EPA 1996a, b).

Municipal Water Supplies

Question 4.6: How do municipal water facilities affect water quality within the Assessment area?

Municipal water supplies are essential to the well-being and growth of communities in the Assessment area. Adequate volumes of clean water allow communities to grow; inadequate or contaminated water supplies can stifle or financially cripple a community. While they provide for human needs (see Chapter 5 of this report for a further discussion of water supply and use), municipal water supplies may also affect aquatic resources. Reservoirs that supply municipal water change the hydrologic regimes and water quality of streams. Reservoirs may stop downstream movement of sediment (sediment will "settle out" in the reservoir bottom), initiate downstream channel erosion (when they release water), and influence downstream water temperatures.

Key Findings

1. Municipal water supplies provide over 80 percent of the drinking water in the Assessment area.
2. The largest drinking water supplies are located in the Meramec, Arkansas, Kiamichi, and Upper White River Basins, which serve about 1.6 million people.
3. Smaller water supplies in the Assessment area are located in less populated watersheds such as the Upper Black and Upper St. Francis River Basins.

Data Sources and Methods of Analysis

Municipal water supply data were retrieved from the BASINS Version 1.0 CD ROM (U.S. EPA 1996a, b). From these data, the Aquatic Team developed a map of drinking water intake sites. These data may contain some inaccurate latitudinal and longitudinal data and incomplete information for some drinking water intakes, but it was the most complete data set available to the team.

Patterns and Trends

Figure 4.7 shows the locations for public water supplies in the Assessment area from which more than 80 percent of the population obtains drinking water. Of the 152 sites identified, over 87 percent are surface water sources (table 4.7). The largest drinking water source is located in the Meramec watershed and supplies the city of St. Louis.

Water supplies may become stressed for localized areas in the future during droughts and after further

Figure 4.7—Locations of public drinking water sources in the Assessment area (U.S. EPA 1996a, b).

Table 4.7—Number of drinking water sites, sources, volume produced, and population served, by watershed

River basin Watershed name	Watershed code (HUC)	Square miles	Drinking water sites	Number of water sources	Volume in Mgal/d	Population served
Osage River Basin						
H.S. Truman Reservoir	10290105	1,211	3	S(3)	9– 500	6,375
Sac	10290106	1,971	3	S(1) U(2)	7,000– 11,4000	13,175
Pomme de Terre	10290107	848	0	NA		
South Grand	10290108	2,048	13	S(13)	22– 891	34,404
Lake of the Ozarks	10290109	1,385	1	U(1)	3	100
Niangua	10290110	1,031	0	NA		
Lower Osage	10290111	1,077	0	NA		
Gasconade River Basin						
Upper Gasconade	10290201	1,788	2	S(1) U(1)	0– 33	19,600
Big Piney	10290202	756	1	S(1)	—	34,900
Lower Gasconade	10290203	1,035	0	NA		
Meramec River Basin						
Meramec	07140102	2,160	6	S(4) U(1) G(1)	0– 88,400,000	1,076,172
Bourbeuse	07140103	837	1	S(1)	500	5,200
Big	07140104	962	1	U(1)	450	3,225
Upper St. Francis River Basin						
Upper St. Francis	08020202	1,298	5	S(4) U(1)	250– 385	9,207
Neosho-Illinois River Basin						
Lake O' the Cherokees	11070206	920	0	NA	—	—
Spring	11070207	2,578	6	S(5) G(1)	500– 750,000	114,235
Elk	11070208	1,031	0	NA		
Lower Neosho	11070209	2,210	9	S(9)	0– 360000	360,000
Illinois	11110103	1,651	7	S(7)	65,000– 90,0000	32,355
Arkansas River Basin						
Dirty-Greenleaf	11110102	789	4	U(4	250,000– 730,000	3,098
Robert S. Kerr Reservoir	11110104	1,807	2	S(2)	0– 200,000	15,373
Poteau	11110105	1,904	14	S(14)	110,000– 3,600,000	56,454
Frog–Mulberry	11110201	1,259	6	S(6)	20,000– 15,000,000	71,876
Dardanelle Reservoir	11110202	1,861	4	S(4)	0– 500,000	27,412
Conway-Point Remove	11110203	1,137	0	NA		
Petit Jean	11110204	1,090	4	S(4)	200,000– 540,000	5,505
Cadron	11110205	769	1	S(1)	2,900,000	25,000
Fourche La Fave	11110206	1,119	2	S(1) U(1)	0– 400,000	7,815
Lower Arkansas-Maumelle	11110207	1,107	1	S(1)	—	132,483
Kiamichi-Little River Basin						
Kiamichi	11140105	1,821	5	S(2) U(3)	36,000– 2,000,000	22,076
Upper Little	11140107	1,409	3	S(2) U(1)	0– 1,000,000	13,068
Mountain Fork	11140108	856	1	S(1)	—	3,800
Lower Little	11140109	1,975	3	S(3)	385,000– 1,200,000	8,318
Ouachita-Saline River Basin						
Ouachita Headwaters	08040101	1,546	7	S(7)	70,000– 425,000	148,873
Upper Ouachita	08040102	1,762	6	S(6)	100,000– 1,500,000	38,919
Little Missouri	08040103	2,097	2	S(2)	0– 50,000	10,467
Upper Saline	08040203	1,709	4	S(4)	0– 440,000	168,483
Upper White River Basin						
Beaver Reservoir	11010001	2,556	4	S(4)	14,400– 13,000,000	79,146
James	11010002	1,448	0	NA		
Bull Shoals Lake	11010003	2,600	3	S(3)	26– 1,800,000	17,570
Middle White	11010004	1,474	5	S(5)	143,000– 2,000,000	17,898
Buffalo	11010005	1,342	0	NA		
North Fork White	11010006	1,836	0	NA		
Little Red	11010014	1,821	7	S(7)	0– 260,000	45,041

(continued)

Table 4.7—Number of drinking water sites, sources, volume produced, and population served, by watershed (continued)

River basin Watershed name	Watershed code (HUC)	Square miles	Drinking water sites	Number of water sources	Volume in Mgal/d	Population served
Upper Black River Basin						
Upper Black	11010007	1,910	2	S(2)	250– 2,000	22,100
Current	11010008	2,625	1	U(1)	205	800
Lower Black	11010009	780	1	S(1)	—	7,000
Spring	11010010	1,217	1	S(1)	—	496
Eleven Point	11010011	1,202	0	NA		
Strawberry	11010012	789	1	U(1)	—	309

HUC = hydrologic unit code; Mgal/d = million gallons per day; S = surface; G = ground water; U = unknown; NA = not applicable; — = not available.
Source: U.S. EPA (1996a, b).

increases in urban sprawl and commercial and industrial development in and around the Assessment area (see Chapter 5 of this report). Careful planning for future water supplies will require collaboration among landowners, developers, municipalities, and other watershed partners to ensure that there are adequate water supplies as the general population increases and climatological events such as severe droughts place additional demands on surface and ground water supplies in the Assessment area.

Implications and Opportunities

Every State is responsible for the protection of drinking water supplies (both surface and ground water sources) as an integral part of their watershed management. Strategies for protecting drinking water supplies are incorporated in the watershed management planning process in some States. Measures should include ways to ensure the appropriate level of treatment of continuous discharges as well as contingency measures to handle spills, emergency bypasses of upstream waste treatment systems, and periods of low water supply.

Toxic Releases

Question 4.7: What are the current status and potential effects of toxic pollutants on aquatic resources in the Assessment area?

As in many other parts of the world, hundreds of toxic chemicals are stored, transported, used, and disposed in the Assessment area. Toxic chemicals include any chemical listed in EPA rules as "Toxic Chemicals Subject to section 313 of the Emergency Planning and Community Right-to-Know Act of 1986." A toxic substance is a chemical or mixture that may present unreasonable risk of injury to health or the environment.

Key Findings

1. Densities of toxic release sites are highest in and near urban areas such as Little Rock, AR; Fort Smith, AR; Springfield, MO; St.Louis, MO; and areas that have large industries or concentrations of industries.
2. The Spring (Neosho-Illinois River Basin), Lower Arkansas-Maumelle, James, and Illinois watersheds have the highest number and density of toxic release sites in the region.
3. Discharge media for toxic releases include land, underground, air, water, and off-site transfer. Of these media, air releases account for 53 percent of all discharges.

Data Sources and Methods of Analysis

The team obtained information on toxic discharges from the EPA's Toxics Release Inventory (U.S. EPA 1996a, b). The Toxics Release Inventory (TRI) contains the annual records of releases of toxic or hazardous substances to air, water, and land. Reports of quantities released to water are based on a variety of data gathering techniques, including direct measurements and estimates provided by the facilities.

Patterns and Trends

Under section 313 of the Emergency Planning and Community Right-to-Know Act, certain manufacturers must report annually the amounts of approximately 650 chemicals (in 29 categories) that they release to the air, land, or water or inject underground. The reports also include information on amounts transferred to off-site locations for treatment or disposal. The locations of toxic release sites in the aquatic study area are displayed (fig. 4.8) from the BASINS data (U.S. EPA 1996a, b). Densities of toxic release sites are highest in and near urban areas such as Little Rock, AR; Fort Smith, AR; Springfield, MO; St. Louis, MO, and areas that have large industries or concentrations of industries. The Spring (Neosho-Illinois River Basin), Lower Arkansas-Maumelle, James, and Illinois watersheds have the highest number and density of toxic release sites in the region (table 4.8). Discharge media for toxic releases include air, land, water, and off-site transfer. Of these media, air releases account for 53 percent of all discharges.

Figure 4.8—Toxics Release Inventory (TRI) sites in the Assessment area by watershed, 1992 (U.S. EPA 1996a, b).

Table 4.8—Number and density of toxic release sites and discharge areas in the aquatic study area

River basin Watershed name	Watershed code (HUC)	Number of sites[a]	Sites per square mile	Number of discharge areas to			
				Air	Land	Water	Off-site
Osage River Basin							
H.S. Truman Reservoir	10290105	1	0.001				1
Sac	10290106	11	0.006	7	2	1	3
Pomme de Terre	10290107	7	0.008	6	1		4
South Grand	10290108	6	0.003	2			3
Lake of the Ozarks	10290109	6	0.004	6			4
Niangua	10290110	2	0.002	1			1
Lower Osage	10290111	4	0.004	3			2
Gasconade River Basin							
Upper Gasconade	10290201	6	0.003	5			1
Big Piney	10290202	6	0.008	2		1	
Lower Gasconade	10290203	0					
Meramec River Basin							
Meramec	07140102	22	0.010	22		1	17
Bourbeuse	07140103	12	0.014	12	2		9
Big	07140104	2	0.002	2	1	1	2
Upper St. Francis River Basin							
Upper St. Francis	08020202	2	0.002	2	1	1	2
Neosho-Illinois River Basin							
Lake O' the Cherokees	11070206	5	0.006	5		1	2
Spring	11070207	73(2)	0.028	49	4	7	30
Elk	11070208	4	0.004	4		1	2
Lower Neosho	11070209	9	0.004	9	1	1	5
Illinois	11110103	35	0.021	35	2	2	5
Arkansas River Basin							
Dirty-Greenleaf	11110102	3	0.004	3	1	1	2
Robert S. Kerr Reservoir	11110104	16	0.009	16	4	4	13
Poteau	11110105	19	0.010	16	1		13
Frog-Mulberry	11110201	3	0.002	3	1	1	3
Dardanelle Reservoir	11110202	10	0.005	10	1		3
Conway-Point Remove	11110203	0					
Petit Jean	11110204	4	0.004	4		2	4
Cadron	11110205	1	0.001	1			
Fourche La Fave	11110206	0					
Lower Arkansas-Maumelle	11110207	56(1)	0.051	56	2	3	31
Kiamichi-Little River Basin							
Kiamichi	11140105	1	0.001	1			1
Upper Little	11140107	4	0.003	4		1	1
Mountain Fork	11140108	5	0.006	3			3
Lower Little	11140109	10	0.005	7	2	2	5
Ouachita-Saline River Basin							
Ouachita Headwaters	08040101	11	0.007	9	1	2	6
Upper Ouachita	08040102	10	0.006	7			3
Little Missouri	08040103	5(1)	0.002	2		1	2
Upper Saline	08040203	13	0.008	8	1	2	6
Upper White River Basin							
Beaver Reservoir	11010001	21(1)	0.008	14	1		12
James	11010002	48	0.033	34	1	2	27
Bull Shoals Lake	11010003	13	0.005	11	1		9
Middle White	11010004	13	0.009	11	2	2	8
Buffalo	11010005	1	0.001				
North Fork White	11010006	1	0.001	1			1
Little Red	11010014	13	0.007	10		1	12

(continued)

Table 4.8—Number and density of toxic release sites and discharge areas in the aquatic study area (continued)

River basin Watershed name	Watershed code (HUC)	Number of sites[a]	Sites per square mile	Number of discharge areas to: Air	Land	Water	Off-site
Upper Black River Basin							
Upper Black	11010007	6	0.003	5			4
Current	11010008	5(1)	0.002	3			1
Lower Black	11010009	3	0.004	3			3
Spring	11010010	4	0.003	3			2
Eleven Point	11010011	0					
Strawberry	11010012	0					

HUC = hydrologic unit code.

[a] Number of closed sites, if any, shown in parentheses.

Source: U.S. EPA (1996a, b).

For the most current information on chemical exposure, the Right-to-Know Computer Network (RTK NET) has TRI data from 1987 through 1996; see the Web site at <http://www.rtk.net/datadoc/tris.html>. Health factsheets for a variety of chemical data are available on the Internet, including the complete text and tables from the public data release documents at EPA's Envirofacts Web site: <http://www.epa.gov/enviro/index_java.html> or at <http://www.epa.gov/chemfact>. The latter Web site includes information on 40 selected TRI chemicals and describes (1) how citizens might be exposed to these chemicals, (2) how exposure to them might affect the public and the environment, (3) what happens to the chemicals in the environment, (4) who regulates them, and (5) who to contact for additional information. A list of TRI chemicals classified as carcinogens by either the Occupational Safety and Health Administration (OSHA) or the EPA is also included, and the Web site explains the basis of the classifications.

The OSHA carcinogens are limited to 0.1 percent concentration, while the EPA uses 1 percent. Amounts of TRI chemicals that are present below the concentration limits in mixtures do not have to be included in threshold and release calculations. The EPA provides answers to frequently asked questions about health effects of 60 hazardous substances in a Toxic Substance and Disease Registry (available at <http://atsdr1.atsdr.cdc.gov:8080/toxfaq.html>). About 50 of these chemicals are also TRI chemicals. It is beyond the scope of this report to identify and characterize toxic compounds in watersheds of the Assessment area or to estimate exposure and effects of toxins upon human health and the environment.

Implications and Opportunities

Because the manufacture of most bioaccumulative chemicals (substances that increase in concentrations in living organisms as they take in contaminated air, water, or food because the substances are very slowly metabolized or excreted) has either been banned or is now strictly regulated, levels of these chemicals should decrease in the Assessment area over time. However, toxic chemicals often persist for long periods in aquatic environments, and opportunities exist to improve future monitoring of toxins in water and aquatic biota. Watersheds with potentially high impacts from toxins deserve special attention.

TRI reports reflect releases of chemicals, not exposures of the public to those chemicals. Release estimates alone are not sufficient to determine exposure or to calculate potential adverse effects on human health and the environment. Release estimates are aggregate annual estimates and do not provide information about peak concentrations. Estimating and measuring release amounts in complex manufacturing processes is not an exact science; estimation techniques need further research and development.

Toxic waste discharges are likely to continue in the Assessment area. Existing regulatory requirements should control point sources of toxic chemicals including follow up on the progress of individual control strategies for those facilities identified under section 304(l) regulations. Although TRI discharges continue, release amounts have declined yearly since the implementation of the TRI program.

Nonpoint Sources

Nonpoint sources of water pollutants are nonidentifiable, diffuse conveyances from which contaminants enter and impair a stream; they often originate from diffuse sources. Nonpoint sources include activities associated with construction, agriculture, or silviculture. This section discusses many of the nonpoint sources within the Assessment area and includes roads and highways, agriculture and silviculture, pesticides, fertilizers, urbanization, mineral extraction, and introduced species.

Roads and Highways

Question 4.8: What are the current status and potential effects of roads and highways on aquatic resources in the Highlands?

Roads, highways, and bridges contribute measurable amounts of pollutants to the Nation's waters (U.S. EPA 1995). The impervious surface of roads and highways prevents the infiltration of rainfall and causes runoff to increase. Runoff may carry sediments, nutrients, oil, grease, gasoline, metals, salts, and other pollutants generated by vehicular traffic and road maintenance. When the polluted runoff enters a stream, water quality can be degraded. Obviously, roads and highways near streams, lakes, and rivers have the greatest potential to deposit pollutants in water bodies.

Sediment is one of the primary pollutants from gravel and dirt roads. Periodic maintenance of the roadbeds and ditches of these roads exposes soil to erosion (as does neglecting road maintenance). The increase in runoff sediment caused by road construction and maintenance can cause physical changes in the aquatic habitat (MacDonald and others 1991). Sediment loads can affect channel shape, sinuosity, the ratio of stream length to valley length, and the relative balance between pools and riffles. Increased sediment can also alter the quantity and quality of habitats for fish and invertebrates.

Road construction that creates a greater impervious surface area and/or interrupts the subsurface lateral flow of water can increase peak runoff flows (MacDonald and others 1991). Careful layout and construction of roads can minimize changes in the volume and route of peak flows. When roads occupy a significant proportion of a watershed, total water yield and flow timing will be observably affected.

Places where roads cross streams can be barriers to fish movement and gravel distribution in streams. Filipek (1993) indicates that in the Ozark and Ouachita Mountains, low water bridges and culverts affect not only fish migration (by impeding fish movement directly or by creating new gravel bars that impede fish) but also affect gravel distribution in these streams.

Riparian areas are transition areas between the uplands and water bodies. The riparian area filters sediments and absorbs nutrients from upland runoff to varying degrees before it reaches streams. Road construction and maintenance within riparian zones, however, can reduce these filtering and absorption processes.

Key Findings

1. All watersheds in the Assessment area have road segments within 100 feet of streams.
2. The Upper Black River, Bull Shoals Lake, Current River, Beaver Reservoir, and Illinois River watersheds have the most road miles within riparian areas in the Assessment area.
3. Class 2 and 3 roads (State highways and county roads) have the highest number of miles within Highlands riparian areas.
4. Class 3 roads (county and national forest roads) have the most miles within riparian areas in national forests.

Data Sources and Methods of Analysis

Data sources are the GIS roads and streams layers. The Aquatic Team built the GIS road layer using 1:100,000 Digital Line Graph (DLG) files. These were assembled in three files for the Assessment area, based on road size and use:

- Class 1 includes Federal interstate highways;
- Class 2 consists of State highways;
- Class 3 includes paved, gravel, and dirt county roads.

The team built the GIS stream layer using the EPA's RF3, which is based on the 1:100,000 scale DLG data. Streams in some portions of the stream layer were not mapped originally at the same density (see "Riparian Areas" in Chapter 2 of this report for a further discussion of the stream layer). To estimate the impacts of roads on Highlands aquatic resources, the team used a buffer of 100 feet (ft) on either side of each road segment in each of the three road files. Then the team intersected the stream layer with the buffered road layer. Next, the team totaled the lengths of streams within these buffers for each watershed. Finally, the team conducted analyses by road class and by watershed.

Patterns and Trends

Table 4.9 displays miles and classes of roads found within riparian areas in the aquatic study area. (Class 1 is Federal interstate highways, Class 2 is State highways, and Class 3 is county roads.) These lands adjacent to streams or lakes can lessen the effects of disturbances in the watersheds above them. Riparian areas cannot make up for mismanagement of the uplands, but they can more readily reduce the impacts to water bodies when uplands are managed properly.

All Assessment area watersheds have roads of varying classes within 100 ft of streams. The Osage, Neosho-Illinois, Arkansas, Upper White, and Upper Black River Basins have the most road miles within riparian areas. Within these river basins and in descending order, the Upper Black, Bull Shoals Lake, Current, Beaver Reservoir, and Illinois watersheds have the most road miles within riparian areas in the Assessment area (table 4.9).

For this analysis, the riparian area is defined as the area within 100 ft of streams. Road segments within 100 ft of streams have a greater potential to degrade water quality than road segments more than 100 ft from streams. "Studies in the Southern Appalachian Mountains have shown that a forested buffer that is 100 ft wide will trap most of the sediment from a newly constructed graveled road" (Swift 1986, SAMAB 1996).

Table 4.10 displays the miles and types of roads found within riparian areas on national forest lands within the Assessment area (there are no Class 1 roads). Class 3 roads have the greatest potential to degrade water quality because they have the most road miles within Highlands' riparian areas (306 mi of roads compared with 133 mi of Class 2 roads). In addition, Class 3 roads are often unsurfaced (dirt), which allows soil to wash from the road's surface into streams.

Implications and Opportunities

An opportunity exists for the Forest Service, States, and counties to work together to reduce the impact of road construction and maintenance on aquatic resources. Simple but effective measures are available to control road runoff and sediment. Examples of these measures are sediment basins and waterbars.

Opportunities also exist to locate new roads and relocate old roads outside the riparian area. The riparian area can filter sediments, absorb nutrients, and delay or catch other pollutants from road runoff. Damage to the riparian area should be prevented or minimized so that the buffering capacity of the riparian area can be maintained.

Road crossings can be designed so that fish and stream gravel can pass freely instream. The opportunity to design road crossings so that fish and stream gravel can pass freely is increasingly being exercised. As old stream crossings that function as fish and gravel barriers deteriorate, there will be more opportunities to replace them with crossings that allow free passage of fish and gravel.

Table 4.9—Miles of roads in riparian areas of the aquatic study area watersheds, by road class

River basin Watershed name	Watershed code (HUC)	Class 1 (Federal interstate highways)	Class 2 (State highways)	Class 3 (paved, gravel and dirt county roads)	Total
		- - - - - - - - - - - - -	- - - - - - *Miles* - - - - - -	- - - - - - - - - - - - -	- - - - -
Osage River Basin					
H.S. Truman Reservoir	10290105	0.1	51.2	26.2	77.5
Sac	10290106	0.8	108.8	51.3	160.9
Pomme de Terre	10290107	0.3	45.9	20.7	66.9
South Grand	10290108	0	128.4	57.6	186.0
Lake of the Ozarks	10290109	0.4	75.3	186.3	262.0
Niangua	10290110	0.7	50.0	46.5	97.2
Lower Osage	10290111	0	42.9	27.9	70.8
Gasconade River Basin					
Upper Gasconade	10290201	1.8	103.8	69.2	174.8
Big Piney	10290202	0.2	47.3	41.3	88.8
Lower Gasconade	10290203	0.8	38.6	38.3	77.7
Meramec River Basin					
Meramec	07140102	1.9	76.7	170.1	248.7
Bourbeuse	07140103	2.6	37.5	18.3	58.4
Big	07140104	0	55.3	102.6	157.9
Upper St. Francis River Basin					
Upper St. Francis	08020202	0	77.3	89.1	166.4
Neosho-Illinois River Basin					
Lake O' the Cherokees	11070206	0.3	44.1	34.9	79.3
Spring	11070207	1.3	101.7	38.4	141.4
Elk	11070208	0	95.5	43.8	139.3
Lower Neosho	11070209	0.3	122.1	90.5	212.9
Illinois	11110103	0.2	158.4	113.4	272.0
Arkansas River Basin					
Dirty-Greenleaf	11110102	3.2	58.0	31	92.2
Robert S. Kerr Reservoir	11110104	4.0	107.3	77.4	188.7
Poteau	11110105	0.2	106.1	120.8	227.1
Frog-Mulberry	11110201	1.8	48.0	85.7	135.5
Dardanelle Reservoir	11110202	3.0	101.6	97.4	202.0
Conway-Point Remove	11110203	1.5	57.2	59.8	118.5
Petit Jean	11110204	0	47.9	58.6	106.5
Cadron	11110205	0.2	54.3	27.0	81.5
Fourche La Fave	11110206	0	49.5	112.1	161.6
Lower Arkansas-Maumelle	11110207	4.3	34.8	142.3	181.4
Kiamichi-Little River Basin					
Kiamichi	11140105	0.2	65.9	48.4	114.5
Upper Little	11140107	0	30.7	59.7	90.4
Mountain Fork	11140108	0	18.7	54.9	73.6
Lower Little	11140109	0	63.4	72.7	136.1
Ouachita-Saline River Basin					
Ouachita Headwaters	08040101	0	108.9	122.8	231.7
Upper Ouachita	08040102	1.7	103.1	91.1	195.9
Little Missouri	08040103	1.8	90.4	103.8	196.0
Upper Saline	08040203	1.5	97.7	85.0	184.2
Upper White River Basin					
Beaver Reservoir	11010001	0	136.9	140.8	277.7
James	11010002	0.1	123.1	87.9	211.1
Bull Shoals Lake	11010003	0.2	146.1	146.6	292.9
Middle White	11010004	0	65.8	100.2	166.0
Buffalo	11010005	0	49.8	69.5	119.3
North Fork White	11010006	0	99.0	94.1	193.1
Little Red	11010014	0.9	60.3	82.0	143.2

Table 4.9—Miles of roads in riparian areas of the aquatic study area watersheds, by road class (continued)

River basin Watershed name	Watershed code (HUC)	Class 1 (Federal interstate highways)	Class 2 (State highways)	Class 3 (paved, gravel and dirt county roads)	Total
		Miles			
Upper Black River Basin					
Upper Black	11010007	0	133.7	161.3	295.0
Current	11010008	0	123.2	166.4	289.6
Lower Black	11010009	0	48.0	38.9	86.9
Spring	11010010	0	60.2	46.7	106.9
Eleven Point	11010011	0	49.2	52.2	101.4
Strawberry	11010012	0	31.1	28.1	59.2
Total		36.3	3,830.7	3,931.6	7,798.6

HUC = hydrologic unit code.

Table 4.10—Miles of roads within riparian areas on national forests in the Assessment area, by road class[a]

National forest	Class 1	Class 2	Class 3	Total
	Miles			
Ouachita	0	78	171	249
Ozark	0	25	64	89
Mark Twain	0	30	70	101
Total	0	133	306	439

[a] Class 1 = Federal interstate highways; Class 2 = State highways; Class 3 = county roads.

Agriculture and Silviculture

Question 4.9: What are the current status and estimated effects of potential erosion from agriculture and silviculture on aquatic resources within the Assessment area?

Agriculture and silviculture are sources of sediment, which is a major nonpoint source pollutant of aquatic habitats. Sediment creates turbidity, fills in stream channels and reservoirs, changes aquatic habitat, and carries nutrients into streams. In 1991 and 1992, States attributed 41 percent of their nonpoint source pollution to agriculture and 3 percent to silviculture (U.S. EPA 1992a).

Key Findings

1. Total potential erosion declined in more than half of the watersheds in the Assessment area for the 3 years studied (1982, 1987, and 1992).
2. The South Grand watershed had the highest average potential erosion rate in 1992.
3. Most of the cropland potential erosion as a percent of total potential erosion came from watersheds along the eastern and western boundaries of the Assessment area for the 3 years studied.
4. The Fourche La Fave, Ouachita Headwaters, and Upper Little River watersheds had the lowest average potential erosion rates for the 3 years studied.
5. Forest potential erosion as a percent of total potential erosion was 3 percent or less for most of the Assessment area watersheds for the 3 years studied.
6. In 1982, 1987, and 1992, watersheds with the highest forest potential erosion as a percent of total potential erosion were in the southern part of the Assessment area.
7. The category with the highest potential erosion in most Assessment area watersheds for the 3 years studied was pasture lands.
8. Most watersheds in the Assessment area had no appreciable potential erosion from rangelands.
9. In more than half of the Assessment area watersheds, potential erosion rates from “other” lands were 2 percent or less of total potential erosion.

“Potential erosion estimates” are tentative predictions of onsite erosion of agricultural and forested lands. Much of the estimated eroded soil is trapped by vegetation or in depressions in the land. A portion of the estimated eroded soil could enter water bodies and become sediment. Land management practices can influence (positively or negatively) the amount of eroded soil that reaches water bodies. Best management practices (BMP’s) and conservation measures can reduce the amount of eroded soil that reaches water bodies. (See Chapter 3 of this report for a discussion of BMP’s.)

Data Sources and Methods of Analysis

The team collected estimates of potential erosion for Assessment area watersheds from the National Resources Inventory (NRI), which is conducted by the Natural Resources Conservation Service (USDA NRCS 1997). The NRI is based on a 0.7 percent sample of all non-Federal rural land in the Nation. Categories of similar land uses were grouped together into a sampling universe (clusters of sites by land use that make data extraction easier). Primary sampling units (PSU’s) were randomly selected within each sampling universe. Within each PSU, three sampling points were selected. The data from each sampling point were multiplied by the number of acres per sampling point in the sampling universe and then summed to give totals for the universe.

Natural Resources Conservation Service personnel made estimates of potential erosion using the Universal Soil Loss Equation at sampling points where agriculture was the primary land use. Agency personnel return to the sampling points every 5 years to collect data about land uses and to make estimates of potential erosion. Data from the 1982, 1987, and 1992 NRI inventories were used in this analysis. Because the Natural Resources Conservation Service did not make potential erosion estimates where forestry was the primary land use, the Aquatic Team provided such estimates for this report.

Patterns and Trends

Table 4.11 displays potential erosion in the aquatic study area by watershed for 1982, 1987, and 1992 using NRI data. Average potential erosion declined in more than half of the Assessment area watersheds for the 3 years studied.

Figure 4.9 shows average potential erosion by watershed for 1992. The South Grand watershed had the highest average potential erosion (2.44 thousand tons/mi^2), and the Spring watershed in the Neosho-Illinois River Basin had the second highest average potential erosion (0.93 thousand tons/mi^2). The Fourche La Fave, Ouachita Headwaters, and Upper Little watersheds had the lowest average potential erosion rates for the years studied (table 4.11).

During 1982, 1987, and 1992, most of the potential cropland erosion as a percent of TPE came from watersheds along the eastern and western boundaries of the Assessment area. Some of the watersheds with a high percentage of TPE from cropland during 1992 were the Upper Black (91 percent), Lower Arkansas-Maumelle (87 percent), Lower Black (69 percent), Harry S. Truman Reservoir (69 percent), Conway-Point Remove (63 percent), and Lower Neosho (60 percent). The Harry S. Truman Reservoir, Lower Arkansas-Maumelle, Upper Black, and Lower Black watersheds experienced reductions in potential cropland erosion as a percent of TPE for the 3 years studied, while the Lower Neosho watershed experienced a slight increase in potential erosion of croplands as a percent of TPE during the same period.

Potential erosion of forest lands was 3 percent of TPE or less for most of the Assessment area watersheds for the years studied. Watersheds with the highest potential forest erosion were in the southern part of the Assessment area. The Fourche La Fave (13 percent), Upper Little River (10 percent), and Upper Ouachita (8 percent) watersheds had the highest percentages of potential forest erosion in 1992.

Pasture lands had the highest potential erosion rates in most Assessment area watersheds for the 3 years studied. The Big Piney (99 percent), Spring (Upper Black River Basin, 97 percent), Buffalo (94 percent), Meramec (87 percent), Dardanelle Reservoir (81 percent), and Elk (79 percent) watersheds had some of the highest percentages of TPE in 1992. Pasture potential erosion increased for 1982, 1987, and 1992 in all of the watersheds listed above.

While most of the Assessment area watersheds had no potential rangeland erosion, some watersheds in the central and southwestern parts of the Assessment area did. The Kiamichi (20 percent), Bull Shoals Lake (18 percent), and North Fork White (13 percent) watersheds had the highest rangeland potential erosion rates in 1992. Rangeland potential erosion in 1992 dropped below the 1982 levels in all three watersheds.

Table 4.11—Potential erosion rates in the aquatic study area, by land use category and year (1992, 1987, 1982)

River basin Watershed name	Watershed code (HUC)	Total potential erosion	Average potential erosion	Potential erosion from croplands		Potential erosion from forest lands		Potential erosion from pasture lands		Potential erosion from rangelands		Potential erosion from other lands	
		k tons	*k tons/mi²*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*
						1992							
Osage River Basin													
H.S. Truman Reservoir	10290105	820	0.68	569	69	4	1	110	13	1	0	136	17
Sac	10290106	1,005	0.51	372	37	7	1	606	60	2	0	19	2
Pomme de Terre	10290107	246	0.29	44	18	3	1	188	77	0	0	11	4
South Grand	10290108	5,001	2.44	2,756	55	3	0	330	7	0	0	1,913	38
Lake of the Ozarks	10290109	421	0.30	65	16	11	3	345	82	0	0	0	0
Niangua	10290110	297	0.29	79	27	8	3	210	71	0	0	0	0
Lower Osage	10290111	527	0.49	89	17	7	1	428	81	0	0	4	1
Gasconade River Basin													
Upper Gasconade	10290201	1,211	0.68	60	5	8	1	1,129	93	0	0	14	1
Big Piney	10290202	311	0.41	2	1	3	1	306	99	0	0	0	0
Lower Gasconade	10290203	395	0.38	39	10	7	2	343	87	0	0	7	2
Meramec River Basin													
Meramec	07140102	776	0.36	84	11	16	2	675	87	0	0	0	0
Bourbeuse	07140103	342	0.41	136	40	4	1	197	58	0	0	4	1
Big	07140104	380	0.40	19	5	7	2	311	82	0	0	42	11
Upper St. Francis River Basin													
Upper St. Francis	08020202	388	0.30	59	15	9	2	321	83	0	0	0	0
Neosho-Illinois River Basin													
Lake O' the Cherokees	11070206	631	0.69	344	55	3	0	169	27	9	1	106	17
Spring	11070207	2,388	0.93	1,582	66	5	0	369	15	35	1	396	17
Elk	11070208	674	0.65	125	19	5	1	534	79	0	0	9	1
Lower Neosho	11070209	831	0.38	495	60	8	1	208	25	102	12	18	2
Illinois	11110103	538	0.33	51	10	9	2	389	72	10	2	78	15
Arkansas River Basin													
Dirty-Greenleaf	11110102	673	0.85	183	27	3	0	408	61	80	12	0	0
Robert S. Kerr Reservoir	11110104	773	0.43	265	34	10	1	345	45	71	9	82	11
Poteau	11110105	574	0.30	37	7	10	2	383	67	18	3	125	22
Frog-Mulberry	11110201	587	0.47	205	35	4	1	378	64	0	0	0	0
Dardanelle Reservoir	11110202	844	0.45	94	11	7	1	686	81	0	0	58	7
Conway-Point Remove	11110203	585	0.51	369	63	6	1	210	36	0	0	0	0
Petit Jean	11110204	344	0.32	27	8	5	1	312	91	0	0	0	0
Cadron	11110205	285	0.37	101	35	3	1	161	57	0	0	19	7
Fourche La Fave	11110206	34	0.03	8	23	4	13	21	64	0	0	0	0
Lower Arkansas-Maumelle	11110207	597	0.54	517	87	5	1	8	1	0	0	67	11
Kiamichi-Little River Basin													
Kiamichi	11140105	644	0.35	9	1	14	2	494	77	128	20	0	0
Upper Little	11140107	136	0.10	0	0	14	10	116	85	0	0	7	5
Mountain Fork	11140108	117	0.14	0	0	7	6	95	81	0	0	15	13
Lower Little	11140109	236	0.12	0	0	17	7	188	80	0	0	31	13
Ouachita-Saline River Basin													
Ouachita Headwaters	08040101	93	0.06	0	0	7	7	86	93	0	0	0	0
Upper Ouachita	08040102	287	0.16	140	49	23	8	107	37	0	0	18	6
Little Missouri	08040103	319	0.15	89	28	20	6	188	59	0	0	23	7
Upper Saline	08040203	628	0.37	38	6	18	3	35	6	0	0	536	85
Upper White River Basin													
Beaver Reservoir	11010001	955	0.37	7	1	15	2	821	86	111	12	0	0
James	11010002	974	0.67	132	14	5	1	821	84	0	0	16	2
Bull Shoals Lake	11010003	1,951	0.75	45	2	15	1	1,509	77	350	18	33	2
Middle White	11010004	509	0.35	137	27	10	2	330	65	31	6	0	0

(continued)

Table 4.11—Potential erosion rates in the aquatic study area, by land use category and year (1992, 1987, 1982) (continued)

River basin Watershed name	Watershed code (HUC)	Total potential erosion	Average potential erosion	Potential erosion from croplands		Potential erosion from forest lands		Potential erosion from pasture lands		Potential erosion from rangelands		Potential erosion from other lands	
		k tons	*k tons/mi^2*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*
						1992 (continued)							
Upper White River Basin (continued)													
Buffalo	11010005	601	0.45	2	0	9	1	563	94	0	0	27	4
North Fork White	11010006	962	0.52	126	13	11	1	679	71	125	13	21	2
Little Red	11010014	408	0.22	69	17	14	3	223	55	0	0	103	25
Upper Black River Basin													
Upper Black	11010007	1,028	0.54	938	91	12	1	78	8	0	0	0	0
Current	11010008	800	0.30	305	38	19	2	476	59	0	0	0	0
Lower Black	11010009	642	0.82	446	69	3	1	173	27	0	0	20	3
Spring	11010010	573	0.47	5	1	7	1	556	97	0	0	5	1
Eleven Point	11010011	470	0.39	21	4	7	1	428	91	0	0	14	3
Strawberry	11010012	454	0.58	31	7	5	1	362	80	54	12	2	0
						1987							
Osage River Basin													
H.S. Truman Reservoir	10290105	1,127	0.93	881	78	4	0	108	10	1	0	133	12
Sac	10290106	1,454	0.74	580	40	6	0	812	56	2	0	55	4
Pomme de Terre	10290107	364	0.43	130	36	3	1	211	58	0	0	21	6
South Grand	10290108	6,100	2.98	3,795	62	3	0	378	6	0	0	1,924	32
Lake of the Ozarks	10290109	546	0.39	128	23	10	2	408	75	0	0	0	0
Niangua	10290110	307	0.30	58	19	8	3	241	78	0	0	0	0
Lower Osage	10290111	504	0.47	94	19	7	1	399	79	0	0	4	1
Gasconade River Basin													
Upper Gasconade	10290201	1,585	0.89	79	5	8	0	1,484	94	0	0	14	1
Big Piney	10290202	178	0.24	7	4	3	2	168	95	0	0	0	0
Lower Gasconade	10290203	554	0.54	194	35	7	1	347	63	0	0	7	1
Meramec River Basin													
Meramec	07140102	879	0.41	192	22	16	2	635	72	0	0	36	4
Bourbeuse	07140103	541	0.65	307	57	4	1	225	42	0	0	4	1
Big	07140104	462	0.48	48	10	7	1	383	83	0	0	24	5
Upper St. Francis River Basin													
Upper St. Francis	08020202	305	0.23	6	2	9	3	290	95	0	0	0	0
Neosho-Illinois River Basin													
Lake O' the Cherokees	11070206	709	0.77	570	80	3	0	106	15	19	3	11	2
Spring	11070207	3,082	1.20	2,131	69	5	0	468	15	33	1	445	14
Elk	11070208	464	0.45	149	32	5	1	301	65	0	0	9	2
Lower Neosho	11070209	799	0.36	475	59	8	1	209	26	107	13	0	0
Illinois	11110103	457	0.28	50	11	9	2	330	72	30	7	37	8
Arkansas River Basin													
Dirty-Greenleaf	11110102	763	0.97	271	36	2	0	409	54	80	11	0	0
Robert S. Kerr Reservoir	11110104	954	0.53	285	30	10	1	300	31	94	10	265	28
Poteau	11110105	413	0.22	27	7	10	2	208	50	42	10	125	30
Frog-Mulberry	11110201	625	0.50	266	42	4	1	315	50	7	1	33	5
Dardanelle Reservoir	11110202	871	0.47	117	13	7	1	689	79	0	0	58	7
Conway-Point Remove	11110203	657	0.58	431	66	6	1	211	32	0	0	9	1
Petit Jean	11110204	402	0.37	41	10	5	1	333	83	0	0	23	6
Cadron	11110205	240	0.31	110	46	3	1	116	48	0	0	11	5
Fourche La Fave	11110206	63	0.06	34	54	4	7	24	39	0	0	0	0
Lower Arkansas-Maumelle	11110207	478	0.43	422	88	6	1	8	2	0	0	43	9

(continued)

Table 4.11—Potential erosion rates in the aquatic study area, by land use category and year (1992, 1987, 1982) (continued)

River basin Watershed name	Watershed code (HUC)	Total potential erosion	Average potential erosion	Potential erosion from croplands		Potential erosion from forest lands		Potential erosion from pasture lands		Potential erosion from rangelands		Potential erosion from other lands	
		k tons	*k tons/mi²*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*
						1987 (continued)							
Kiamichi-Little River Basin													
Kiamichi	11140105	461	0.25	6	1	14	3	286	62	155	34	0	0
Upper Little	11140107	80	0.06	0	0	14	17	66	83	0	0	0	0
Mountain Fork	11140108	117	0.14	0	0	7	6	95	81	0	0	15	13
Lower Little	11140109	224	0.11	18	8	17	8	190	85	0	0	0	0
Ouachita-Saline River Basin													
Ouachita Headwaters	08040101	96	0.06	0	0	7	7	90	93	0	0	0	0
Upper Ouachita	08040102	215	0.12	127	59	23	11	65	30	0	0	0	0
Little Missouri	08040103	402	0.19	129	32	20	5	220	55	0	0	33	8
Upper Saline	08040203	2,263	1.32	31	1	18	1	76	3	0	0	2,138	94
Upper White River Basin													
Beaver Reservoir	11010001	917	0.36	9	1	15	2	774	84	118	13	0	0
James	11010002	1,336	0.92	221	17	5	0	1,051	79	0	0	59	4
Bull Shoals Lake	11010003	1,765	0.68	59	3	14	1	1,327	75	334	19	32	2
Middle White	11010004	690	0.47	185	27	10	1	282	41	113	16	101	15
Buffalo	11010005	758	0.56	5	1	9	1	691	91	0	0	53	7
North Fork White	11010006	1,002	0.55	105	11	11	1	754	75	111	11	20	2
Little Red	11010014	619	0.34	352	57	14	2	200	32	0	0	54	9
Upper Black River Basin													
Upper Black	11010007	1,318	0.69	1,187	90	12	1	88	7	0	0	30	2
Current	11010008	1,003	0.38	325	32	19	2	658	66	0	0	0	0
Lower Black	11010009	774	0.99	585	76	3	0	171	22	0	0	14	2
Spring	11010010	416	0.34	4	1	8	2	399	96	0	0	5	1
Eleven Point	11010011	579	0.48	37	6	7	1	535	92	0	0	0	0
Strawberry	11010012	316	0.40	32	10	5	2	263	83	4	1	12	4
						1982							
Osage River Basin													
H.S. Truman Reservoir	10290105	1,474	1.22	1,232	84	4	0	127	9	4	0	108	7
Sac	10290106	1,655	0.84	591	36	6	0	999	60	9	1	50	3
Pomme de Terre	10290107	349	0.41	88	25	2	1	254	73	0	0	5	1
South Grand	10290108	7,326	3.58	3,750	51	2	0	495	7	0	0	3,078	42
Lake of the Ozarks	10290109	638	0.46	90	14	10	2	538	84	0	0	0	0
Niangua	10290110	288	0.28	45	16	8	3	234	81	0	0	0	0
Lower Osage	10290111	613	0.57	185	30	6	1	418	68	0	0	3	1
Gasconade River Basin													
Upper Gasconade	10290201	976	0.55	71	7	8	1	883	90	0	0	14	1
Big Piney	10290202	181	0.24	4	2	3	2	174	96	0	0	0	0
Lower Gasconade	10290203	621	0.60	219	35	6	1	395	64	0	0	0	0
Meramec River Basin													
Meramec	07140102	1,210	0.56	317	26	16	1	877	72	0	0	0	0
Bourbeuse	07140103	664	0.79	404	61	4	1	252	38	0	0	4	1
Big	07140104	567	0.59	238	42	7	1	322	57	0	0	0	0
Upper St. Francis River Basin													
Upper St. Francis	08020202	510	0.39	57	11	9	2	444	87	0	0	0	0
Neosho-Illinois River Basin													
Lake O' the Cherokees	11070206	603	0.66	456	76	3	0	137	23	6	1	0	0
Spring	11070207	3,341	1.30	2,363	71	4	0	611	18	32	1	331	10

(continued)

Table 4.11—Potential erosion rates in the aquatic study area, by land use category and year (1992, 1987, 1982) (continued)

River basin Watershed name	Watershed code (HUC)	Total potential erosion	Average potential erosion	Potential erosion from croplands		Potential erosion from forest lands		Potential erosion from pasture lands		Potential erosion from rangelands		Potential erosion from other lands	
		k tons	*k tons/mi²*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*	*k tons*	*%*
						1982 (continued)							
Neosho-Illinois River Basin (continued)													
Elk	11070208	566	0.55	222	39	5	1	330	58	0	0	9	2
Lower Neosho	11070209	873	0.40	510	58	8	1	207	24	132	15	17	2
Illinois	11110103	446	0.27	21	5	9	2	275	62	37	8	104	23
Arkansas River Basin													
Dirty-Greenleaf	11110102	882	1.12	342	39	2	0	422	48	116	13	0	0
Robert S. Kerr Reservoir	11110104	755	0.42	317	42	10	1	222	29	110	15	96	13
Poteau	11110105	387	0.20	62	16	10	3	246	63	69	18	0	0
Frog-Mulberry	11110201	383	0.30	150	39	4	1	188	49	7	2	33	9
Dardanelle Reservoir	11110202	638	0.34	134	21	7	1	439	69	0	0	58	9
Conway-Point Remove	11110203	679	0.60	429	63	6	1	244	36	0	0	0	0
Petit Jean	11110204	337	0.31	38	11	5	2	271	80	0	0	23	7
Cadron	11110205	482	0.63	334	69	3	1	141	29	0	0	4	1
Fourche La Fave	11110206	59	0.05	34	57	4	7	21	36	0	0	0	0
Lower Arkansas-Maumelle	11110207	510	0.46	475	93	6	1	9	2	0	0	21	4
Kiamichi-Little River Basin													
Kiamichi	11140105	500	0.27	5	1	14	3	344	69	138	28	0	0
Upper Little	11140107	114	0.08	0	0	14	12	93	82	0	0	7	6
Mountain Fork	11140108	83	0.10	0	0	7	8	61	74	0	0	15	18
Lower Little	11140109	150	0.08	38	26	17	11	94	63	0	0	0	0
Ouachita-Saline River Basin													
Ouachita Headwaters	08040101	73	0.05	10	13	7	9	56	77	0	0	0	0
Upper Ouachita	08040102	275	0.16	171	62	23	8	81	30	0	0	0	0
Little Missouri	08040103	447	0.21	175	39	20	4	222	50	0	0	31	7
Upper Saline	08040203	2,317	1.36	28	1	18	1	131	6	0	0	2,140	92
Upper White River Basin													
Beaver Reservoir	11010001	1,051	0.41	5	0	15	1	911	87	120	11	0	0
James	11010002	1,354	0.94	231	17	4	0	1,076	79	0	0	43	3
Bull Shoals Lake	11010003	1,834	0.71	64	4	14	1	1,353	74	370	20	31	2
Middle White	11010004	577	0.39	167	29	10	2	186	32	113	20	100	17
Buffalo	11010005	775	0.58	5	1	9	1	709	91	0	0	53	7
North Fork White	11010006	978	0.53	134	14	11	1	645	66	169	17	20	2
Little Red	11010014	1,050	0.58	777	74	14	1	237	23	0	0	22	2
Upper Black River Basin													
Upper Black	11010007	1,262	0.66	1,171	93	12	1	79	6	0	0	0	0
Current	11010008	1,199	0.46	372	31	19	2	807	67	0	0	0	0
Lower Black	11010009	750	0.96	564	75	3	0	178	24	0	0	5	1
Spring	11010010	424	0.35	13	3	8	2	398	94	0	0	5	1
Eleven Point	11010011	553	0.46	111	20	7	1	421	76	0	0	15	3
Strawberry	11010012	218	0.28	32	15	5	2	168	77	4	2	10	4

HUC = hydrologic unit code; k = thousand; mi² = square mile.
Source: USDA NRCS (1997).

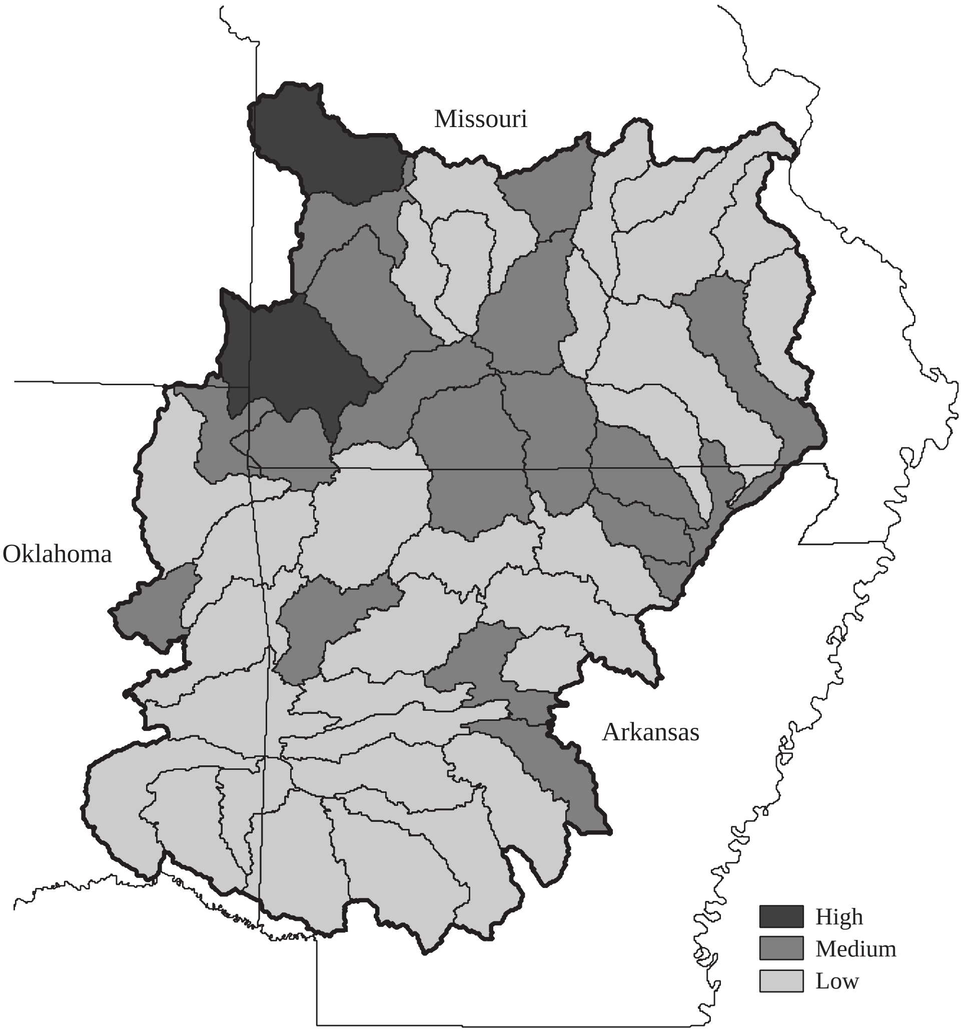


Figure 4.9—Average potential erosion in the aquatic study area by watershed for all land use categories in 1992 (USDA NRCS 1997).

The Natural Resources Conservation Service defines “other” lands (table 4.11) as developed land and other rural land including marshlands, farmsteads, barren land such as salt flats, and land enrolled in the Conservation Reserve Program. In more than half of the Assessment area watersheds, potential erosion rates from other lands are 2 percent or less TPE. The watersheds with the highest potential erosion from “other” lands are in the southeastern, east central, and western portions of the Assessment area. The Upper Saline (85 percent), South Grand (38 percent), and Little Red (25 percent) watersheds had the highest potential erosion rates for “other” lands in 1992.

Implications and Opportunities

Best management practices and other conservation measures appear to be working, because total erosion declined in more than half of the Ozark-Ouachita Highlands area watersheds for the 3 years studied. Since pasture lands had the highest potential erosion in most Assessment area watersheds for 1982, 1987, and 1992, it is apparent that pasture management needs improvement.

Pesticides—Applications and Distributions

Question 4.10: Which pesticides are most frequently applied in the Assessment area, and to what extent are they distributed?

Pesticides are chemicals, primarily synthetic organic compounds, that are not naturally present in water, air, or soil and are used to control unwanted plants or animals (Ware 1989). These chemicals may have effects other than those intended for their use, including impacts on non-target organisms; accumulation in soil, water, and organisms; and degradation of water quality.

Key Findings

Ozark Plateaus

1. Approximately 4.4 million pounds (lbs) of active ingredients per year from 130 pesticides were applied on 25 crop types within the Ozark Plateaus Province from 1987 through 1991.
2. The herbicides 2,4-D, atrazine, propanil, metolachlor, alachlor, trifluralin, dicamba, and glyphosate were the eight pesticides used most extensively on or in the Ozark Plateaus.
3. The most frequently applied pesticide was 2,4-D; an estimated 750,000 lbs per year of 2,4-D were applied in the Ozark Plateaus.

Arkansas Valley

1. Approximately 771,000 lbs of active ingredients per year from 128 pesticides were applied on 25 crop types within the Arkansas Valley from 1987 to 1991.
2. The seven pesticides used most extensively in the Arkansas Valley were the herbicides 2,4-D, propanil, trifluralin, atrazine, metolachlor, and dicamba and the fungicide sulfur.
3. The most frequently applied pesticide was 2,4-D; an estimated 108,000 lbs per year of 2,4-D were applied in the Arkansas Valley.

Ouachita Mountains

1. Approximately 356,000 lbs of active ingredients per year from 127 pesticides were applied on 22 crop types within the Ouachita Mountains from 1987 to 1991.
2. The herbicides 2,4-D, dicamba, atrazine, metolachlor, trifluralin, and glyphosate and the fungicide, sulfur, were the seven pesticides used most extensively in the Ouachita Mountains.
3. The most frequently applied pesticide in the Ouachita Mountains was 2,4-D, with an estimated application of 65,000 lbs per year.

Data Sources and Methods of Analysis

Data about pesticide applications on croplands are available for 130 pesticides and 25 crop types from 1987 through 1991 (Gianessi and Puffer 1991, 1992a, 1992b). In this report, data from crop and pasture applications of pesticides only are considered because data from other land uses were not available in computerized data bases. However, pesticide use in forest areas is minimal in comparison with its use on crops (Courtenay 1996). Pesticide use in urban areas is confined to a minor part of the Assessment area. The Aquatic Team estimated pesticide use from county-level totals. For counties located along the boundary of the Highlands or for counties included more than once because of their position in multiple physiographic sections within the Assessment area, the team applied a correction factor based on the percentage of the county within the Assessment or physiographic area.

Patterns and Trends

Ozark Plateaus. Approximately 4.4 million lbs of active ingredients per year from 130 pesticides were applied on 25 crop types within the Ozark Plateaus from 1987 through 1991 (table 4.12). The herbicides 2,4-D, atrazine, propanil, metolachlor, alachlor, trifluralin, dicamba, and glyphosate were the eight pesticides used most extensively throughout the Ozark Plateaus. Use of these herbicides accounts for approximately 63 percent of the total pesticides applied in the Ozark Plateaus. Pesticide use generally was greatest in areas where the

Table 4.12—Estimated annual cropland and pasture applications of selected pesticides in the Assessment area, pesticide type, and use, 1987 through 1991

Pesticide	Active ingredient applied	Type	Use
	k lb/year		
			Ozark Plateaus
2,4-D	750	Herbicide	Grains, pasture, selected fruits and vegetables
Atrazine	494	Herbicide	Corn and sorghum
Propanil	463	Herbicide	Rice
Metolachlor	289	Herbicide	Vegetables, nuts, and cotton
Alachlor	257	Herbicide	Vegetables, cotton, and nuts
Trifluralin	187	Herbicide	Grains, vegetables, and nuts
Dicamba	167	Herbicide	Corn and forage
Glyphosate	165	Herbicide	Rice, cotton, soybeans, and sorghum
Other[a]	1,628		
Total	4,400		
			Arkansas Valley
2,4-D	108	Herbicide	Grains, pasture, selected fruits and vegetables
Sulfur	78	Fungicide	Fruits and vegetables
Propanil	66	Herbicide	Rice
Trifluralin	54	Herbicide	Grains, vegetables, and nuts
Atrazine	46	Herbicide	Corn and sorghum
Metolachlor	43	Herbicide	Vegetables, nuts, and cotton
Dicamba	40	Herbicide	Corn and forage
Other[b]	336		
Total	771		
			Ouachita Mountains
2,4-D	65	Herbicide	Grains, pasture, selected fruits and vegetables
Sulfur	48	Fungicide	Fruits and vegetables
Dicamba	26	Herbicide	Corn and forage
Atrazine	26	Herbicide	Corn and sorghum
Metolachlor	17	Herbicide	Vegetables, nuts, and cotton
Trifluralin	18	Herbicide	Grains, vegetables, and nuts
Glyphosate	16	Herbicide	Rice, cotton, soybeans, and sorghum
Other[c]	211		
Total	356		
Total applied in the Assessment area	5,521		

k lb/year = thousand pounds per year.

[a] Additional 122 pesticides with application rates of less than 150,000 pounds per year of active ingredient.

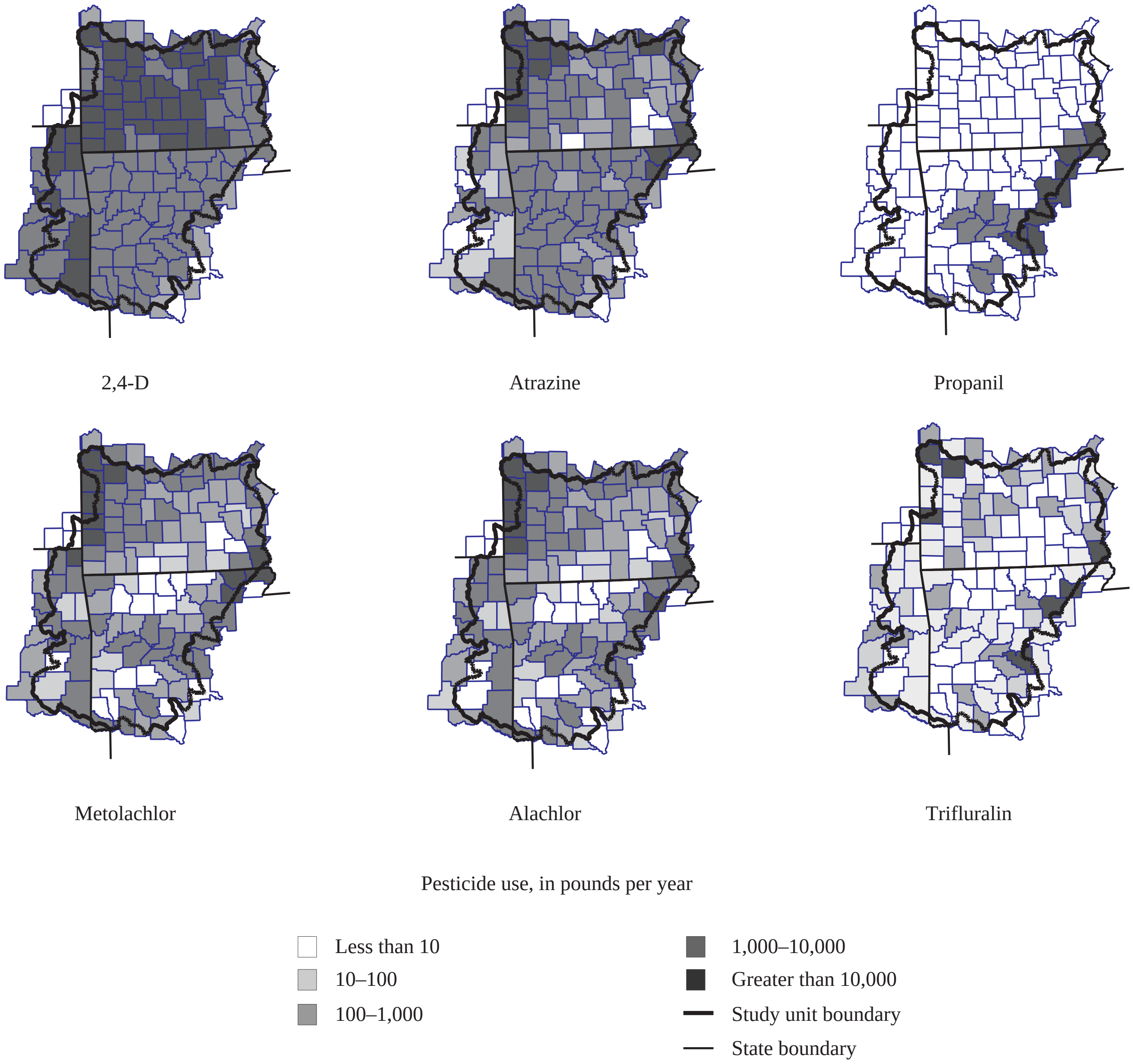
[b] Additional 121 pesticides with application rates less than 40,000 pounds per year of active ingredient.

[c] Additional 120 pesticides with application rates less than 15,000 pounds per year of active ingredient.

Source: Active ingredient applied from Gianessi and Puffer (1991, 1992a, b); description of use modified from Baldwin and others (1994), Becker and others (1992), Johnson and Jones (1994), Sine (1991), Spradley (1991, 1992).

dominant land use was pasture land in the Springfield and Salem Plateaus and in croplands in the Osage Plains and Mississippi Alluvial Plain.

The most frequently applied pesticide in the Assessment area was 2,4-D (fig. 4.10). A selective herbicide, 2,4-D was most often applied to control broadleaf weeds in pastures and cropland. Within the Ozark Plateaus, 2,4-D was applied most heavily in areas where pasture was the dominant crop type (in the Springfield and Salem Plateaus). An estimated 750,000 lbs/year of 2,4-D were applied in the 90 counties of the Ozark Plateaus. Usage per county within the Ozark Plateaus ranged from 1 lb/year in several counties in Arkansas, Missouri, and Oklahoma to 14,000 lbs/year in Wright County, MO. The median usage in this area was 184 lbs/year.


2,4-D

Atrazine

Propanil

Metolachlor

Alachlor

Trifluralin

Figure 4.10—Major pesticide use in the Assessment area by county, 1987 through 1991 (calculated from data in Gianessi and Puffer 1991; 1992a, b).

Atrazine, propanil, metolachlor, alachlor, trifluralin, dicamba, and glyphosate were the other most frequently used pesticides in the Ozark Plateaus. All of these pesticides are herbicides used to control various weeds and grasses, primarily in cropland areas. Use of these pesticides within counties of the Ozark Plateaus ranges from 1 to about 141,000 lbs/year, with median per county application ranging from about 15 to 37,000 lbs/year.

Arkansas Valley. Approximately 771,000 lbs/year of active ingredients from 128 pesticides were applied on 25 crop types within the Arkansas Valley from 1987 through 1991. The herbicides 2,4-D, propanil, trifluralin, atrazine, metolachlor, and dicamba, and the fungicide, sulfur, were the seven pesticides used most extensively in the Arkansas Valley, accounting for approximately 56 percent of the total pesticides applied (table 4.12).

The most frequently applied pesticide in the Arkansas Valley was 2,4-D (table 4.12, fig. 4.10), applied mainly to control broadleaf weeds in pasture and cropland. An estimated 108,000 lbs/year of 2,4-D were applied in the 32 counties in the Arkansas Valley. Usage ranged from 1 lb/year in several counties in Arkansas and Oklahoma to 6,000 lbs/year in Muskogee County, OK. The median usage in the Assessment area was 144 lbs/year.

Sulfur, propanil, trifluralin, atrazine, metolachlor, and dicamba were the other most frequently used pesticides in the Arkansas Valley. With the exception of sulfur—a fungicide used on fruits and vegetables—these pesticides are herbicides used to control various weeds and grasses primarily in cropland areas. Use of each of these pesticides ranged from 1 to about 34,000 lbs/year in individual counties, with median county application rates ranging from about 47 to 4,500 lbs/year.

Ouachita Mountains. Approximately 356,000 lbs of active ingredients per year from 127 pesticides were applied on 22 crop types within the Ouachita Mountains part of the Assessment area from 1987 to 1991. The herbicides 2,4-D, dicamba, atrazine, metolachlor, trifluralin, and glyphosate and the fungicide sulfur were the seven pesticides used most extensively throughout the Ouachita Mountains. Use of these pesticides accounts for approximately 59 percent of the total pesticides applied in the Ouachita Mountains (table 4.12).

The most frequently applied pesticide in the Ouachita Mountains was 2,4-D (table 4.12, fig. 4.10). This herbicide most often was applied to control broadleaf weeds in pasture and cropland. An estimated 65,000 lbs/year of 2,4-D were applied in the 26 counties of the Ouachita Mountains from 1987 through 1991. Usage ranged from 1 lb/year in several counties in Arkansas and Oklahoma to 4,900 lbs/year in McCurtain County, OK. The median usage in this area was 135 lbs/year.

Sulfur, dicamba, atrazine, metolachlor, trifluralin, and glyphosate were the other most frequently used pesticides in the Ouachita Mountains (table 4.12, fig. 4.10). With the exception of sulfur, these pesticides are herbicides used to control various weeds and grasses primarily in cropland areas. Use of each of these pesticides ranges from 1 to about 17,000 lbs/year in individual counties, with median county application rates ranging from about 10 to 300 lbs/year.

Pesticides in Surface Water

Question 4.11: What are the current and potential effects of pesticides on surface water in the Highlands?

Pesticides in surface water discussed in this report include a wide variety of classes of herbicides and insecticides. However, data about pesticides affecting water quality for the Assessment area are limited. The Ozark Plateaus NAWQA study recently increased the amount of available pesticide data for that province (Bell and others 1996, 1997).

Key Findings

Ozark Plateaus

1. Pesticide data are available for 1,002 samples from 141 surface water sampling sites in the Ozark Plateaus.
2. Many sites were sampled only once (42 sites) or twice (19 sites) during the 1970 through 1990 period of record.
3. About 50 percent of the 1,002 samples were collected in the mid-1970's and early 1980's.
4. Thirty-four of the 50 pesticides were below the detection limit for all the samples collected; 16 pesticides were detected in 132 samples collected from 43 sites.
5. The pesticide detected most often was the insecticide toxaphene, detected in 17 of 866 samples from 5 of 112 sites. The concentration of toxaphene in samples with detections ranged from 0.1 to 6.0 milligrams per liter (mg/L).

Arkansas Valley

1. Pesticide data are available for 53 samples from 14 sites in the Arkansas Valley.
2. Many sites were sampled only once (four sites) or twice (seven sites) during the 1975 through 1995 period of record.
3. About 65 percent of the 53 samples were collected in the early and mid-1980's.
4. Three of the nine pesticides were below the detection limit for all the samples collected; six pesticides were detected in three samples collected from three sites.
5. Five pesticides (DDE, DDT, aldrin, dieldrin, and lindane) were detected in 3 of 53 samples from 3 of 14 sites. The maximum concentration for these pesticides was 0.001 mg/L, except for DDT (0.002 mg/L).

Ouachita Mountains

1. Pesticide data are available for 245 samples from 19 sites in the Ouachita Mountains.
2. About 64 percent of the 245 samples were collected in the late 1970's and early 1980's.
3. Sixteen of 23 pesticides were below the detection limit for all the samples collected; 7 pesticides were detected in 13 samples collected from 10 sites.
4. The most commonly detected pesticide is methyl parathion, found in 10 of 234 samples at 10 of 20 sites, with concentrations ranging from 0.001 to 0.002 mg/L.

Data Sources and Methods of Analysis

Pesticide concentration data (here the term "pesticide" is used to refer to both pesticides and pesticide metabolites, the latter being a product of the chemical breakdown of pesticides in the environment) and other water quality data are collected by many Federal, State, and local governmental agencies for a variety of purposes. Numerous sources of pesticide data were available for the Assessment area, but the Aquatic Team used data collected by Federal or State governmental agencies and stored in computerized data bases only (table 4.13). Three Federal and three State agencies collected and maintained records of pesticide data for the majority of the surface water sampling sites in the Assessment area during the period of record (water years 1970 through 1990 for the Ozark Plateaus and 1975 through 1995 for the Arkansas Valley and Ouachita Mountains). Each agency has different objectives for collecting pesticide data; these objectives affect the spatial, temporal, and hydrologic distributions of the data. No long-term pesticide monitoring networks were in operation in the Assessment area during the period of record.

Most of the available computerized pesticide data resides in two national data bases: (1) the Geological Survey's national Water Data Storage and Retrieval System (WATSTORE), and (2) The EPA's STORET.

The initial retrieval from WATSTORE and STORET located about 80,000 samples from 2,300 sample sites in the Assessment area for the water years 1970 through 1990 (Ozark Plateaus) and 1975 through 1995 (Ouachita Province). The Aquatic Team searched these 80,000 samples for pesticide data, using more than 700 pesticide names, and then applied several additional screening techniques: (1) for cases in which more than one agency collected samples at sites that were in close proximity to each other, the team combined these sites to represent a single site; (2) for cases in which more

Table 4.13—Major sources of pesticide data for the aquatic study area

Agency	Data collection purpose, type, and accessibility
Federal agencies	
U.S. Army Corps of Engineers	Resource assessment on Corps-developed projects; variety of water-quality data, sometimes collected in cooperation with other Federal agencies; data available from STORET and WATSTORE.
U.S. Environmental Protection Agency	Regulatory. Wide variety of water-quality data, sometimes collected in cooperation with State agencies; all data in STORET; information on well construction and streamflow available.
U.S. Geological Survey	Water resources assessment and research; limited monitoring network for ground and surface water quality; all data are computerized in WATSTORE including some State agency data; information on streamflow and well construction available.
State agencies	
Arkansas Dept. of Pollution Control and Ecology	Regulatory monitoring of 110 surface water sites statewide, 46 sites within the Assessment area; samples analyzed for inorganic constituents, with some pesticide data and fish-tissue analysis for metals and organics; data are computerized in WATSTORE and STORET; information available on streamflow.
Kansas Dept. of Health and Environment	Monitoring network of surface and ground water quality originally in cooperation with the U.S. Geological Survey, but independently since 1990; 20 years of records, virtually all data in STORET; chemical and biological analyses for approximately 240 surface water sites statewide, 15 sites within the aquatic study area, of which 30 to 40 percent have streamflow data.
Oklahoma Dept. of Environmental Quality	Monitoring ambient water quality and assessment of hazardous waste sites; most data in STORET or other computerized data base; some fish tissue and bed sediment data available, some pesticide data available; some streamflow information available.

than one sample was collected at a particular site on a single day, the team used data from the first sample of the day only to avoid creating bias in the statistical analysis; and (3) the team excluded from the final data set any pesticides represented by fewer than five samples. The final data set for this report contains 1,300 samples from 173 sites. All of the surface water pesticide data for the Ozark Plateaus described in this report is from the Ozark Plateaus NAWQA study contained in Bell and others (1996). Table 4.14 summarizes the number of pesticide sampling sites and samples collected for the Assessment area by agency.

Patterns and Trends

Spatial and temporal distributions of pesticide data. The spatial and temporal distributions (sampling places and time periods) of pesticide data are important factors in evaluating the significance of that data. When assessing how representative and suitable data are for statistical analysis, important factors are site and basin characteristics, land use, and spatial and temporal distributions.

Spatial distribution of the surface water sampling sites is not uniform. Pesticide data are available for

Table 4.14—Numbers of pesticide sampling sites and samples collected in physiographic areas of the Ozark-Ouachita Highlands, by monitoring agency

	Ozark Plateaus		Arkansas Valley		Ouachita Mountains	
Agency	Sites	Samples	Sites	Samples	Sites	Samples
U.S. Army Corps of Engineers	1	2	0	0	0	0
U.S. Environmental Protection Agency	39	70	0	0	0	0
U.S. Geological Survey	30	158	1	2	1	7
AR Dept. of Pollution Control and Ecology	46	582	13	51	18	238
KS Dept. of Health and Environment	17	168	0	0	0	0
OK Dept. of Environmental Quality	8	22	0	0	0	0
Total	141[a]	1,002	14	53	19	245

[a] The Illinois River near Tahlequah, OK, was sampled by the U.S. Geological Survey and Oklahoma Department of Environmental Quality (and therefore was counted twice here).

1,002 samples from 141 surface water sites in the Ozark Plateaus, for 53 samples from 14 sites in the Arkansas Valley, and for 245 samples from 19 sites in the Ouachita Mountains (fig. 4.11 and table 4.15). The density of sampling sites is greatest in the Springfield Plateau and Osage Plains and least for the St. Francois Mountains and western part of the Salem Plateau, Arkansas Valley, and Ouachita Mountains. In the Ozark Plateaus, most surface water sampling sites have drainage basins in the Springfield (45 sites) and Salem (43 sites) Plateaus; fewer have drainage basins in the Osage Plains (18 sites) and Boston Mountains (3 sites). Thirty-one surface water sites have drainage basins that cover parts of two or more physiographic areas within the Assessment's borders. All or part of the drainage basins for 8 of the 11 sites where 20 or more samples were collected are located in the Springfield Plateau.

In general, sites were sampled infrequently in the mid-1970's and early 1980's. In the Ozark Plateaus, many sites were sampled only once (42 sites) or twice (19 sites) during the water years 1970 through 1990. The sites with the most samples collected are the White River near Norfork, AR (site 33, 39 samples), and the Neosho River at Chetopa, KS (site 82, 33 samples). About 50 percent of the 1,002 samples were collected in the mid-1970's and early 1980's. The 5 years in which the largest number of samples were collected are 1982 (124 samples), 1981 (117 samples), 1974 (97 samples), 1975 (83 samples), and 1973 (82 samples). Samples were collected in 16 or more years at the Spring River near Waco, MO (site 106, 17 years), and the Neosho River at Chetopa, KS (site 82, 16 years). The White River near Norfork, AR (site 33), had the most consecutive years (water years 1981 to 1987) in which three or more samples were collected.

In the Arkansas Valley, many sites were sampled only once (four sites) or twice (seven sites) during the water years 1975 through 1995. The sites with the most samples collected are the Petit Jean River near Booneville, AR (site 147, 18 samples), and the Fourche La Fave River near Gravelly, AR (site 151, 11 samples). About 65 percent of the 53 samples were collected in the early and mid-1980's. The 2 years in which the largest number of samples were collected are 1984 (14 samples) and 1985 (8 samples). The Petit Jean River near Booneville, AR (site 147), had the most consecutive years (water years 1976 through 1982) in which at least one sample was collected.

In the Ouachita Mountains, most sites were sampled more than twice during the water years 1975 to 1995. The sites with the most samples collected are the Little River near Horatio, AR (site 165, 34 samples), and Cossatot River near Lockesburg, AR (site 167, 31 samples), both just south of the Ouachita Mountains. About 64 percent of the 245 samples were collected in the late-1970's and early 1980's. The 2 years in which the largest number of samples were collected are 1982 (36 samples) and 1981 (31 samples). The Cossatot River near Lockesburg, AR (site 167), had the most consecutive years (water years 1975 through 1982) in which at least one sample was collected.

Assessment of conditions at surface water sites. Water quality is affected by factors related to physiography, geology, land use, and other human activities.

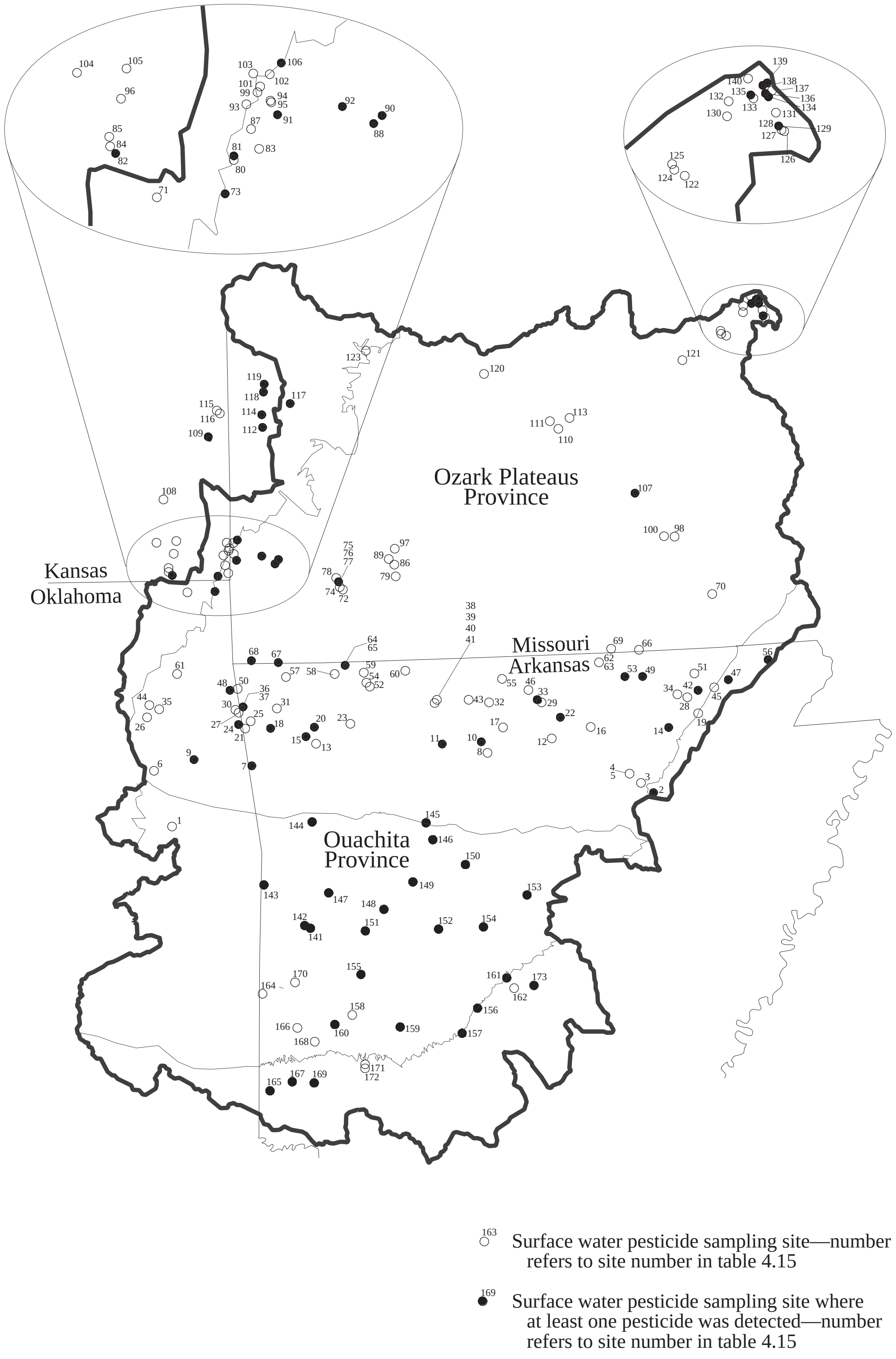


Figure 4.11—Locations of surface water pesticide sampling sites and sites where pesticides were detected in the Assessment area (Bell and others 1996).

Table 4.15—Surface water sampling sites for which pesticide data are available

Site number in fig. 4.11	Site name	Site number in fig. 4.11	Site name
1	Illinois River at Highway 64 Bridge, OK	58	White River at Beaver Dam near Eureka Springs, AR
2	White River at Oil Trough, AR	59	Kings River near Berryville, AR
3	White River near Salado, AR	60	Long Creek near Denver, AR
4	White River at Batesville, AR	61	Neosho River near Langley, OK
5	White River above Batesville, AR	62	South Fork of Spring River near Moko, AR
6	Grand Neosho River near Fort Gibson Dam, OK	63	South Fork of Spring River near Salem, AR
7	Baron Fork at Dutch Mills, AR	64	White River at Beaver, AR
8	Bear Creek west of Marshall, AR	65	White River near Beaver, AR
9	Illinois River near Tahlequah, OK	66	Spring River near Thayer, MO
10	Buffalo River near St. Joe, AR	67	Little Sugar Creek at Caverna, MO
11	Buffalo River near Hasty, AR	68	Butler Creek near Sulphur Springs, AR
12	North Sylamore Creek near Fifty Six, AR	69	Myatt Creek near Lanton, MO
13	White River below Fayetteville, AR	70	Current River below Hawes Campground, MO
14	Strawberry River near Smithville, AR	71	Neosho River near Commerce, OK
15	West Fork White River east of Fayetteville, AR	72	Spring River near Verona, MO
16	Mill Creek near Melbourne, AR	73	Spring River at Devil's Prominade Bridge, OK
17	Buffalo River near Harriet, AR	74	Spring River 0.6 mi. upstream from U.S. 60 Bridge, MO
18	Illinois River at Savoy, AR	75	Unnamed creek between Syntex and Spring, MO
19	Black River at Black Rock, AR	76	Spring River west of Verona, MO
20	White River near Goshen, AR	77	Douger Brook at State Route P Bridge, MO
21	Illinois River south of Siloam Springs, AR	78	Spring River 2.4 mi. downstream of Douger Bridge, MO
22	White River at Calico Rock, AR	79	James River near Boaz below Wilson Creek, MO
23	Holman Creek near Huntsville, AR	80	Spring River at Baxter Springs, KS
24	Illinois River near Watts, OK	81	Spring River near Baxter Springs, KS
25	Illinois River near Siloam Springs, AR	82	Neosho River at Chetopa, KS
26	Grand Neosho River above Industrial Park, OK	83	Shoal Creek near Galena, KS
27	Sager Creek near Siloam Springs, AR	84	Neosho River near Chetopa, KS
28	Spring River at Imboden, AR	85	Labette Creek near Chetopa, KS
29	North Fork River at Norfork, AR	86	James River 2 mi. above Wilson Creek, MO
30	Flint Creek near West Siloam Springs, OK	87	Short Creek near Galena, KS
31	Osage Creek near Elm Springs, AR	88	Jones Creek near Fidelity, MO
32	Crooked Creek at Yellville, AR	89	Wilson Creek downstream of South Creek, MO[a]
33	White River near Norfork, AR	90	Center Creek above Fidelity, MO
34	Spring River at Ravenden, AR	91	Turkey Creek near Joplin, MO
35	Neosho River at State Highway 33 Bridge, OK	92	Center Creek near Carterville, MO
36	Spavinaw Creek north of Sycamore, OK	93	Shawnee Creek near Crestline, KS
37	Flint Creek north of Siloam Springs, AR	94	Center Creek near Smithfield, MO
38	Crooked Creek at Harrison, AR	95	Center Creek south of Smithfield, MO
39	Crooked Creek above Harrison, AR	96	Neosho River near Oswego, KS
40	Crooked Creek near Harrison, AR	97	Wilson Creek upstream of South Creek, MO[b]
41	Crooked Creek below Harrison, AR	98	Current River above Powder Mill, MO
42	Eleven Point River near Pocahontas, AR	99	Spring River near Crestline, KS
43	Crooked Creek at Pyatt, AR	100	Jacks Fork above Two Rivers, MO
44	Pryor Creek at Highway 69a Bridge, OK	101	Spring River near Galena, KS
45	Black River at Pocahontas, AR	102	Spring River south of Waco, MO
46	Hicks Creek near Mountain Home, AR	103	Cow Creek near Lawton, KS
47	Current River near Pocahontas, AR	104	Labette Creek near Labette, KS
48	Spavinaw Creek near Sycamore, OK	105	Lightning Creek near Oswego, KS
49	Spring River near Hardy, AR	106	Spring River near Waco, MO
50	Spavinaw Creek near Cherokee City, AR	107	Current River below Montauk State Park, MO
51	Eleven Point River near Ravenden Springs, AR	108	Neosho River water station no. 1, KS
52	Osage Creek above Berryville, AR	109	Marmaton River near Fort Scott, KS
53	South Fork Spring River at Saddle, AR	110	Devil's Elbow on Big Piney, MO
54	Osage Creek below Berryville, AR	111	Gasconade at Highway Y, MO
55	White River at Bull Shoals Dam near Flippin, AR	112	Marmaton River near Nevada, MO
56	Black River near Corning, AR	113	Gasconade River near Jerome, MO
57	Mckisic Creek tributary near Bentonville, AR	114	Little Osage River near Horton, MO

(continued)

Table 4.15—Surface water sampling sites for which pesticide data are available (continued)

Site number in fig. 4.11	Site name	Site number in fig. 4.11	Site name
115	Little Osage River near Fulton, KS	144	Mulberry River at I40 near Mulberry, AR
116	Little Osage River at Fulton, KS	145	Big Piney Creek at highway 164 near Dover, AR
117	Osage River above Schell City, MO	146	Illinois Bayou near Dover, AR
118	Marais des Cygnes drainage ditch, MO	147	Petit Jean River near Booneville, AR
119	Miami Creek near Butler, MO	148	Dutch Creek at Shark, AR
120	Osage Gasconade, Bagnell Dam, MO	149	Chickalah Creek near Chickalah, AR
121	Meramec River at Meramec Park, MO	150	White Oak Creek near Atkins, AR
122	Calvey Creek no. 1, MO	151	Fourche La Fave River near Gravelly, AR
123	Tebo Creek, Henry Co. Highway PP, MO	152	South Fourche La Fave River at Hollis, AR
124	Calvey Creek no. 2, MO	153	Stone Dam Creek near Conway, AR
125	Calvey Creek no. 3, MO	154	Maumelle River at Williams Junction, AR
126	Meramec River at Highway 21 Bridge, MO	155	Ouachita River near Mount Ida, AR
127	Romaine Creek near mouth, MO	156	Ouachita River near Malvern, AR
128	Sugar Creek near mouth, MO	157	Ouachita River near Donaldson, AR
129	Saline Creek before confluence of Sugar Creek, MO	158	South Fork Caddo River at Fancy Hill, AR
130	Meramec River upstream of I-44 Bridge at Times Beach, MO	159	Caddo River near Amity, AR
131	Meramec River below Fenton and upstream of Marina, MO	160	Little Missouri River near Langley, AR
132	Meramec River downstream of Glencoe, MO	161	Saline River west of Benton, AR
133	Meramec River upstream of Valley Park Bridge, MO	162	Saline River near Shaw, AR
134	Chrysler car plant-industrial waste, MO	163	Kiamichi River near Big Cedar, OK
135	Fishpot Creek at Hanna Road Bridge, St. Louis, MO	164	Mountain Fork near Hatfield, AR
136	Grand Glaize Creek at Marshall Road Bridge, MO	165	Little River near Horatio, AR
137	Meramec R. near Kirkwood, MO, wastewater-treatment intake	166	Cossatot River near Umpire, AR
		167	Cossatot River near Lockesburg, AR
138	Grand Glaize Creek at Carmen Road Bridge, MO	168	Saline River near Burg, AR
139	Sugar Creek near Ozark View Subdivision, St. Louis, MO	169	Saline River near Lockesburg, AR
140	Grand Glaize Creek Below Sulphur Springs Road, MO	170	Prairie Creek near Mena, AR
141	Poteau River east of Waldron, AR	171	Prairie Creek at Murfreesboro, AR
142	Poteau River northwest of Waldron, AR	172	Prairie Creek near Murfreesboro, AR
143	James Fork near Hackett, AR	173	Hurricane Creek near Sardis, AR

[a] Original site name is “Wilson Creek, downstream”; reference to South Creek added for clarification.

[b] Original site name is “Wilson Creek, upstream”; reference to South Creek added for clarification.

Because of the limited spatial distribution of sampling sites and gaps in the temporal distribution of the samples, the available pesticide data are insufficient to provide an analysis of the effects of these factors on water quality in the Ozark-Ouachita Highlands area. The following sections provide a descriptive statistical summary of recent historical pesticide data collected at surface water sites in the Assessment area.

Descriptive statistics are used to show the central tendency and variation in the pesticide data. The minimum, maximum, and 50th percentile (median) of samples with detected concentrations are presented. The median is used to represent the central tendency of the data instead of the mean because the median is less sensitive to extreme values. The median is not reported unless five or more observations exceeded the detection limit. The maximum detection limit shows the censored concentration with the highest value for a particular parameter.

The locations of the 56 sites within the Assessment area where at least 1 pesticide was detected are shown in figure 4.11. (See table 4.15 for the site names.) Pesticides were detected in most parts of the Assessment area where sampling sites are located, but primarily in the southern, western, and extreme northeastern parts of the Ozark Plateaus and in the Arkansas Valley. A statistical summary of pesticide data collected for 50 pesticides in the Ozark Plateaus, 9 pesticides in the Arkansas Valley, and for 23 pesticides in the Ouachita Mountains is shown in table 4.16. In the Ozark Plateaus, 34 of the 50 pesticides were below the detection limit for all the samples collected; 16 pesticides were detected in 132 samples collected from 43 sites. In the

Table 4.16—Statistical summary of detected pesticide concentrations from surface water sampling sites in the Ozark Plateaus (water years 1970 through 1990), the Arkansas Valley, and Ouachita Mountains (1975 through 1995)

STORET parameter code[a]	Parameter name	Pesticide type	Minimum detected concentration	Median detected concentration	Maximum detected concentration	Samples	Sites	Sites with a detectable concentration	Samples with a detectable concentration	Max. detection limit
			mg/L	*mg/L*	*mg/L*					*mg/L*
						Ozark Plateaus				
34541	1,2-dichloropropane, total	F				54	26	0	0	10
39730	2,4-D, total	H	0.02	0.03	0.61	514	76	9	13	0.8
34601	2,4-dichlorophenol, total	G				55	27	0	0	52
39360	DDD, total	I	0.01	–	0.01	312	54	1	1	1.0
39365	DDE, total	M	0.001	0.001	0.01	718	75	15	16	1.0
39370	DDT, total	I	0.001	0.002	0.023	794	88	14	15	10
39305	o,p’-DDT, total	I				90	11	0	0	10
39300	p,p’-DDT, total	I				169	48	0	0	1.1
39040	DEF, total	D				17	2	0	0	0.01
39250	PCN, total	I				59	16	0	0	5.0
77825	Alachlor, total recoverable	H	0.015	0.66	4.2	115	23	5	6	0.5
39330	Aldrin, total	I	0.001	0.001	0.001	977	122	13	14	1.0
39337	Alpha benzene hexachloride, total	I	0.02	–	0.02	93	44	3	3	0.19
39338	Beta benzene hexachloride, total	I				72	30	0	0	0.38
39062	Chlordane, cis isomer, ww, total	I				10	3	0	0	0.1
39350	Chlordane, total	I	0.2	0.3	0.5	353	76	3	7	3.8
39065	Chlordane, trans isomer, ww, total	I				10	3	0	0	0.1
39071	Chlordane-nonachlor, trans isomer, ww, total	I				10	3	0	0	0.1
81403	Chloropyrifos, total	I				62	28	0	0	10
34704	Cis-1,3-dichloropropene, total	F				51	23	0	0	1.0
34699	Trans-1,3-dichloropropene, total	F				52	24	0	0	1.0
39570	Diazinon, total	I	0.01	–	0.01	60	14	1	1	0.1
39380	Dieldrin, total	I	0.001	0.001	0.01	990	132	15	15	2.0
39011	Disyston, total	I				17	2	0	0	0.01
39388	Endosulfan I, total	I				188	50	0	0	1.0
34361	Endosulfan I, ww, recoverable	I				70	29	0	0	0.38
34356	Endosulfan beta, total	I				70	29	0	0	0.63
34351	Endosulfan sulfate, total	I				70	29	0	0	1.3
39398	Ethion, total	I				46	10	0	0	0.01
39421	Heptachlor epoxide, dissolved	I				7	7	0	0	1.0
39420	Heptachlor epoxide, total	I				438	97	0	0	1.0
39410	Heptachlor, total	I	0.014	–	0.23	439	97	1	3	1.0
39700	Hexachlorobenzene, total	I				71	32	0	0	10
39340	Lindane, total	I	0.012	0.052	0.29	194	59	6	12	0.2
39782	Lindane, total	I	0.03	–	0.07	810	81	1	3	10
39530	Malathion, total	I				235	60	0	0	1.0
39480	Methoxychlor, total	I				365	69	0	0	50
39600	Methyl parathion, total	I				510	59	0	0	7.0
39356	Metolachlor, ww	H				80	17	0	0	0.25
81408	Metribuzin, ww	H	0.57	–	0.57	101	17	1	1	0.1
39755	Mirex, total	I				60	14	0	0	0.01
39540	Parathion, total	I				51	11	0	0	0.01
39034	Perthane, total	I				34	10	0	0	0.1
39023	Phorate, total	I				17	2	0	0	0.01
39760	Silvex, total	H				99	17	0	0	0.01
39055	Simazine, total	H				843	100	0	0	0.5
39402	Toxaphene, suspended, total	I				20	14	0	0	2.5
39400	Toxaphene, total	I	0.1	0.7	6.0	866	112	5	17	7.0
34757	Triazine screen by enzyme ww, recoverable	H	1.0	4.0	5.0	5	5	5	5	–
39786	Trithion, total	I				46	10	0	0	0.01

(continued)

Table 4.16—Statistical summary of detected pesticide concentrations from surface water sampling sites in the Ozark Plateaus (water years 1970 through 1990), the Arkansas Valley, and Ouachita Mountains (1975 through 1995) (continued)

STORET parameter code[a]	Parameter name	Pesticide type	Minimum detected concentration	Median detected concentration	Maximum detected concentration	Samples	Sites	Sites with a detectable concentration	Samples with a detectable concentration	Max. detection limit
			mg/L							*mg/L*
						Arkansas Valley				
39730	2,4-D, total	H				19	7	–	–	0.01
39365	DDE, total	I	–	–	0.001	46	13	3	3	0.002
39370	DDT, total	I	0.001	–	0.002	46	15	3	3	0.004
39330	Aldrin, total	I	–	–	0.001	46	13	3	3	0.002
39380	Dieldrin, total	I	–	–	0.001	46	15	3	3	0.002
39782	Lindane, total	I	–	–	0.001	46	16	3	3	0.01
39530	Malathion, total	I				12	4	0	0	0.001
39600	Methyl parathion, total	I	–	–	0.001	47	16	2	2	0.01
39400	Toxaphene, total	I				51	16	0	0	1
						Ouachita Mountains				
39730	2,4-D, total	H	0.04	–	0.04	125	13	1	1	0.01
39365	DDE, total	I	–	–	0.001	219	17	6	6	1
39370	DDT, total	I	0.001	0.002	0.003	221	19	7	7	4
39300	p,p'-DDT, total	I				23	3	0	0	0.01
77825	Alachlor, total recoverable	H				11	3	0	0	0.01
39330	Aldrin, total	I				242	14	0	0	0.03
39337	Alpha benzene hexachloride, total	I				22	3	0	0	0.01
39338	Beta benzene hexachloride, total	I				22	3	0	0	0.01
39350	Chlordane, total	I				17	4	0	0	0.1
81403	Chloropyrifos, total	I				11	3	0	0	0.01
39570	Diazinon, total	I				19	5	0	0	0.1
39380	Dieldrin, total	I	–	–	0.001	231	18	7	7	0.06
34361	Endosulfan I, ww, recoverable	I				23	3	0	0	0.01
34356	Endosulfan beta, total	I				23	3	0	0	0.01
34351	Endosulfan sulfate, total	I				23	3	0	0	0.06
39420	Heptachlor epoxide, total	I				29	4	0	0	0.01
39410	Heptachlor, total	I				29	4	0	0	0.01
39340	Lindane, total	I				29	4	0	0	0.01
39782	Lindane, total	I	0.01	0.01	0.01	214	18	5	5	0.01
39530	Malathion, total	I				93	14	0	0	0.1
39480	Methoxychlor, total	I				15	5	0	0	0.07
39600	Methyl parathion, total	I	0.001	0.001	0.002	234	20	10	10	0.1
39400	Toxaphene, total	I	0.1	0.35	0.7	244	18	3	6	1

mg/L = milligrams per liter; ww = whole water; – = unknown; F = soil fumigant; H = herbicide; G = germicide; I = insecticide; M = metabolite; D = defoliant.

[a] EPA's Storage and Retrieval code assigned to a parameter based on factors including the medium type and the analytical method used for the analysis.

Arkansas Valley, three of the nine pesticides were below the detection limit for all the samples collected; six pesticides were detected in three samples collected from three sites. In the Ouachita Mountains, 16 of 23 pesticides were below the detection limit for all the samples collected; 7 pesticides were detected in 13 samples collected from 10 sites.

In the Ozark Plateaus, the insecticide toxaphene (detected in 17 of 866 samples from 5 of 112 sites) was the pesticide with the most number of detections. The concentration of toxaphene in samples with detections ranged from 0.1 to 6.0 milligrams per liter (mg/L). The toxaphene sample having the maximum concentration was collected at the White River near Norfork, AR (site 33), in 1982. Site 33 had 12 toxaphene detections between 1981 and 1985. Other sites that had toxaphene samples above the detection limit include: Strawberry River near Smithville, AR (site 14; 2 samples, 1975, 1982); Spavinaw Creek north of Sycamore, OK (site 36; 1 sample, 1975); Spavinaw Creek near Sycamore, OK (site 48; 1 sample, 1975); and South Fork Spring River at Saddle, AR (site 53; 1 sample, 1985).

Six other pesticides were detected in 12 or more samples: DDE was detected in 16 of 718 samples from 15 of 75 sites; dieldrin was detected in 15 of 990 samples from 15 of 132 sites; DDT was detected in 15 of 794 samples from 14 of 88 sites; aldrin was detected in 14 of 977 samples from 13 of 122 sites; 2,4-D was detected in 13 of 514 samples from 9 of 76 sites; lindane (parameter code 39340) was detected in 12 of 194 samples from 6 of 59 sites. The maximum concentration for these six pesticides was less than 1.0 mg/L. The samples with the maximum concentration of these six pesticides were collected prior to 1983, with the exception of DDE, which was collected in 1990 at the Illinois River near Tahlequah, OK (site 9).

In the Arkansas Valley, five pesticides (DDE, DDT, aldrin, dieldrin, and lindane) were detected in 3 of 53 samples from 3 of 14 sites. The maximum concentration for these pesticides was 0.001 mg/L, except for DDT (0.002 mg/L). The three samples were collected at James Fork near Hackett, AR (site 143), Petit Jean River near Booneville, AR (site 147), and Fourche La Fave River near Gravelly, AR (site 151), in the mid-1970's.

In the Ouachita Mountains, methyl parathion had the most detections; it was found in 10 of 234 samples at 10 of 20 sites with concentrations ranging from 0.001 to 0.002 mg/L. The two methyl parathion samples having the maximum concentration were collected at the Hurricane Creek near Sardis, AR (site 173), in 1976 and the Ouachita River near Malvern, AR (site 156), in 1976.

For the Assessment area, the highest percentage of samples with concentrations above the detection limit were those analyzed for triazine herbicides and metabolites using an enzyme screening technique. All five samples collected in the northwestern part of the Assessment area in 1990 had concentrations above the detection limit. These concentrations ranged from 1.0 mg/L at the Marmaton River near Nevada, MO (site 112), to 5.0 mg/L at the Marais des Cygnes, MO (site 118). Of the other 15 pesticides that had 5 or more detectable concentrations, only lindane (6.2 percent) and alachlor (5.2 percent) had detections in more than 4 percent of the samples.

Comparison of pesticide data with selected quality criteria and standards. The EPA has established quality criteria (suggested but nonenforceable values) or standards (legally enforceable values) for six pesticides detected in surface water at sites in the Assessment area. The maximum concentrations of these pesticides in surface water samples summarized in this report are compared with selected quality criteria and standards and are shown in table 4.17.

The acute aquatic life criterion or criteria (AALC) established by the EPA (Nowell and Resek 1994) provide a basis of comparison with the maximum

Table 4.17—Comparison of maximum detected pesticide concentrations in surface water samples by physiographic area, with selected quality criteria and standards

	Maximum concentration[a]				
Pesticide	Ozark Plateaus	Arkansas Valley	Ouachita Mountains	AALC[b]	Drinking water standard MCL[b]
			mg/L		
Alachlor	4.2	—	nd	nsg	2.0
Chlordane	0.5	—	nd	2.4	2.0
DDT total	0.023	0.002	0.003	1.1	nsg
Dieldrin	0.01	0.001	0.001	2.5	nsg
Heptachlor	0.23	—	nd	0.52	0.4
Toxaphene	6.0	nd	0.7	nsg	3.0

AALC = acute aquatic life criteria; MCL = maximum contaminant level; mg/L = milligrams per liter; — = no samples analyzed; nd = not detected; nsg = no standard or guideline established.

[a] Maximum concentration of samples given in this report.

[b] Criteria and standards established by the U.S. EPA (AALC, MCL) listed in Nowell and Resek (1994).

concentration of each of the detected pesticides having an AALC value. The AALC is a national numerical criterion designed to prevent unacceptable short-term effects on a variety of species of fish, benthic invertebrates, and zooplankton. None of the four detected pesticides that have an AALC value (chlordane, DDT, dieldrin, or heptachlor) exceeded that value.

The maximum contaminant level (MCL) established by the EPA (Nowell and Resek 1994) provides a basis of comparison with the maximum concentration of each of the detected pesticides having an MCL value (the level to which a contaminant must be removed to meet Safe Drinking Act requirements). Because the MCL applies to treated drinking water, the comparison of concentrations of detected pesticides in this report with the MCL is merely for informational purposes.

The comparison of detected pesticides with selected quality criteria and standards suggests that pesticides do not pose any widespread or persistent problems in the Assessment area. However, a complete evaluation was not possible because of the limited spatial and temporal distributions of samples, limited number of criteria and MCL's, and the synergistic effects of multiple pesticides. The AALC were not exceeded by any samples, and the MCL was exceeded at two sites, one just outside the Assessment area, the other near Norfolk, AR.

Pesticides in Ground Water

Question 4.12: What are the current and potential effects of pesticides on ground water in the Highlands?

Pesticides in ground water considered in this report include a wide range of classes of herbicides and insecticides. Recent activities and completion of the Ozark Plateaus NAWQA study have provided abundant data about pesticides in the ground water of the Ozark Plateaus. However, there is a shortage of information for general, non-site-specific pesticide data in the ground waters of the Ouachita Province.

Key Findings

Ozark Plateaus Province

1. Pesticides were detected in 80 of 229 samples of ground water from 73 of 215 sites.
2. Twenty pesticides were detected; a maximum of five pesticides was detected in any one sample.
3. The most commonly detected pesticides are tebuthiuron, atrazine, prometon, desethylatrazine, and simazine. Maximum concentrations range from 0.003 to 1.0 mg/L.
4. The occurrence and distribution of pesticides are related to land use. Samples with detectable pesticides come from sites having a higher percent of land used for agriculture than samples from sites with no pesticides detected.
5. Pesticides are detected more often in samples from springs than in samples from wells.

Ouachita Province

1. For the Ouachita Province, very little data are available from monitoring pesticides in ground water.
2. Commonly applied pesticides in forest land—2,4-D, dichlorprop, hexazinone, and picloram were not found at any of the eight Ouachita Mountains sites sampled in 1986.

Data Sources and Methods of Analysis

Several studies have investigated the pesticide ground water quality in areas in or adjacent to the Ozark Plateaus. Ground water samples were collected from near surface aquifers in all or parts of 12 States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin) and analyzed for selected herbicides (Kolpin and others 1994). Ground water samples were collected in 1990 and 1991 from four counties in west central Missouri and analyzed for selected herbicides (Ziegler and others 1994), although little of these data are from within the Assessment area. Pesticide data were available for 103 samples collected from 1970 through 1990 from 92 ground water sites within the Ozark

Plateaus NAWQA study (Bell and others 1996). Most of these data were from Ziegler and others (1994) with only seven sites sampled in the Springfield Plateau and Ozark aquifers.

Pesticide data and interpretations presented in this report for the Ozark Plateaus are derived from the Ozark Plateaus NAWQA study (Adamski 1997). Ground water samples from 215 wells and springs in the Springfield Plateau and Ozark aquifers were collected between 1993 and 1995 and analyzed for 88 pesticides and metabolites.

Very little ambient ground water monitoring data are available for pesticides in the Ouachita Province. Cavalier and Lavy (1987) analyzed for pesticides at eight sites in the Ouachita Mountains during two sampling events in May and August of 1987. The sites sampled comprised five wells and two springs at seven national forest recreation areas and one well located near a small community. These ground water samples were analyzed for four of the herbicides most commonly applied in forest settings—2,4-D, dichlorprop, hexazinone, and picloram.

Patterns and Trends

Pesticides were detected in about one-third of the samples collected in the Ozark Plateaus (Adamski 1997a). Pesticides were detected in 80 of 229 ground water samples (35 percent) from 73 of the 215 sites (fig. 4.12). Pesticides were detected in samples from 43 springs and 30 wells.

Twenty pesticides were detected in the Ozark Plateaus (table 4.18) with a maximum of five pesticides detected in any one sample. The most commonly detected pesticides were tebuthiuron (31 detections), atrazine (30), prometon (25), desethylatrazine, a metabolite of atrazine (19), and simazine (18). These compounds are herbicides that are commonly used on

Table 4.18—Pesticides detected in ground water and their range of concentrations in the Ozark Plateaus

Pesticide	Detections		Range of concentrations	Use
	Total	*From estimates*[a]	*mg/L*	
Atrazine	30	6	0.001– 1.0	Herbicide
Benfluralin	1		0.003	Herbicide
Carbaryl	4	4	0.012– 0.03	Insecticide
Carbofuran	2	2	0.007– 0.016	Insecticide
Chlorpyrifos	2	1	0.003– 0.013	Insecticide
DCPA	3		0.002– 0.014	Herbicide
Desethylatrazine	19	19	0.002– 0.35	None (metabolite)
Dieldrin	2		0.025– 0.057	Insecticide (banned)
Diuron	2	2	0.01 – 0.18	Herbicide
Lindane	2		0.028– 0.032	Insecticide
Linuron	1		0.016	Herbicide
Metolachlor	5		0.002– 0.003	Herbicide
Metribuzin	3	1	0.004– 0.14	Herbicide
p,p’–DDE	10	10	0.001– 0.003	None (metabolite)
Prometon	25	15	0.002– 0.88	Herbicide
Propanil	2		0.007– 0.012	Herbicide
Propargite		1	0.008	Acaricide
Simazine	18	13	0.001– 0.026	Herbicide
Tebuthiuron	31	9	0.005– 0.24	Herbicide
Trifluralin	1		0.003	Herbicide

mg/L = milligrams per liter.

[a] Detections for which the reported concentration was an estimated value.

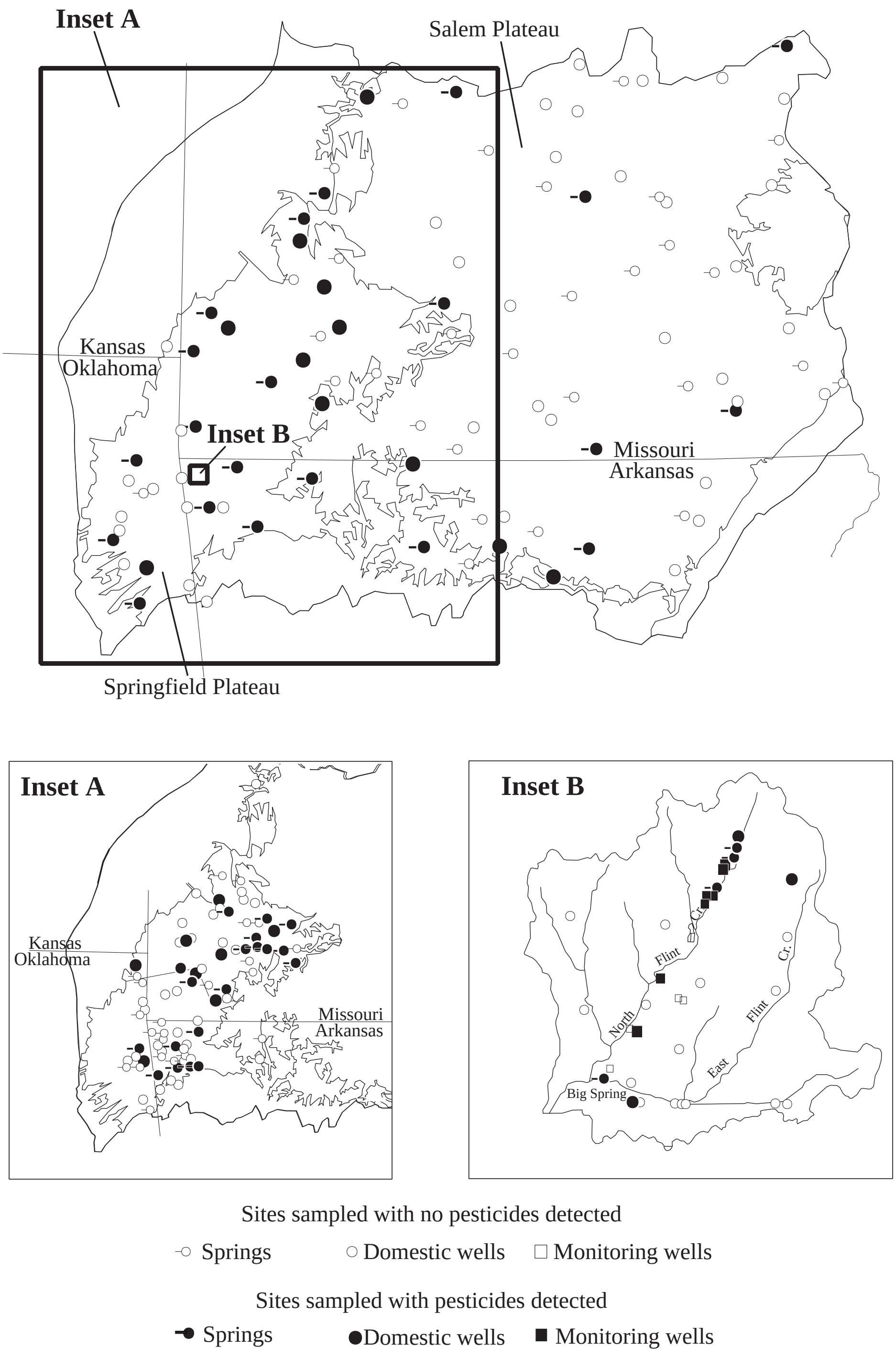


Figure 4.12—Locations of ground water pesticide sampling sites and sites where pesticides were detected in the Ozark Plateaus Province (Adamski 1997a).

pastures and non-crop areas. Atrazine is commonly used to control weeds in cornfields (Thomson 1989). All other pesticides were detected in 10 or fewer samples. Sixty-eight other pesticides were not detected in any samples. For example, Alachlor and 2,4-D, two of the most commonly used pesticides in the Ozark Plateaus (Bell and others 1996), were not detected in any samples.

Maximum pesticide concentrations ranged from 0.003 (benfluralin, metolachlor, p,p'-DDE, and trifluralin) to 1.0 mg/L (atrazine). No pesticide exceeded MCL's or health advisory levels for drinking water set by the EPA (Nowell and Resek 1994).

The occurrence of pesticides in ground water of the Springfield Plateau and Ozark aquifers confirms the vulnerability of these aquifers to surface contamination. Analysis indicates pesticides were detected statistically more often in samples collected from the Springfield Plateau aquifer than in samples from the Ozark aquifer. Pesticides were detected in 18 of 36 samples (50 percent) from the Springfield Plateau aquifer and in 14 of 63 samples (22 percent) from the Ozark aquifer collected during the survey of 1993 from the Ozark Plateaus NAWQA study (Adamski 1997a). The relation between pesticide occurrence and aquifer probably results from greater percent agricultural land use around sites in the Springfield Plateau aquifer compared to sites in the Ozark aquifer.

Pesticide detections were related to land use in Ozark Plateaus samples with tritium activities greater than 2.5 picocuries per liter (pCi/L). Tritium activities greater than about 2.5 pCi/L in ground water indicate that some portion of the water was recharged to the ground water system within the past 40 years (Plummer and others 1993); therefore, the water could be affected by relatively recent land uses.

Statistically, there were more land uses for agriculture around sites with samples that had detectable pesticide concentrations than around sites with samples that had no detectable pesticides within the Ozark Plateaus. Conversely, percent forest cover was statistically less for sites with samples that had detectable pesticide concentrations than for sites with samples that had no detectable pesticides.

Pesticides were detected statistically more often in samples from springs than in samples from domestic wells in the Ozark Plateaus. Pesticides were detected in samples collected from about 47 percent of the springs and about 22 percent of the wells.

Pesticide detections were related to nitrite plus nitrate and phosphorus concentrations in samples from sites in agricultural areas (greater than 80 percent agricultural land use) of the Springfield Plateau aquifer. Median nitrite plus nitrate and phosphorus concentrations were statistically greater in samples with detectable pesticide concentrations (median nitrite plus nitrate = 3.0 mg/L as nitrogen; median phosphorus = 0.02 mg/L) than in samples with no pesticides detected (median nitrite plus nitrate = 1.6 mg/L as nitrogen; median phosphorus < 0.01 mg/L). These results suggest that the hydrogeologic conditions and land uses that allow elevated concentrations of nitrite plus nitrate and phosphorus in ground water also allow pesticides to occur in ground water.

The pesticides p,p'-DDE and dieldrin were detected in 10 and 2 samples, respectively, in the Ozark Plateaus. The EPA banned DDT in 1973 and dieldrin in 1984 (Ware 1989). The occurrence of p,p'-DDE, a metabolite of DDT, and dieldrin in ground water samples indicates the great stability and persistence of these compounds in the environment.

In the Ouachita Province, the pesticides 2,4,-D, dichlorprop, hexazinone, and picloram were not detected at eight sites distributed across the central area of the Ouachita Mountains (Cavalier and Lavy 1987). Five wells and two springs at seven national forest recreation areas and one well located near a small community were sampled twice during 1986. These sites represented land uses that were predominantly "forested." The pesticides analyzed were chosen as representative because of the frequency of their use in the area and for transport and persistence characteristics favoring potential introduction into the ground water system. The springs sampled had a relatively low discharge (less than 1 cubic foot per second) and, as such, are possibly indicative of short flowpath conditions within smaller basins. The wells sampled were relatively shallow (less than 200 ft) and representative of shallow to intermediate aquifer depths.

The limited pesticide data available in the Ouachita Province make broad interpretation difficult. However, the pesticides analyzed do not appear to be problematic with respect to ground water in the central area of the Ouachita Mountains.

Implications and Opportunities

The presence of pesticides in ground water of the Ozark Plateaus, which was somewhat unexpected because of the relatively low pesticide use in most of the province, indicates that water in both the Springfield Plateau and Ozark aquifers is susceptible to surface contamination. Like nutrient concentrations, pesticide detections in the Ozark Plateau aquifers were related to land use. Increased pesticide applications could easily result in higher concentrations for ground water in the Ozark Plateaus.

Pesticide data in ground water are limited for the Ouachita Province. Only four pesticides were analyzed at eight sites distributed across the central part of the Ouachita Mountains. None of these pesticides were detected, but certainly more data are needed to completely assess the Ouachita Province aquifers.

Animal Wastes

Question 4.13: What are the current status and potential effects of animal confinement and waste on aquatic resources in the Assessment area?

Livestock and poultry wastes are a major source of nutrient loading in parts of the Assessment area. The nutrient composition of animal wastes varies widely with respect to animal species, feed consumption and content, and age (Fulhage 1989). Animal wastes contain three major nutrients (nitrogen, phosphorus, and potassium) essential for plant production and are, therefore, used as a fertilizer for pasture lands. The quantity of nutrients ultimately available for use by plants from livestock and poultry wastes varies substantially from the amount initially excreted. The types of animal production housing and waste handling systems used plus different storage times greatly affect the nitrogen and phosphorus content of animal wastes. The longer animal wastes remain in the soil before plant uptake, the more nutrients can be lost through mineralization, volatilization, denitrification, leaching, and erosion.

Fulhage (1989) indicates that more than one-half of the nitrogen content of manure will be either used by plants or volatilized to the atmosphere. Phosphorus in manure is found in the organic form but is not readily available to plants until it is broken down by bacteria (a slow process). Also, phosphorus tends to remain attached to soil that can erode into receiving waters and cause excessive plant and algae growth (Fulhage 1989).

Key Findings

1. An estimated 358,300 tons (7 tons per square mile (tons/mi^2)) of nitrogen and 123,400 tons (3 tons/mi^2) of phosphorus were available from animal wastes in the Ozark Plateaus in 1992.
2. An estimated 82,312 tons (6 tons/mi^2) of nitrogen and 29,460 tons (2 tons/mi^2) of phosphorus were available from animal wastes in the Arkansas Valley in 1992.
3. An estimated 57,555 tons (4 tons/mi^2) of nitrogen and 20,207 tons (2 tons/mi^2) of phosphorus were available from animal wastes in the Ouachita Mountains in 1992.

Data Sources and Methods of Analysis

The Aquatic Team obtained the data used in the discussion of animal waste nutrient contributions from two sources: (1) Davis and others (1995) for the Ozark Plateaus and (2) Puckett (1997) for the Arkansas Valley and Ouachita Mountains. To facilitate the comparison of estimates between the two sources of data, the Aquatic Team developed a correction factor that relates the values of animal populations and nutrient contributions to the Ozark Plateaus provided by Davis and others (1995) with the values provided by Puckett (1997). The team then applied the correction factor to animal population and animal waste contribution estimates for the Arkansas Valley and Ouachita Mountains provided by Puckett (1997).

Patterns and Trends

Amounts of nitrogen and phosphorus available from the animal wastes produced by livestock and poultry within the Assessment area in 1992 are shown in table 4.19. An estimated 498,166 tons (7 tons/mi^2) of nitrogen and 173,067 tons (2 tons/mi^2) of phosphorus

Table 4.19—Estimated animal populations and nutrient contributions from animal wastes by physiographic area in 1992

Animal	Animal population	Nitrogen	Phosphorus
		Tons	*Tons*
		Ozark Plateaus[a]	
Beef cattle	4,264,000	264,000	85,300
Dairy cattle	231,000	17,300	3,100
Swine	1,087,000	22,400	7,500
Chickens[c]	498,325,000	29,200	12,400
Turkeys[c]	25,178,000	25,000	15,100
Total		358,300	123,400
		Arkansas Valley[b]	
Beef cattle	838,763	52,000	16,768
Dairy cattle	26,884	2,013	360
Swine	304,627	6,278	2,102
Chickens[c]	272,612,423	16,441	6,866
Turkeys[c]	5,617,476	5,580	3,365
Total		82,312	29,460
		Ouachita Mountains[b]	
Beef cattle	553,816	34,448	11,187
Dairy cattle	4,412	331	60
Swine	362,836	7,477	2,503
Chickens[c]	258,658,370	15,299	6,457
Turkeys[c]	496	0	0
Total		57,555	20,207
Total, Assessment area		498,167	173,067

[a] Davis and others (1995).

[b] Puckett (1997).

[c] Chicken and turkey populations are totals produced during a year; nutrient contributions adjusted based on the average number of chickens and turkeys produced on a single day. Multiple flocks of chickens (6) and turkeys (2.25) are produced each year.

were available from animal waste. The Ozark Plateaus Province—with an estimated 358,300 tons (7 tons/mi^2) of nitrogen and 123,400 tons (3 tons/mi^2) of phosphorus—had the largest nutrient contributions from animal wastes for that year. The Arkansas Valley had an estimated 82,312 tons (6 tons/mi^2) of nitrogen and 29,460 tons (2 tons/mi^2) of phosphorus available from animal waste. The Ouachita Mountains had an estimated 57,555 tons (4 tons/mi^2) of nitrogen and 20,207 tons (2 tons/mi^2) of phosphorus available from animal waste.

Fertilizers

Question 4.14: What are the current status and potential effects of fertilizer applications on aquatic resources within the Assessment area?

Fertilizers are a nonpoint source of nitrogen and phosphorus. Most of the dissolved nitrogen that enters streams from runoff of agricultural fertilizers occurs as nitrate (Puckett 1994). Soil erosion may add considerable amounts of suspended phosphorus to streams (Hem 1985). Trends in concentrations of nitrate and total phosphorus at sites in river basins in the United States were investigated by Smith and others (1987) and Smith and others (1993). Studies such as these demonstrate the effects of fertilizers on the concentrations of nitrogen and phosphorus found at those sites.

Key Findings

Ozark Plateaus Province

1. In 1985, nitrogen fertilizer application rates for the counties within the Ozark Plateaus ranged from an estimated 0 to 12 tons/mi^2.
2. Phosphorus fertilizer application rates in 1985 for the counties within the Ozark Plateaus ranged from an estimated 0 to 5 tons/mi^2.

Arkansas Valley

1. In 1985, nitrogen fertilizer application rates for the counties within the Arkansas Valley ranged from an estimated 0 to 12 tons/mi^2.
2. Phosphorus fertilizer application rates in 1985 for the counties within the Arkansas Valley ranged from an estimated 0 to 1 ton/mi^2.

Ouachita Mountains

1. In 1985, nitrogen fertilizer application rates for the counties within the Ouachita Mountains ranged from an estimated 0 to 3 tons/mi^2.
2. Phosphorus fertilizer application rates in1985 for the counties within the Ouachita Mountains ranged from an estimated 0 to 0.5 ton/mi^2.

Data Sources and Methods of Analysis

The Aquatic Team obtained the data used in the discussion of fertilizer use in the Assessment area from Alexander and Smith (1990). Their study included nitrogen and phosphorus fertilizers commercially available for farm and nonfarm applications. Fertilizer applications were estimated from county-level totals. For counties located along the boundary of the Assessment area or for counties included more than once because of their position in multiple river basins, a correction factor was applied based on the percentage of the county within the Assessment area or river basin.

Patterns and Trends

Ozark Plateaus Province. Use of nitrogen and phosphorus fertilizers in the Ozark Plateaus part of the Assessment area has increased substantially since 1965. Estimates (Alexander and Smith 1990) indicate that uses of nitrogen and phosphorus fertilizers have increased 147 percent and 52 percent, respectively, from 1965 through 1985.

The application rates for nitrogen and phosphorus fertilizer in the Ozark Plateaus are well below the national median. Estimates of nitrogen and phosphorus fertilizer application rates for 1985 were computed as a ratio of fertilizer use to fertilized acreage. The national median of nitrogen fertilizer application rate was 28 tons/mi^2; median application rates by State ranged from 14 to 64 tons/mi^2. Nitrogen fertilizer application rates in 1985 for the counties within the Ozark Plateaus ranged from an estimated 0 to 12 tons/mi^2. The national median of phosphorus fertilizer application rate was 6 tons/mi^2; median application rates by State ranged from 3 to 17 tons/mi^2. Phosphorus fertilizer application rates (1985) for the counties within the Ozark Plateaus ranged from an estimated 0 to 5 tons/mi^2 (Alexander and Smith 1990).

Fertilizer use differed substantially among the Ozark Plateaus river basins (table 4.20). Annual nitrogen fertilizer use in 1965 ranged from 0.49 ton/mi^2 in the Upper St. Francis River Basin to 2.34 tons/mi^2 in the Osage River Basin. In 1985, annual nitrogen fertilizer use ranged from 1.24 tons/mi^2 in the Upper St. Francis to 4.93 tons/mi^2 in the Osage River Basin. Nitrogen fertilizer use in the Osage and the Neosho-Illinois River Basins nearly equaled the combined total nitrogen

Table 4.20—Estimated nitrogen and phosphorus fertilizer use by major river basin, 1965 and 1985

River basin		Nitrogen fertilizer			Phosphorus fertilizer		
		1965	1985	Increase	1965	1985	Increase
	Acres	*Tons per square mile*		*Percent*	*Tons per square mile*		*Percent*
				Ozark Plateaus			
Upper Black	5,435,238	1.27	3.05	140	0.33	0.47	42
Gasconade	2,180,647	1.27	3.22	153	0.34	0.56	65
Meramec	2,553,402	0.79	1.89	139	0.21	0.33	57
Neosho-Illinois	5,948,454	1.50	4.13	175	0.42	0.68	62
Osage	6,332,800	2.34	4.93	110	0.62	0.86	39
Upper St. Francis	849,216	0.49	1.24	153	0.13	0.22	69
Upper White	7,170,362	0.83	2.45	195	0.21	0.36	71
				Arkansas Valley			
Arkansas River	8,225,920	0.48	1.60	233	0.13	0.21	62
				Ouachita Mountains			
Kiamichi-Little	3,874,560	0.24	1.25	421	0.07	0.18	157
Ouachita-Saline	4,555,520	0.20	0.94	370	0.05	0.12	140

Source: Alexander and Smith (1990).

fertilizer use in the rest of the entire Ozark Plateaus Province. Annual phosphorus fertilizer use in 1965 ranged from 0.13 ton/mi^2 in the Upper St. Francis to 0.62 ton/mi^2 in the Osage River Basin. In 1985, annual phosphorus fertilizer use ranged from 0.22 ton/mi^2 in the Upper St. Francis River Basin to 0.86 ton/mi^2 in the Osage River Basin. As with nitrogen fertilizer use, nearly half of the total phosphorus fertilizer used in the Ozark Plateaus was applied in the Osage and Neosho-Illinois River Basins.

The physiographic area with the largest nitrogen fertilizer use in 1985 was the Mississippi Alluvial Plain (about 8 tons/mi^2) followed by the Osage Plains (about 7 tons/mi^2), Salem and Springfield Plateaus (each about 3 tons/mi^2), and the Boston Mountains (about 2 tons/mi^2). The largest phosphorus fertilizer use in 1985 occurred in the Mississippi Alluvial Plain and the Osage Plains (each about 1 ton/mi^2), followed by the Springfield and Salem Plateaus (each about 0.5 ton/mi^2), and the Boston Mountains (about 0.2 ton/mi^2).

Arkansas Valley. Fertilizer use in the Arkansas Valley also has increased substantially. Fertilizer use estimates (Alexander and Smith 1990) indicate that nitrogen and phosphorus fertilizer use increased 233 percent and 62 percent, respectively, from 1965 to 1985 (table 4.20).

The application rates for nitrogen and phosphorus fertilizer in the Arkansas Valley are well below the national median. Estimates of nitrogen and phosphorus fertilizer application rates for 1985 were computed as a ratio of fertilizer use to fertilized acreage. The national median of nitrogen fertilizer application rate was 28 tons/mi^2; median application rates by State ranged from 14 to 64 tons/mi^2. Nitrogen fertilizer application rates in 1985 for the counties within the Arkansas Valley ranged from an estimated 0 to 12 tons/mi^2. The national median of phosphorus fertilizer application rates was 6 tons/mi^2; median application rates by State ranged from 3 to 17 tons/mi^2. Phosphorus fertilizer application rates in 1985 for the counties within the Arkansas Valley ranged from an estimated 0 to 1 ton/mi^2 (Alexander and Smith 1990).

Ouachita Mountains. Fertilizer use in the Ouachita Mountains part of the Assessment area also has increased substantially since 1965 (table 4.20). Fertilizer use estimates (Alexander and Smith 1990) indicate that nitrogen and phosphorus fertilizer use increased 396 percent and 149 percent, respectively, from 1965 to 1985.

The application rates for nitrogen and phosphorus fertilizer in the Ouachita Mountains are well below the national median. Estimates of nitrogen and phosphorus fertilizer application rates for 1985 were computed as a ratio of fertilizer use to fertilized acreage. The national median of nitrogen fertilizer application rate is 28 tons/mi^2; median application rates by State ranged from 14 to 64 tons/mi^2. Nitrogen fertilizer application rates in 1985 for counties within the Ouachita Mountains ranged from an estimated 0 to 3 tons/mi^2. The national median of phosphorus fertilizer application rate was 6 tons/mi^2; median application rates by State ranged from 3 to 17 tons/mi^2. Phosphorus fertilizer application rates in 1985 for counties within the Ouachita Mountains ranged from an estimated 0 to 0.5 ton/mi^2 (Alexander and Smith 1990).

Urbanization

Question 4.15: What are the current status and potential effects of urbanization on aquatic resources within the Assessment area?

Increases in the human population serve as an indicator of the many environmental stresses resulting from urbanization. Construction, sewage treatment facilities and other utilities, changes in runoff patterns from pavement and other impervious artificial surfaces, and stream channelization (cleaning, straightening, and/or paving stream banks) are all activities or actions associated with urbanization that have the potential to stress or damage aquatic ecosystems (Lull and Sopper 1969).

Key Findings

1. The 1990 population of the Assessment watersheds was 3,361,301.
2. Between 1980 and 1990, an 8 percent population increase occurred within the Assessment watersheds.
3. Twenty-four watersheds experienced population increases of 7 percent or more between 1980 and 1990.
4. Between 1980 and 1990, the rate of urbanization was greater within the Assessment area than nationwide.
5. Two Assessment area watersheds (the Upper Little River in southeastern Oklahoma and the Little Missouri in southern Arkansas) had a 7 percent decrease in population from 1980 to 1990.

Data Sources and Methods of Analysis

The Aquatic Team obtained data from the "Surf Your Watershed" Web site (U.S. EPA 1997a). To estimate population and population density for each watershed, the EPA used the internal point of each U.S. Census block group to locate it within a specific watershed (hydrologic unit with an eight-digit code). Each block group was then associated with a specific watershed. The block groups for each watershed were then combined to form an area roughly, but not exactly, equal to the watershed area. Population density was computed by dividing the total watershed population by the approximate watershed area. Percent changes in populations from 1980 to 1990 were computed by the following equation $(pop_{90}-pop_{80})/pop_{80}$ (U.S. EPA 1997a).

Any watershed that had a decline in population between 1980 and 1990 or had a population density of less than 6.88 persons/mi^2 was placed in a "no change" category. Population density values less than 6.88 persons/mi^2 are considered to be low enough to pose minimal impacts on water quality.

If a watershed had greater than 6.88 persons/mi^2 and a population change between 0 and 7 percent, it was placed in the category "0 to 7 percent increase" (fig. 4.13). All watersheds with changes greater than 7 percent were grouped in the "greater than 7 percent increase" category (U.S. EPA 1997a).

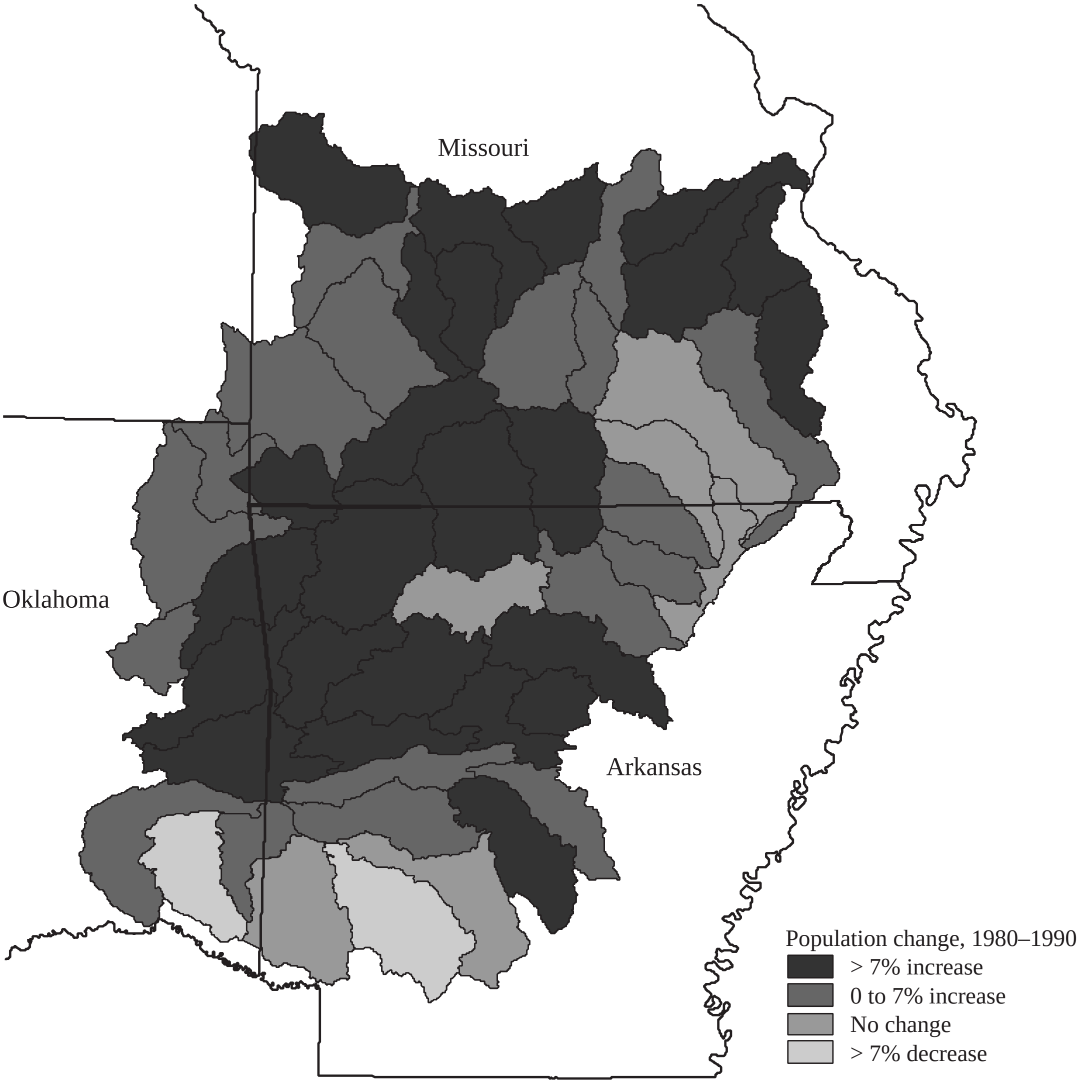


Figure 4.13—Human population changes from 1980 to 1990 by watershed (U.S. EPA 1997a).

Patterns and Trends

The 1990 population of the Assessment watersheds was 3,361,301 (table 4.21). Between 1980 and 1990, there was an overall population increase of 8 percent (rounded) within the Assessment watersheds. Of the 50 watersheds, 24 had population increases greater than 7 percent between 1980 and 1990; 4 watersheds had increases in population equal to or greater than 19 percent. The aquatic systems within these watersheds have a greater vulnerability or potential to be stressed and possibly damaged as a result of this increased urbanization. Nationwide, 30 percent of the 2,202 watersheds had population increases greater than 7 percent in the same decade. Within the Interior Highlands area, 48 percent of the watersheds had population increases greater than 7 percent in the same decade. Between 1980 and 1990, the rate of urbanization was greater within the Assessment area than nationwide (U.S. EPA 1997a).

Two Assessment area watersheds (the Upper Little River in southeastern Oklahoma and the Little Missouri River in southern Arkansas) had a 7 percent decrease in population from 1980 to 1990. This trend suggests

Table 4.21—Human population and percent change in population from 1980 to 1990, by watershed

River basin Watershed name	Watershed code (HUC)	1980 population	1990 population	Change (rounded)
				Percent
Osage River Basin				
H.S. Truman Reservoir	10290105	19,058	19,367	2
Sac	10290106	76,878	81,269	6
Pomme de Terre	10290107	23,710	27,199	15
South Grand	10290108	75,118	85,335	14
Lake of the Ozarks	10290109	44,392	53,616	21
Niangua	10290110	23,738	27,287	15
Lower Osage	10290111	26,525	28,658	8
Gasconade River Basin				
Upper Gasconade	10290201	65,988	66,910	1
Big Piney	10290202	16,455	17,334	5
Lower Gasconade	10290203	23,111	23,416	1
Meramec River Basin				
Meramec	07140102	277,030	311,029	12
Bourbeuse	07140103	40,175	45,200	13
Big	07140104	71,448	81,248	14
Upper St. Francis River Basin				
Upper St. Francis	08020202	36,607	40,186	10
Neosho-Illinois River Basin				
Lake O' the Cherokees	11070206	51,354	52,130	2
Spring	11070207	209,541	218,000	4
Elk	11070208	45,463	56,154	24
Lower Neosho	11070209	77,081	80,382	4
Illinois	11110103	140,648	163,593	16
Arkansas River Basin				
Dirty-Greenleaf	11110102	55,840	57,203	2
Robert S. Kerr Reservoir	11110104	117,905	125,602	7
Poteau	11110105	71,516	77,522	8
Frog-Mulberry	11110201	42,879	46,952	9
Dardanelle Reservoir	11110202	62,365	70,704	13
Conway-Point Remove	11110203	64,988	79,624	23
Petit Jean	11110204	17,395	19,069	10
Cadron	11110205	21,096	24,569	16
Fourche La Fave	11110206	8,119	8,409	4
Lower Arkansas-Maumelle	11110207	303,968	308,855	2
Kiamichi-Little River Basin				
Kiamichi	11140105	18,878	19,009	1
Upper Little	11140107	28,691	26,614	-7
Mountain Fork	11140108	10,980	11,129	1
Lower Little	11140109	42,366	41,855	-1
Ouachita-Saline River Basin				
Ouachita Headwaters	08040101	74,811	77,035	3
Upper Ouachita	08040102	52,122	51,657	-1
Little Missouri	08040103	34,289	31,992	-7
Upper Saline	08040203	68,403	78,750	15
Upper White River Basin				
Beaver Reservoir	11010001	84,541	94,184	11
James	11010002	181,014	215,140	19
Bull Shoals Lake	11010003	73,781	83,049	13
Middle White	11010004	47,337	49,301	4
Buffalo	11010005	14,520	13,747	-5
North Fork White	11010006	31,979	36,389	14
Little Red	11010014	55,828	60,423	8

(continued)

Table 4.21—Human population and percent change in population from 1980 to 1990, by watershed (continued)

River basin Watershed name	Watershed code (HUC)	1980 population	1990 population	Change (rounded)
				Percent
Upper Black River Basin				
Upper Black	11010007	55,366	55,303	0
Current	11010008	32,102	31,801	-1
Lower Black	11010009	19,322	19,206	-1
Spring	11010010	40,065	40,093	0
Eleven Point	11010011	14,853	14,705	-1
Strawberry	11010012	12,885	13,097	2
Total		3,104,524	3,361,301	8

HUC = hydrologic unit code.
Source: U.S. EPA (1997a).

that aquatic resources within these watersheds had decreased vulnerability or potential to be stressed by urbanization.

Implications and Opportunities

Increases in population can mean many things to a watershed. There may be a demand for new home construction, or land uses within the watershed may shift from forested or rural to urban. Increased demands for roads, schools, sewage treatment plants, water supplies, and solid waste disposal may occur. In step, the tax base may increase sufficiently to meet these new demands and even improve inadequate existing facilities. The Aquatic Team felt there were too many factors involved related to the effects of urbanization to draw reasonable implications.

In areas of population increases, national forest lands can reasonably anticipate increases in demand and requests for recreational opportunities, special use permits, firewood harvesting, and access to public lands.

Mineral Extraction

Question 4.16: What are the current status and potential effects of activities associated with the exploration and extraction of minerals on aquatic resources within the Assessment area?

The Assessment area is rich in mineral diversity, which includes lead, zinc, quartz crystal, natural gas, coal, and various stones. The national forests in the Assessment area are important sources for many of these minerals. Chapter 7 of the *Ozark-Ouachita Highlands Assessment: Social and Economic Conditions* (USDA FS 1999a) discusses the significance and value of these mineral resources.

Extractions of some mineral resources have adversely affected aquatic systems within the Assessment area. Effects of mining-related extraction activities primarily come from two sources: (1) increased sediment discharges into streams from present-day operations and (2) runoff waters leaching metals and chemicals into streams from abandoned, unreclaimed mines and ore tailings left by historical operations. (The historical operations took place before modern environmental laws were enacted.)

Key Findings

1. In 1996, approximately 692 mining-related operations for hardrock and coal extraction occurred in the Assessment area.
2. The primary mining activity in the Assessment area is surface mining of common variety minerals that generally go to the building and road construction industries.
3. Several abandoned, historical mine sites continue to contribute to chemical and metal leachates and runoff, increasing acidity in some cases and affecting aquatic resources within the Assessment area.
4. Effects on aquatic resources from present-day mining activities are primarily associated with increased sedimentation of streams caused by instream gravel and sand extraction.
5. Approximately 595 mi of rivers, streams, and lakes are impaired as a result of mining activities within the Assessment area.

Data Sources and Methods of Analysis

The Aquatic Team developed a data base for the Assessment area mines from seven data bases obtained from (1) the U.S. Department of Labor, Mine Safety and Health Administration (MSHA); (2) the three State mine permitting and regulating agencies; and (3) Forest Service records for the Ouachita, Ozark-St. Francis, and Mark Twain National Forests. These data are used throughout this section as the basis for discussions of mine and mining-related statistics, mine locations by counties, and mineral commodities within the Assessment area in 1996. Chapter 7 of this Assessment's *Social and Economic Conditions* (USDA FS 1999a) provides further details on how the data base was developed and used.

Water quality data were obtained from the State 305(b) reports for Arkansas, Missouri, and Oklahoma (AR DPCE 1996, MO DNR 1994, OK DEQ 1996). These reports show the type and cause of effects on aquatic resources in each State. Each State took a slightly different approach to evaluating overall water quality issues. However, enough similarities exist in the State reports for them to complement each other. To produce an analysis of the effects of mining activities on the aquatic resources in the Assessment area, the Aquatic Team compared locations and types of mines in each of the Assessment watersheds with the States' information on affected aquatic resources.

Patterns and Trends

In 1996, approximately 692 mining-related operations for hardrock and coal extraction occurred in the Assessment area (table 4.22). The largest number of operations extracted common variety minerals such as building stone and aggregate materials, sand and gravel, and clay. The extraction of this commodity group caused the most major and minor effects on water quality in the Assessment area.

Table 4.22—Number of mining-related operations for selected mineral commodity groups in the Assessment area in 1996

Mineral commodity group	Number
Hardrock and coal	
Common variety mineral materials (stone, aggregate, sand and gravel, clay)	535
Quartz (quartz crystal and #1 industrial grade quartz)	58
Coal	43
Industrial minerals (barite, novaculite, tripoli, cement, gypsum)	27
Metallic minerals (bauxite, lead, zinc, iron, vanadium)	23
Other gem minerals (diamond, wavellite, turquoise)	6
Gas and oil	
Natural gas wells (producing)	6,426

Source: AR DPCE (1997), MO DNR (1997), OK DM (1996), USDA Forest Service (1996).

Many laws are concerned with the extraction of these products precisely because of their impact on the environment. In particular, the removal of instream gravel that results in increased stream sediment and turbidity is listed in the States' water quality reports as an "effects contributor" in 14 Assessment area stream segments (AR DPCE 1996, MO DNR 1994, OK DEQ 1996). Gravel exploration and extraction are not relegated to a particular area or zone but occur on a number of streams throughout the Assessment area. Instream gravel removal is prohibited within State-designated extraordinary resource waters. Other controls, such as the Arkansas Act 827 of 1991 that requires a State permit for instream gravel removal operations, result in operations with more environmental accountability. The likely future trend throughout the Assessment area will be fewer unregulated instream gravel removal operations.

Arkansas, Missouri, and Oklahoma 305(b) reports for 1996 show the various activities affecting the quality of aquatic resources within the Assessment area. Table 4.23 is a synopsis of the effects from both past and present Assessment area mining activities and shows that mineral exploration and development has affected the area's aquatic resources. The most common mining activities were historic metal ore, coal, and instream gravel extractions (AR DPCE 1996; MO DNR 1994, 1996b; OK DEQ 1996).

Several Assessment area watersheds have aquatic resources that are still being affected by abandoned lead-zinc and coal mines. Unregulated mining practices took place at these sites between the early 1800's and mid-1900's. Chemical runoff and leachates developing from unused metals coming into contact with rainwater have had an adverse effect on the pH of many of the Assessment area watersheds.

The States' water quality reports indicate how many miles of Assessment area streams are affected by mining activity (table 4.23). The "Impaired Waters" section in this chapter shows, according to GIS data, how many stream miles have been affected. Resource extraction (mining) in Arkansas is noted in the 1996 *Arkansas Water Quality Inventory Report* (AR DPCE 1996) as a "major effects contributor" to segments of four streams totaling 116 mi in length (Hurricane Creek, Lost Creek, Crooked Creek, and Kings River). Resource extraction merits a "minor effects contributor" rating for another 83.9 mi of stream segments in three streams (James Fork, Illinois River, and War Eagle Creek).

In Missouri, approximately 79 mi of streams in 10 watersheds are affected by past or present resource extraction activities. Erosion of abandoned mine tailings into streams has seriously affected 18.5 mi of classified streams, including 3 mi that were severe enough to preclude their use as aquatic habitat (MO DNR 1994).

The 1996 *Oklahoma Water Quality Assessment Report* states that 23 streams and lakes (269 mi) are partially affected by past or present mining-related activities. These streams are within four Oklahoma watersheds. Eighteen streams are located in the Lake O' the Cherokees system in Delaware, Craig, Mayes, and Ottawa Counties. These streams are primarily contaminated by acids from metal extraction that occurred in the Oklahoma portion of the old Tri-State Lead-Zinc Mining District between 1910 and the 1940's (OK DEQ 1996). Approximately 130 mi of the Lake O' the Cherokees system are affected, including bays, coves, and associated inlets and streams. Table 4.24 shows that approximately 595 mi of rivers, streams, and lakes are impaired as a result of past or present mining activities within the Assessment area.

Implications and Opportunities

Protecting the quality of aquatic resources is critical to continued prosperity in the Interior Highlands. The effects of historical mining operations continue to plague parts of the Assessment area. Today's environmental awareness and improved extraction and reclamation technologies are a vast improvement over the techniques of the past. Most present-day effects on aquatic resources are from sedimentation resulting from operations taking place directly in streams. These are much less harmful than the chemical runoff and harmful leachates allowed by previous environmental regulations. Opportunities exist for continued cooperation between State and Federal agencies and industry to study and implement Assessment area reclamation practices that have protected aquatic resources most successfully.

Table 4.23—Mining-related effects on streams in the Assessment area by State, stream, and watershed

Stream	Watershed code (HUC)	Miles[a]	Mining effects[b]	Effects contributors[c]
			Arkansas	
Hurricane Creek	08040203	31	RE, minerals—major	Historic mining: bauxite
Lost Creek	08040203	34	RE, minerals—major	Historic mining: bauxite
James Fork	11110105	18	RE—minor	
Illinois River	11110103	1.8	RE, S—minor	
Illinois River	11110103	11	S—major, RE minor	
Illinois River	11110103	22.5	S—major, RE—minor	
Crooked Creek.	11010003	32	RE, S—major	
War Eagle Creek	11010001	30.6	S—major, RE—minor	
War Eagle Creek	11010001	28	RE, S—major	
Kings River	11010001	19	RE, S—major	
			Missouri	
Saline, Goose, Village Creeks	08020202	4	RE, S—major	Historic mining: lead-zinc
Osage River	10290111	0.2	D—minor	
Osage River	10290111	0.2	D—minor	
Barkers, tributary	10290108	1	A—minor	Historic mining: coal
Tebo Creek, east	10290109	2.5	A	Historic mining: coal
Tebo Creek, mid	10290110	9	A	Historic mining: coal
Meramec River	07140102	0.2	D—minor	
Meramec River	07140102	0.2	D—minor	
Shibboleth Creek	07140104	0.5	S—minor	
Big, Flat River, Shaw Branch	07140104	45	M—major, S—minor	Historic mining: lead-zinc
Black River	11010007	0.2	D—minor	
Center Creek	11070207	11	M—major & minor	Historic mining: lead-zinc
Turkey Creek	11070208	3	M—major & minor	Historic mining: lead-zinc
Grove Creek	11070209	2	M—major & minor	Historic mining: lead-zinc
			Oklahoma	
Lake O' the Cherokees	11070209	130[d]	RE—minor	
Sans Bois Creek	11110104	38[d]	AM—minor	
Beaver Creek	11110104	15[d]	PA—minor	
Sallisaw Creek	11110104	38[d]	AM—minor	
Arkansas River	11110104	19[d]	OP—minor	
Brazil Creek	11110105	29[d]	OP—minor	

HUC = hydrologic unit code; RE = resource extraction; PA = petroleum activities; AM = abandoned mine tailings; S = siltation; OP = open pit; M = metals; D = dredging; A = acidity.

[a] Stream miles actually impaired as reported in the States' 1996 Water Quality Reports. See the "Impaired Waters" section of Chapter 4 for numbers taken from Geographic Information System data.

[b] Major and minor effects on aquatic resources from mine-related contributions.

[c] State listed contributors to effects on aquatic resources.

[d] Approximate stream length.

Source: AR DPCE (1996), MO DNR (1994, 1996b), OK DEQ (1996).

Table 4.24—Stream miles impaired by historic, gravel, sediment, and other mining activities by State

State	Historic	Instream gravel	Sediment	Other
	Stream miles			
Arkansas	84.0	98.8	64.1	0
Missouri	77.5	1.0	0.5	0
Oklahoma[a]	130	0	86	53

[a] Oklahoma did not report actual stream reach distances; approximate stream lengths shown here.
Source: AR DPCE (1996), MO DNR (1994), OK DEQ (1996).

Introduced Species

Question 4.17: What effects are introduced aquatic species having on the Assessment area?

Burr and Warren (1986) define "introduced species" as an individual, group, or population of organisms that occur in a particular locale due to human actions that inadvertently or deliberately moved the species from one place to another. They further categorized these introductions as "exotic"—a species introduced from a foreign country whose entire native range is outside the country where found—and "transplanted"—a species moved outside its native range but within a country where it occurs naturally. These two categories were further described as: (1) established—an introduced species with a permanent population that is unlikely to be eliminated by human or natural causes; (2) possibly established—an introduced species without the status of a permanent population but reproducing in an area where its elimination by humans would be impractical; (3) localized—a confirmed, reproducing population of an introduced species that can be eliminated using standard methods; and (4) reported—an introduced species collected without evidence of reproduction. These categories are used for individual species discussed in this report.

Key Findings

1. Introduced species such as zebra mussels, common carp, and a number of aquatic weeds have become pests.
2. Arkansas, Missouri, and Oklahoma are making concerted efforts to retard the spread of zebra mussels both through general public education and the education of individual anglers and boaters.
3. It is likely that zebra mussels eventually will show up in most lakes and reservoirs in the Assessment area as the result of a transient boating public. Zebra mussels are expected to ravage the native mussel fauna as well as disrupt the food chain of any water body they colonize.
4. Nonindigenous species (non-native or transplanted species) require constant management attention to reduce the likelihood of introduced species, particularly exotics (non-natives), becoming established.

Data Sources

The Geological Survey, Biological Resources Division, Gainesville, FL, provided the majority of the information for "Introduced Species" from data bases they maintain on nonindigenous aquatic species for the United States. This data base is specific only by State. The Geological Survey office furnished individual species summaries, and the Aquatic Team accessed their home page for additional species factsheets. For more information, see their Web site at <http://www.nfrcg.gov>.

Patterns and Trends

The species lists maintained by the Geological Survey, Biological Resources Division, reflect documented stockings over the course of this century and earlier. Not all of these fish species can presently be found in Assessment area waters. Since 1900, 46 fish species have been introduced into Arkansas waters (statewide, not just the Arkansas portion of the Assessment area) of which 20 are established and 10 are either unknown or questionable as to their establishment. During the same time, Missouri has had 38 fish species introduced with 15 established and 11 of questionable or unknown status, and Oklahoma has had 45 fish species introduced with 19 established and 18 of questionable or unknown status. The differences between total numbers introduced and established plus questionable or unknown status reflect those introduced species that did not develop reproducing populations. The majority of these introduced species are game fish stocked to provide recreational fishing. By virtue of these fish being "moved," they are classified as introduced species. While the green sunfish in a landlocked pond is an introduced species, that same species would not be considered "introduced" in another lake built on a stream containing native green sunfish. Common carp, established across the Nation for more than a century, are still considered an established exotic even though they are established in just about every water body other than the coldest trout streams and most remote mountain lakes.

Zebra mussels and Asian clams are the only two exotic mussels established in the three States in the Assessment area. Zebra mussels are present in the Arkansas River in the Assessment area in Arkansas and Oklahoma. Asian clams are present in aquatic habitats throughout the Assessment area. The daphnia, a zooplankton, is established in several reservoirs within each State within the Assessment area. It too is an established exotic. Arkansas has had 19 aquatic plant introductions; Missouri, 18; and Oklahoma, 12—all of which are established but not necessarily within the Assessment area of the three States. The following summaries provide information about species considered most significant to the States in the Assessment area. More details on these species are available from the earlier referenced Geological Survey Web site.

Asian or Asiatic clams. This mussel species can be found throughout Arkansas in such rivers as the Arkansas, Boeuf, Little, Ouachita, Red, Spring, St. Francis, Strawberry, Sulphur, and White. Similar widespread distribution also occurs in Missouri. This mussel has been found in the following Missouri rivers: Big, Black, Bourbeuse, Little Black, Meramec, Mississippi, Missouri, Moreau, Osage, and St. Francis. In Oklahoma, they have been found in the Arkansas, Little, and Red Rivers, and in Lakes Overholser and Thunderbird. According to Foster and Fuller (1997), Asian or Asiatic clams are an established exotic from temperate to tropical Southern Asia west to the Eastern Mediterranean; Africa, except in the Sahara desert; and Southeastern Asian islands south into Central and Eastern Australia. They were first documented in this country in 1938 along the banks of the Columbia River near Knappton, WA. The most prominent effect of the introduction of the Asian clam has been biofouling, especially of complex power plant and industrial water systems, drinking water supplies, and irrigation canals and pipes. It also alters benthic (lake or stream bottom) substrate and competes with native species for limited food and space. Densities of this species have been documented in the thousands per square meter, often dominating the benthic community.

Zebra mussels (*Dreissena polymorpha*). In Arkansas, zebra mussels are flourishing in the Arkansas River and can be found in the Mississippi and White Rivers. In Missouri, this species is found in the Mississippi River only. In Oklahoma, it is found in the Arkansas and Verdigris Rivers. Every year the densities at measured sites continue to increase.

According to the Geological Survey, Biological Resources Division (USDI GS BRD 1997b), this species is an established exotic originating from the Balkans, Poland, and the former Soviet Union. They were first discovered in North America in 1988; by 1990, zebra mussels had been found in all of the Great Lakes. In 1991, they escaped the Great Lakes Basin and found their way into the Hudson and Illinois Rivers. The Illinois River was their avenue to expansion into the Mississippi River drainage. Their rapid advance through the Mississippi River drainage is attributed to barge traffic. It is theorized that mussels attached to barge hulls were scraped or fell off during routine navigation of the Mississippi and major tributaries. Overland dispersal occurs when people move boats via trailer from contaminated to uncontaminated waters (zebra mussels adhere to boat hulls and motors). Live zebra mussels have been found on two houseboats in Lake Ouachita that were recently moved there from the Arkansas River.

Zebra mussels are fouling water intake structures and water lines at hydroelectric and nuclear power plants, public water supply plants, and industrial facilities. Navigational and recreational boating is affected by increased drag due to attached mussels. Smaller zebra mussels can be sucked into engine cooling systems, causing overheating and damage. Navigational buoys have reportedly sunk from the weight of attached zebra mussels. Continued attachment of zebra mussels can cause corrosion of steel and concrete affecting its structural integrity. Navigation locks in the Arkansas River system are being cleaned of mussels at great expense. Zebra mussels also attach themselves to the hard surfaces of native mussels. Some native mussel shells have more than 10,000 zebra mussels attached to them. The more rare native mussels species are not likely to survive the smothering by zebra mussel attachments or the competition for limited food resources. The fact that under cool, humid conditions, zebra mussels can stay alive for several days out of the water makes them even more dangerous to native populations. It is expected that zebra mussels will upset the food chain for other species as well.

The high population levels of zebra mussels and their filter-feeding habits reduce plankton availability for other species and increase light penetration that stimulates growth of aquatic vegetation. The resulting decline of smaller, plankton-dependent fish will likely diminish the prey base (food chain) for recreational fish species; and consequently their populations will also decline. Clearing the water column of plankton can also lead to increased aquatic vegetation beds where sunlight can penetrate to lake bottoms. Aquatic vegetation beds provide cover and act as nurseries for some species of fish. If they become excessive, they can upset predator and prey relationships and diminish recreational fisheries. Excessive vegetation beds can also seriously hamper fishing from the shore and, if extensive enough, may seriously impact boating. Arkansas, Missouri, and Oklahoma are making concerted efforts to retard the spread of zebra mussels through general public education and, more specifically, through the education of anglers and boaters. Zebra mussels are likely to show up eventually in most lakes and reservoirs with a transient boating public, but the slowing of the spread of zebra mussels is worth the effort. At this time, no control measures are known for eradicating the species in the wild, but scientists continue to investigate possible control measures.

Daphnia lumholtzi. An established exotic from tropical and subtropical lakes in east Africa, east Australia, and the Asian subcontinent of India (USDI GS BRD 1997a), *Daphnia lumholtzi* has been found in Lake Dardanelle in Arkansas; Robert S. Kerr Reservoir, Ten Killer Ferry, and Lake Texoma in Oklahoma; and Harry S. Truman, Harrisonville, Stockton, Nehai, Tonkayea, Montrose, Pomme De Terre, Lake of the Ozarks, Monroe, Bull Shoals, Norfork, Mark Twain, Thomas Hill, and Atkinson Reservoirs in Missouri. The impacts of this invader are not yet known. One recent study indicates it does not appear to be displacing other daphnia species in the Norris Reservoir. It also has not shown up in stomach samples of fish from the same reservoir. It may be too soon to detect the ecological effects of this exotic on aquatic habitats in the Assessment area.

Grass carp or white amur (*Ctenopharyngodon idella*). This species of carp is an established exotic from eastern Asia (from the Amur River of eastern Russia and China south to the West River of Southern China). Both authorized and unauthorized stockings of grass carp have taken place in the United States for biological control of unwanted aquatic vegetation. These carp were introduced into the United States in 1963 at Auburn, AL, and Stuttgart, AR. The first release of this species into open waters took place at Stuttgart, AR, when fish escaped the Fish Farming Experimental Station. The species spread rapidly thereafter as a result of widely scattered research projects, agency stockings, interstate distributions from private hatcheries by individuals, and natural dispersal from stocked sites. Nico and Fuller (1997) have documented the reproduction of grass carp populations in the following rivers: Mississippi, Missouri, Illinois, Ohio, and Trinity (in Texas). Grass carp have a short gut and can digest only 50 percent of the up to 100 lbs of plant material they eat each day. The undigested portion is excreted and therefore enriches the aquatic habitat and promotes algal blooms. These blooms can reduce water clarity and decrease oxygen levels. Removal of aquatic vegetation by carp can have negative effects on native fish through the elimination of food sources, shelter, and spawning substrates supported by the vegetation. On the other hand, grass carp are used extensively for aquatic vegetation control when vegetation becomes excessive and begins to seriously interfere with boating and fishing. At low population densities, grass carp may feed on preferred rather than on target plant species. Grass carp may also reduce aquatic vegetation that is desirable for waterfowl and other wildlife species. It is believed that grass carp imported from China were the source of the introduced Asian tapeworm *Bothriocephalus opsarichthydis*; these carp are known to have spread the parasite to other fish in Arkansas. The stocking of grass carp is not prohibited in Arkansas, Missouri, and Oklahoma.

Eurasian or spike water milfoil (*Myriophyllum spicatum*). This milfoil is one of the most widely distributed of the exotic aquatic plants; it now occurs in 42 States. It has become a significant problem in Missouri's Lake of the Ozarks and Bootheel region water bodies. In Oklahoma, it is well established in reservoirs in Stevens, Sequoyah (within the Assessment area), and Cleveland Counties. It has been a major nuisance in the Kerr Reservoir. The first report of this species' presence in Arkansas came, most recently, from Lake Ouachita. In the lakes, reservoirs, and ponds it invades, the milfoil's abundant growth usually causes problems such as the displacement of native vegetation. The best method for minimizing dispersal and impacts of this aggressive, submerged plant is to prevent inadvertent transfer of milfoil from one water body to another on the motors of trailers and boats.

Purple loosestrife (*Lythrum salicaria*). Predominantly occurring in the northeastern corner of Missouri, most populations of purple loosestrife are located around the edges of lakes and ponds. A single stand was reported in 1985 in Craighead County in northeastern Arkansas; however, it has not been verified if this reported occurrence still exists. In Oklahoma, an isolated population has been reported since 1992 at a roadside location in Oklahoma City. These reported occurrences are outside the Assessment area. Purple loosestrife is responsible for large-scale deterioration of wetlands and loss of wildlife habitat throughout the Northern and Northeastern United States. This species can be found as far south as the piney woods region of east Texas. Recent reports have also been received of occurrences in Tennessee Valley Authority (TVA) lakes and streams.

Other aquatic problem plants. The following 10 aquatic plants (in alphabetical order) have also been reported in the Assessment States as causing problems. Each is discussed briefly.

- Alligatorweed (*Alternanthera philoxeroides*) is found throughout southeastern Arkansas where it ranges as far north as Perry County (within the southern quarter of the Assessment area). The species was recently identified in Oklahoma within the Lower Verdigris watershed in Wagoner County just to the west of the Assessment area. Usually found emerging from the edges of lakes, streams, and ditches, alligatorweed is a problem aquatic plant in the Southern States.
- Bog bulrush (*Scirpus mucronatus*) is a relatively new Eurasian species introduction to the Midwest. Bog bulrush has been collected from ponds in eastern Missouri.
- Brazilian waterweed (*Egeria densa*) has been reported in the Eleven Point River of Missouri and is expected to eventually appear throughout the Eleven Point and other watersheds in the Missouri Ozarks. This species is established in southern Oklahoma and central Arkansas and is well known as a pest in lakes and streams in 30 States nationwide.
- Brittle naiad or waternymph (*Najas minor*) is abundant in areas of the Missouri Bootheel and in the Lake of the Arbuckles, Murray County, OK. An aggressive weed in many States, brittle waternymph thrives in impounded and polluted areas. It is common in Tennessee reservoirs of the TVA. Native *Najas* species are often dominated by brittle waternymph.
- Creeping yellowcress (*Rorippa sylvestris*) has been reported in swampy woods and wet ditches along the Mississippi River in Missouri and in Arkansas. This species has also been reported in moist, rocky banks of Hickory Creek in western Missouri. Creeping

yellowcress forms spreading, massive colonies in wet or riverine environments by budding from the roots.

- Curly pondweed (*Potamogeton crispus*) currently occurs in springs, lakes, and ponds throughout Missouri. Occurrences of it have been reported in a dozen counties in Oklahoma, including Cherokee and Bryan, and in northwest Arkansas. Curly pondweed is very aggressive in aquatic habitats in the northern regions of the United States.
- Dotted duckweed (*Spirodela punctata*) is reported in ponds in the western and southwestern areas of Missouri and throughout Oklahoma. In the Southeastern United States, dotted duckweed can blanket ponds, competing with native *Lemna* species and blocking light to other submersed plant species. However, dotted duckweed is sensitive to long periods of cold temperatures and may be expected to occur only in localized areas of the Assessment area.
- European waterclover (*Marsilea quadrifolia*) is spreading westward from the Northeastern United States and has been reported in northern Missouri. In 1985, this species' southernmost range was within the Lower Missouri-Morreau watershed. At that time, the native *Marsilea vestita* (listed as endangered in Missouri) was no longer found within the State.
- Watercress (*Rorippa nasturtium-aquaticum*) is found throughout the temperate United States. It is found in Missouri, Oklahoma, and Arkansas where it can dominate the vegetation of cold water springs and streams and lakeshores.
- Yellow floatingheart (*Nymphoides peltata*) forms dense mats covering ponds and stream channels and is prevalent in southern Oklahoma. Occurrences of this species have additionally been reported in northwest Arkansas and in Missouri.

Implications and Opportunities

Introduced aquatic species have the potential to seriously disrupt indigenous aquatic fauna and flora. However, as in the case of largemouth bass and bluegill, some stockings can be quite beneficial. As discussed in "Commercially and Recreationally Important Species" in Chapter 2, a number of species have been successfully introduced, resulting in tremendous benefit to fisheries. These are examples of species, native to this Nation, being stocked into aquatic systems with either natural predators or the fisheries management resources needed to limit any negative impacts. Exotic aquatic species introductions—either accidental or the result of well-intentioned actions—have resulted in environmental calamities of varying magnitudes.

All planned introductions (even native, but particularly exotic species) need to be well researched and thought out in advance and thoroughly reviewed before implementation. All applicable laws, executive orders, regulations, and governmental and scientific organizational policies should be examined prior to approving nonindigenous species introductions. Potential genetic impacts of such introductions on indigenous species should also be considered when deciding the merits and sources of fishes to use in introductions (such as are being considered in the three Assessment area States for walleye, sauger, and smallmouth bass; see Chapter 2, "Commercially and Recreationally Important Species").

Measures to educate the public about the devastation caused by zebra mussels and nonindigenous aquatic plant introductions must continue and may need to be expanded and intensified. Once many of these introduced species become established, they simply cannot be controlled, let alone eliminated. Prevention is the strongest recourse. It is clear that more research on methods to control zebra mussels and protect native mussel fauna in the Assessment area is needed.

Where not already in place, State and Federal agencies should develop and use protocols that would help prevent the spread of introduced species. For instance, fisheries sampling equipment is a prime candidate for spreading unwanted species if not decontaminated properly between uses in affected and unaffected water bodies.

Efforts to track the spread of introduced species should continue and all information updates kept current and easily accessible. A central clearinghouse for this information (such as that provided by the Geological Survey) is very useful at the national level. Similar, additional State-level clearinghouses would be very helpful.

Chapter 5: Water Supply and Use

The Ozark-Ouachita Highlands encompass headwaters for 13 major rivers (the Gasconade, Meramac, St. Francis, Neosho, Illinois, White, Black, Kiamichi, Little, Ouachita, and Saline Rivers, and portions of the Arkansas and Osage Rivers). These rivers serve instream and offstream water needs for much of the South-Central United States. Streamflow from these rivers eventually empties into the Mississippi River. The purpose of this chapter is to compare water supply with past and present water uses in the Assessment area and examine trends in uses that may occur in the future.

Past and Present Supply and Use

Question 5.1: What are the past and current water supplies and uses in the Assessment area?

Currently, the supply of water in the Highlands vastly exceeds use in most areas. In a few locations, however, use has risen to consume a substantial portion of the supply.

Key Findings

1. Total withdrawals of water in the Assessment area in 1995 were 6,622 million gallons per day (gal/d). Of these withdrawals, 1,322 million gal/d (20 percent) were consumed and not returned to a stream.
2. Twenty-two percent of the total 1995 withdrawals came from ground water pumping; the other 78 percent of withdrawals came from surface water.
3. Hydropower plants used almost 103 billion gal/d of surface water to produce electricity.
4. From 1985 to 1995, withdrawals increased in four categories of offstream water use (domestic and public, commercial, thermoelectric, and irrigation) and decreased in three other categories (industrial, mining, and livestock).
5. Increases in withdrawals, especially those at thermoelectric plants and for irrigation, far outpaced decreases, resulting in substantial net increases.
6. In 1995, 64 percent of withdrawn water was for cooling at thermoelectric plants; another 20 percent was for crop irrigation.
7. Annual precipitation in the Assessment area averages about 44 inches, of which roughly 70 percent evaporates. The rest is available as streamflow, to recharge ground water reservoirs, or for offstream use.
8. Across the entire area in the average year, only 6.7 percent of the 53.7 billion gal/d of water yield is withdrawn for offstream use, and only 1.2 percent is consumed.
9. Withdrawals vary widely across watersheds and exceed 20 percent of available water in four watersheds. In three of these watersheds (South Grand, Illinois, and Dardanelle Reservoir), withdrawals for thermoelectric plants account for 83 to 97 percent of total withdrawals. In the other watershed (Lower Black), irrigation accounts for 97 percent of total withdrawals.

Comparisons of Water Supply and Use

Data Sources and Methods of Analysis

The USDI Geological Survey has estimated the Nation's water use at 5-year intervals since 1950. Early estimates were for whole States and even larger watersheds. In 1985, however, the agency began estimating use for counties and watersheds (hydrologic units) that tend to be slightly larger than a typical county. State totals for these periodic surveys of water use have been published in Geological Survey circulars; for example, the 1990 data are found in Solley and others (1993). The Geological Survey also provides detailed water use and supply estimates as data files. For this report, the Aquatic Team summed estimates of water use and supply for counties and watersheds within the aquatic study area. Estimates are reported for various water uses including domestic, municipal, industrial, agricultural (for irrigation), thermoelectric (largely for cooling), and hydroelectric uses. All uses except hydroelectric involve offstream withdrawals. Of the water withdrawn, a portion is consumed (e.g., by being incorporated into a product or evaporated from an irrigated field) and is removed from the immediate water environment; the remainder returns to the stream or perhaps seeps into ground water storage where it is available to be used again. The other principal data for this report are estimates of water supply. The team estimated supply by subtracting evapotranspiration from precipitation using monthly data from 1962 to 1988. The team estimated precipitation from data of weather stations within the Assessment area. Evapotranspiration was estimated using the Complementary Relationship Areal Evapotranspiration model (Morton 1965, 1983), which is based on the complementary relation between potential and actual evapotranspiration (Bouchet 1963). This model uses meteorological data including precipitation, humidity, solar radiation, albedo (reflectivity of the Earth's surface), and temperature. These data were mapped spatially using Geographic Information System technology, and missing data points were then estimated by interpolation to achieve a grid cell size of 10 kilometers (km) for input to the model. Claessnes (1996) describes the complete methodology. To verify the model's accuracy, model estimates of average annual evapotranspiration were compared with estimates computed as precipitation minus runoff for 164 relatively undisturbed watersheds in the United States. The average error in estimation across these watersheds was less than 2 percent of average annual precipitation (Claessnes 1996).

The Aquatic Team projected future withdrawals in the Assessment area based on county-level estimates of future population and income to the year 2040 provided by the USDC's Bureau of Economic Analysis (USDC BEA 1992) and on assumptions about rates of change in other factors affecting water use. These assumed rates of change, listed below, are based on an assessment of national water uses over the past 35 years (Brown 1998). The rates of change are applied to the 1995 withdrawal levels of the Assessment area.

Patterns and Trends

Counties. The Assessment area comprises major portions of Arkansas and Missouri plus a small section of Oklahoma. Water withdrawals in Arkansas and Missouri have risen sevenfold since 1950 (fig. 5.1). Withdrawals within the Assessment area have also risen. Rates of increase for the two States and for the Assessment area have been similar since 1985; there was about a 25 percent increase from 1985 to 1990 and about a 7 percent increase from 1990 to 1995.

Total withdrawals in the Assessment area in 1995 were 6,622 million gal/d (table 5.1). Of these withdrawals, 1,322 million gal/d (20 percent) were consumed. Twenty-two percent of the total withdrawals came from ground water pumping; the other 78 percent was withdrawn from surface water. In addition, almost 103 billion gal/d of surface water were used to produce electricity at hydropower plants.

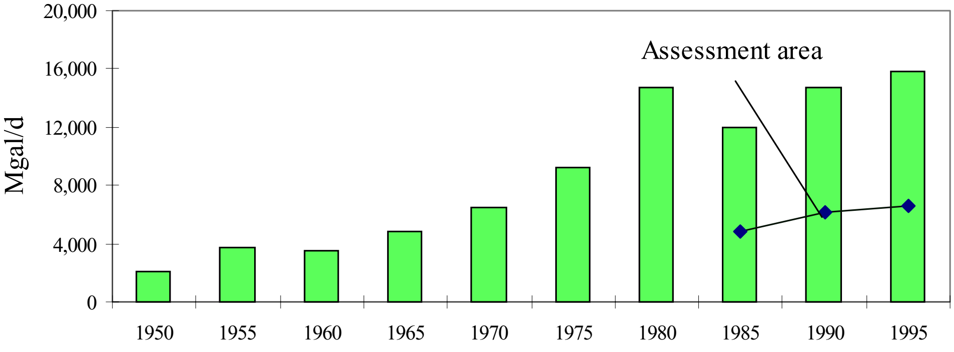


Figure 5.1—Total water withdrawals in million gallons per day (Mgal/d) in Arkansas and Missouri from 1950 to 1995, including 1985 to 1995 withdrawals in the Assessment area.

Table 5.1—Fresh water uses in the Ozark-Ouachita Highlands, 1985–1995

Uses	1985	1990	1995
	Million gallons/day		
Withdrawal			
Domestic and public	440	464	538
Commercial	97	277	203
Industrial	139	114	136
Thermoelectric	2,947	3,901	4,234
Mining	29	26	11
Livestock	210	149	184
Crop irrigation	986	1,216	1,315
Total	4,847	6,148	6,622
Consumptive use	1,006	1,205	1,322
Hydroelectric water use	141,942	116,793	102,884

Source: Solley and others (1988, 1993).

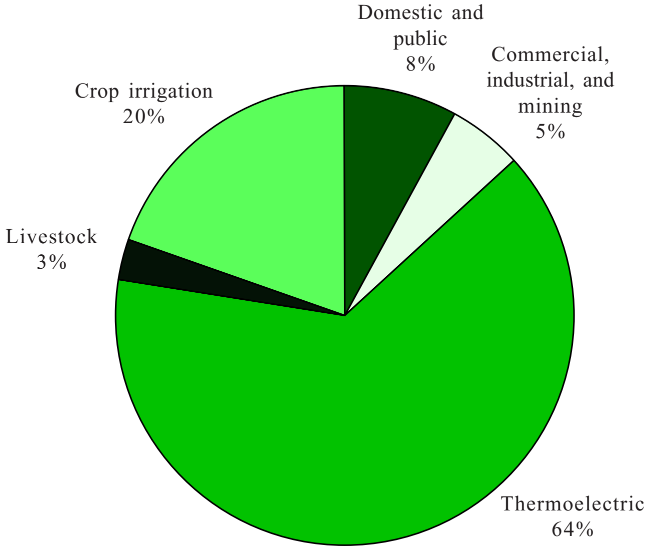


Figure 5.2—Categories of water withdrawals in the Assessment area for 1995.

From 1985 to 1995, withdrawals increased for four categories of water use: (1) domestic and public, (2) commercial, (3) thermoelectric, and (4) crop irrigation. Withdrawals decreased during this period for the other three categories: (1) industrial, (2) mining, and (3) livestock (table 5.1). Increases, especially those at thermoelectric plants and for irrigation, far outpaced decreases, resulting in substantial net increases.

In 1995, 64 percent of withdrawn water was for cooling at thermoelectric plants, and another 20 percent was for crop irrigation (fig. 5.2). Domestic and public uses (public includes parks, government offices, and firefighting) account for another 8 percent, with the remaining 8 percent for commercial, industrial, mining, and livestock.

Table 5.2 lists 1995 withdrawals by county and shows that withdrawals for the largest water users are unevenly distributed. Thermoelectric plants use water in 15 of the 107 counties in the Assessment area and very large amounts in 8 of those counties. The eight counties with the large thermoelectric plants account for 64 percent of the total Assessment area withdrawals. Irrigation is more widespread but uses very large quantities of water in only six counties. Hydroelectric plants operate in 22 counties and use enormous quantities of water, although nearly all of this use occurs instream.

Watersheds. Water availability and use were compared for watersheds within the Assessment area (table 5.3). Total withdrawals shown in table 5.3 are considerably less than those in tables 5.1 and 5.2 because the watersheds included in table 5.3 omit some areas of high water use on the perimeter of the Assessment area that are included in the county-based tables.

Precipitation in the Assessment area averages about 44 inches (in.) annually, of which roughly 70 percent evaporates; and the rest is available as streamflow to recharge ground water reservoirs or for offstream use. It should be noted that the model for computing evapotranspiration has a greater margin of error when used for specific years than when used to estimate a mean over several years, so these estimates must be used with caution. Across the entire area in the average year, only 6.7 percent of the 53.7 billion gal/d of water yield is withdrawn for offstream use, and only 1.2 percent is consumed. However, the portion withdrawn varies widely across watersheds and exceeds 20 percent in four watersheds. In three of these watersheds (South Grand, Illinois, and Dardanelle Reservoir), withdrawals for thermoelectric plants account for 83 to 97 percent of total withdrawals. In the other watershed (Lower Black), irrigation accounts for 97 percent of total withdrawals. Note that because thermoelectric plants return nearly all of their withdrawals to the stream,

Table 5.2—Water use by State and county in 1995 in the Ozark-Ouachita Highlands

County	Domestic and public	Commercial	Industrial	Offstream withdrawal thermo-electric	Offstream withdrawal, mining	Live-stock	Crop irrigation	Total	Hydroelectric
	Million gallons per day								
				Arkansas					
Baxter	2.73	1.23	1.23	0	0	0.34	0	6	999
Benton	11.77	0.94	0.94	319.27	0	2.92	0.45	336	0
Boone	2.71	0.36	0.35	0	0	1.15	0.03	5	0
Carroll	2.91	1.45	1.45	0	0.01	1.44	0.02	7	8,073
Clark	2.20	0.57	1.10	0	0	0.33	0.96	5	337
Cleburne	3.95	0.24	0.13	0	0	2.37	0.10	7	848
Conway	1.55	0.16	20.66	0	0	1.62	4.55	29	0
Crawford	12.33	1.22	1.66	0	0	0.62	0.06	16	0
Faulkner	7.38	1.48	1.48	0	0	0.93	0.63	12	0
Franklin	2.64	0.40	0.32	8.23	0	0.89	0.08	13	15,018
Fulton	1.00	72.02	0.02	0	0	0.62	0.09	74	0
Garland	9.81	3.08	5.47	247.15	0	0.76	0.01	266	2,275
Hot Spring	3.13	0.24	0.76	0	0	0.30	3.67	8	1,326
Howard	3.87	0	1.14	0	0	0.84	0	6	0
Independence	3.83	1.57	1.60	8.56	0	0.78	20.23	37	0
Izard	2.19	0.09	0.09	0	0	0.56	0	3	0
Jackson	1.96	0.09	0.09	0	0	7.72	288.42	298	0
Johnson	2.14	0.61	0.53	0	0	0.64	0.31	4	0
Lawrence	1.27	1.05	0.18	0	0	0.41	278.48	281	0
Logan	2.75	0.37	0.36	0	0	1.07	0.37	5	0
Lonoke	4.35	0.11	1.07	0	0	71.66	295.75	373	0
Madison	1.62	0.37	0.36	0	0	1.30	0	4	0
Marion	1.07	0.11	0.10	0	0	0.46	0	2	4,718
Montgomery	1.12	0.03	0.05	0	0	0.42	0.04	2	0
Newton	0.63	0.01	0	0	0	0.33	0.06	1	0
Perry	0.94	0.05	0.04	0	0	0.37	2.98	4	0
Pike	0.92	0.23	0.22	0	0	0.50	0	2	185
Polk	3.22	0.36	0.36	0	0	0.69	0.23	5	0
Pope	5.66	34.99	2.53	967.12	0	0.92	1.22	1,012	8,948
Pulaski	47.70	7.20	7.28	0	0	0.71	23.37	86	0
Randolph	1.57	0.12	0.11	0	0	0.49	78.14	80	0
Saline	7.88	0.39	0.98	0	0.12	0.25	0.07	10	0
Scott	1.11	0.47	0.46	0	0	0.70	0	3	0
Searcy	1.06	0.08	0.08	0	0	0.54	0	2	0
Sebastian	17.88	6.93	6.93	0	0	0.52	0.11	32	0
Sevier	1.57	0.94	0.94	0	0	0.92	0	4	0
Sharp	1.14	0.21	0.21	0	0	0.46	0	2	0
Stone	0.91	0.19	0.18	0	0	0.52	0	2	0
Van Buren	1.92	0.02	0.02	0	0	0.56	0	3	0
Washington	13.96	5.36	5.33	0	0	2.60	0.12	27	0
White	6.36	1.04	1.03	0	0	3.13	102.46	114	0
Yell	3.55	2.99	0.31	0	0	1.02	1.83	10	0
				Missouri					
Barry	2.55	0.23	2.55	0	0	1.80	0.18	7	0
Barton	1.33	0.23	0.02	0	0	0.76	2.40	5	0
Benton	1.08	0.10	0	0	0	0.69	0.02	2	4,127
Bollinger	0.77	0.20	0	0	0	0.43	8.32	10	0
Butler	4.35	0.16	0	0	0	0.13	151.11	156	0
Camden	2.70	0.21	0.12	0	0	0.36	0.32	4	161
Carter	0.50	0.02	0	0	0	0.12	0.01	1	0
Cedar	1.03	0.20	0.19	0	0	0.66	0.01	2	353
Christian	3.03	0.09	0.59	0	0	0.88	0.12	5	0
Cole	7.35	0.92	0.18	0	0	0.58	0.25	9	0
Crawford	1.69	0.34	0	0	0	0.40	0.03	2	0
Dade	0.53	0.12	0	0	0	0.91	2.25	4	0
Dallas	1.03	0.06	0.01	0	0	0.91	0.07	2	0
Dent	0.96	0.16	0	0	0	0.48	0.12	2	0

(continued)

Table 5.2—Water use by State and county in 1995 in the Ozark-Ouachita Highlands (continued)

County	Domestic and public	Commercial	Industrial	Offstream withdrawal thermo-electric	Offstream withdrawal, mining	Live-stock	Crop irrigation	Total	Hydroelectric
	Million gallons per day								
				Missouri (continued)					
Douglas	1.16	0.09	0	0	0	1.06	0.34	3	0
Franklin	7.69	0.37	0.04	957.51	0	0.94	0.01	967	0
Gasconade	1.64	0.29	0	0	0	0.52	0.10	3	0
Greene	24.09	3.96	4.68	141.72	0	1.30	0.15	176	0
Henry	1.64	0.10	0	354.9	0	0.89	0.47	358	0
Hickory	0.52	0.03	0	0	0	0.51	0.01	1	0
Howell	3.40	0.29	0.30	0	0	1.35	0.07	5	0
Iron	0.70	0.05	4.21	0	0	0.16	0.01	5	0
Jasper	11.30	1.73	7.75	1.68	0	0.93	2.52	26	0
Jefferson	10.95	0.79	3.22	819.8	0	0.27	0.18	835	0
Laclede	2.84	0.62	0.42	0	0	1.12	0.04	5	0
Lawrence	2.17	0.30	0.70	0	0	1.57	0.58	5	0
McDonald	1.97	0.34	1.13	0	0	1.37	0.48	5	0
Madison	0.91	0.16	0	0	0	0.26	0.02	1	0
Maries	0.56	1.94	0.06	0	0	0.67	0.06	3	0
Miller	1.52	0.29	0	0	0	1.20	0.15	3	8,382
Morgan	1.20	0.04	0.06	0	0	0.85	0.25	2	0
Newton	4.62	0.50	0.65	0	0	1.36	0.11	7	0
Oregon	2.89	0.23	0.02	0	0	0.78	0.09	4	0
Osage	0.82	0.16	0	32.47	0	1.28	0.05	35	0
Ozark	4.13	0.07	0	0	0	0.86	0.17	5	0
Phelps	3.12	0.25	0	0	0	0.41	0.12	4	0
Polk	2.39	0.20	0.01	0	0	1.55	0.19	4	0
Pulaski	6.05	0.91	0.16	0	0	0.33	0.03	7	0
Reynolds	0.42	0.02	0.22	0	2.89	0.15	0.01	4	0
Ripley	1.18	0.04	0	0	0	0.24	17.72	19	0
St. Clair	0.64	0.03	0	0	0	0.69	0.15	2	0
Ste. Genevieve	1.11	0.05	0.16	0	0	0.47	0	2	0
St. Francois	4.70	0.55	0	299.05	1.78	0.36	0.10	307	0
Shannon	0.56	0.08	0.05	0	0	0.27	0.01	1	0
Stone	2.24	0.87	0.12	0	0	0.58	0.02	4	0
Taney	8.28	0.55	0.27	0	0	0.37	0.04	10	3,623
Texas	1.83	0.07	0.57	0	0	1.43	1.47	5	0
Washington	1.49	0.42	0.06	0	6.63	0.27	0.01	9	0
Wayne	1.38	0.14	0.10	0	0	0.16	0.02	2	0
Webster	2.04	0.10	0	0	0	1.36	0.71	4	0
Wright	1.56	0.10	0.03	0	0	1.45	0.65	4	0
				Oklahoma					
Adair	2.10	2.12	0.52	0	0	2.46	2.44	10	0
Atoka	53.75	0.11	0	0	0	1.45	0.15	55	0
Cherokee	4.80	14.24	0.01	0	0	1.36	2.57	23	3,583
Delaware	1.30	1.32	0.36	0	0	2.87	0.02	6	0
Haskell	1.07	0.54	0	0	0	2.52	0.01	4	3,687
Latimer	0.89	0.23	0.03	0	0	0.89	0.17	2	0
Le Flore	7.89	1.38	0.77	0	0	2.75	1.45	14	15,393
McCurtain	5.32	1.81	1.27	0	0	2.83	0.07	11	605
Mayes	59.37	0.46	11.81	10.92	0	1.90	0	84	9,231
Muskogee	6.09	4.39	21.39	44.34	0	2.11	5.22	84	10,010
Ottawa	0.41	0.83	1.41	0	0	2.39	0	5	0
Pittsburg	3.77	2.73	1.07	0	0	2.71	0.11	10	0
Pushmataha	0.93	0.29	0	0	0	1.21	0.22	3	0
Sequoyah	9.14	1.50	0.31	0	0	1.33	1.80	14	1,000
Totals	519.70[a]	201.09[a]	135.75	4,212.72[a]	11.43	182.61	1,311.39[a]	6,575[a]	102,884

[a] Totals differ from table 5.1 as a result of rounding.

Table 5.3—Average annual water availability (from precipitation) compared with withdrawals and consumptive use in the Highlands in 1995

River basin Watershed name	Watershed code (HUC)	Water availability from precipitation	Yield	Withdrawal		Consumptive use	
		- - - - - - - *Million gallons per day*		- - - - - - -	*% of yield*	*Mgal/d*	*% of yield*
Osage River Basin							
H.S. Truman Reservoir	10290105	2,395	703	4	0.6	2.5	0.4
Sac	10290106	3,904	1,150	18	1.5	7.7	0.7
Pomme de Terre	10290107	1,661	465	5	1.1	2.4	0.5
South Grand	10290108	3,844	1,249	366	29.3	9.2	0.7
Lake of the Ozarks	10290109	2,686	765	8	1.0	2.8	0.4
Niangua	10290110	2,053	629	5	0.8	2.4	0.4
Lower Osage	10290111	2,071	603	7	1.2	2.9	0.5
Gasconade River Basin							
Upper Gasconade	10290201	3,548	1,268	12	0.9	4.9	0.4
Big Piney	10290202	1,506	527	5	0.9	1.9	0.4
Lower Gasconade	10290203	1,960	624	5	0.7	1.8	0.3
Meramec River Basin							
Meramec	07140102	4,091	1,268	60	4.8	10.6	0.8
Bourbeuse	07140103	1,602	497	7	1.4	2.0	0.4
Big	07140104	1,806	519	12	2.3	2.4	0.5
Upper St. Francis River Basin							
Upper St. Francis	08020202	3,826	1,164	10	0.9	3.5	0.3
Neosho-Illinois River Basin							
Lake O' the Cherokees	11070206	1,857	622	9	1.5	4.9	0.8
Spring	11070207	5,058	1,760	42	2.4	14.1	0.8
Elk	11070208	2,080	786	8	1.0	4.1	0.5
Lower Neosho	11070209	4,357	1,326	120	9.1	21.6	1.6
Illinois	11110103	3,424	1,350	381	28.2	14.4	1.1
Arkansas River Basin							
Dirty-Greenleaf	11110102	1,527	416	68	16.3	20.5	4.9
Robert S. Kerr Reservoir	11110104	3,741	1,269	54	4.2	15.9	1.3
Poteau	11110105	4,025	1,476	18	1.2	7.0	0.5
Frog-Mulberry	11110201	2,753	1,056	23	2.2	6.9	0.7
Dardanelle Reservoir	11110202	4,047	1,381	1,017	73.6	8.5	0.6
Conway- Pt. Remove	11110203	2,585	811	29	3.5	9.9	1.2
Petit Jean	11110204	2,337	764	8	1.0	4.4	0.6
Cadron	11110205	1,774	593	18	3.0	2.1	0.3
Fourche La Fave	11110206	2,562	880	8	0.9	3.9	0.4
Lower Ark-Maumelle	11110207	2,628	908	110	12.2	46.9	5.2
Kiamichi-Little River Basin							
Kiamichi	11140105	4,075	1,377	14	1.0	6.8	0.5
Upper Little	11140107	3,320	1,294	5	0.4	2.7	0.2
Mountain Fork	11140108	2,033	839	7	0.9	2.2	0.3
Lower Little	11140109	4,788	1,640	17	1.0	8.0	0.5
Ouachita-Saline River Basin							
Ouachita Hdwaters	08040101	3,912	1,474	271	18.4	4.8	0.3
Upper Ouachita	08040102	4,372	1,377	46	3.3	11.3	0.8
Little Missouri	08040103	5,238	1,747	7	0.4	4.5	0.3
Upper Saline	08040203	4,264	1,519	9	0.6	2.2	0.1
Upper White River Basin							
Beaver Reservoir	11010001	5,379	2,261	29	1.3	12.9	0.6
James	11010002	2,896	1,003	177	17.6	11.4	1.1
Bull Shoals Lake	11010003	5,328	1,615	19	1.2	5.9	0.4
Middle White	11010004	3,269	979	28	2.9	14.8	1.5
Buffalo	11010005	2,867	1,130	2	0.2	1.5	0.1
North Fork White	11010006	3,672	1,196	8	0.7	3.9	0.3
Little Red	11010014	4,149	1,420	46	3.2	27.8	2
Upper Black River Basin							
Upper Black	11010007	4,098	1,339	174	13.0	121.0	9
Current	11010008	5,546	1,842	70	3.8	49.3	2.7
Lower Black	11010009	1,723	549	124	22.5	90.3	16.5
Spring	11010010	2,599	843	82	9.7	4.2	0.5
Eleven Point	11010011	2,601	872	5	0.5	2.2	0.3
Strawberry	11010012	1,666	508	8	1.6	5.8	1.1
Total[a]		159,502	53,652	3,583	6.7	635.3	1.2

HUC = hydrologic unit code; Mgal/d = million gallons per day.

[a] Totals differ from table 5.2 because watersheds included here omit some areas included in counties.

consumption in those three watersheds is low. Irrigation, however, tends to consume 50 percent or more of withdrawals, as demonstrated by the much higher portion of water yield that is consumed in the Lower Black watershed.

Table 5.3 reports average annual water use per watershed. In dry years, watersheds yield much less than normal. These yield differences are substantial. For 1963—the driest year in the 1962 to 1988 study period—water yield is estimated to have been about 8.4 billion gal/d or only 15 percent of the mean. Total 1995 withdrawals represent 43 percent of the 1963 water supply. For 1980—the "next driest" year of the record—water yield equaled about 23 billion gal/d or about 42 percent of the mean. Total 1995 withdrawals represented 16 percent of the 1980 available water supply. The respective portions of available supply that would have been consumed, given 1995 use levels, are 8 percent for 1963 weather conditions and 3 percent for 1980 conditions.

An important caution to this analysis at the watershed level is that the streamflow available in a given watershed may receive flow from an upstream watershed; only the watersheds of the headwaters rely solely on streamflow generated within their boundaries. Of the four watersheds mentioned above that experience relatively high withdrawal levels, the Lower Black is on the Black River, which receives flow from several headwater streams in upstream watersheds, and the Dardanelle Reservoir takes its water from the Arkansas River. The thermoelectric plants in the South Grand and Illinois watersheds are in the headwaters and thus rely on relatively limited water supplies. There are few, if any, users between the intake and outflow points of the thermoelectric plants in these watersheds, so effects of such plants using a large quantity of water on other users are likely to be minimal.

Future Patterns and Trends

Question 5.2: What future trends are likely for water use and supply?

Adequate water supplies are critical for long-term economic growth of any area or community. This section calculates future water demands for the Assessment area. The Aquatic Team projects that overall future use will remain a small fraction of the water supply in most years to come.

Key Findings

1. Domestic and public withdrawals are projected to increase from 143 gallons per day (gal/d) per person in 1995 to 156 in 2040. Total domestic and public withdrawals are thus projected to increase from 538 million gal/d in 1995 to 675 in 2040.
2. Total industrial and commercial withdrawals are projected to drop from 339 million gal/d in 1995 to 214 in 2040.
3. Total annual energy production at thermoelectric plants in the Assessment area is projected to increase from 75 billion kilowatt hours (kWh) in 1995 to 107 billion kWh in 2040.
4. Total withdrawals for thermoelectric plants are projected to drop from 4.2 billion gal/d in 1995 to 3.8 in 2040.
5. Acres of crops irrigated are expected to increase from 798 thousand in 1995 to 1,226 thousand in 2040. Total irrigation withdrawals are projected to increase from 1.3 billion gal/d in 1995 to 2.0 billion gal/d in 2040.
6. Total withdrawals are projected to increase until 2020 and remain rather stable after that, staying within 5 percent of 1995 withdrawals. Essentially the increases in withdrawals for domestic and public use and for irrigation are largely balanced by the decreases in withdrawals for industrial, commercial, and thermoelectric uses.

Withdrawals

Assumptions and Projections

The Aquatic Team projected domestic and public withdrawals based on two assumptions. First, the team assumed the number of persons per household (i.e., per occupied housing unit) will drop at a rate of 1 percent per decade. With this assumption, persons per household will drop from 2.52 in 1995 to 2.41 in 2040. Second, the team assumed withdrawals per household will increase at a rate of 1 percent per decade. Based on this assumption, withdrawals per household increase from 359 gallons per day (gal/d) in 1995 to 376 in 2040.

Given these two assumptions, domestic and public withdrawals are projected to increase from 143 gal/d per person in 1995 to 156 in 2040. Total domestic and public withdrawals are thus projected to increase from 538 million gal/d in 1995 to 675 in 2040 (fig. 5.3). Based on Geological Survey estimates for 1995, about two-thirds of those amounts are attributable to domestic use, with the remainder allotted to public uses and losses.

The team projected industrial and commercial withdrawals based on estimates of future populations and income and assumptions about the rate of change in withdrawals per dollar of income. The Bureau of Economic Analysis projects per capita income in the Assessment area, in 1990 dollars, to increase from $15,005 in 1995 to $22,350 in 2040. The team assumed that withdrawals per $1,000 of income, which has been dropping steadily since 1960 due largely to enhanced efficiency and recycling (Brown 1998), will continue dropping at the somewhat lower rate than the previous rate of 20 percent per decade. Given this assumption, withdrawals per $1,000 of income drop from 6 gal in 1995 to 2.2 gal in 2040. Given these two assumptions, total industrial and commercial withdrawals are projected to drop from 339 million gal/d in 1995 to 214 in 2040 (fig. 5.4).

The team projected withdrawals at thermoelectric plants based on estimates of future populations and assumptions about the rate of change in energy use per person and in water use per kilowatt hour (kWh) produced. The team assumed that per capita use of energy generated at thermoelectric plants will increase by 5 percent per decade. Given this assumption, the team projected that the use of energy generated at thermoelectric plants would increase from 19,917 kWh per person per year in 1995 to 24,814 in 2040. This trend, along with the expected population increase, yields an increase in total annual energy production at thermoelectric plants in the Assessment area from 75 billion kWh in 1995 to 107 billion in 2040 (fig. 5.5).

The team assumed that water withdrawals per kWh, which have dropped consistently since 1960 with increased recycling (Brown 1998), will continue decreasing at the somewhat lower rate than the previous rate of 10 percent per decade. Given this rate of decrease, water withdrawals per kWh produced at thermoelectric plants in the Assessment area drop from 21 gal/kWh in 1995 to 13 in 2040. This trend, along with the increase in energy production, causes total withdrawals for thermoelectric plants to drop from 4.2 in 1995 to 3.8 billion gal/d in 2040 (fig. 5.5).

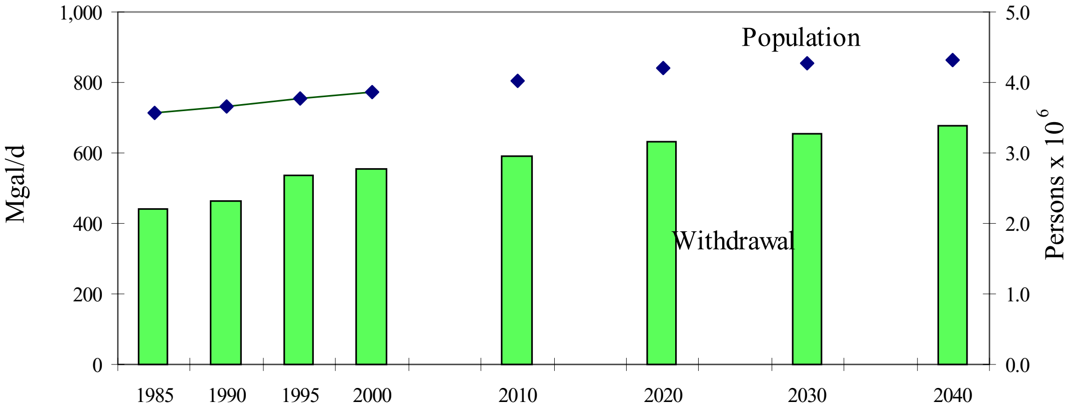


Figure 5.3—Past and projected millions of gallons of water withdrawals per day (Mgal/d) for domestic and public purposes in the Assessment area and population in millions (persons x 10^6).

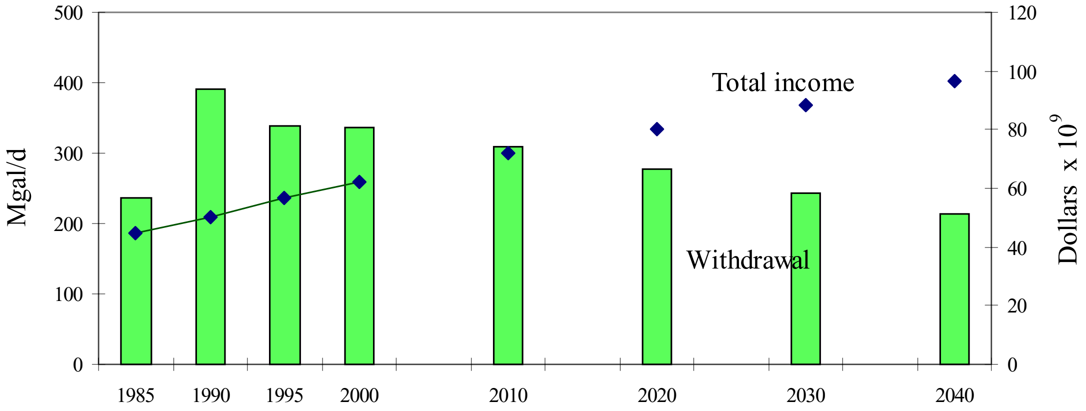


Figure 5.4—Past and projected millions of gallons of water withdrawals per day (Mgal/d) for industrial and commercial purposes and costs in billions of 1990 dollars (dollars x 10^9).

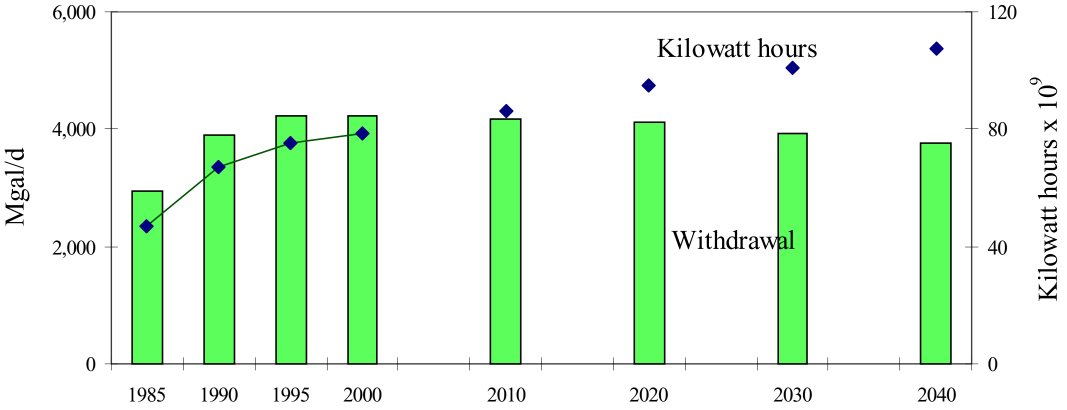


Figure 5.5—Past and projected millions of gallons of water withdrawals per day (Mgal/d) for thermoelectric purposes and billions of kilowatt hours of energy production.

Water withdrawals for crop irrigation were projected based on assumptions about withdrawals per acre and number of acres irrigated. The team assumed future withdrawals per acre will remain constant at the 1985 to 1995 average of 22.2 in. They also assumed that future numbers of acres irrigated will increase at a rate of 10 percent per decade. Acres irrigated are thus expected to increase from 798 thousand in 1995 to 1,226 thousand in 2040 (fig. 5.6). Total irrigation withdrawals are thus projected to increase from 1.3 in 1995 to 2.0 billion gal/d in 2040.

Figure 5.7 shows the future change in total withdrawals compared with the 1995 total withdrawal. Total withdrawals are projected to increase until 2020 and remain rather stable after that, staying within 5 percent of the 1995 withdrawal. Essentially, the increases in withdrawals for domestic and public use and for irrigation are largely balanced by the decreases in withdrawals for industrial, commercial, and thermoelectric uses.

These projections are based, by necessity, on educated guesses about future trends in population, income, and the various factors that affect withdrawals in the different water use categories. To give an idea of the sensitivity of the projections to the assumptions, consider the effect of an increase in energy use per person of 10 percent per decade, rather than the 5 percent increase assumed above. In this case, 2040 total withdrawals increase by 18 percent over 1995 withdrawals, rather than the net increase of under 5 percent shown in fig. 5.7. Finally, it should be noted that these projections ignore site specific changes that may place considerable pressure on local water supplies.

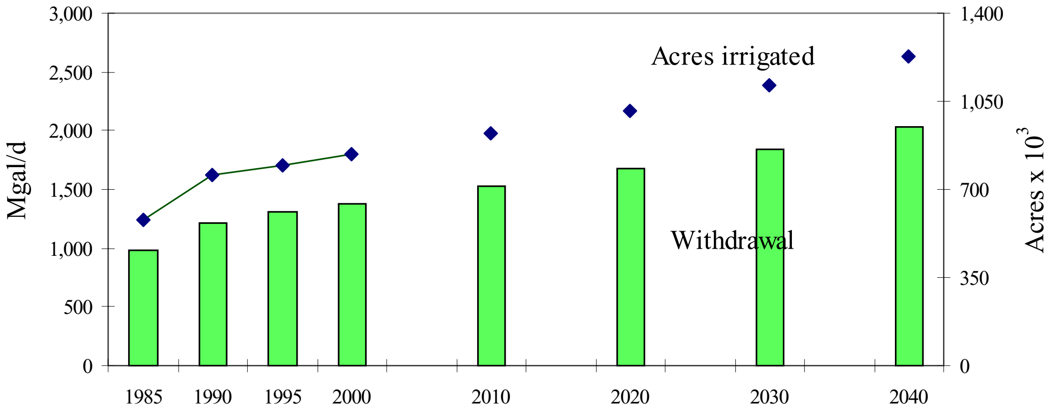


Figure 5.6—Past and projected millions of gallons of water withdrawals per day (Mgal/d) for crop irrigation and thousands of acres irrigated (acres x 10^3).

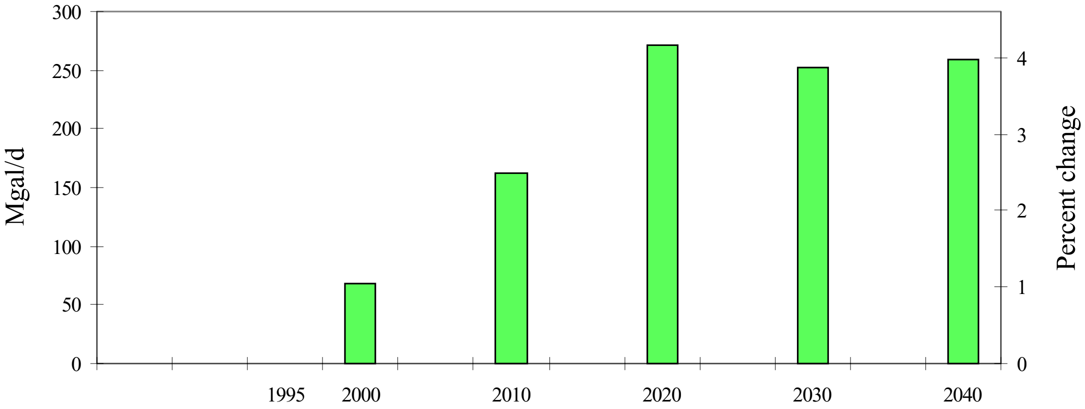


Figure 5.7—Projected net change in millions of gallons of water per day (Mgal/d) withdrawn for all purposes and percent increases compared to 1995 withdrawals (as a baseline).

While the overall picture is one of water abundance, many communities and cities in the Highlands face future shortages and are actively seeking new supplies for domestic, industrial, and commercial use. Little Rock, AR, for instance, which currently has two reservoirs in the Ouachita Mountains, seeks a third source to meet its long-term needs. Fort Smith, AR, seeks to expand its existing water supply lake. Many smaller communities (e.g., Benton and Marshall, AR) are actively looking for new supplies. For a variety of reasons, it is highly likely that communities will look to Federal and State lands for as least some of their freshwater needs.

Implications and Opportunities

In the typical year, water availability in the Assessment area as a whole is ample and easily supports current and expected future water needs. With over 40 in. of average annual precipitation and relatively low levels of crop irrigation in comparison to drier portions of the United States, water use in the Assessment region is relatively secure. However, as in most locations, severe droughts can cause short-term disruptions in water use, especially in localized areas of unusually heavy withdrawals. The individual users most likely to be affected during droughts are those using the most water—thermoelectric plants and farmers. Reservoir storage within the region helps lower the severity of such disruptions, as does temporarily increased reliance on ground water. A comprehensive list of users with potential shortages would be helpful for planning efforts.

References

Adams, Tim; Hook, Donal. 1993. Implementation and effectiveness monitoring of forestry best management practices on harvested sites in South Carolina. Rep. BMP-3. Columbia, SC: South Carolina Forestry Commission. 32 p.

Adamski, J.C. 1987. The effect of agriculture on the quality of ground water in a karstified carbonate terrain, northwest Arkansas. Fayetteville, AR: University of Arkansas. 124 p. M.S. thesis.

Adamski, J.C. 1997a. Nutrients and pesticides in ground water of the Ozark Plateaus in Arkansas, Kansas, Missouri, and Oklahoma. Wat.-Resour. Inv. Rep. 96-4313. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 28 p.

Adamski, J.C. 1997b. [Hydrologist, USDI Geological Survey, Little Rock, AR.] Personal communication. [Not paged]. [On file at the USDI Geological Survey offices, Little Rock, AR.]

Adamski, J.C.; Petersen, J.C.; Freiwald, D.A. [and others]. 1995. Environmental and hydrologic setting of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma. Wat.-Resour. Inv. Rep. 94-4022. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 69 p.

Ahlstedt, Steven A.; Jenkinson, John J. 1987. Distribution and abundance of *Potamilus capax* and other freshwater mussels in the St. Francis River system, Arkansas and Missouri. Fin. Rep. for Memphis District, U.S. Army Corps of Engineers. Knoxville, TN: Tennessee Valley Authority. 67 p. + field notes.

Ahlstedt, Steven. A.; Jenkinson, John J. 1991. Distribution and abundance of *Potamilus capax* and other freshwater mussels in the St. Francis River system, Arkansas and Missouri, U.S.A. Walkerana. 5(14): 225–261.

Albin, D.R. 1965. Water resources reconnaissance of the Ouachita Mountains, Arkansas. Wat.-Supp. Pap. 1809–55. Washington, DC: U.S. Department of the Interior, Geological Survey. 14 p.

Alexander, R.B.; Smith, R.A. 1990. County-level estimates of nitrogen and phosphorus fertilizer use in the United States. Open-File Rep. 90-130. Reston, VA: U.S. Department of the Interior, Geological Survey. 12 p.

Alexander, R.B.; Smith, R.A.; Schwarz, G.E. 1993. Correction of stream quality trends for the effects of laboratory measurement bias. Water Resources Research. 29(11): 3821–3833.

Allan, J. David; Flecker, Alexander S. 1993. Biodiversity conservation in running waters. BioScience. 43(1): 32–43.

Anderson, R.K.; Wells, J.S. 1967. Oil and gas. In: Mineral and water resources of Missouri. Vol. 43. Washington, DC: Missouri Division of Geological Survey and Water Resources: 243–252.

Angermeier, Paul L. 1995. Ecological attributes of extinction-prone species: loss of freshwater fishes of Virginia. Conservation Biology. 9(1): 143–158.

Angermeier, Paul L.; Karr, James R. 1994. Biological integrity versus biological diversity as policy directives. BioScience. 44(10): 690–697.

Arbenz, J.K. 1989a. The Ouachita system. In: Bally, A.W.; Palmer, A.R., eds. The geology of North America—an overview. Vol. A. Boulder, CO: Geological Society of America: 371–396.

Arbenz, J.K. 1989b. Ouachita thrust belt and Arkoma Basin. In: Hatcher, R.D., Jr.; Thomas, W.A.; Viele, G.W., eds. The geology of North America—an overview. Vol. F-2, The Appalachian-Ouachita orogeny in the United States. Boulder, CO: Geological Society of America: 621–634.

Arkansas Department of Pollution Control and Ecology (AR DPCE). 1980, 1984, 1986, 1992. Arkansas water quality inventory report (section 305(b) report). Little Rock, AR: Arkansas Department of Pollution Control and Ecology. [Various pagination].

Arkansas Department of Pollution Control and Ecology (AR DPCE). 1991. Regulation No. 2, as amended, regulation establishing water quality standards for surface waters of the State of Arkansas. Little Rock, AR: Arkansas Department of Pollution Control and Ecology. 73 p.

Arkansas Department of Pollution Control and Ecology (AR DPCE). 1994. Arkansas water quality inventory report (section 305(b) report). Little Rock, AR: Arkansas Department of Pollution Control and Ecology. 247 p.

Arkansas Department of Pollution Control and Ecology (AR DPCE). 1996. Arkansas water quality inventory report (section 305(b) report). Little Rock, AR: Arkansas Department of Pollution Control and Ecology. 418 p.

Arkansas Department of Pollution Control and Ecology (AR DPCE), Mining Division. 1997. Permitted mine reference information for Arkansas. Little Rock, AR: State of Arkansas, Arkansas Department of Pollution Control and Ecology, Mining Division. [Various pagination].

Arkansas Game and Fish Commission (AR GFC). 1995a. 1996 baitfish, mussel and fish farmers regulations. Little Rock, AR: Arkansas Game and Fish Commission. 2 p.

Arkansas Game and Fish Commission (AR GFC). 1995b. 1996 turtling regulations, commercial fishing regulations, and temporary and emergency closures. Little Rock, AR: Arkansas Game and Fish Commission. 4 p.

Arkansas Game and Fish Commission (AR GFC). 1996. A summary of 1997 Arkansas fishing regulations. Little Rock, AR: Arkansas Game and Fish Commission. 62 p.

Arkansas Geological Commission (AR GC). 1985. Mineral resources of Arkansas. Bulletin 6. Little Rock, AR: Arkansas Geological Commission. 84 p.

Arkansas Highway and Transportation Department (AR HTD). 1984. Relocation of the pink mucket pearly mussel (*Lampsilis orbiculata*) in the Spring River near Ravenden, Lawrence County, Arkansas. Rep. submitted to the Endangered Species Office, USDI Fish and Wildlife Service, Jackson, MS. Little Rock, AR: Arkansas Highway and Transportation Department. 9 p.

Arkansas Multi-Agency Wetlands Planning Team (AR M-AWPT). 1997. Arkansas wetland strategy. Little Rock, AR: Multi-Agency Wetlands Planning Team: 4–20.

Armstrong, Michael L. [Assistant Fisheries Chief, Arkansas Game and Fish Commission, Little Rock, AR.] Commercial harvest of fish in Arkansas. 1997. [Not paged]. [Personal communication on file at the Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Austin, S.H. 1994. Best management practice implementation and effectiveness. Charlottesville, VA: Virginia Department of Forestry, Forest Resources and Utilization Branch. [Various pagination].

Baker, C.H., Jr.; Leonard, R.B. 1995. Hydrochemistry of aquifer systems and relation to regional flow patterns in Cretaceous and older rocks underlying Kansas, Nebraska, and parts of Arkansas, Colorado, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Wat. Resour. Inv. Rep. 94-4144. Lawrence, KS: U.S. Department of the Interior, Geological Survey. 53 p.

Baldwin, F.L.; Boyd, J.W.; Guy, C.B. 1994. Recommended chemicals for weed and brush control. Rep. MP 44. Fayetteville, AR: University of Arkansas Cooperative Extension Service. 136 p.

Barks, J.H. 1978. Water quality in the Ozark National Scenic Riverways, Missouri. Wat.-Supp. Pap. 2048. Washington, DC: U.S. Department of the Interior, Geological Survey. 57 p.

Barling, Rowan D.; Moore, Ian D. 1994. Role of buffer strips in management of waterway pollution: a review. Environmental Management. 18: 543–558.

Becker, S.A.; Smith, G.S.; O'Day, M.; Jarman, J. 1992. Pesticide use surveys, Missouri, 1992. Columbia, MO: University of Missouri Agricultural Statistics Service. 56 p.

Bedinger, M.S.; Emmett, L.F.; Jeffery, H.G. 1963. Ground-water potential of the alluvium of the Arkansas River between Little Rock and Fort Smith, Arkansas. Wat.-Supp. Pap. 1669-L. Washington, DC: U.S. Department of the Interior, Geological Survey. 29 p.

Bedinger, M.S.; Pearson, F.J., Jr.; Reed, J.E. [and others]. 1979. The waters of Hot Springs National Park, Arkansas—their nature and origin. Prof. Pap. 1044-C. Washington, DC: U.S. Department of the Interior, Geological Survey. 33 p.

Bell, R.W.; Davis, J.V.; Femmer, S.R.; Joseph, R.L. 1997. Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—organic compounds in surface water, bed sediment, and biological tissue, 1992–95. Wat.-Resour. Inv. Rep. 97-4031. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 30 p.

Bell, R.W.; Joseph, R.J.; Freiwald, D.A. 1996. Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—summary of information on pesticides, 1970–90. Wat.-Resour. Inv. Rep. 96-4003. Little Rock, AR: USDI Geological Survey. 51 p.

Bergman, K.H.; Ropelewski, C.F.; Halpert, M.S. 1986. The record Southeast drought of 1986. Weatherwise. 39(10): 262–266.

Beveridge, T.R.; Vineyard, J.D. 1990. Geologic wonders of Missouri. Educ. Ser. 4. Rolla, MO: Missouri Division of Geology and Land Survey. 391 p.

Bouchard, Raymond W.; Robison, Henry W. 1980. An inventory of the decapod crustaceans (crayfish and shrimps) of Arkansas with a discussion of their habitats. Proceedings of the Arkansas Academy of Science. 34: 22–30.

Bouchet, R.J. 1963. Evapotranspiration réelle et potentielle, signification climatique. In: Proceedings; International Association of Scientific Hydrology; symposium at Berkeley, CA. International Association of Scientific Hydrology. 62: 134–142.

Brady, N.C. 1984. The nature and properties of soils. 9th ed. New York: Macmillan. 750 p.

Branson, Branley A. 1973. Significant pelecypod records from Oklahoma. The Nautilus. 87(1): 8–10.

Branson, Branley A. 1982. The mussels (Unionacea: Bivalvia) of Oklahoma—part 1: Ambleminae. Proceedings of the Oklahoma Academy of Science. 62: 38–45.

Branson, Branley A. 1983. The mussels (Unionacea: Bivalvia) of Oklahoma—part 2: The Unioninae, Pleurobemini and Anodontini. Proceedings of the Oklahoma Academy of Science. 63: 49–59.

Branson, Branley A. 1984. The mussels (Unionacea: Bivalvia) of Oklahoma—part 3: Lampsilini. Proceedings of the Oklahoma Academy of Science. 64: 20–36.

Brown, A.V.; Burks, S.L.; Francko, D. [and others]. 1991. Evaluation and assessment of factors affecting water quality of the Illinois River in Arkansas and Oklahoma. [Final report to the U.S. Environmental Protection Agency.] 157 p.

Brown, T.C. [Economist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO]. 1998. Past and future fresh water use in the United States. [Not paged]. [Report on file at USDA Forest Service, Rocky Mountain Research Station. Fort Collins. CO.]

Bryant, C.T.; Lyford, F.P.; Stafford, K.L.; Johnson, D.M. 1983. Hydrology of area 42, Western Region, Interior Coal Province, Arkansas. Open-File Rep. 82-636. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 62 p.

Buchanan, Alan C. 1980. Mussels (naiades) of the Meramec River Basin, Missouri. Aquat. Ser. No. 17. Jefferson City, MO: Missouri Department of Conservation. 68 p.

Buchanan, Alan C. 1993. Densities of the Curtis pearly mussel and other naiades at selected sites in the Little Black and Castor Rivers. Jefferson City, MO: Missouri Department of Conservation. 6 p.

Buchanan, Alan C. 1997. Draft tables on 1993–96 mussel harvest for Missouri. Columbia, MO: Missouri Department of Conservation, Fisheries Research Section, Fish and Wildlife Research Center. [Various pagination]. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Burnley, Timothy W. 1996. [District Fisheries Biologist, Arkansas Game and Fish Commission, Brinkley, AR.] Mussel harvest report for 1995. 8 p. [Unpublished report on file at Arkansas Game and Fish Commission, Brinkley, AR.]

Burnley, Timothy W. [District Fisheries Biologist, Arkansas Game and Fish Commission, Brinkley, AR.] 1997. Mussel harvest report for 1996. 11 p. [Unpublished report on file at Arkansas Game and Fish Commission, Brinkley, AR.]

Burns & McDonnell [Corporation]. 1992a. Distribution of the Arkansas fatmucket mussel (*Lampsilis powelli*) in the North Fork of the Saline River. [Prepared for Hope Engineers, Benton, AR.] 31 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Burns & McDonnell [Corporation]. 1992b. Report on surveys for the Arkansas fatmucket mussel. [Prepared for Hope Engineers and the Saline County Rural Development Authority, Benton, AR.] 85 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Burr, Brooks M.; Mayden, Richard L. 1992. Phylogenetics and North American freshwater fishes. In: Mayden, Richard L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 18–75.

Burr, Brooks M.; Warren, Melvin L., Jr. 1986. A distributional atlas of Kentucky fishes. Sci. and Tech. Ser. 4. Frankfurt, KY: Kentucky Natural Preservation Commission. 398 p.

Caplan, W.M. 1957. Subsurface geology of northwestern Arkansas. Info. Circ. 19. Little Rock, AR: Arkansas Geological and Conservation Commission. 14 p.

Caplan, W.M. 1960. Subsurface geology of pre-Everton rocks in northern Arkansas. Info. Circ. 21. Little Rock, AR: Arkansas Geological and Conservation Commission. 17 p.

Cavalier, T.C.; Lavy, T.L. 1987. Eastern Arkansas ground water tested for pesticides. Arkansas Farm Research. May-June: 11.

Ceas, Patrick A.; Page, Lawrence M. 1997. Systematic studies of *Etheostoma spectabile* complex (Percidae; subgenus *Oligocephalus*), with descriptions of four new species. Copeia. 1997: 496–552.

Christenson, Scott. 1995. Contamination of wells completed in the Roubidoux aquifer by abandoned zinc and lead mines, Ottawa County, Oklahoma. Wat.-Resour. Inv. Rep. 95-4150. Oklahoma City, OK: U.S. Department of the Interior, Geological Survey. 114 p.

Christian, Alan D. 1995. Analysis of the commercial mussel beds in the Cache and White Rivers in Arkansas. Jonesboro, AR: Arkansas State University, Department of Biological Science. 197 p. M.S. thesis.

Claessnes, Luc. 1996.The complementary relationship in regional evapotranspiration and long-term large-scale water budgets. Fort Collins, CO: Colorado State University, Department of Civil Engineering. 159 p. M.S. thesis.

Clarke, Arthur H. 1987. Status survey of *Lampsilis streckeri* Frierson (1927) and *Arcidens wheeleri* (Ortmann and Walker, 1912). [Final report to the USDI Fish and Wildlife Service.] Jackson, MS: ECOSEARCH, Inc. 24 p. + appendix.

Clarke, Arthur H.; Obermeyer, Brian K. 1996. A survey of rare and possibly endangered freshwater mussels (Mollusca: Unionidae) of the Spring River Basin (with observations on the Elk River Basin) in Missouri. [A report for the USDI Fish and Wildlife Service.] Jackson, MS: ECOSEARCH, Inc. 34 p. + appendices.

Clesceri, Lenore S.; Greenberg, Arnold E.; Trussell, R. Rhodes, eds. 1989. Standard methods for the examination of water and wastewater. 17th ed. Washington, DC: American Public Health Association. 1,712 p.

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association. 74(368): 829–836.

Clingenpeel, J.A.; Cochran, B.G. 1992. Using physical, chemical and biological indicators to assess water quality on the Ouachita National Forest utilizing basin area stream survey methods. Proceedings of the Arkansas Academy of Science. 46: 33–35.

Cordova, R.M. 1963. Reconnaissance of the ground-water resources of the Arkansas Valley Region, Arkansas. Wat.-Supp. Pap. 1669-BB. Washington, DC: U.S. Department of the Interior, Geological Survey. 33 p.

Courtenay, J. [Silviculturist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.] 1996. Personal communication. [Not paged]. [Notes on file at the USDI Geological Survey, Little Rock, AR.]

Coveney, R.M.; Hilpman, P.L.; Allen, A.V.; Glascock, M.D. 1987. Radionuclides in Pennsylvanian black shales of the Midwestern United States. In: Marikos, M.A.; Hansman, R.H. Geologic causes of natural radionuclide anomalies. Spec. Publ. 4. Rolla, MO: Missouri Division of Geology and Land Survey: 25–42.

Cross, Frank B.; Mayden, Richard L.; Stewart, James D. 1986. Fishes in western Mississippi Basin (Missouri, Arkansas and Red Rivers). In: Hocutt, Charles H.; Wiley, Edward O., eds. The zoogeography of North American freshwater fishes. New York: John Wiley. 363–412.

Dahl, T.E. 1990. Wetland losses in the United States: 1780's to 1980's. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 21 p.

Davidson, Chris L. 1997. Analysis of mussel beds in the Little Missouri and Saline Rivers, Blue Mountain, Ozark, and Dardanelle Lakes, Arkansas. Jonesboro, AR: Arkansas State University, Department of Biological Science. 156 p. M.S. thesis.

Davidson, Chris L.; Harp, George. L.; Harris, John. L. 1997. A survey of mollusca (Bivalvia:Unionacea) from Myatt Creek, Fulton County, Arkansas. Journal of the Arkansas Academy of Science. 51: 193–196

Davis, J.V.; Howland, J.R. 1993. Stream water quality: Missouri. In: Paulsen, R.V.; Chase, E.B.; Williams, J.S.; Moody, D.W., comps. National water summary 1990–91—hydrologic events and stream water quality. Wat.-Supp. Pap. 2400. Washington, DC: U.S. Department of the Interior, Geological Survey: 351–360.

Davis, J.V.; Petersen, J.C.; Adamski, J.C.; Freiwald, D.A. 1995. Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—analysis of information on nutrients, suspended sediment, and suspended solids, 1970–92. Wat.-Resour. Inv. Rep. 95-4042. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 112 p.

Davis, J.V.; Schumacher, J.G. 1992. Water-quality characterization of the Spring River Basin, southwestern Missouri and southeastern Kansas. Wat.-Resour. Inv. Rep. 90-4176. Rolla, MO: U.S. Department of the Interior, Geological Survey. 112 p.

Devall, M.S.; Rudis, V.A. 1991. The Ouachita Mountains landscape at the time of settlement. In: Proceedings; restoration of old growth forests in the Interior Highlands of Arkansas and Oklahoma. Morrilton, AR: USDA Forest Service, Ouachita National Forest, and Winrock International Institute for Agricultural Development: 121–137.

Dolloff, C. Andrew; Hankin, David G.; Reeves, Gordon H. 1993. Basin-wide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 p.

Downing, Steve. [Owner, Oklahoma Shell Company, Locust Grove, OK.] 1997. Personal communication concerning commercial shelling in Oklahoma. [Not paged]. [Notes on file at the Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs AR.]

Duchrow, R.M. 1984. Water quality survey of the Osage River system, 1975–76. Jefferson City, MO: Missouri Department of Conservation. 356 p.

Ecological Consultants, Inc. 1984. Handbook of the mussels of the St. Francis, White, and Cache Rivers, Arkansas and Missouri. Proj. DACW66-78-C-0147. Memphis, TN: U.S. Army Corps of Engineers. 62 p. + appendices A–B.

Eisenhour, D.J. 1996. Systematics of the western species of *Macrhybopsis aestivalis* complex (Cypriniformes:Cyprinidae) [Abstract]. In: Program and abstracts, annual meeting, American Society of Ichthyologists and Herpetologists; 1996 June 13–19; New Orleans, LA: University of New Orleans: 132–133.

Environmental Working Group. [Accessed 1997]. Where you live. <http://wyl.ewg.org/>. [Maps, various pagination].

Farwick, Jeffrey J. [Regional Fisheries Biologist, Arkansas Fish and Game Commission, Brinkley, AR.] 1997. Commercial fish harvest data tables for 1974–1991. 11 p. [Unpublished report on file at the Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs AR.

Feder, G.L. 1979. Geochemical survey of waters of Missouri. Prof. Pap. 954-E. Washington, DC: U.S. Department of the Interior, Geological Survey. 78 p.

Femmer, S.R. 1997. Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—habitat characteristics at selected sites, 1993–95. Open-File Rep. 97-236. Rolla, MO: U.S. Department of the Interior, Geological Survey. 44 p.

Fenneman, N.M. 1938. Physiography of Eastern United States. New York: McGraw-Hill. 689 p.

Filipek, Stephen P. 1993. The impact of forest practices on warmwater and coldwater fisheries: similarities and differences. Fisheries Tech. Rep. No. FR-93-1. Little Rock, AR: Arkansas Game and Fish Commission. 53 p.

Fink, Doyle. 1996. [District Manager, U.S. Department of Labor, Mine Safety and Health Administration (USDL MSHA), Dallas TX.] Mine safety information in the Assessment area. [Various pagination]. [Unpublished report on file in the office of the Forest Minerals Geologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Florida Department of Environmental Protection (FL DEP). 1997. Biological assessment of the effectiveness of forestry best management practices—Okaloosa, Gadsden, Taylor, and Clay Counties. Qual. Assur. Plan 319. Tallahassee, FL: Bureau of Laboratories—Florida Department of Environmental Protection. [Various pagination].

Ford, John. 1992. [Staff Hydrologist, Missouri Department of Natural Resources, Water Quality Division, Jefferson City, MO.] Personal communication. [Not paged]. [Notes on file at the USDI Geological Survey, Little Rock, AR.]

Foster, A.M.; Fuller, Pam. [Accessed March 4, 1997]. Nonindigenous aquatic species *Corbicula fluminea*. <http://www.nfrcg.g.gov/nas/nas.htm>. 7 p.

Foti, T.L.; Glenn, S.M. 1991. The Ouachita Mountains landscape at the time of settlement. In: Proceedings; restoration of old growth forests in the Interior Highlands of Arkansas and Oklahoma. Morrilton, AR: USDA Forest Service, Ouachita National Forest; Winrock International Institute for Agricultural Development: 49–65.

Freiwald, D.A. 1991. National Water-Quality Assessment program—Ozark Plateaus. Open-File Rep. 91-162. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 2 p.

Frezon, S.E.; Glick, E.E. 1959. Pre-Atoka rocks of northern Arkansas. Prof. Pap. 314-H. Washington, DC: U.S. Department of the Interior, Geological Survey. 18 p.

Fulhage, C.D. 1989. Reduce environmental problems with proper land application of animal wastes. 2d ed. Manual 121, WQ 201. Jefferson City, MO: Missouri Department of Natural Resources. 4 p.

Gebert, W.A.; Graczyk, D.J.; Krug, W.R. 1987. Average annual runoff in the United States, 1951–80. Hydro. Inv. Atl. HA-710. Washington, DC: U.S. Department of the Interior, Geological Survey. 1 sheet. scale 1:7,500,000.

Gianessi, L.P.; Puffer, C.A. 1991. Herbicide use in the United States, national summary report. Rev. ed. Washington, DC: Resources for the Future. 128 p.

Gianessi, L.P.; Puffer, C.A. 1992a, Fungicide use in U.S. crop production. Washington, DC: Resources for the Future. [Various pagination].

Gianessi, L.P.; Puffer, C.A. 1992b, Insecticide use in U.S. crop production. Washington, DC: Resources for the Future. [Various pagination].

Gibson, Mike. [Assistant Fisheries Chief, Hatcheries, Arkansas Game & Fish Commission, Little Rock, AR.] 1997. Fish stocking records for Arkansas for selected species for 1990–1996. 120 p. [Personal correspondence on file at the Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Gilliom, R.J.; Helsel, D.R. 1986. Estimation of distributional parameters for censored trace-level water-quality data I. Estimation techniques. Water Resources Research: 22(2): 135–146.

Gordon, Mark E. 1979. Mollusca of the Illinois River, Arkansas. Proceedings of the Arkansas Academy of Science. 33: 35–37.

Gordon, Mark E. 1980. Freshwater mollusca of the Elk River, White River above Beaver Reservoir, and Frog Bayou Drainages of the southwestern Ozarks. Fayetteville, AR:

University of Arkansas, Department of Zoology. 265 p. M.S. thesis.

Gordon, Mark E. 1982. Mollusca of the White River, Arkansas and Missouri. The Southwestern Naturalist. 27(3): 347–352.

Gordon, Mark E. 1985. Mollusca of Frog Bayou, Arkansas. The Nautilus. 99(1): 6–9.

Gordon, Mark E.; Durkee, P.A.; Runke, H.M.; Zimmerman, H.J. 1984. Mussel fauna of the Black and Spring Rivers in northeastern Arkansas. Proj. # DAC03-83-0-0181. [Prepared for U.S. Army Corps of Engineers, Little Rock, AR.] 27 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Gordon, Mark E.; Harris, John L. 1983. Distribution and status of fourteen species of freshwater mussels considered rare or endangered in Arkansas. Proj. #G6301. Little Rock, AR: Arkansas Natural Heritage Commission. 23 p. + appendices I–II.

Gordon, M.E.; Kraemer, Louise R.; Brown, Arthur V. 1980. Unionacea of Arkansas: historical review, checklist, and observations on distributional patterns. Bulletin of the American Malacological Union, Inc. 1979: 31–37.

Grady, James M.; LeGrande, William H. 1992. Phylogenetic relationships, modes of speciation, and historical biogeography of the madtom catfishes, genus *Noturus Rafinesque* (Siluriformes: Ictaluridae). In: Mayden, Richard L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 747–777.

Gregory, Stanley V.; Swanson, Frederick J.; McKee, W. Arthur; Cummins, Kenneth W. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. BioScience. 41: 540–551.

Hackney, Courtney T.; Adams, S. Marshall; Martin, William H., eds. 1992. Biodiversity of the Southeastern United States: aquatic communities. New York: John Wiley. 779 p.

Halberg, H.N.; Bryant, C.T.; Hines, M.S. 1968. Water resources of Grant and Hot Spring Counties, Arkansas. Wat.-Supp. Pap. 1857. Washington, DC: U.S. Department of the Interior, Geological Survey. 64 p.

Haley, B.R. 1982. Geology and energy resources of the Arkoma Basin, Oklahoma and Arkansas. UMR Journal. 3: 43–53.

Ham, W.E. 1959. Correlation of pre-Stanley strata in the Arbuckle-Ouachita Mountain regions. In: Cline, L.M.; Hilseweck, W.J.; Feray, D.E., eds. The geology of the Ouachita Mountains, a symposium; 1959 March; Dallas, TX. Dallas, TX: Dallas Geological Society, Ardmore Geological Society: 71–91.

Hamilton, S.W.; Morse, J.C. 1990. Southeastern caddisfly fauna: origins and affinities. Florida Entomology. 73: 578–600.

Harper, Jack L. [Southeastern Region Fish Supervisor, Oklahoma Department of Wildlife Conservation, Caddo, OK.] 1997. Fish stocking records for southeastern Oklahoma. [Various pagination]. [Reports on file at the Forest Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Harris, John L. 1986. Systematics, distribution, and biology of fishes currently allocated to *Erimystax* Jordan, a subgenus of *Hybopsis* (Cyprinidae). Knoxville, TN: University of Tennessee. 335 p. Ph.D. dissertation.

Harris, John L. 1987. Survey of mussel beds in the White River between river miles 90–94 and 240–243. [Prepared for Mobley Construction Co., Inc., Morrilton, AR.] 40 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1989a. Mussel survey of the Caddo River below the DeGray Reservoir regulating dam near Caddo Valley, Clark County, Arkansas. [Prepared for JDJ Energy Co., Inc., Little Rock, AR.] 11 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1989b. Mussel survey of the Ouachita River near Arkadelphia, Clark County, Arkansas in the vicinity of the proposed Bowater Paper Plant. [Prepared for Sirrene Environmental Consultants, Greenville, SC.] 19 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1991a. A mussel survey of Lake Dardanelle in the vicinity of the proposed River Mountain Pumped Storage Project. [Prepared for CPS Arkansas, Inc., Greenwich, CT.]19 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1991b. Survey for *Lampsilis powelli* at Site 2, South Fork Watershed Project, Montgomery County, Arkansas. [Prepared for U.S. Department of Agriculture, Soil Conservation Service, Little Rock, AR.] 18 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1991c. Survey for *Lampsilis rafinesqueana* in the Illinois River at the proposed Siloam Springs water intake structure. [Prepared for McClelland Consulting Engineers, Inc., Fayetteville, AR.] 10 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1992a. Status of *Lampsilis streckeri* in segments of the Middle, South, and Archey Forks of the Little Red River, Stone and Van Buren Counties, Arkansas. [Prepared for the U.S. Department of the Interior, Fish and Wildlife Service, Endangered Species Office, Jackson, MS.] 23 p. + field notes. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1992b. Survey of the South Fourche La Fave River and major tributaries. [Prepared for the USDA Forest Service, Ouachita National Forest, Hot Springs, AR.] 18 p. + field notes. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1993. Habitat characterization and species associates of the speckled pocketbook (*Lampsilis streckeri* Frierson) in the Middle Fork Little Red River, Arkansas. [Prepared for the U.S. Department of the Interior, Fish and Wildlife Service, Endangered Species Office, Jackson, MS.] 28 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1994a. Microhabitat and population analysis of *Lampsilis powelli* (Lea, 1852) in the South Fork Ouachita River, Montgomery County, Arkansas. [Prepared for the U.S. Department of Agriculture, Forest Service, Ouachita National Forest, Hot Springs, AR.] 26 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1994b. Mussel survey of the White River between river miles 260.0–264.0 in Independence and Jackson Counties, Arkansas. [Prepared for Mobley Construction Co., Inc., Morrilton, AR.] 11 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1994c. Survey of the freshwater mussels (Mollusca: Unionidae) of the Poteau River drainage in Arkansas. [Prepared for the U.S. Department of Agriculture, Forest Service, Ouachita National Forest, Hot Springs, AR.] 23 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1995. Mussel survey of the White River between river miles 264.0–274.0 near Oil Trough, Independence County, Arkansas. [Prepared for Mobley Construction Co., Inc., Morrilton, AR.] 14 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1996. The freshwater mussel resources of the Buffalo National River, Arkansas: phase I qualitative survey: location, species composition, and status of mussel beds. [Prepared for the U.S. Department of the Interior, Buffalo National River, Harrison, AR.] 19 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L. 1997a. [Consulting Malacologist, Little Rock, AR.] Personal communications. [Various pagination]. [Notes on file at the Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Harris, John L. 1997b. Status survey of *Lampsilis rafinesqueana* Frierson, the Neosho mucket, in Arkansas. [Prepared for the U.S. Department of the Interior, Endangered Species Office, Vicksburg, MS.] 6 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harris, John L.; Gordon, Mark E. [n.d.]. Arkansas mussels. Little Rock, AR: Arkansas Game and Fish Commission. 32 p.

Harris, John L.; Gordon, Mark E. 1987. Distribution and status of rare and endangered mussels (Mollusca: Margaritiferidae, Unionidae) in Arkansas. Proceedings of the Arkansas Academy of Science. 41: 49–56.

Harris, John L.; Gordon, Mark E. 1988. Status survey of *Lampsilis powelli* (Lea, 1852). [Prepared for the U.S. Department of the Interior, Fish and Wildlife Service, Office of Endangered Species, Jackson, MS.] 44 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Harvey, E.J. 1980. Ground water in the Springfield-Salem Plateaus of southern Missouri and northern Arkansas. Wat.-Resour. Inv. 80-101. Rolla, MO: U.S. Department of the Interior, Geological Survey. 66 p.

Harvey, E.J., Skelton, John; Miller, D.E. 1983. Hydrology of carbonate terrane—Niangua, Osage Fork, and Grandglaize Basins, Missouri. Wat. Resour. Rep. 35. Rolla, MO: U.S. Department of the Interior, Geological Survey. 132 p.

Helsel, D.R.; Cohn, T.A. 1988. Estimation of descriptive statistics for multiply censored water-quality data. Water Resources Research. 24(12): 1997–2004.

Helsel, D.R.; Hirsch, R.M. 1992. Statistical methods in water resources. Amsterdam, Netherlands: Elsevier. 522 p.

Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. Wat.-Supp. Pap. 2254. Washington, DC: U.S. Department of the Interior, Geological Survey. 263 p.

Hirsch, R.M.; Alley, W.M.; Wilber, W.G. 1988. Concepts for a National Water-Quality Assessment program. Circ. 1021. Reston, VA: U.S. Department of the Interior, Geological Survey. 42 p.

Hirschboeck, K.K. 1991. Climate and floods. In: Paulson, R.W.; Chase, E.B.; Roberts, R.S.; Moody, D.W., comps. National water summary 1988–89—hydrologic events and floods and droughts. Wat.-Supp. Pap. 2375. Denver, CO: U.S. Department of the Interior, Geological Survey: 67–98.

Hobbs, Horton H., Jr. 1989. A checklist of the American crayfishes (Decapoda: Astacidae, Cambaridae, and Parastacidae). Smithsonian Contrib. to Zoology No. 480. Washington, DC: Smithsonian Institution Press. 236 p.

Hobbs, Horton H., Jr.; Brown, Arthur V. 1987. A new troglobitic crayfish from northwestern Arkansas (Decapoda: Cambaridae). Proceedings of the Biological Society of Washington. 100(4): 1040–1048.

Hobbs, Horton H., Jr.; Robison, Henry W. 1985. A new burrowing crayfish (Decapoda: Cambaridae) from southwestern Arkansas. Proceedings of the Biological Society of Washington. 98(4): 1035–1041.

Hobbs, Horton H., Jr.; Robison, Henry W. 1988. The crayfish subgenus *Girardiella* (Decapoda: Cambaridae) in Arkansas, with the description of two new species and a key to the members of the gracilis group in the genus *Procambarus*. Proceedings of the Biological Society of Washington. 101(2): 391–413.

Hobbs, Horton H., Jr.; Robison, Henry W. 1989. On the crayfish genus *Fallicambarus* (Decapoda: Cambaridae) in Arkansas, with notes on the *fodiens* complex and descriptions of two new species. Proceedings of the Biological Society of Washington. 102: 651–697.

Hoelman, L.H., II, comp. 1989. STORET—seminar documentation overview TSO. Washington, DC: U.S. Environmental Protection Agency. 4 p.

Humphries, Julian M.; Cashner, Robert C. 1994. *Notropis suttkusi*, a new cyprinid from the Ouachita uplands of Oklahoma and Arkansas, with comments on the status of Ozarkian populations of *N. rubellus*. Copeia. 1994(1): 82–90.

Hunsaker, Carolyn T.; Levine, Daniel A. 1995. Hierarchical approaches to the study of water quality in rivers. BioScience. 45: 193–203.

Hutchison, N.E., comp. 1975. WATSTORE user's guide—National Water Data Storage and Retrieval System. Open-File Rep. 75-426. Reston, VA: U.S. Department of the Interior, Geological Survey. 1: v-vi.

Imes, J.L. 1990a. Major geohydrologic units in and adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma—Ozark aquifer. Hydro. Inv. Atl. HA-711-E. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Imes, J.L. 1990b. Major geohydrologic units in and adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma—Ozark confining unit. Hydro. Inv. Atl. HA-711-F. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Imes, J.L. 1990c. Major geohydrologic units in and adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma—Springfield Plateau aquifer. Hydro. Inv. Atl. HA-711-G. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Imes, J.L. 1990d. Major geohydrologic units in and adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma—St. Francois aquifer. Hydro. Inv. Atl. HA-711-C. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Imes, J.L. 1990e. Major geohydrologic units in and adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma—St. Francois confining unit. Hydro. Inv. Atl. HA-711-D. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Imes, J.L. 1990f. Major geohydrologic units in and adjacent to the Ozark Plateaus Province, Missouri, Arkansas, Kansas, and Oklahoma—Western Interior Plains confining system. Hydro. Inv. Atl. HA-711-H. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Imes, J.L.; Emmett, L.F. 1994. Geohydrology of the Ozark Plateaus aquifer system in parts of Missouri, Arkansas, Oklahoma, and Kansas. Prof. Pap. 1414-D. Washington, DC: U.S. Department of the Interior, Geological Survey. 127 p.

Imes, J.L.; Smith, B.J. 1990. Areal extent, stratigraphic relation, and geohydrologic properties of regional geohydrologic units in southern Missouri. Hydro. Inv. Atl. HA 711-I. Washington, DC: U.S. Department of the Interior, Geological Survey. 1:750,000 scale.

Jenkinson, John J.; Ahlstedt, Steven A. 1987. A search for additional populations of *Potamilus capax* in the St. Francis and Cache River watersheds, Arkansas and Missouri. [Final report for the Memphis District, U.S. Army Corps of Engineers.] 304 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Johnson, D.R.; Jones, B.F. 1994. Insecticide recommendations for Arkansas—1994. Rep. MP 144. Little Rock, AR: University of Arkansas Cooperative Extension Service. 132 p.

Johnson, Richard I. 1980. Zoogeography of the North American Unionacea (Mollusca: Bivalvia) north of the maximum Pleistocene glaciation. Bulletin Museum of Comparative Zoology. 149(2): 77–189.

Johnston, Carol A. 1994. Cumulative impacts to wetlands. Wetlands. 14(1): 49–55.

Kansas Department of Health and Environment (KS DHE). 1988. Kansas water quality assessment 1986–1987. Topeka, KS: Kansas Department of Health and Environment. 144 p.

Karl, T.R.; Quayle, R.Q. 1981. The 1980 summer heat wave and drought in historical perspective. Monthly Weather Review. 109(10): 2055–2073.

Karl, T.R.; Quinlan, F.; Ezell, D.S. 1987. Drought termination and amelioration—its climatological probability. Journal of Climate and Applied Meteorology. 26(9): 1198–1209.

Karl, T.R.; Young, P.J. 1987. The 1986 Southeast drought in historical perspective. Bulletin of the American Meteorological Society. 68(7): 773–778.

Karr, James R.; Fausch, Kurt D.; Angermeier, Paul L. [and others]. 1986. Assessing biological integrity in running waters: a method and its rationale. Spec. Publ. 5. Champaign, IL: Illinois Natural History Survey. 28 p.

Keys, James E., Jr.; Carpenter, C.A.; Hooks, S. [and others]. 1995. Ecological units of the Eastern United States: first approximation. [Map]. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 1 p.

Kiilsgaard, T.H.; Hayes, W.C.; Heyl, A.V. 1967. Lead and zinc. In: Mineral and water resources of Missouri. Washington, DC: Missouri Division of Geological Survey and Water Resources: 43:41–63.

Kisvarsanyi, E.B. 1981. Geology of the Precambrian St. Francois terrane, southeastern Missouri. Rep. of Inv. 64. Rolla, MO: Missouri Division of Geology and Land Survey. 58 p.

Kleeschulte, M.J.; Mesko, T.O.; Vandike, J.E. 1985. Appraisal of the groundwater resources of Barton, Vernon, and Bates Counties, Missouri. Wat. Resour. Rep. 36. Rolla, MO: Missouri Division of Geology and Land Survey. 74 p.

Koch, Leroy M. [Fisheries Management Specialist, Missouri Department of Conservation, Columbia, MO.] 1993. 1992 Missouri mussel harvest. Jefferson City, MO: Missouri Department of Conservation. 10 p. [Unpublished report on file in the Fish and Wildlife Research Center in the Fisheries Research Section of the Missouri Department of Conservation, Columbia, MO.]

Kolpin, D.W.; Burkhart, M.R.; Thurman, E.M. 1994. Herbicides and nitrate in near-surface aquifers in the midcontinental United States, 1991. Wat.-Supp. Pap. 2413. Washington, DC: U.S. Department of the Interior, Geological Survey. 34 p.

Kurklin, J.K.; Jennings, D. 1993. Stream water quality: Oklahoma. In: Paulsen, R.V.; Chase, E.B.; Williams, J.S.; Moody, D.W., comps. National water summary 1990–91—hydrologic events and stream water quality. Wat.-Supp. Pap. 2400: Washington, DC: U.S. Department of the Interior, Geological Survey: 445–454.

Lamonds, A.G. 1972. Water-resources reconnaissance of the Ozark Plateaus Province, northern Arkansas. Hydro. Inv. Atl. HA-383. Washington, DC: U.S. Department of the Interior, Geological Survey. 2 sheets. 1:500,000 scale.

Leahy, P.P.; Rosenshein, J.S.; Knopman, D.S. 1990. Implementation plan for the National Water-Quality Assessment program. Open-File Rep. 90-174. Reston, VA: U.S. Department of the Interior, Geological Survey. 10 p.

Lee, David S.; Gilbert, Carter R.; Hocutt, Charles H. [and others]. 1980 et seq. Atlas of North American freshwater fishes. Raleigh, NC: North Carolina State Museum of Natural History. 854 p.

Leidy, V.A.; Morris, E.E. 1990. Hydrogeology and quality of ground water in the Boone Formation and Cotter Dolomite in karst terrain of northwestern Boone County, Arkansas. Wat.-Resour. Inv. Report 90-4066. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 57 p.

Limbird, Robert L.; Ahlert, James E. 1993. Commercial fishing harvest on Blue Mountain and Nimrod. Russellville, AR: Arkansas Game and Fish Commission. 6 p. [Unpublished report on file at the Arkansas Game and Fish Commission, Russellville, AR.]

Limbird, Robert L.; Ahlert, James E. 1996. Commercial fishing harvest on Blue Mountain and Nimrod. Russellville, AR: Arkansas Game and Fish Commission. 6 p. [Unpublished report on file at the Arkansas Game and Fish Commission, Russellville, AR.]

Limbird, Robert L.; Ahlert, James E. 1997. Commercial fishing harvest on Blue Mountain and Nimrod. Russellville, AR: Arkansas Game and Fish Commission. 6 p. [Unpublished report on file at the Arkansas Game and Fish Commission, Russellville, AR.]

Littell, Richard. 1992. Endangered and other protected species. Washington, DC: The Bureau of National Affairs, Inc. 185 p. + appendices.

Lull, Howard W.; Sopper, William E. 1969. Hydrologic effects from urbanization of forested watersheds in the Northeast. Res. Pap. NE-146. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 31 p.

MacDonald, H.C.; Zachry, D.L.; Jeffus, Hugh. 1975. Northern Arkansas groundwater inventory. Misc. Publ. 26. Fayetteville, AR: Arkansas Water Resources Research Center. 186 p.

MacDonald, Lee H.; Smart, Alan W.; Wissmar, Robert C. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA 910/9-91-001. Seattle, WA: U.S. Environmental Protection Agency. 166 p.

Maddy, D.V.; Lopp, L.E.; Jackson, D.L. [and others]. 1991. National water information system user's manual—water-quality system. Reston, VA: U.S. Department of the Interior, Geological Survey: volume 2, chapter 2.

Marcher, M.V.; Bergman, D.L.; Slack, L.J. [and others]. 1987. Hydrology of area 41, Western Region, Interior Coal Province, Oklahoma and Arkansas. Open-File Rep. 84-129. Oklahoma City, OK: U.S. Department of the Interior, Geological Survey. 86 p.

Marcher, M.V.; Bergman, D.L.; Stoner, J.D.; Blumer, S.P. 1981. Preliminary appraisal of the hydrology of the Blocker area, Pittsburg County, Oklahoma. Open-File Rep. 81-1187. Oklahoma City, OK: U.S. Department of the Interior, Geological Survey. 48 p.

Marcher, M.V.; Bergman, D.L.; Stoner, J.D.; Blumer, S.P. 1983a. Preliminary appraisal of the hydrology of the Red Oak area, Latimer County, Oklahoma. Wat.-Resour. Inv. Rep. 83-4166. Oklahoma City, OK: U.S. Department of the Interior, Geological Survey. 44 p.

Marcher, M.V.; Bergman, D.L.; Stoner, J.D.; Blumer, S.P. 1983b. Preliminary appraisal of the hydrology of the Rock Island area, Le Flore County, Oklahoma. Wat.-Resour. Inv. Rep. 83-4013. Oklahoma City, OK: U.S. Department of the Interior, Geological Survey. 35 p.

Marcher, M.V.; Huntzinger, T.L.; Stoner, J.D.; Blumer, S.P. 1983c. Preliminary appraisal of the hydrology of the Stigler area, Haskell County, Oklahoma. Wat.-Resour. Inv. Rep. 82-4099. Oklahoma City, OK: U.S. Department of the Interior, Geological Survey. 37 p.

Mather, Charles M. 1990. Status survey of the western fanshell and the Neosho mucket in Oklahoma. [Final report to the Oklahoma Department of Wildlife Conservation.] 22 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Matthews, W.J.; Robison, H.W. 1988. The distribution of the fishes of Arkansas: a multivariate analysis. Copeia. 1988(2): 358–374.

Matthews, William J.; Hough, Daniel J.; Robison, Henry W. 1992. Similarities in fish distribution and water quality patterns in streams of Arkansas: congruence of multivariate analyses. Copeia. 1992(2): 296–305.

Maxwell, James R.; Edwards, Clayton J.; Jensen M.E. [and others]. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). Gen. Tech. Rep. NC-176. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 72 p.

Mayden, R.L. 1985. Biogeography of Ouachita Highland fishes. The Southwestern Naturalist. 30: 195–211.

Mayden, Richard L. 1987a. Historical ecology and North American Highland fishes: a research program in community ecology. In: Matthews, William J.; Heins, David C., eds. Community and evolutionary ecology of North American stream fishes. Norman, OK: University of Oklahoma Press: 210–220.

Mayden, Richard L. 1987b. Pleistocene glaciation and historical biogeography of North American Central-Highland fishes. In: Johnson, W.C., ed. Quaternary environments of Kansas. Kansas Geol. Surv. Guidebook Ser. 5. Kansas City, KS: Kansas Geological Survey: 141–152.

Mayden, Richard L. 1988a. Systematics of the *Notropis zonatus* species group, with description of a new species from the Interior Highlands of North America. Copeia. 1988(1): 153–173.

Mayden, Richard L. 1988b. Vicariance biogeography, parsimony, and evolution in North American freshwater fishes. Systematic Zoology. 37: 329–355.

Mayden, Richard L.; Burr, Brooks M.; Page, Lawrence M.; Miller, Robert R. 1992. The native freshwater fishes of North America. In: Mayden, Richard L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 827–863.

McAllister, Don E.; Platania, Steven P.; Schueler, Frederick W. [and others]. 1986. Ichthyofaunal patterns on a geographic grid. In: Hocutt, Charles H.; Wiley, Edward O., eds. The zoogeography of North American freshwater fishes. New York: John Wiley. 17–51.

McCracken, M.H. 1967. Structure. In: Mineral and water resources of Missouri. Vol. 43. Washington, DC: Missouri Division of Geological Survey and Water Resources: 20–21.

McCracken, M.H. 1971. Structural features of Missouri. Rep. of Inv. no. 49. Rolla, MO: Missouri Division of Geological Survey and Water Resources. 99 p.

McFarland, J.D.; Bush, W.V.; Wise, O.A.; Holbrook, Drew. 1979. A guidebook to the Ordovician-Mississippian rocks of north-central Arkansas. GB-79-1. Little Rock, AR: Arkansas Geological Commission. 25 p.

McNab, A.L.; Karl, T.R. 1991. Climate and droughts. In: Paulson, R.W.; Chase, E.B.; Roberts, R.S.; Moody, D.W., comps. National water summary 1988–89—hydrologic events and floods and droughts. Wat.-Supp. Pap. 2375. Denver, CO: U.S. Department of the Interior, Geological Survey: 89–98.

Meehan, W.R., ed. 1991. Influences of forest and rangeland management on salmonide fishes and their habitats. Spec. Publ. 19. Bethesda, MD: American Fisheries Society. 751 p.

Meek, Seth E.; Clark, H.W. 1912. The mussels of the Big Buffalo Fork of White River, Arkansas. U.S. Bur. of Fish. Doc. 759. Washington, DC: U.S. Bureau of Fisheries: 1–20.

Mehlhop, Patricia; Miller, Estelle K. 1989. Status and distribution of *Arkansia wheeleri* (syn. *Arcidens wheeleri*) (Ortmann & Walker, 1912) in the Kiamichi River, Oklahoma. [Report to the USDI Fish and Wildlife Service, Tulsa, OK.] 142 p. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Merritt, Richard W.; Cummins, Kenneth W., eds. 1996. An introduction to the aquatic insects of North America. 3d ed. Dubuque, IA: Kendall/Hunt. 862 p.

Miller, Andrew C.; Harris, John L. 1987. A survey for molluscs in the White River near Newport, Arkansas, 1986. Misc. Paper EL-87-5. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station. 25 p + appendix A.

Miller, Andrew C.; Hartfield, Paul D. 1986. A survey for live mussels in the Black and Spring Rivers, Arkansas, 1985. Misc. Paper EL-86-7. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station. 13 p.

Miller, Andrew C.; Nelson, D.A. 1984. A survey for mussels on the Black and Spring Rivers, Arkansas 16–17 November 1983. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station. 9 p.

Miller, Rudolph J.; Robison, Henry W. 1973. The fishes of Oklahoma. Stillwater, OK: Oklahoma State University Press. 246 p.

Minckley, William L.; Deacon, James E., eds. 1991. Battle against extinction: native fish management in the American West. Tucson, AZ: University of Arizona Press. 517 p.

Missouri Department of Conservation (MO DC). [n.d.] Trout fishing in Missouri. Jefferson City, MO: Missouri Department of Conservation. 37 p.

Missouri Department of Conservation (MO DC). 1996. Discover outdoor Missouri: a map and guide to recreational opportunities on Missouri Department of Conservation areas and other public lands. Jefferson City, MO: Missouri Department of Conservation. 2 p.

Missouri Department of Conservation(MO DC). 1997. Wildlife code of Missouri. Jefferson City, MO: Missouri Department of Conservation. 145 p.

Missouri Department of Natural Resources (MO DNR). 1980. Missouri—the Cave State. Missouri Div. of Geol. and Land Surv. Fact Sheet 15. Rolla, MO: Missouri Department of Natural Resources. 2 p.

Missouri Department of Natural Resources (MO DNR). 1994. Missouri water quality report 1994. Jefferson City, MO: Missouri Department of Natural Resources. 57 p.

Missouri Department of Natural Resources (MO DNR). 1996a. Code of State regulations. Rules of the Department of Natural Resources, Division 20—Clean Water Commission, Chapter 7—water quality. Jefferson City, MO: Missouri Department of Natural Resources. 136 p.

Missouri Department of Natural Resources (MO DNR). 1996b. Missouri water quality report 1996. Jefferson City, MO: Missouri Department of Natural Resources. 79 p.

Missouri Department of Natural Resources (MO DNR), Mining Division. 1997. Permitted mine reference information for Missouri. Jefferson City, MO: Missouri Department of Natural Resources, Mining Division. [Various pagination]. [Unpublished report on file in the office of the Forest Minerals Geologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Morton, F.I. 1965. Potential evaporation and river basin evaporation. Journal of the Hydraulic Division. ASCE. 91(HY6): 67–97.

Morton, F.I. 1983. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology. 66: 1–76.

Mott, D.N. 1991. Water quality report 1985–1990: Buffalo National River. Harrison, AR: U.S. Department of the Interior, National Park Service. 36 p.

Moulton, S.R.; Stewart, K.W. 1996. Caddisflies (Trichoptera) of Interior Highlands of North America. Memoirs of the American Entomological Institute. No. 56. Gainesville, FL: American Entomological Institute. 313 p.

Murphy, Dennis D. 1991. Invertebrate conservation. In: Kohm, Kathryn A., ed. Balancing on the brink of extinction, the

Endangered Species Act and lessons for the future. Washington, DC: Island Press. 181–198.

Namias, J. 1966. Nature and possible causes of the Northeastern United States drought during 1962–65. Monthly Weather Review. 94(9): 543–554.

Namias, J. 1982. Anatomy of Great Plains protracted heat waves (especially the 1980 U.S. summer drought). Monthly Weather Review. 110(1): 824–838.

Namias, J. 1983. Some causes of United States drought. Journal of Climate and Applied Meteorology. 22(1): 30–39.

Namias, J. 1985. Hydrologic aspects of drought. In: Beran, M.A.; Rodier, J.A., eds. UNESCO—World Meteorological Organization, a contribution to the international hydrologic programme. Paris: UNESCO—World Meteorological Organization: 27–64.

National Council of the Paper Industry for Air and Stream Improvement (NCASI). 1994. Southern regional review of State nonpoint source control programs and best management practices for forest management operations. Tech. Bull. No. 686. New York: National Council of the Paper Industry for Air and Stream Improvement. 152 p.

National Drought Mitigation Center. [Accessed 1997]. A historical look at the Palmer Drought Severity Index. <http://enso.unl.edu/ndmc/climate/palmer/pdsihist.htm>. 1 p.

Nelson, Paul W. 1987. Wetland. In: Holst, Sue, ed. The terrestrial natural communities of Missouri. Jefferson City, MO: Missouri Department of Natural Resources and Missouri Department of Conservation: 138–164.

Nico, Leo; Fuller, Pam. [Accessed September 26, 1997]. Nonindigenous aquatic species *Ctenopharyngodon idella*. <http://www.nfrcg.g.gov/nas/nas.htm>. 4 p.

Nowell, L.H.; Resek, E.A. 1994. National standards and guidelines for pesticides in water, sediment, and aquatic organisms: application to water-quality assessments. In: Ware, G.W., ed. Reviews of environmental contamination and toxicology. Vol. 140. New York: Springer-Verlag: 1–64.

Oesch, Ronald D. 1984. Missouri naiades. A guide to the mussels of Missouri. Jefferson City, MO: Missouri Department of Conservation. 270 p.

Ogden, A.E. 1980. Hydrogeologic and geochemical investigation of the Boone—St. Joe limestone aquifer in Benton County, Arkansas. Publ. 68. Fayetteville, AR: Arkansas Water Resources Research Center. 133 p.

Oklahoma Department of Environmental Quality (OK DEQ). 1996. Oklahoma water quality assessment report (305(b)), September 30, 1996. Oklahoma City, OK: State of Oklahoma. 303 p.

Oklahoma Department of Mines (OK DM). 1997. Permitted mine reference information for Oklahoma. Oklahoma City, OK: State of Oklahoma, Oklahoma Department of Mines. [Various pagination]. [Unpublished report on file in the office of the Forest Minerals Geologist, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Oklahoma Department of Wildlife Conservation (OK DWC). 1996a. Oklahoma fishing regulations, 1997. Oklahoma City, OK: Oklahoma Department of Wildlife Conservation. 12 p.

Oklahoma Department of Wildlife Conservation (OK DWC). 1996b. Wildlife conservation code of 1997. Oklahoma City, OK: Oklahoma Department of Wildlife Conservation: 9–50.

Oklahoma Water Resources Board (OK WRB). 1996. Water quality standards, Oklahoma Administrative Code (OAC) Title 785, as amended through July 1, 1996. Oklahoma City, OK: Oklahoma Water Resources Board. 73 p.

Oliver, Mark L. [Regional Fisheries Biologist, Arkansas Game and Fish Commission, Mountain Home, AR.] 1997. Information on lake trout stocking and harvest in Greers Ferry Lake and other stocking practices in the Ozarks. [Not paged]. [Notes on file at the Forest Supervisor’s office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Page, Lawrence M.; Burr, Brooks M. 1991. A field guide to freshwater fishes. Boston: Houghton Mifflin Co. 432 p.

Palmer, W.C. 1965. Meteorological drought. Washington, DC: U.S. Department of Commerce, U.S. Weather Bureau. 55 p.

Penn, G.H., Jr. 1957. Variation and subspecies of the crawfish *Orconectes palmeri*. Tulane Studies in Zoology. 5: 231–262.

Perrin, Carl A. [Biologist, Arkansas Game and Fish Commission, Mayflower, AR.] 1997. Personal communication on fish stocking. [Not paged]. [Notes on file at the Forest Supervisor’s office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Petersen, J.C. 1988. Statistical summary of selected water-quality data (water years 1975 through 1985) for Arkansas rivers and streams. Wat.-Resour. Inv. Rep. 88-4112. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 182 p.

Petersen, J.C. 1992. Trends in stream water-quality data in Arkansas during several time periods between 1975 and 1989. Wat.-Resour. Inv. Rep. 92-4044. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 182 p.

Petersen, J.C.; Green, W.R.; Keith, W.E. 1993. Stream water quality: Arkansas. In: Paulson, R.W.; Chase, E.B.; Roberts, R.S.; Moody, D.W., comps. National water summary 1990–91—hydrologic events and stream water quality. Wat.-Supp. Pap. 2400. Washington, DC: U.S. Department of the Interior, Geological Survey: 179–186.

Pflieger, W.L. 1971. A distributional study of Missouri fishes. Lawrence, KS: University of Kansas, Museum of Natural History. 20(3): 225–570.

Pflieger, W.L. 1975. The fishes of Missouri. Jefferson City, MO: Missouri Department of Conservation. 343 p.

Pflieger, William L. 1989. Aquatic community classification system for Missouri. Jefferson City, MO: Missouri Department of Conservation. 70 p.

Pflieger, William L. 1996. The crayfishes of Missouri. Jefferson City, MO: Missouri Department of Conservation. 152 p.

Plafkin, J.L.; Barbour, M.T.; Porter, K.D. [and others], eds. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA/444/4-89/001. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards. 162 p.

Platts, W.S.; Megahan, W.F.; Minshall, G.W. 1983. Methods for evaluating stream, riparian, and biotic conditions. Gen. Tech. Rep. INT-138. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Station. 70 p.

Plebuch, R.O.; Hines, M.S. 1967. Water resources of Pulaski and Saline Counties, Arkansas. Wat.-Supp. Pap. 1839-B. Washington, DC: U.S. Department of the Interior, Geological Survey. 25 p.

Plummer, L.N.; Michel, R.L.; Thurman, E.M.; Glynn, P.D. 1993. Environmental tracers for age dating young ground water. In: Alley, W.M., ed. Regional ground-water quality. New York: Van Nostrand Reinhold: 255–294.

Posey, William R., II. 1997. Location, species composition, and community estimates for mussel beds in the St. Francis and Cache Rivers in Arkansas. Jonesboro, AR: Arkansas State University, Department of Biological Science. 177 p. M.S. thesis.

Posey, William R., II; Harris, John L.; Harp, George L. 1996. New distributional records for freshwater mussels in the Ouachita River, Arkansas. Proceedings of the Arkansas Academy of Science. 50: 96–98.

Poulton, B.C.; Stewart, K.W. 1991. The stoneflies (Plecoptera) of the Ozark and Ouachita Mountains. Memoirs of the American Entomological Society. No. 38. American Entomological Society, Academy of Natural Sciences, Philadelphia, PA. 116 p.

Probst, W.E.; Rabeni, C.F.; Covington, W.G; Marteney, R.E. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Transactions of the American Fisheries Society. 113: 283–294.

Puckett, L.J. 1994. Nonpoint and point sources of nitrogen in major watersheds of the United States. Wat.-Resour. Inv. Rep. 94-4001. Reston, VA: US Department of Interior, Geological Survey. 6 p.

Puckett, Larry J. [Ecologist, USDI Geological Survey, Reston, VA.] 1997. Written communication concerning animal waste nutrients. [Not paged]. [Unpublished report on file at the USDI Geological Survey, Little Rock, AR.]

Rabeni, Charles F. 1992. Trophic linkage between stream centrarchids and their crayfish prey. Canadian Journal of Fisheries and Aquatic Sciences. 49: 1714–1721.

Rafferty, M.D. 1985. The Ozarks outdoors. Norman, OK: University of Oklahoma Press. 389 p.

Rafferty, Milton. 1980. The Ozarks—land and life: Norman, OK: University of Oklahoma Press. 282 p.

Reffalt, William. 1991. The endangered species lists: chronicles of extinction. In: Kohm, Kathryn A., ed. Balancing on the brink of extinction, the Endangered Species Act and lessons for the future. Washington, DC: Island Press: 77–85.

Reimer, Rollin D. 1969. A report on the crawfishes (Decapoda, Astacidae) of Oklahoma. Proceedings of the Oklahoma Academy of Science. 48: 49–65.

Right-To-Know Network. [Accessed November 7, 1997]. Superfund sites. <http://www.rtk.net/www/rtknet/webpage/databas3.html#SUPERFUND >. Washington, DC: RTK Net. [Various pagination].

Robertson, C.E.; Smith, D.C. 1981. Coal resources and reserves of Missouri. Rep. of Inv. 66. Rolla, MO: Missouri Division of Geology and Land Survey. 49 p.

Robinson, John W. 1995. Missouri commercial fish harvest, 1993. Jefferson City, MO: Missouri Department of Conservation. 14 p.

Robinson, John W. 1998. Missouri commercial fish harvest, 1994–1996. Jefferson City, MO: Missouri Department of Conservation. 15 p.

Robison, Henry W. 1986. Zoogeographic implications of the Mississippi River Basin. In: Hocutt, Charles H.; Wiley, Edward O., eds. The zoogeography of North American freshwater fishes. New York, NY: John Wiley. 267–285.

Robison, Henry W.; Allen, Robert T. 1995. Only in Arkansas. Fayetteville, AR: The University of Arkansas Press. 121 p.

Robison, Henry W.; Buchanan, T.M. 1988. Fishes of Arkansas. Fayetteville, AR: The University of Arkansas Press. 536 p.

Robison, Henry W.; Leeds, G. 1996. Distribution and natural history aspects of the Arkansas endemic crayfish, *Cambarus causeyi* Reimer. Proceedings of the Arkansas Academy of Science. 50: 105–109.

Rohm, C.M.; Giese, J.W.; Bennett, C.C. 1987. Evaluation of an aquatic ecoregion classification of streams in Arkansas. Journal of Freshwater Ecology. 4: 127–140.

Ross, H.H. 1965. Pleistocene events and insects. In: Wright, H.E., Jr.; Frey, D.G., eds. The quaternary of the United States. Princeton, NJ: Princeton University Press: 583–596.

Rust, Peter J. 1993. Analysis of the commercial mussel beds in the Black, Spring, Strawberry, and Current Rivers in Arkansas. Jonesboro, AR: Arkansas State University, Department of Biological Science. 118 p. M.S. thesis.

Schluter, Dolph; Ricklefs, Robert E. 1993. Species diversity: introduction to the problem. In: Ricklefs, Robert E.; Schluter, Dolph, eds. Species diversity in ecological communities. Chicago: The University of Chicago Press: 1–10.

Searight, W.V. 1967. Coal. In: Mineral and water resources of Missouri. Vol. 43. Washington, DC: Missouri Division of Geological Survey and Water Resources: 235–242.

Sheldon, Andrew L. 1987. Rarity: patterns and consequences for stream fishes. In: Matthews, William J.; Heins, David C., eds. Community and evolutionary ecology of North American stream fishes. Norman, OK: University of Oklahoma Press: 203–209.

Shepard, William D.; Covich, Alan P. 1982. The unionid fauna of Ft. Gibson Reservoir and the Grand (Neosho) River in Oklahoma. Comments on a proposed increase in water level. The Southwestern Naturalist. 27(3): 359–361.

Sietman, B.E.; Sadler, J.L. 1994. Resurvey of the Meramec River Basin naiad fauna. [Final report for the U.S. Department of the Interior, Fish and Wildlife Service.] Columbia, MO: Missouri Department of Conservation. [Not paged].

Sine, C., ed. 1991. Farm chemicals handbook. Willoughby, OH: Meister Publishing Company. [Various pagination].

Slack, L.J. 1983. Hydrology of an abandoned coal-mining area near McCurtain, Haskell County, Oklahoma. Wat.-Resour. Inv. Rep. 83-4202. Washington, DC: U.S. Department of the Interior, Geological Survey. 117 p.

Smil, Vaclav. 1997. Global population and the nitrogen cycle. Scientific American. 277(7): 76–81.

Smith, James. [Northeastern Region Fish Supervisor, Oklahoma Department of Wildlife Conservation, Porter, OK.] 1997. Fish stocking records for northeast Oklahoma. [Not paged]. [Unpublished report on file at the Forest Supervisor's office, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Smith, K.L. 1986. Sawmill. Fayetteville, AR: The University of Arkansas Press. 246 p.

Smith, R.A.; Alexander, R.B.; Lanfear, K.J. 1993. Stream water quality in the conterminous United States—status and trends of selected indicators during the 1980's. In: Paulsen, R.W.; Chase, E.B.; Williams, J.S.; Moody, D.W. comps. National water summary 1990–91—hydrologic events and stream water quality. Wat.-Supp. Pap. 2400. Washington, DC: U.S. Department of the Interior, Geological Survey. 590 p.

Smith, Richard A.; Alexander, Richard B.; Wolman, M. Gordon. 1987. Water-quality trends in the Nation's rivers. Science. 235: 1607–1615.

Solley, W.B.; Merk, C.F.; Pierce, R.R. 1988. Estimated use of water in the United States in 1985. Circ. 1004. Washington, DC: U.S. Department of the Interior, Geological Survey. 82 p.

Solley, W.B.; Pierce, R.R.; Pearlman, H.A. 1993. Estimated use of water in the United States in 1990. Circ. 1081. Washington, DC: U.S. Department of the Interior, Geological Survey. 76 p.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian Assessment aquatic technical report. Report 2 of 5. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 166 p.

Spradley, P. 1991. Survey of pesticide use on the major vegetable crops in Arkansas—1990. Rep. ETB 173. Little Rock, AR: University of Arkansas Cooperative Extension Service. 52 p.

Spradley, P. 1992. Survey of pesticide use on the major fruit crops in Arkansas—1991. Rep. ETB 175. Little Rock, AR: University of Arkansas Cooperative Extension Service. 71 p.

Stark, William J.; Eschelle, Anthony A.; Fisher, William L. 1995. Genetic structure of stream populations of smallmouth bass in eastern Oklahoma. Federal Aid Rep. F-41-R, Job 17. Oklahoma City, OK: Oklahoma Department of Wildlife Conservation. 63 p.

Steedman, Robert J. 1988. Modification and assessment of the index of biotic integrity to quantify stream quality in southern Ontario. Canadian Journal of Fisheries and Aquatic Sciences. 45: 492–501.

Steele, K.F.; Adamski, J.C. 1987. Land use effects on ground water quality in carbonate terrain. Publ. 129. Fayetteville, AR: Arkansas Water Resources Research Center. 71 p.

Steele, K.F.; Widmann, R.K.; Wickliff, D.S.; Parr, D.L. 1986. The effect of rainstorm events on spring water chemistry in limestone terrain. In: Proceedings; Association of Ground Water Scientists and Engineers, Southern regional ground water conference; 1985 September 18–19; San Antonio, TX. Worthington, OH: National Water Well Association:. 50–66.

Stoeckel, Joseph N.; Lewis, Lindsey; Harlan, J. 1996. Mulberry River freshwater mussel survey. [Prepared for the U.S. Department of Agriculture, Forest Service, Ozark-St. Francis National Forests, Russellville, AR.] 52 p. [Unpublished report in the Forest Supervisor's office, USDA Forest Service, Ozark-St. Francis National Forests, Russellville, AR.]

Stone, C.G. 1994. Paleozoic rocks of the western frontal Ouachita Mountains and Arkoma Basin, Arkansas: summary. In: Suneson, N.H.; Hemish, L.A., eds. Geology and resources of the eastern Ouachita Mountains frontal belt and southeastern Arkoma Basin, Oklahoma. Guidebook 29. Oklahoma City: Oklahoma Geological. Survey: 293–294.

Strahler, Arthur N. 1964. Geology: part II—quantitative geomorphology of drainage basins and channel networks. In: Chow, V.T., ed. Handbook of applied hydrology. New York: McGraw-Hill: 4–39–76.

Stroud, R.B.; Arndt, R.H.; Fulkerson, F.B.; Diamond, W.G. 1969. Mineral resources and industries of Arkansas. U.S. Bureau of Mines Bull. 645. Washington, DC: U.S. Bureau of Mines. 418 p.

Sullavan, J.N. 1974. Drainage areas of streams in Arkansas—White River Basin. Open-file Rep. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 123 p.

Sullavan, J.N.; Terry, J.E. 1970. Drainage areas of streams in Arkansas—Arkansas River Basin. Open-file Rep. Little Rock, AR: U.S. Department of the Interior, Geological Survey. 75 p.

Swift, Lloyd W., Jr. 1986. Filter strip widths for forest roads in the Southern Appalachians. Southern Journal of Applied Forestry. 10: 27–34.

Swift, Lloyd W., Jr. 1988. Forest access roads: design, maintenance, and soil loss. In: Swank, Wayne; Crossley, D.A., Jr., eds. Forest hydrology and ecology at Coweeta: ecological studies. New York: Springer-Verlag. Vol. 66: 313–324.

Taylor, Christopher A.; Warren, Melvin L., Jr.; Fitzpatrick, J. F., Jr. [and others]. 1996. Conservation status of crayfishes of the United States and Canada. Fisheries. 21(4): 25–38.

Thomas, W.A. 1977. Structural and stratigraphic continuity of the Ouachita and Appalachian Mountains. In: Stone, C.G., ed. Proceedings; symposium on the geology of the Ouachita Mountains; 1973 April 5–7; Little Rock, AR. MP-13. Little Rock, AR: Arkansas Geological Commission: 9–24.

Thompson, Richard L. [Chemist Supervisor, Arkansas Division of Pollution Control and Ecology, Little Rock, AR.] 1990. Personal communication. [Not paged]. [Notes on file with USDI Geological Survey, Little Rock, AR.]

Thompson, T.L. 1991. Paleozoic succession in Missouri—part 2: Ordovician System. Rep. of Inv. 70. Rolla, MO: Missouri Division of Geology and Land Survey. 282 p.

Thomson, W.T. 1989. Agricultural chemicals book II: herbicides. Fresno, CA: Thomson. 330 p.

Tikrity, S.S. 1968. Tectonic genesis of the Ozark uplift. St. Louis, MO: Washington University. 196 p. Ph.D. dissertation.

Todd, C. Stan. March 5, 1993, May 12, 1994, and May 8, 1995. Mussel harvest report for 1992 through 1994. 6 p. each. [Unpublished reports on file at the Arkansas Game and Fish Commission, Brinkley, AR.]

Tukey, J.W. 1977. Exploratory data analysis. Reading, MA: Addison-Wesley. 688 p.

Turgeon, D.D.; Bogan, A.E.; Coan, E.V. [and others]. 1988. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. Spec. Publ. 16. Bethesda, MD: American Fisheries Society. 277 p.

Turner, Victor. 1995. Arkansas SCORP '95: Statewide Comprehensive Outdoor Recreation Plan. Little Rock, AR: Arkansas Department of Parks and Tourism. 112 p.

U.S. Army Corps of Engineers (U.S. ACE). 1967. Water resources development in Missouri. In: Mineral and water resources of Missouri. Vol. 43. Washington, DC: Missouri Division of Geological Survey and Water Resources: 349–399.

U.S. Army Corps of Engineers (U.S. ACE). 1976. Navigation charts, McClellan-Kerr Arkansas River navigation system, Catoosa, Oklahoma to mouth White River. Bicentennial Issue. Little Rock, AR, and Tulsa, OK: U.S. Army Corps of Engineer Districts. 148 p.

U.S. Army Corps of Engineers (U.S. ACE). 1987. Wetlands delineation manual. Tech. Rep. Y-87-1. Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station Environmental Laboratory. 100 p.

U.S. Bureau of Outdoor Recreation (U.S. BOR). 1973. The Gasconade River—a summary of the Federal-State team findings. Ann Arbor, MI: United States Bureau of Outdoor Recreation, Lake Central Region. 25 p.

U.S. Department of Agriculture, Forest Service (USDA FS). 1994. Wetlands role of the Forest Service. FS-534. Washington, DC: U.S. Department of Agriculture, Forest Service. 12 p.

U.S. Department of Agriculture, Forest Service (USDA FS). 1996. Permitted mine reference information for: Mark Twain National Forest, MO, Ouachita National Forest, AR and OK. Russellville, AR: U.S. Department of Agriculture, Forest Service, Ozark National Forest. [Various pagination].

U.S. Department of Agriculture, Forest Service (USDA FS). 1997a. Rare invertebrates, North America. Rep. 15. [Based on the report of The Nature Conservancy and the Natural Heritage Central data bases.] Washington, DC: U.S. Department of Agriculture, Forest Service, Threatened, Endangered, and Special Concern Program. 212 p.

U.S. Department of Agriculture, Forest Service (USDA FS). 1997b. Rare vertebrates, United States. Rep. 17. [Based on the report of The Nature Conservancy and the Natural Heritage Central data bases.] Washington, DC: U.S. Department of Agriculture, Forest Service, Threatened, Endangered, and Special Concern Program. 186 p.

U.S. Department of Agriculture, Forest Service (USDA FS). 1999a. Ozark-Ouachita Highlands Assessment: social and economic conditions. Gen. Tech. Rep. SRS-34. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 300 p.

U.S. Department of Agriculture, Forest Service (USDA FS). 1999b. Ozark-Ouachita Highlands Assessment: terrestrial vegetation and wildlife. Gen. Tech. Rep. SRS-35. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 201 p.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 1997. Data base information. [Various pagination]. [Derived from unpublished data from the Natural Resources Inventory data base, Dallas, TX.]

U.S. Department of Commerce, Bureau of Economic Analysis (USDC BEA). 1992. County projections to 2040 (all States). Washington, DC: U.S. Department of Commerce, Bureau of Economic Analysis. [Various pagination].

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1992. Appendix C.3. important wetlands: Arkansas. In: Regional wetlands concept plan. Atlanta, GA: USDI Fish and Wildlife Service: 65–79.

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1996. Endangered and threatened wildlife and plants: review of plant and animal taxa that are candidates for listing as endangered or threatened species. Washington, DC: USDI Fish and Wildlife Service, Division of Endangered Species. [Not paginated].

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997a. Endangered and threatened species: review of plant and animal taxa. Federal Register. 62(182): 49397–49411.

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997b. List of endangered and threatened wildlife and plants, May 31, 1997. Washington, D.C: USDI Fish and Wildlife Service, Division of Endangered Species. 42 p.

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997c. 1996 national survey of fishing, hunting, and wildlife-associated recreation: State overview, preliminary findings. Washington, DC: USDI Fish and Wildlife Service. 27 p.

U.S. Department of the Interior, Geological Survey (USDI GS). 1990. Land use and land cover digital data from 1:250,000- and 1:100,000-scale maps. Data Users Guide 4. Reston, VA: U.S. Department of the Interior, Geological Survey. 33 p.

U.S. Department of the Interior, Geological Survey (USDI GS). 1991. In: Paulson, R.W.; Chase, E.B.; Roberts, R.S.; Moody, D.W., comps. National water summary 1988–89—hydrologic events and floods and droughts. Wat.-Supp. Pap. 2375. Washington, DC: U.S. Department of the Interior, Geological Survey. 591 p.

U.S. Department of the Interior, Geological Survey, Biological Resources Division (USDI GS BRD). [Accessed March 4, 1997a]. Nonindigenous aquatic species, *Daphnia lumholtzi*. <http://www.nas.nfrcg.gov.htm>. Washington, DC: U.S. Department of the Interior, Geological Survey, Biological Resources Division. 2 p.

U.S. Department of the Interior, Geological Survey, Biological Resources Division (USDI GS BRD). [Accessed March 4, 1997b]. Nonindigenous aquatic species, *Dreissena polymorpha*. <http://www.nfrcg.g.gov/nas/nas.htm>. Washington, DC: U.S. Department of the Interior, Geological Survey, Biological Resources Division. 6 p.

U.S. Department of Labor, Mine Safety and Health Administration (USDL MSHA). 1997. Mining Accident and Injury Statistics data base. <http//www.msha.gov>. Washington, DC: U.S. Department of Labor, Mine Safety and Health Administration. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). 1987. Quality criteria for water 1986. EPA 440/5-86-001. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards. 453 p.

U.S. Environmental Protection Agency (U.S. EPA). 1989a. Nonpoint sources, agenda for the future. WH-556. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards. 31 p.

U.S. Environmental Protection Agency (U.S. EPA). 1989b. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA/440/4-89-001. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards. 172 p.

U.S. Environmental Protection Agency (U.S. EPA). 1990. Biological criteria. EPA-440/5-90-004. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards. 41 p.

U.S. Environmental Protection Agency (U.S. EPA). 1992a. Managing nonpoint source pollution: Final report to Congress on section 319 of the Clean Water Act (1989). A841R292101. Washington, DC: U.S. Environmental Protection Agency. 197 p.

U.S. Environmental Protection Agency (U.S. EPA). 1992b. National study of chemical residues in fish: volumes 1 & 2. EPA 823-R-92-008a and EPA 823-R-92-008b. Washington, DC: U.S. Environmental Protection Agency, Office of Science and Technology. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). 1992c. National water quality inventory: 1992 report to Congress. EPA 841-R-94-001. Washington, DC: U.S. Environmental Protection Agency. 328 p.

U.S. Environmental Protection Agency (U.S. EPA). 1992d. Protecting the Nation's wetlands, oceans, and watersheds: an overview of programs and activities. Washington, DC: U.S. Environmental Protection Agency. 20 p.

U.S. Environmental Protection Agency (U.S. EPA). 1993. U.S. Environmental Protection Agency Regulations and Standards. EPA 840-B-92-002. Washington, DC: U.S. Environmental Protection Agency. 162 p.

U.S. Environmental Protection Agency (U.S. EPA). [Accessed November 1995]. Pollution control programs for roads, highways and bridges. EPA-841-F-95-008c. <http://www.epa.gov/owow/NPS/education/control.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). 1996a. BASINS. Version 1.0. CD-ROM. Region 6 U.S. EPA-823-C-96-006. Washington, DC: U.S. Environmental Protection Agency, Office of Science and Technology.

U.S. Environmental Protection Agency (U.S. EPA). 1996b. BASINS. Version 1.0. CD-ROM. Region 7 U.S. EPA-823-C-96-007. Washington, DC: U.S. Environmental Protection Agency, Office of Science and Technology.

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997a]. Index of Watershed Indicators: attachment C. <ftp://ftp.epa.gov/surf/iwi/>. Washington, DC: U.S. Environmental Protection Agency. 16 p.

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997b]. Envirofacts Warehouse: hazardous waste data. <http://www.epa.gov/enviro/html/rcris/rcris_query_java.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997c]. Envirofacts Warehouse homepage, <http://www.epa.gov/enviro/index_java.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997d]. Envirofacts Warehouse: safe drinking water information. <http://www.epa.gov/enviro/html/sdwis/sdwis_query.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997e]. Envirofacts Warehouse: Superfund. <http://www.epa.gov/enviro/html/cerclis/cerclis_query.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997f]. Envirofacts Warehouse: Toxics Release Inventory. <http://www.epa.gov/enviro/html/tris/tris_query_java.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997g]. Envirofacts Warehouse: water discharge permits. <http://www.epa.gov/enviro/html/pcs/pcs_query.html>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997h]. Environmental indicators of water quality in the United States. EPA 841-R-96-002. <http://www.epa.gov/OWOW/indic>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

U.S. Environmental Protection Agency (U.S. EPA). [Accessed June 28, 1997i]. Laws and regulations. <http://www.epa.gov/epahome/rules.html> and <http://www.epa.gov/superfund/index.htm>. Washington, DC: U.S. Environmental Protection Agency. [Various pagination].

Vaughn, Caryn C. 1995. Determination of the status and habitat preference of the Neosho mucket in Oklahoma. [Annual Performance Report to the Oklahoma Department of Wildlife and Conservation, Oklahoma City, OK.] 7 p. + field notes. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Vaughn, Caryn C. 1996a. Determination of the status and habitat preference of the Neosho mucket in Oklahoma. [Annual Performance Report to the Oklahoma Department of Wildlife and Conservation, Oklahoma City, OK.] 7 p. + field notes. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Vaughn, Caryn C. 1996b. Survey of mussel assemblages in the Glover River. [Final report to The Nature Conservancy, Oklahoma Field Office.] 4 p. + appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Vaughn, Caryn C. 1997. Regional patterns of mussel species distributions in North American rivers. Ecography. 20: 107–115.

Vaughn, Caryn C.; Mather, Charles M.; Pyron, M.; Mehlhop, Patricia. 1996. The current and historical mussel fauna of the Kiamichi River, Oklahoma. The Southwestern Naturalist. 41(3): 325–328.

Vaughn, Caryn C.; Pyron, M. 1995. Population ecology of the endangered Ouachita rock pocketbook mussel, *Arkansia wheeleri* (Bivalvia: Unionacea), in the Kiamichi River, Oklahoma. American Malacological Bulletin. 11: 145–151.

Vaughn, Caryn C.; Pyron, M.; Certain, D. L. 1993. Habitat use and reproductive biology of *Arkansia wheeleri* (Mollusca: Unionidae) in the Kiamichi River, Oklahoma. [Final report to the Oklahoma Department of Wildlife Conservation, Oklahoma City, OK.] 50 p. + tables, figures, and appendices. [Unpublished report on file with John Harris, Malacologist, Little Rock, AR.]

Vaughn, Caryn C.; Taylor, C.M.; Eberhard, K.J.; Craig, M. 1994. Survey for *Arkansia wheeleri* and other rare unionids in the Tiak District. [Final Report to the U.S. Department of Agriculture, Forest Service, Ouachita National Forest, Hot Springs, AR.] 30 p. [Unpublished report on file with Ouachita National Forest, Hot Springs, AR.]

Vineyard, J.D.; Feder, G.L.; Pflieger, W.L.; Lipscomb, R.G. 1974. Springs of Missouri. Rep. 29. Rolla, MO: Missouri Division of Geological Survey and Water Resources. 212 p.

Wallace, Charles R. 1996. Annual report: Oklahoma commercial fishery statistics, 1995. Oklahoma City, OK: Oklahoma Department of Wildlife Conservation. 12 p.

Wallace, J.M.; Hobbs, P.V. 1977. Atmospheric science: an introductory survey. New York: Academic Press. 467 p.

Ware, G.W. 1989. The pesticide book. 3d ed. Fresno, CA: Thomson. 340 p.

Warren, Melvin L., Jr.; Angermeier, Paul L.; Burr, Brooks M.; Haag, W.R. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the Southeastern United States. In: Benz, George W.; Collins, David E., eds. Aquatic fauna in peril: the Southeastern perspective. Spec. Publ. 1. Decatur, GA: Lens Design and Communications, Southeast Aquatic Research Institute. 105–164.

Warren, Melvin L., Jr.; Burr, Brooks M. 1994. Status of freshwater fishes of the United States: overview of an imperiled fauna. Fisheries. 19(1): 6–18.

Warren, R.E. 1991. Ozarkian fresh-water mussels (Unionidea) in the upper Eleven Point River, Missouri. American Malacological Bulletin. 8(2): 131–137.

Wharton, H.M.; Larsen, K.G.; Sweeney, P.H. [and others]. 1975. Guidebook to the geology and ore deposits of selected mines in the Viburnum Trend, Missouri. Rep. of Inv. 58. Rolla, MO: Missouri Geological Survey. 56 p.

Wheeler, H.E. 1918. The mollusca of Clark County, Arkansas. Nautilus. 31: 109–125.

White, D.S. 1977. Changes in the freshwater mussel populations of the Poteau River system, Le Flore County, Oklahoma. Proceedings of the Oklahoma Academy of Science. 57: 103–105.

Williams, Austin B. 1954. Speciation and distribution of the crayfishes of the Ozark and Ouachita Provinces. The University of Kansas Science Bulletin. 36(2): 803–918.

Williams, A.B.; Abele, L.G.; Felder, D.L. [and others]. 1989a. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. Spec. Publ. 17. Bethesda, MD: American Fisheries Society. 77 p.

Williams, Jack E.; Johnson, James E.; Hendrickson, Dean A. [and others]. 1989b. Fishes of North America: endangered, threatened, or of special concern. Fisheries. 14(6): 2–20.

Williams, Jack E.; Neves, Richard J. 1992. Introducing the elements of biological diversity in the aquatic environment. In: Williams, Jack E.; Neves, Richard J., eds. Reprint of special session 6, biological diversity in aquatic management. Transactions of the 57th North American Wildlife and Natural Resources Conference, Wildlife Management Institute. Washington, DC: Wildlife Management Institute: 345–345.

Williams, James D.; Warren, Melvin L., Jr.; Cummings, Kevin S. [and others]. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries. 18(9): 6–22.

Wise, O.A.; Caplan, W.M. 1979. Silurian and Devonian rocks of northern Arkansas. Circ. 25. Little Rock, AR: Arkansas Geological Commission. 14 p.

Wright, J.C. 1994. The detection of trends and changes in streams and rivers of Oklahoma. Norman, OK: University of Oklahoma. 209 p. M.S. thesis.

Wulff, Brenda. [Clerk-Typist, Missouri Department of Conservation, Sweet Springs, MO.] 1997. Fish stocking records for selected game fish species for 1994–1996. [Various pagination]. [On file with the Forest Supervisor, USDA Forest Service, Ouachita National Forest, Hot Springs, AR.]

Yu, U.S.; Zou, S. 1993. Relating trends of principal components to trends of water quality constituents. Water Resources Bulletin. 29(5): 797–806.

Ziegler, A.C.; Wilkison, D.H.; Maley, R.D. 1994. Occurrence of selected pesticides, nutrients, selected trace elements, and radionuclides in ground and surface water from west-central Missouri: July 1990–March 1991. Open-File Rep. 93-362. Rolla, MO: U.S. Department of the Interior, Geological Survey. 71 p.

Glossary of Terms

404 permit: a permit issued under section 404 of the CWA for activities that require dredging and any filling of materials into the waters of the United States.

adsorb: to bond molecularly.

aerate: to introduce air into a liquid.

algal blooms: noticeable growth of algae.

alkalinity: relative measure of basicity of a substance; opposite of acidity; relative ability of a substance to donate electron pairs to other substances or receive a hydrogen atom from other substances. Any substance with a pH higher than 7 is considered to be basic or have high alkalinity.

alluvial: of, found in, or made of, alluvium.

alluvial fan: the fan-like pattern of a drainage or stream where it issues from a gorge or a divide upon a plain or of a stream at its confluence with a larger body of water.

alluvium: sediment gradually deposited by moving water on, for example, flooded land, lakebeds, streambeds, alluvial fans, or ocean floors.

ammonia: NH_3; gas that is very soluble in water; can be used to create fertilizers and acid-neutralizing substances.

anomalously: unusually.

anticline: an upfold or arch of stratified rock in which the beds or layers bend downward in opposite directions from the crest.

antidegradation policy: requirement that State standards be sufficient to maintain existing beneficial uses of navigable waters, and prevent degradation. The U.S. Environmental Protection Agency (EPA) requires that State water quality standards include “a statewide antidegradation policy” to ensure the maintenance of existing instream water uses and the level of water quality necessary to protect the existing uses.

aquifer: an underground geological formation or group of formations that contain water, a source of ground water for wells and springs.

areal: of, relating to, or involving area.

areal additivity: an increase in one factor accompanying an increase in area.

atmospheric deposition: the addition of elements or substances found in the air to the surface of the Earth.

assessment: the act of estimating or determining the significance, importance, or value of something.

background source: a natural source, as opposed to a human-caused source; any recorded or observed activity in nature that is other than that being tested for.

barite: a white, yellow, or colorless mineral consisting of native barium sulfate $BaSO_4$.

basal: of or relating to the foundation.

baseline: scientifically gathered data on any subject that provide a description of initial or “base” conditions.

basement: a compact, firm rock underlying less firmly consolidated earth materials.

basin: the entire tract of land drained by a river and its tributaries.

benthic: of or pertaining to the bottom of a stream, lake, sea, or ocean.

best management practices (BMP’s): methods, measures, and practices selected by an agency to meet its need to control nonpoint sources. BMP’s include but are not limited to structural and nonstructural controls and operation and maintenance procedures. BMP’s can be applied before, during, and after activities to reduce or eliminate water pollution caused by the activities.

biotic: of or pertaining to life; caused or produced by living beings.

bituminous: having the quality of hydrocarbons that are usually dark brown or black and occur naturally or are obtained as residues.

buffering capacity: the ability of a solution to accept additions of acid or alkali and not significantly change pH.

buffers: strips of vegetation separating a water body from land that could generate nonpoint pollution. Such buffers vary in width and length and can range from narrow vegetated filter strips to extensive wetland or riparian areas. See **nonpoint source**.

Cambrian Period: the first period of the Paleozoic Era that began approximately 545 million years B.P. (before present) and ended 495 million years B.P.

Carboniferous: pertaining to the portion of geologic time between the Devonian and the Permian periods that began approximately 360 million years B.P. and ended 286 million years B.P., including the Mississipian and Pennsylvanian periods.

carcinogen: a cancer-causing agent.

Carlson Trophic State Index: a formula to derive trophic status: 9.8 natural log [chlorophyll-A] + 30.6.

category 1: taxa for which USDI Fish and Wildlife Service (USDI FWS) has sufficient information to support proposals to list them as endangered or threatened species, but for which proposed rules have not been issued.

category 2: formerly taxa for which USDI FWS had information to indicate that proposing to list them as endangered or threatened was possibly appropriate but for which persuasive data were not currently available.

Cenozoic Era: the fourth and current era of geologic time, including the Quarternary and Tertiary periods, that began approximately 65 million years B.P.

censored values: a set of figures in which greater than 5 percent of the total number of data values are flagged as less than a certain detection limit or as not detected.

channelization: the modification of a channel by clearing, excavation, realignment, lining, or other means to increase its capacity for water flow.

cherty: substance resembling flint and consisting essentially of cryptocrystalline quartz or fibrous chalcedony.

chlorophyll-A: a measure of algal standing crop and primary productivity, pigment that allows photosynthesis to occur in plants.

chroma: a color dimension that refers to the strength or purity of the dominant soil color or the degree of saturation of the dominant color.

clastic: fragmented.

colloid: a substance in a fine state of subdivision with particles too small to be seen in a microscope that is dispersed in a solid, liquid, or gaseous medium.

condition score: classification system for the water quality of watersheds that uses the following categories as determined by the EPA: better water quality, water quality with less serious problems, or water quality with more serious problems.

confining unit/confining system: relatively impervious layers of rock that separate an aquifer from other aquifers.

confluence: portion of a stream where two or more streams come together.

conglomerate: a rock consisting of pebbles and gravel embedded in a loosely cementing material.

consumptive use: that part of withdrawn water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (also referred to as water consumed).

contaminant: an unwholesome or undesirable element that causes water to be polluted or unfit for use, e.g., bacteria from raw sewage in a lake used for fishing and swimming.

contaminant source: the origin of the undesirable element that causes water to be polluted, e.g., a sewage treatment plant could be the primary source of bacteria that impairs a stream. See **impairment.**

convectional: thermally or mechanically created upward or downward movement of a limited part of the atmosphere.

convective precipitation events: atmospheric turbulence with rainfall, snow, or icy precipitation caused by the collision of warm and cool air masses that sets up convection-like atmospheric circulations with warm air rising and cool air falling sequentially.

conveyance: a channel or passage for conduction or transmission, as a pipe, canal, conduit, or ditch.

creel limits: limits on the number of fish that may be caught.

creel survey: a survey of anglers.

Cretaceous Period: the third and last period of the Mesozoic Era that began approximately 144 million years B.P. and ended 65 million years B.P.

currently stable species: a species or subspecies the status of which is relatively unchanging throughout all or a significant portion of its range.

dendritic: a type of delta, alluvial, or wetland drainage in which water flows through a branching, interlacing pattern of channels.

detection limit: the lower limit of an analytical method.

Devonian Period: the fourth period of the Paleozoic Era that began approximately 417 million years B.P. and ended 360 million years B.P.

digestion: the extraction of soluble materials.

dissolutioning: dissecting something into its component parts.

dolomite: a limestone or marble rich in magnesium carbonate.

drought: abnormal dryness, most often recognized during seasons when substantial precipitation is expected but fails to occur. Drought also is associated with higher than normal surface temperatures and drier than normal atmospheric moistures.

drusy: covered with minute crystals or containing cavities lined with crystals.

easement: an interest in real property that conveys use or other rights but not ownership.

ecological section: an area or region of land designated for study purposes that has distinct geology, landforms, soils, flora, and fauna that set it apart from surrounding geographic areas.

ecological-hydrologic unit: a combined unit of analysis created by superimposing ecological sections on hydrologic units to analyze animal species occurrence, richness, density, and distribution.

ecology: the branch of biology that deals with relationships between living organisms and their environment.

ecoregion: a region with distinctive, identifiable ecological attributes.

ecosystem management: an ecological approach to natural resource management to assure productive, healthy ecosystems by blending social, economic, physical, and biological needs and values.

ecotone: a transitional zone between two adjacent communities, containing species characteristic of both as well as other species occurring only within the zone.

effluent: that which flows out or forth; the outflow of a sewer, septic tank, or industrial facility.

Element Occurrence Record (EOR): documentation for the occurrence of a species in a specific location, as recorded by a State natural heritage agency or The Nature Conservancy.

embayment: bay or formation resembling a bay.

endangered species: a species or subspecies in danger of extinction throughout all or a significant portion of its range, as rated and listed by the USDI FWS.

endemic (endemism): species restricted to a particular geographic area; for aquatic species, usually limited to one or a few small streams, a single drainage, or an ecological section.

Environmental Quality Incentives Program (EQIP): USDA NRCS cost-share program for riparian restoration.

epeirogenic uplift: relief-producing deformation of the Earth's crust.

escarpment: a steep slope or cliff formed by erosion or faulting.

estuarine: of or relating to an estuary, which is an inlet or arm of the sea, especially the lower portion or wide mouth of a river where salty tide meets freshwater current.

eutrophic: the second highest trophic state. Eutrophic lakes have accumulated high levels of nitrogen, phosphorous, and other nutrients, and are thus often very green due to large algal blooms.

eutrophication: a cumulative process by which lakes receive (1) agricultural runoff (nutrients such as nitrogen and phosphorus), (2) rural and urban sewage and industrial effluents, and (3) natural nutrients (such as leaves and fallen trees), supporting increased algal and other aquatic plant growth and gradually filling lakes with sediment and decaying organic matter; process of elevation of trophic state.

evapotranspiration: total water loss from the soil, including that by direct evaporation and that by transpiration from the surfaces of plants.

extirpation: elimination of a species in part of its range, e.g., from a State, river basin, or watershed.

extraordinary resource waters: water bodies and their watersheds that are characterized by scenic beauty, scientific values, broad scope recreation potential, and intangible social values.

extratropical: any climatic zone outside of the tropics.

extreme precipitation event: an event occurring within 24 hours that results in 2 or more inches of moisture.

extreme temperature: an occurrence of maximum or minimum temperature greater than 20 ºF above or below normal for a particular day.

fault: a fracture in the Earth's crust accompanied by a displacement of one side of the fracture with respect to the other and in a direction parallel to the fracture.

Federal status: category assigned to plant and animal species by the USDI FWS: threatened, endangered, potentially endangered, or candidate. Candidate species are those for which the USDI FWS has sufficient information to initiate listing under the Endangered Species Act.

fertilizer: chemically prepared substance that provides nutrients to soil.

fissile: capable of being split, cleft, or divided.

floodplain: a lowland area adjoining a watercourse.

fold: a bending into an arch or a trough of rock produced by forces after the depositing or consolidation of the rock

freshwater: water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids; generally, more than 500 mg/L of dissolved solids is undesirable for drinking and many industrial uses.

fungicides: chemicals used to kill unwanted fungi.

game fish: any fish species that may be legally caught for recreational purposes.

geochemical: of, relating to, or using the methods of the science that concerns itself with the chemical composition of and actual or possible changes of substances within the Earth's crust.

geomorphology: a science that deals with the land and submarine relief features of the Earth's surface and seeks a genetic interpretation of them; physiography.

glauconitic: resembling glauconite, a mineral of dull green iron potassium silicate.

global ranks: ranks assigned to plant and animal species by The Nature Conservancy and State heritage programs based on the number of occurrences of each species and denoted by "G" and a number (1-5) or a letter code: **G?**, **G_Q_**, **G_T_**, **G1**, **G2**, **G3**, **G4**, and **G5**. Two G, T, or S rankings together (e.g., G2G3) indicate the range in uncertainty about the status of the taxa. Also see **State ranks** and individual **G** and **S** rankings**.**

G?: unranked, or rank uncertain. See **global ranks** and **State ranks**.

G_Q_: questionable taxonomic assignment.

G_T_: rank of a subspecies or variety (e.g., G5T1 denotes a critically imperiled subspecies of a globally secure species).

G1: extremely rare and critically imperiled species, as determined by the network of State natural heritage programs, The Nature Conservancy, and other experts with five or fewer occurrences, very few remaining individuals and/or especially vulnerable to extinction.

G2: very rare and imperiled, with 6 to 20 occurrences, few remaining individuals, and/or extremely vulnerable to extinction.

G3: characterized by at least one of the following: (1) very rare and local throughout its range, (2) very rare and found locally (sometimes abundantly within that area) in a restricted range, or (3) vulnerable to extinction; usually fewer than 100 occurrences are known.

G4: apparently secure globally, although possibly quite rare in parts of its range, especially at the periphery; usually 100 to 1,000 occurrences.

G5: demonstrably secure globally, though possibly quite rare in parts of its range, especially at the periphery; usually at least 1,000 occurrences.

ground water: generally, all subsurface water (as distinct from surface water); specifically, that part of the subsurface water in the saturated zone (a zone in which all voids are filled with water) where the water is under pressure greater than atmospheric.

ground water divides: places where the flow of ground water changes direction markedly; structures that separate one aquifer from another; see **confining unit/confining system**.

growing season: the portion of the year when soil temperatures 19.7 inches below the soil surface are higher than biologic zero (5 ºC). For ease of determination, this period can be approximated by the number of frost-free days.

herbaceous growth: plant growth having the nature of an herb or herbs, as distinguished from woody plants.

herbicides: chemicals used to kill unwanted plant pests.

herptiles: amphibians and reptiles.

hydraulic: of, involving, moved, or operated by a fluid, especially water under pressure.

hydraulic conductivities: the ability of water to move through strata of different permeablities while under the hydraulic gradient.

hydric soil: a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic (oxygen-lacking) conditions that favor the growth and regeneration of hydrophytic vegetation.

hydroelectric power water use: the use of water in the generation of electricity at plants where the turbine generators are driven by falling water. Hydroelectric water use is classified as an instream use in this report.

hydrogeology: water and terrain interactions.

hydrologic unit: a geographic area representing part or all of a surface drainage basin or distinct hydrologic feature as delineated by the Office of Water Data Coordination on State hydrologic unit maps; each hydrologic unit is identified by an eight-digit number; in this report, hydrologic units are also referred to as watersheds.

hydrologic unit code (HUC): an eight-digit code used to catalog watersheds.

hydrology: the science dealing with the study of water on the surface of the land, in soil and underlying rocks, and in the atmosphere.

hypereutrophic: the highest trophic state. Hypereutrophic lakes have received exceptionally large amounts of nitrogen, phosphorus, and other nutrients and consequently have very heavy growths of algae and other plants.

hypolimnetic releases: discharges from reservoirs of deeper, colder water with lower oxygen.

igneous: rocks formed by solidification from a molten or partially molten state.

impaired or threatened waters: water body that is not supporting or may not support potentially beneficial uses. After a State pollution control agency monitors and evaluates streams and lakes to see if their beneficial uses are being protected, the State designates contaminated waters as impaired or threatened.

impairment: adverse change that results in a water body not fully supporting its designated beneficial uses (e.g., as a domestic water supply, swimming area, or fishery). Impairment may result from a point source (e.g., untreated sewage flowing out of a pipe directly into a water body or one of its tributaries) or a nonpoint source (e.g., erosion moving from a field into a stream).

impounded: confined and stored as by a reservoir or dam.

impoundments: human-engineered and dammed lakes, ponds, and reservoirs.

industrial water use: water used in processing, such as smelting, refining petroleum, or slurry pipeline operations.

inorganics: being or composed of matter other than plant or animal; minerals.

instream: within the aquatic environment of a stream, river, or channel.

instream use: water that is used, but not withdrawn, from a ground or surface water source for such purposes as hydroelectric power generation, navigation water quality improvement, fish propagation, and recreation. Sometimes called nonwithdrawal use or in-channel use.

Interior Highlands: that region of the South-Central United States that contains the Ozarks Plateaus Province and Ouachita Province; more or less equivalent to the Ozark-Ouachita Highlands.

introduced species: species that has been intentionally or accidentally released in a locale by humans.

irrigation water use: artificial application of water on lands to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands such as parks and golf courses.

Jurassic Period: the second period of the Mesozoic Era that began approximately 213 million years B.P. and ended 144 million years B.P.

karst: an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.

kilowatt hour (kWh): unit of work or energy equal to that expended in 1 hour at a steady level of 1 kilowatt.

kriging: statistically spacing instrument readings or other data over distance.

lake retention time: period of time until the volume of lake water is replaced entirely by new water.

land use: particular function to which a region is being put, e.g., agricultural or forested.

leachate: any element or compound that is separated from strata, landfills, or other sources through percolating chemical processes.

legislatively designated waters: streams and lakes that Congress and/or State legislatures have designated for special recognition and protection.

lithology: study of the outermost solid layers of the Earth or description (e.g., structure, composition, color) of rock found in a geological area.

loess: an unstratified loamy soil material distributed by wind.

management indicator species (MIS): species whose population changes are believed to indicate the effects of management activities.

meander: a turn or bend in a stream.

mesotrophic: the second lowest trophic state. Mesotrophic lakes have received somewhat more nutrients and have greater aquatic plant growth than oligotrophic lakes.

Mesozoic Era: the third era of geologic time, including the Cretaceous, Jurassic, and Triassic periods, that began approximately 248 million years B.P. and ended 65 million years B.P. This era is characterized by the predominance of reptilian life forms.

million gallons per day (Mgal/d): a rate of flow of water.

Mississippian Period: the fifth period of the Paleozoic Era that began approximately 360 million years B.P. and ended 320 million years B.P.

mussel: an aquatic bivalve mollusk that is especially abundant in waters of the Central United States and has a shell with a lustrous lining.

National Priorities List (NPL): a published list of hazardous waste sites in the United States that are eligible for extensive, long-term cleanup under the Superfund program.

National Resources Inventory (NRI): a statistically based, nationwide inventory of land uses and natural resource conditions and trends (e.g., erosion potential) on rural, non-Federal lands.

native species: species that is within its known historical range and for which there is no evidence of humans having artificially introduced it.

nitrate: salts of nitric acid formed from reaction of nitric acid with metals, their oxides, and hydroxides.

nitrite: family of compounds containing the NO_2^- ion; usually bonded to other compounds through one of the oxygen atoms to form substances such as nitric acid.

nitrogen fixation: act of converting nitrogen as it is found in air into a form usable by plants and animals, e.g., the making of nitrogen fertilizer.

nonpoint source: any nonidentifiable conveyance from which contaminants (pollutants) enter and impair a stream, e.g., erosion moving soil from a field into a lake. See **point source, buffers**.

nonpoint source pollution: a diffuse source of pollution not regulated as a point source. May include atmospheric deposition, agricultural runoff, and sediment from land-disturbing activities.

novaculite: a very hard, fine-grained siliceous rock that outcrops in the Ouachita Mountains (AR, OK).

nutrient: chemical substances or compounds taken in by living things that are necessary to sustain growth and life, e.g., nitrogen and phosphorus.

nutrient loading: an effect of urbanization, concentrated animal production (e.g., poultry and hog farming) and intensive, high-input agriculture whereby runoff and residues containing treated and untreated human and animal waste, nitrogen fertilizers, and other nutrient-rich elements load soils and water bodies, creating "nutrient sinks" (areas containing high nutrient levels) that increase problems such as algal blooms in water bodies and impaired drinking water supplies.

offstream use: water withdrawn or diverted from a ground or surface water source for public water supply, industry, irrigation, livestock, thermoelectric power generation, and other uses. Sometimes called off-channel use or withdrawal.

oligotrophic: the lowest trophic state. Oligotrophic lakes received low levels of nitrogen, phosphorus, and other nutrients and thus have little algae or other aquatic plant growth.

Ordovician Period: the second period of the Paleozoic Era that began approximately 495 million years B.P. and ended 445 million years B.P.

organic: of or pertaining to living things; compounds containing carbon that also have either carbon-carbon or carbon-hydrogen bonds.

orogeny: mountain building era.

orographic: of or relating to mountains.

orthophosphate: PO_4^{3-}; form of phosphorus most readily used by aquatic plants because of its solubility in water.

oxidation (or oxidize): chemical process by which oxygen is added to a compound or electrons are removed; the process of rusting; combustion.

Paleozoic Era: the second era of geologic time (Cambrian Period through Permian Period) that began approximately 545 million years B.P. and ended 248 million years B.P.

parent material: substance from which soils are derived, e.g., limestone, sandstone, shale.

pearl blanks: a round piece of shell inserted in commercial pearl oysters to stimulate pearl formation.

Pennsylvanian Period: the sixth period of the Paleozoic Era that began approximately 320 million years B.P. and ended 286 million years B.P.

per capita use: the average amount of water used per person during a standard time period, e.g. per day or per year.

percolation: the slow passage of a liquid through a filtering medium.

perennial stream: streams that flow throughout the year.

permeability: the rate at which liquids pass through soil.

Permian Period: the seventh and last period of the Paleozoic Era that began approximately 286 million years B.P. and ended 248 million years B.P.

pH: the negative logarithm of hydrogen ion activity. Substances with lower pH's are more likely to donate hydrogen ions to other substances. Substances with higher pH's are more likely to accept hydrogen ions from other substances. A pH of 7 is considered neutral. Anything with a pH lower than 7 is considered acidic, anything higher is considered alkaline. A difference of 1 pH unit indicates a tenfold change in hydrogen ion activity.

phosphorus: an active nonmetal that forms compounds used in foods, explosives, matches, agricultural chemicals, soaps, and some special metal alloys; nutrient essential to plants and animals.

physiography: the study of the surface features of the land.

physiographic area: a geographic area defined by its surface features.

Pleistocene Age (Epoch): a division of geologic time that began approximately 1,800,000 years B.P. and ended 10,000 years B.P.

point source: any single, identifiable conveyance from which pollutants enter the waters of the United States, e.g., wastewater discharge pipes, stormwater drains, mine pits, ditches, channels, tunnels, industrial facilities, smokestacks, and conduits. See **nonpoint source**.

point source pollution: contamination or impairment from a known specific point of origination, such as sewer outfalls or pipes.

pollutant: something that causes something else to be unclean, contaminated, or impaired.

pollution: the act of impairing or the state of being impaired, e.g., mill wastes can cause pollution in streams.

population density: number of persons per unit area, i.e., people per square mile.

porosity: the state of being capable of absorbing moisture.

potential erosion: erosion that is determined by a mathematical formula designed to estimate the amount of actual erosion that is possible from an area of land characterized by a predominant use of the land.

Pre-Cambrian Era: the first era of geologic time that began when Earth was formed and ended approximately 545 million years B.P.

precipitable water: water that may fall as rain or frozen precipitation.

precipitate: (1) the deposition of condensed material, such as rain; (2) the condensed and solidified result of chemical processes.

precipitation: a deposit on the Earth of rain, mist, hail, sleet, or snow; also, the amount of water deposited.

precipitation gradient: the rate of change in the amount of rain, snow or icy precipitation over a prescribed distance.

primary mineralization: mineralization that occurs while a stratum is being deposited.

province: in the context used in the report, a geographic area having particular geologic and landform characteristics.

***P*-value:** probability.

Quarternary Period: the current period of geologic time that began approximately 1.6 million years B.P.

rare species: any native species that exists in a State in small numbers.

relief: differences in height, collectively, of landforms in a given area (e.g., from valley floor to mountain top).

reservoir: an artificial lake in which water is impounded for a variety of uses.

residuum: rock and soil material that is weathered in place.

resource extraction: the removal of natural resources from the Earth for use by human beings.

rhyolitic: of or relating to a very acid volcanic rock.

riparian zone/riparian area: in this report, the area of land on either side of streams, channels, rivers, and other water bodies. These areas are normally distinctly different from the surrounding lands because of unique soil and vegetation characteristics (e.g., wetter soil than adjacent soil conditions where aquatic vegetative communities thrive), and they generally provide corridors for wildlife use.

road class: classification of roads using the following designations: Class 1 is Federal interstate highways, Class 2 is State highways, and Class 3 is county roads.

rootwads: large clumps or networks of exposed roots.

runoff: water that drains from the land into stream or river channels after precipitation.

secchi depth: a visibility measurement to determine the underwater depth at which equal black and white quarters of a disk cannot be distinguished from each other by the human eye.

secondary mineralization: mineralization that occurs after a stratum is initially deposited.

section 303(d): part of the Clean Water Act that requires designated use and water quality criteria components be contained in water quality standards.

sediment: material created by activities (mechanical and chemical) and deposited by water, wind, or glaciers.

sensitive species: a term used for species of special concern by some States.

shale: a fissile rock that has been formed by the consolidation of clay, mud, or silt, has a finely stratified or laminated structure parallel to the bedding, and is composed of minerals that have been essentially unaltered since deposition.

siltation: the process whereby waterborne soil constituents are deposited in succeeding layers by the force of gravity on flooded land, lakebeds, streambeds, alluvial fans, and ocean floors.

Silurian Period: the third period of the Paleozoic Era that began approximately 445 million years B.P. and ended 417 million years B.P.

silviculture: the theory and practice of controlling forest establishment, growth, composition, and structure.

soil series: groups of soils with similar characteristics.

soil tilth: the texture and friability (crumbling quality) of soil, often apparent after plowing or shovel testing.

special concern: a term used by some States for certain native species determined to require monitoring and/or special management.

species density: total number of native species per square mile.

species richness: the total number of native species within a particular region.

State 305(b) reports: water quality reports submitted by each State to the EPA; these reports show the type and cause of effects on aquatic resources in each State.

State ranks: ranks assigned to the species by State heritage programs based on number of known occurrences of each species in the State. The ranks (**S1** through **S5**) are the same as **global ranks**, which are described in detail under this term.

S1: Critically Imperiled—Critically imperiled species in a State because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the State. Typically, there are five or fewer occurrences of a critically imperiled species or there are very few remaining individuals or acres in which they occur.

S2: Imperiled—Imperiled species in a State because of rarity or because of some factor(s) making it very vulnerable to extirpation from the State. Typically, there are 6 to 20 occurrences of an imperiled species or there are few remaining individuals or acres in which they occur.

S3: Vulnerable—Vulnerable species in a State because it is rare or uncommon. Typically, 21 to 100 occurrences of the species are found only in a restricted range (even if abundant at some locations); or because of other factors making the species vulnerable to extirpation.

SH: Historical—Element occurred historically in the State (with an expectation that it may be rediscovered), perhaps having not been verified in the past 20 years, and is suspected to be present still. Naturally, an element would be SH without such a 20-year delay if the only known occurrences in a State were destroyed or if it had been extensively and unsuccessfully looked for. The SH rank should be reserved for elements for which some effort has been made to relocate occurrences, rather than simply ranking all elements not known from verified extant occurrences with this rank.

SX: Extirpated—Element is believed to be extirpated from the State (or province or other subnational unit).

stewardship: careful and responsible management of resources.

STOrage and RETrieval system (STORET): EPA's oldest and largest computerized environmental repository for water quality and biological monitoring data. For more information, see the Web site at <http://www.epa.gov/OWOW/STORET/>.

strata: layers of rock.

stratigraphic: pertaining to strata, or layers, as in a description of layers of rock types.

stratigraphy: the arrangement of strata.

stream reach: a segment of a stream.

streamside management area (SMA) or streamside management zone (SMZ): a designated area that consists of the stream itself and an adjacent area of varying width where management practices that might affect water quality, fish, or other aquatic resources are modified. An SMA is an area that acts as a filter and absorption zone for sediments, maintains shade, protects riparian and terrestrial riparian habitat; protects channels and stream banks, and promotes floodplain stability.

stream type: a combination of three landscape-scale attributes that determine the classification of a moving body of water: (1) hydrologic unit, (2) ecological section, and (3) stream size.

stressor: pressure or change brought upon an ecosystem by pollution sources such as contaminants and toxins.

subsidence: something that is deposited, such as sediment.

Superfund: a congressionally mandated fund administered by the EPA to clean up designated toxic landfills and other U.S.

sites that contain levels of toxins and contaminants that are deemed a threat to public and environmental health.

Superfund site: a hazardous waste site that poses health and environmental threats, particularly through contaminated drinking, surface, or ground water.

surface water: an open body of water such as a stream or lake.

suspended sediment: matter that would usually sink to the bottom of a liquid that has been mixed with, but not dissolved in a liquid.

suspended solid: material in a suspending medium that, when removed, would retain the properties of the solid state of matter.

syncline: a trough of layered rock in which the beds dip toward each other from either side.

taxa: two or more taxonomic groups or entities.

taxon: a taxonomic group or entity, the name applied to a taxonomic group in a formal system of nomenclature.

taxonomy: classification of organisms into categories according to their natural relationships.

tectonic: relating to rock structures formed by forces that deform the Earth's crust.

temperature gradient: the rate of change of temperature over a set distance.

temporal: having to do with time. Temporal distribution of data includes sampling time periods and frequency.

Tertiary Period: the first period of the Cenozoic Era that began approximately 65 million years B.P. and ended 1.6 million years B.P.

thermoelectric power water use: water used to generate thermoelectric power.

threatened species: a species or subspecies that is likely to become endangered throughout all or a significant portion of its range and listed as such by the USDI FWS.

topography: the configuration of a surface (usually the Earth's surface) including its relief and the position of its natural and artificial features.

total maximum daily load (TMDL): the sum of (1) a waste load allocation (WLA), or that portion of a surface water's loading capacity that is allocated to an existing or future point source discharge; (2) a load allocation (LA), or that portion of the surface water's loading capacity that is due to either existing or future nonpoint source pollution or to natural background sources; and (3) a margin of safety (MS), or that portion of a surface water's loading capacity that is allocated to uncertainty.

total potential erosion (TPE): the sum of potential erosion estimates for cropland, forest, pasture, rangeland, and "other" land.

toxics: pollutants that reach poisonous levels in the air, water or soil; examples include heavy metals, pesticides, herbicides, fertilizers, and other nutrients.

transmissivity: the ability of an aquifer to transmit water.

Triassic Period: the first period of the Mesozoic Era that began approximately 248 million years B.P. and ended 213 million years B.P.

tributary: a stream feeding a larger stream, river, or lake.

trophic status: the degree of eutrophication of a lake. It includes the designations of oligotrophic, mesotrophic, eutrophic, and hypereutrophic. Trophic status provides insight into the lake's productivity and its future.

turbid: murky; opaque or clouded with suspended matter.

turbidity: a measure of water clarity.

ubiquitous: existing everywhere.

unconformities: breaks in the depositional sequence of rock from dislocations, erosion, and nondeposition.

unionacean bivalves: aquatic lifeforms commonly referred to as mussels, clams, naiads, or unionids.

Universal Soil Loss Equation (USLE): an equation developed to predict soil losses due to runoff from specific field areas in specified agricultural cropping and management systems. The equation consists of a rainfall and runoff factor, soil erodibility factor, slope-length factor, slope-steepness factor, cover and management factor, and support practice factor.

vulnerability: capability of being injured. A watershed with low vulnerability can easily tolerate increases of pollutants while a watershed with a high vulnerability cannot easily absorb increases in pollutants.

vulnerability indicator: a condition of aquatic system quality that, when present, points to a threat to the aquatic system; examples of vulnerability indicators are fish and wildlife consumption advisories and contaminated sediments.

vulnerability scores: classification system of water quality that categorizes watersheds as either having high or low vulnerability to stressors as determined by the EPA.

Water Data Storage and Retrieval System (WATSTORE): USDI's Geological Survey data base, a part of the National

Water Information System (NWIS). Files are maintained for the storage of (1) surface water, quality of water, and ground water data measured daily or more frequently, (2) annual peak values and peaks above a base flow for streamflow stations, (3) chemical analyses for surface and ground water sites, (4) geologic and inventory data for ground water sites, and (5) water use summary data. For more information, consult the following on the Internet: <http://water.usgs.gov/public/nawdex/wats/intro.html>.

water quality: information about the chemical, physical and/or biological characteristics, overall usefulness, and varieties of streams, lakes, and ground water.

water quality standard: a standard that defines the goals for a water body or portion of a water body, by designating the beneficial use or uses to be made of the water and by setting criteria necessary to protect the uses. Water quality standards should provide for the protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water, and should take into consideration the use and value of public water supplies. Such standards establish water quality goals for a specific water body and serve as the regulatory basis for the establishment of water quality-based treatment controls and strategies beyond the technology-based treatment required by sections 301(b) and 306 of the CWA.

water use: (1) in a restrictive sense, water that is actually used for a specific purpose, such as for domestic use, irrigation, or industrial processing. In this report, the quantity of water use for a specific category is the combination of self-supplied withdrawals and public supply deliveries; (2) more broadly, water use pertains to human interaction with and influence on the hydrologic cycle, and includes elements such as water withdrawal, delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, and instream use. See **offstream use** and **instream use**.

water year: a 12-month period from October 1st through September 30th; a water year is designated by the calendar year in which it ends (e.g., the 1998 water year was from October 1, 1997, through September 30, 1998).

watershed: the area of land above a given point on a stream that contributes water to the volume of a body of surface water; also referred to as hydrologic unit or drainage basin.

wetlands: those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (U.S. ACE 1987). Wetlands generally include (1) swamps, marshes, bogs, and similar areas, and (2) lands that are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface of the land and is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following attributes: (1) at least periodically, the land predominantly supports hydrophytes (plants dependent on saturated soils or a water medium); (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

Wetlands Reserve Program (WRP): USDA NRCS cost-share program for restoring wetlands. For more information, see the following Web site: <http://www.nrcs.usda.gov/NRCSProg.html#Anchor-Wetlands>.

wind shear: an increase in wind speed with a shift in the height and wind direction from southerly to southwesterly and westerly.

withdrawal: water removed from the ground or diverted from a surface water source for use. See **offstream use**.

zoogeography: geographic distribution of animals.

Glossary of Abbreviations and Acronyms

AALC: acute aquatic life criterion or criteria

AFS: American Fisheries Society

AR DPCE: Arkansas Department of Pollution Control and Ecology

AR GC: Arkansas Geological Commission

AR GFC: Arkansas Game and Fish Commission

AR HTD: Arkansas Highway and Transportation Department

AR M-AWPT: Arkansas Multi-Agency Wetlands Planning Team

BASINS: Better Assessment Science Integrating Point and Nonpoint Sources

BMP's: best management practices

B.P.: before the present time

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980, P.L. 96-510 Stat. 2767, 42 U.S.C. 9601-9675

CERCLIS: Comprehensive Environmental Response, Compensation, and Liability Information System; the data base is maintained by the EPA

CFR: Code of Federal Regulations

CTA: Conservation Technical Assistance program

CWA: Clean Water Act

DLG: Digital Line Graph (USDI GS data)

EOR's: Element Occurrence Records

EPA: U.S. Environmental Protection Agency

EQIP: Environmental Quality Incentives Program

ESA: Endangered Species Act

EWP: Emergency Watershed Protection

FL DEP: Florida Department of Environmental Protection

FR: Federal Register

ft: foot or feet

ft/d: feet per day

ft^2/d: square feet per day

ft^3/s: cubic feet per second

FWPCA: Federal Water Pollution Control Act

gal/d: gallon or gallons per day

gal/min: gallon or gallons per minute

GIRAS: Geographic Information Retrieval and Analysis System (USDI GS data)

GIS: Geographic Information System

HUC: hydrologic unit code

in.: inch or inches

IWI: Index of Watershed Indicators

KS DHE: Kansas Department of Health and Environment

kWh: kilowatt hour

lb: pound or pounds

MCL: maximum contaminant level

Mgal/d: million gallons per day

mg/L: milligrams per liter

mi: mile or miles

mi/h: miles per hour

MIS: management indicator species

MO DC: Missouri Department of Conservation

MO DNR: Missouri Department of Natural Resources

MS: margin of safety

MSHA: Mine Safety and Health Administration

µg/L: micrograms per liter

NAWQA: National Water-Quality Assessment program

NCASI: National Council of the Paper Industry on Air and Stream Improvement

NPDES: National Pollutant Discharge Elimination System

NPL: National Priorities List

NRI: National Resources Inventory

NSP: Nonpoint Source Pollution

NWP's: nationwide permits

OK DEQ: Oklahoma Department of Environmental Quality

OK DM: Oklahoma Department of Mines

OK DWC: Oklahoma Department of Wildlife Conservation

OK WRB: Oklahoma Water Resources Board

ORW: Outstanding Resource Water

OSHA: Occupational Safety and Health Administration

PCS: Permits Compliance System

pH: hydrogen ion concentration; relative measure of acidity or alkalinity.

P.L.: Public Law (Federal)

***P*-value:** probability

RF1: River File version 1 (EPA data base)

RF2: River File version 2 (EPA data base)

RF3: River File version 3 (EPA data base)

SCORP: the Statewide Comprehensive Outdoor Recreation Plan in Arkansas

SMA: Streamside Management Area (also called SMZ)

SMZ: Streamside Management Zone (also called SMA)

STATSGO: State Soil Geographic data base

STORET: EPA's data STOrage and RETrieval system

STP: sewage treatment plant

TMDL: Total Maximum Daily Load

TPE: total potential erosion

TRI: Toxics Release Inventory

TRIS: Toxic Release Inventory System

U.S. ACE: U.S. Army Corps of Engineers

U.S. BOR: U.S. Bureau of Outdoor Recreation

U.S.C.: United States Code

U.S. DOA: U.S. Department of the Army

U.S. EPA: U.S. Environmental Protection Agency

USDA: U.S. Department of Agriculture

USDA FS: U.S. Department of Agriculture, Forest Service

USDA NRCS: U.S. Department of Agriculture, Natural Resources Conservation Service

USDC: U.S. Department of Commerce

USDC BEC: U.S. Department of Commerce, Bureau of Economic Analysis

USDI: U.S. Department of the Interior

USDI FWS: U.S. Department of the Interior, Fish and Wildlife Service

USDI GS: U.S. Department of the Interior, Geological Survey

USDI GS BRD: U.S. Department of the Interior, Geological Survey, Biological Resources Division

USDI NPS: U.S. Department of the Interior, National Park Service

USDL Mine Safety and Health Administration: U.S. Department of Labor, Mine Safety and Health Administration

WATSTORE: Water Data Storage and Retrieval System

WLA: waste load allocation

WRP: Wetlands Reserve Program

List of Tables

Page

List of Figures

U.S. Department of Agriculture, Forest Service. 1999. Ozark-Ouachita Highlands Assessment: aquatic conditions. Report 3 of 5. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 317 p.

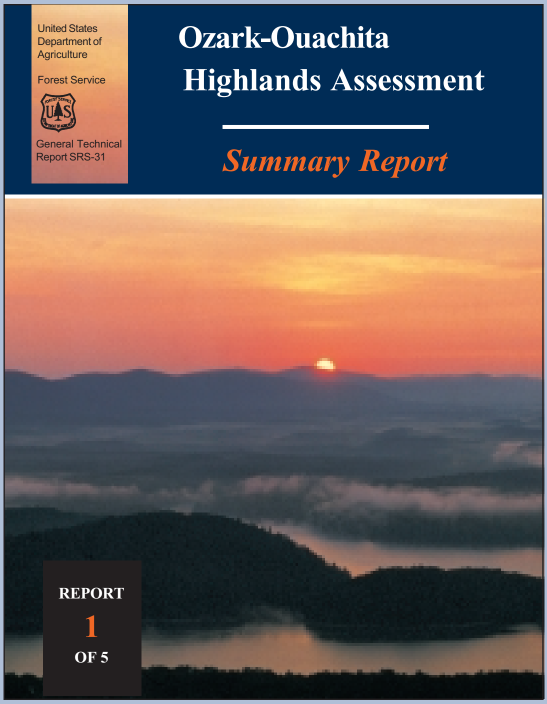
This publication provides citizens, private and public organizations, scientists, and others with information about the aquatic conditions in or near national forests in the Ozark-Ouachita Highlands: the Mark Twain in Missouri, the Ouachita in Arkansas and Oklahoma, and the Ozark-St. Francis National Forests in Arkansas. This report includes water quality analyses, status of aquatic species, aquatic and riparian habitat conditions, water laws and policies, effects of human activities, and water resource usage and trends in the Ozark-Ouachita Highlands Assessment area.

Keywords: Climate, crayfishes, fishes, geology, invertebrates, lakes, land use, mussels, nonpoint sources, point sources, rivers, soils, threatened and endangered species, water.

The Forest Service, U.S. Department of Agriculture, provides leadership in the management, protection, and use of the Nation's forests and rangelands. The Agency takes an ecological approach to the implementation of multiple-use management, providing sustained yields of renewable resources such as water, forage, wildlife, wood, and recreation. The Forest Service has embraced ecosystem management as its operating philosophy and is committed to the preservation of wilderness, biodiversity, and landscape beauty as well as the protection of the basic resources of soil, water, and air quality.

The Forest Service is responsible for the 191.8-million-acre National Forest System, with its 155 national forests and 20 grasslands in 44 States, Puerto Rico, and the Virgin Islands. In addition, the Agency works with State land management organizations to help private landowners apply good natural resource management practices on their lands. The International Program of the Forest Service enables the Agency to share its technical expertise and managerial skills with other nations. The Research and Development Program of the Forest Service conducts extensive research to enhance and protect productivity on all of America's forests and rangelands, with special attention to long-term natural resource issues of national and international scope.

This report is one of five that documents the results of the Ozark-Ouachita Highlands Assessment. Three of the remaining reports examine *Air Quality*, *Social and Economic Conditions*, and *Terrestrial Vegetation and Wildlife*, respectively, and the fourth provides an overall summary.



United States
Department of
Agriculture

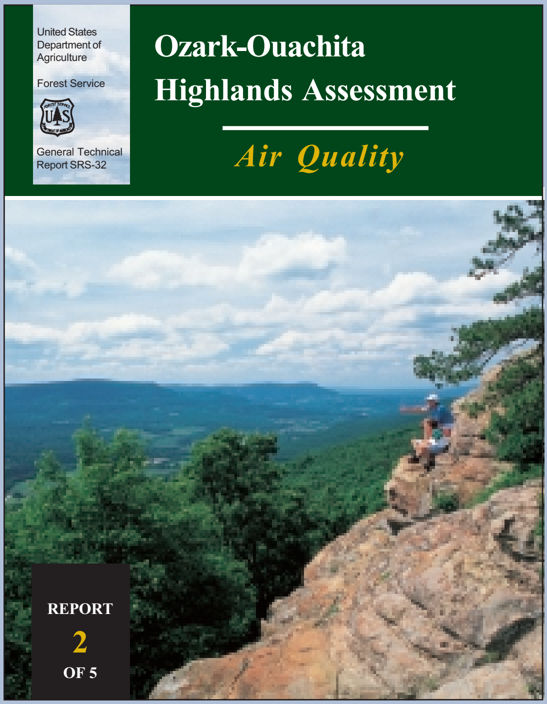
Forest Service

General Technical
Report SRS-31

Ozark-Ouachita
Highlands Assessment

Summary Report

REPORT
1
OF 5



United States
Department of
Agriculture

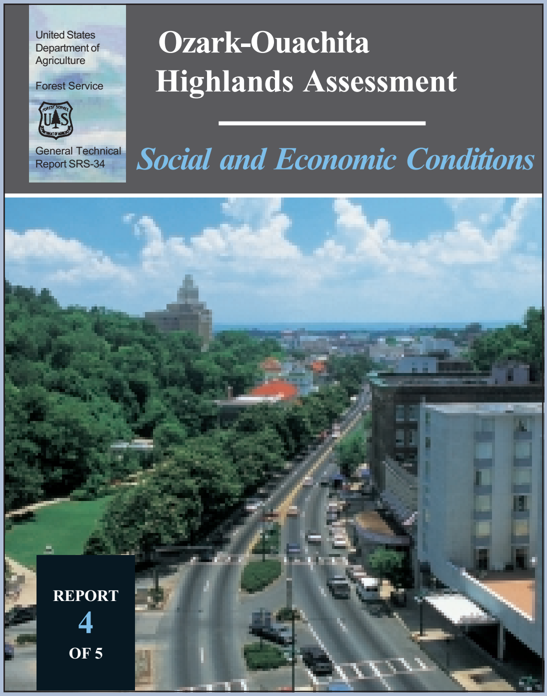
Forest Service

General Technical
Report SRS-32

Ozark-Ouachita
Highlands Assessment

Air Quality

REPORT
2
OF 5



United States
Department of
Agriculture

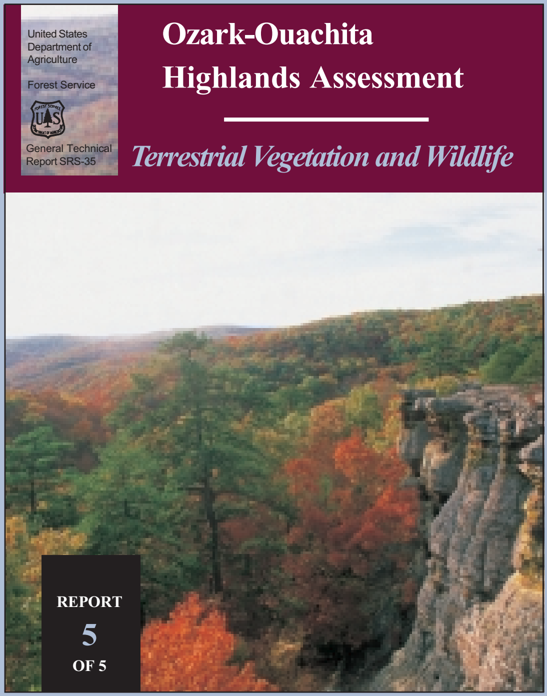
Forest Service

General Technical
Report SRS-34

Ozark-Ouachita
Highlands Assessment

Social and Economic Conditions

REPORT
4
OF 5



United States
Department of
Agriculture

Forest Service

General Technical
Report SRS-35

Ozark-Ouachita
Highlands Assessment

Terrestrial Vegetation and Wildlife

REPORT
5
OF 5