Water Resources Report Number 60

TOPICS IN WATER USE: CENTRAL MISSOURI

Integrity and excellence in all we do

MISSOURI DEPARTMENT OF NATURAL RESOURCES
Geological Survey and Resource Assessment Division
(formerly the Division of Geology and Land Survey)
Mimi R. Garstang, Director and State Geologist
P.O. Box 250, Rolla, MO 65402-0250
Phone: (573) 368-2125 FAX: (573) 368-2111
e-mail: dglspubs@mail.dnr.state.mo.us

Library of Congress Catalog Card Number: 2002 141308
Missouri Classification Number: MO/NR Ge9:60

Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division, 2002, ***Topics in Water Use: Central Missouri***, Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division, Water Resources Report Number 60, 92 p., 27 figs., 5 tbls.

As a recipient of federal funds, the Missouri Department of Natural Resources cannot discriminate against anyone on the basis of race, color, national origin, age, sex or handicap. If anyone believes he/she has been subjected to discrimination for any of these reasons, he/she may file a complaint with either the Missouri Department of Natural Resources or the Office of Equal Opportunity, U.S. Department of the Interior, Washington, DC, 20240.

Table of Contents

Page

1. INTRODUCTION 1
   The Regional Approach (Economic, Environmental, Social and Political Boundaries) 1
   Ancient Missourians 3
   Census Data 3
   The Watershed-Based Approach 4
   Temporal Aspect of Water Use 4

2. ACKNOWLEDGMENTS 7

3. REGIONAL DESCRIPTION 9
   Colleges and Universities 9
   Regional Transportation 9
   Population Characteristics 13
   Industry, Commerce, and Agriculture 15
   Physical Characteristics 15
   Implications for Water Resources 28
   Recreation 29

4. REGIONAL WATER USE OVERVIEW 31
   Problems with Water Resources Management 31
   Public Water Supply 32
   Domestic Water Use 32
   Industrial and Commercial Water Use 34
   Agricultural Water Use 34
   Water Use in Power Production 34
   Other Instream Flow Uses 35

5. WATER USE PROBLEMS 37
   Drinking Water Use 37
   Overuse of Groundwater in Site Specific Areas 37
   Lack of Spring Protection 44
   Surface Water Quality Threats from Pollutants 46
   Unplugged Abandoned Wells 47
   Private Water Well Construction and Water Quality 49
   Aging Infrastructure of Small Public Water Supply Systems 51
   Untreated Residuals from the Production of Drinking Water 52

   Agricultural Water Use 53
   Land Application of Animal Manure 53
   Lack of Coordination of Levee Construction 56
   Loss of Riparian Corridor 57
   Pesticides Runoff 59
   Excessive Instream Sedimentation 59

Industrial Water Use 60
Low Flow in the Missouri River 60
Low Levels of Dissolved Oxygen 63
Missouri River - Basin-wide Agreements 64
Missouri River - Vision for the Future 65
Dam Discharges and Instream Flows 66

Recreational Water Use 66
Septic Systems and Lake of the Ozarks 66
Missouri River Marinas 68
Competition for Water at Lake of the Ozarks 69
Anderson Cove at Lake of the Ozarks 70

Environmental Protection Water Use 71
Flora and Fauna 71
Aquatic Species Loss 71
Exotic Species Infestation 73
Stream Bank Erosion 75
Stream Channelization 75
Sand and Gravel Mining 77
Stream Sedimentation Problems 79
Urbanization and Roadway Construction 80
Missouri River Habitat Loss 81
Habitat Loss, Osage and Blackwater River Systems 84

6. WATER USE OPPORTUNITIES AND REGIONAL OBSERVATIONS 87
Missouri River 87
Missouri River Master Manual Review 87
Development of Commercial Navigation Facilities on the Missouri River 88
Missouri River - Potential Water Supply for Large Quantity Users 88
Recreation and Habitat Restoration 88
Best Land Use Practices 89
Riparian Corridors Protection 89
Missouri Water Law 89

7. COMMENTS RECEIVED 91

List of Figures

Figure **Page**

1. Missouri Department of Natural Resources' regional office service areas 2
2 Map showing counties of central Missouri and counties with highest "open country" rate of growth 5
3. Locations of colleges and universities of central Missouri 8
4. Major roads and cities in central Missouri 10
5. Railways in central Missouri 11
6. Barge terminals along the Missouri River in central Missouri 12
7. Average annual precipitation for Missouri 16
8. Physiographic provinces of Missouri 17
9. Freshwater-salinewater transition zone 18
10. Generalized geologic map of Missouri 20
11. Two-digit hydrologic units of Missouri 22
12. Four-digit hydrologic units of Missouri 23
13. Six-digit hydrologic units of Missouri 24
14. Eight-digit hydrologic units of Missouri 25
15. Eleven-digit hydrologic units of Missouri 26
16. Fourteen-digit hydrologic units of Missouri 27
17. National and state forest lands, state parks and historic sites in the central Missouri region 28
18. Locations of public water supply wells in Missouri 33
19. Idealized "cone of depression" from pumpage of a high-yield well 38
20. Graph of groundwater level decline in Dresden observation well 42
21. Graph of groundwater level in Pettis county R-12 school observation well 43
22. Recharge area of Maramec Spring 45
23. Private water well test results from U.S. Centers for Disease Control, 1994 study 50
24. Locations of confined animal feeding operations (CAFOs) in the central Missouri, 1988-1998 55
25. Locations of Missouri River water intakes in central Missouri 62
26. Missouri River Fish and Wildlife Mitigation 82
27. Channelization Process at Indian Cave Bend, Nebraska 83

List of Tables

Table **Page**

1. Central Missouri Region counties and their population statistics 13
2. Summarized census data for central Missouri counties 14
3. Generalized section of Missouri's geologic units 21
4. Number of state and federal recreational facilities in central Missouri 29
5. Missouri endangered species ranking system 72

1. Introduction

According to the Missouri Water Resources Law (Sections 640.400 to 640.435, RSMo), the state water resources plan is to address water needs for the following uses: drinking, agriculture, industry, recreation and environmental protection. Addressing water "needs" requires us to establish why these needs exist in the first place. In some cases, an existing water need is tied to one or more unresolved water problems. For example, communities "need" clean water. To meet this need, communities may have to address problems with water supply infrastructure, adequate quantity and, at the same time, source water quality. This report takes a step toward addressing the water needs of central Missouri by identifying problems it faces.

As noted in the legislation, there are many aspects of water use problems. Missouri water law is concerned both with protecting private individual water rights and protecting the public health and welfare. In addition to social and economic needs, there are the environmental needs of the forests, fish and wildlife of Missouri. There are the facets of quantity and quality of the water resources, themselves. And there are the political jurisdictions that administer public water supplies under Missouri statutes. It is within this matrix of considerations that we have approached these regional water use problems and opportunities as well as the broader topic of State Water Planning.

To ensure equal consideration for all uses, emphasis was placed on identifying water use problems in each topical area identified in the Water Resources Law. Similar topics sometimes are addressed in more than one category, reflecting the different viewpoints of those who raised these topics as water use problems.

When reading the water use problems identified in central Missouri, it will become apparent that many of them are, in fact, very closely related. In addition, because of the diverse perspectives the various contributors bring to this effort, what, from one standpoint, may appear to be a "serious problem," may not seem so, from another. For these reasons, the following problems underscore the importance of working cooperatively in addressing the water use problems facing central Missouri.

The Regional (Economic-Environmental-Social-Political Boundary) Approach

Water resource professionals commonly subdivide the state into physiographic units, such as watersheds or aquifers. While this approach is important for resource-based discussions, it inadequately addresses water use problems. While the water supply side is chiefly focused on where the water resource is located, its quantity and quality, the water use side is focused primarily upon administering demands, needs, and the purposes the water serves. In this series of reports, we have chosen to address the subject using the broad geographic similarities of the six field service areas of the Department of Natural Resources (figure 1). Each of these regions has distinctive physiographic features and socio-economic characteristics, as well as being composed of counties, and therefore was chosen for the ease of referencing water use problems. This approach allows us to recognize Missouri's diversity, and lends itself well to Phase 2 of the State Water Plan.

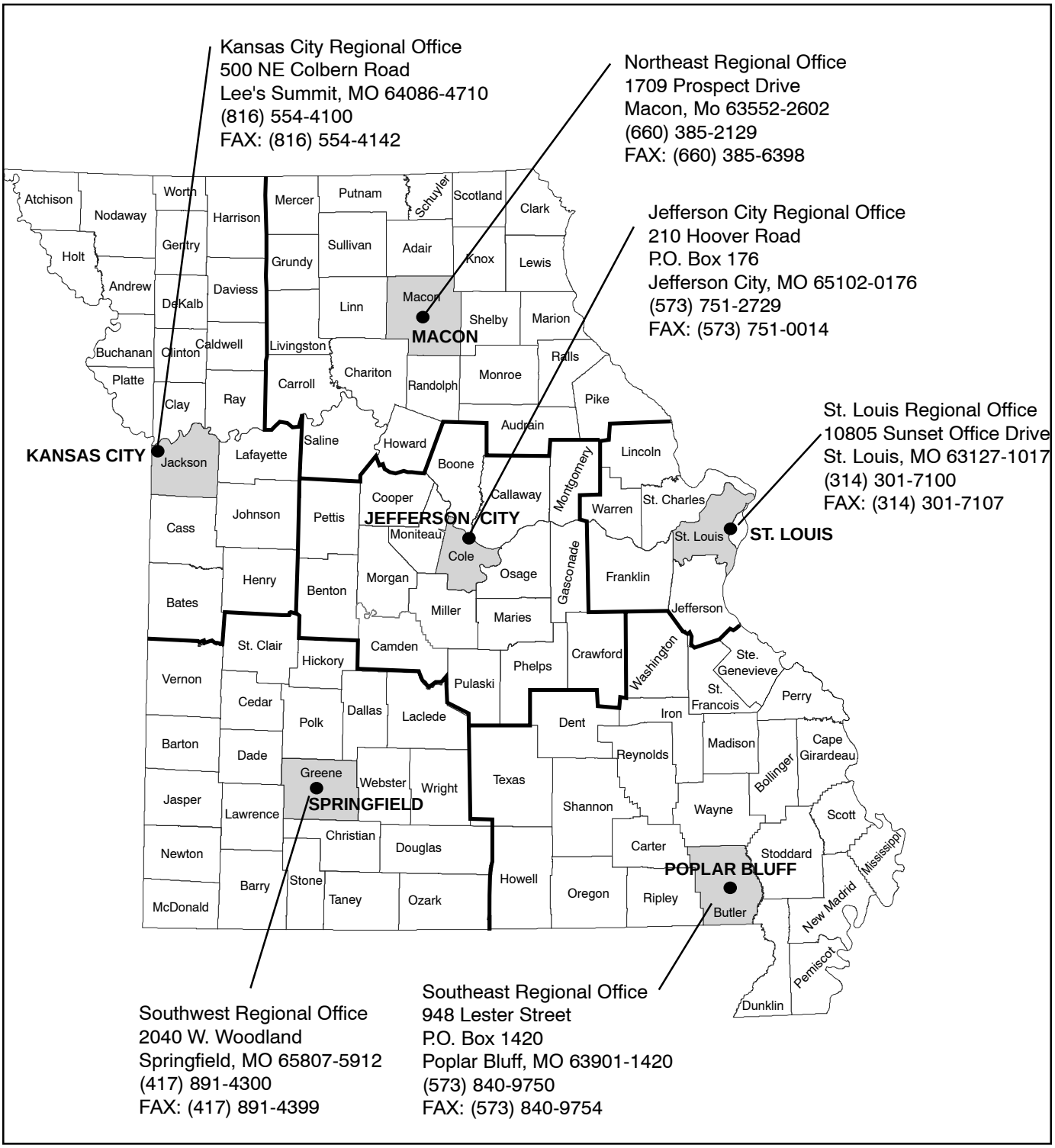

Figure 1. Missouri Department of Natural Resources' regional office service areas.

The area served by the department's Jefferson City Regional Office is the focus of this report. Staff from this office and other state agencies dealing with water resources were the primary sources of information for this effort. This enables us to draw upon the insight and experience of field staff who, by virtue of their work, deal with many water use problems facing Central Missouri on a daily basis.

Ancient Missourians

In 1999, archaeologists working under contract to the Missouri Department of Transportation (MoDOT) unearthed a prehistoric Native American village in Callaway County, along what is now State Highway 94, where a small creek flows across the floodplain on its way to the Missouri River. This 3,000- year-old village housed as many as 100 to 150 residents, in probably ten large, timber-framed, circular dwellings. Notable is the fact that the village was located near a water source at a time period when (scientists tell us) the climate was warmer and drier than today, called the Hypsithermal Period, part of the post-glacial (or inter-glacial) age in which we now live (MoDOT, 1991). The site, on the edge of the floodplain of the Missouri River, had been buried under about three feet of clay and mud sediment. The cultural period to which the village belongs is what is termed the Late Archaic Period, which ranges from 3,000 to 1,000 years, B.C. (MoDOT, 2001). The fact that people lived in this part of Missouri that long ago is of interest, and the fact that they located their village where water could be obtained during drouth times, are indications to us of the importance of water in all times.

Census Data

The Missouri Office of Social and Economic Data Analysis (OSEDA) has analyzed 1998 census estimates made in advance of the Year 2000 decennial national census. OSEDA points out that there has been a general movement of people into "open country", that is, unincorporated areas. Since 1990, there has been an estimated statewide increase of 12.7 percent in the number of Missourians living in open country, versus an estimated increase of only three per cent living inside the city limits of incorporated places. In 1998, it was estimated that 36 percent of the population of Missouri lived outside town or city limits (OSEDA, 1999).

By contrast, in 1910, nationally, 40 percent of the people lived in rural places, most of them on farms (OSEDA, 1999). Today, few of the people living in open country are farm families. This is not the only difference. The expectations of services from county governments by farm families in 1910 and the expectations of services from county governments by rural nonfarm dwellers in the 1990s are vastly different. Water supply and wastewater treatment are two of the areas where expectations have changed since 1910.

According to the U.S. Department of Agriculture (USDA) five-year census of agriculture, from 1992 to 1997, the number of farms in Missouri grew from 98,082 to 98,860. In this same time span, the average size of farms in Missouri increased from 275 acres to 292 acres.

In the central Missouri region, according to 1998 census estimates, some counties grew rapidly in population, others did not. Among the largest rates of increase in open country population were Benton County (21.7 percent), Camden County (22.4 percent), and Morgan County, (19.3 percent). All of these counties lie near the Lake of the Ozarks, a major tourist destination and vacation home location (figure 2).

The trend toward open country living seems to be attributable to several factors: Lower property values in open country (less cost to buy house and land), a preference to have a larger piece of land on which to live (less crowded), perhaps to farm on a small scale, and a preference for rural living. According to OSEDA, it generally is more a lifestyle choice than an economic choice. Regardless of the reason, this movement to unincorporated territory is creating new challenges for county governments and rural agencies responsible for providing public services such as public drinking water districts, wastewater treatment facilities, fire protection agencies, solid waste management districts, school districts, law enforcement (sheriff's departments), and other utilities (OSEDA, 1999). The water use demands placed upon the water

resources by lifestyle choices to a large extent determine and frame the context of the water use problem.

The Watershed Based Approach

Watersheds are defined as the areas of land that drain surface water runoff into a central watercourse. The watershed usually bears the name of its stream, such as the Osage River Watershed. In the 1990s, federal and state environmental planners began to put a greater emphasis on consideration of water resources and water problems within a watershed context. In this manner, they hoped to take into consideration all the factors that affect water quality, from a geographical perspective. Comprehensive watershed assessment, planning, and management of water resources makes sense, but political boundaries (cities, counties, states) rarely follow watershed boundaries. Indeed, boundaries often follow watercourses, effectively dividing any watershed where this occurs. A case in point would be the Missouri River, a boundary for all the counties along the river within the central Missouri region. Therefore, cooperation and coordination among all the jurisdictions within any watershed is critical to taking a watershed approach to the solving of problems like nonpoint source pollution. More on this topic appears in the Regional Description section.

Concerning this watershed based approach, segments of the separate watersheds are further subdivided into increasingly smaller "hydrologic units" so that distinct watersheds may be broken into more manageable sizes for study. Watersheds (or hydrologic units) have been assigned identification numbers so that the several agencies working with them can be in agreement on the piece of land they are studying. There are 2-digit, 4-digit, 6-digit, 8-digit, 11-digit, and 14-digit watersheds. The more digits, the smaller the watershed identified. The watershed approach has been endorsed by leading federal agencies like the Environmental Protection Agency and the U.S. Department of Agriculture. It should be remembered that these watersheds define surface water drainage areas only, and while interacting with groundwater areas and political boundaries, they are but pieces of the bigger picture of the interrelationships of water supply and water use. A detailed explanation of watersheds with illustrations can be found in Chapter 3 - Regional Description in the Water Resources section.

Temporal Aspect of Water Use

Times change, and styles change. Per capita, more water is used today than every before. Hydropower use has evolved from water wheels that turned the stones of grist mills of early Missourians to the large electrical generating plants of today. Bathing, clothes washing, and other occasional uses of water by Missouri's previous generations was nothing compared to the water use demands of today's large population of Missourians. Greater demands, in each generation, have resulted in efforts to supply ever-greater quantities of finite supplies of water to our population. Not only is it just more people using more water, but rather more people using greater quantities of water in a greater variety of ways.

Sources:

Meinkoth, Michael, Archaeological Field Director, Missouri Department of Transportation (MoDOT), Jefferson City, Mo., November, 2001, personal communication to Richard M. Gaffney, Missouri Department of Natural Resources.

Missouri Department of Transportation (MoDOT), 1999, The Callaway farms site, leaflet authored and published by Cultural Resources staff of the department, Jefferson City, Mo., for public distribution.

Office of Social and Economic Data Analysis (OSEDA), 1999, available online at http://www.oseda.missouri.edu/

U.S. Geological Survey, Rolla, Mo., information concerning hydrologic units.

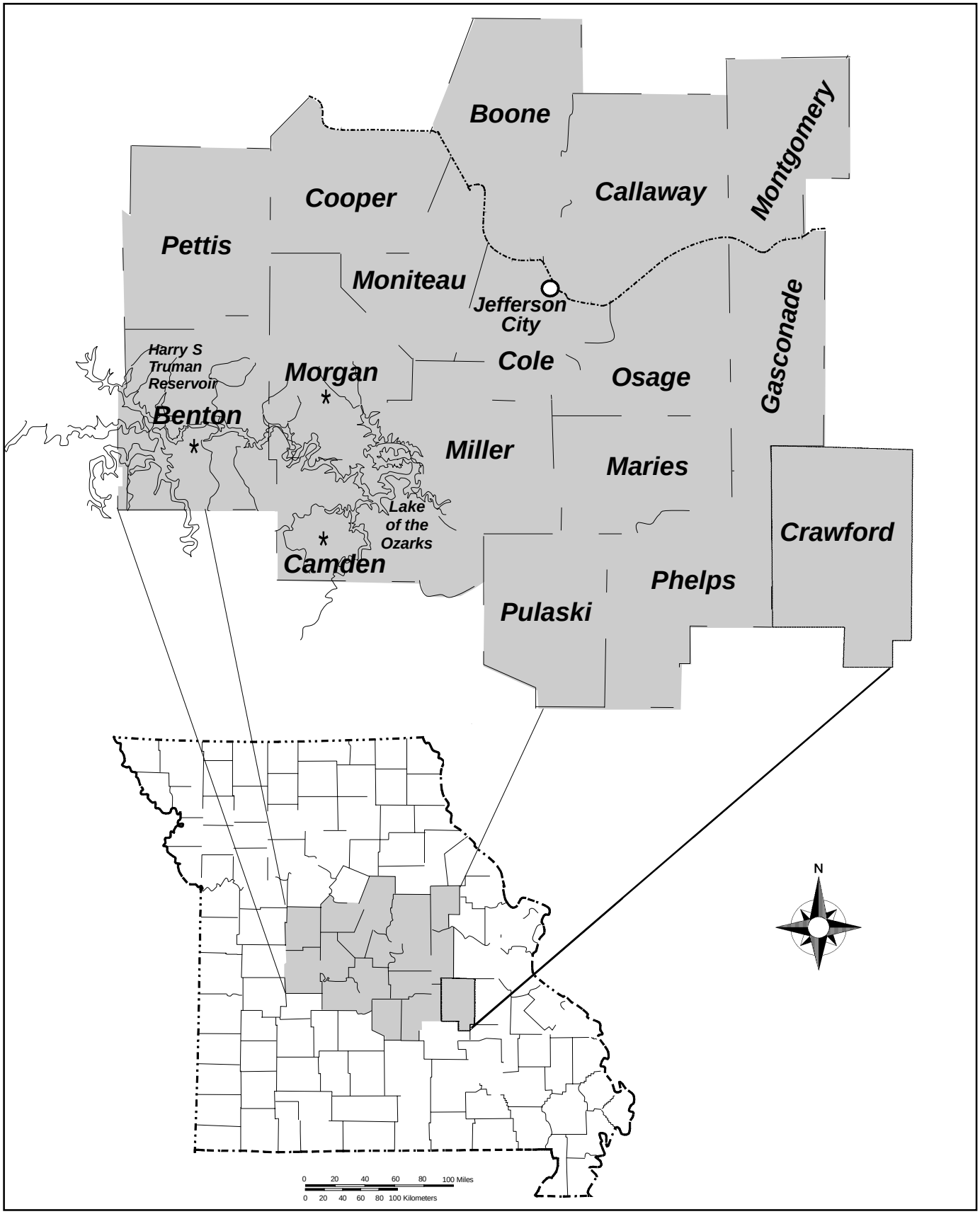

Figure 2. Map showing counties of central Missouri and counties with highest ìopen countryî rate (✻) of growth.

2. Acknowledgments

We thank the following people for their guidance and support in the preparation of this State Water Plan report: Stephen M. Mahfood, Director of the Missouri Department of Natural Resources, Dr. J. Hadley Williams, former Director of the department's Division of Geology and Land Survey (DGLS) and State Geologist, and Mimi Garstang, former Assistant Director and presently Director and State Geologist of the department's Geological Survey and Resource Assessment Division (GSRAD) (previously DGLS).

The State Water Planning staff is grateful for the help of the department's Water Protection and Soil Conservation Division (formerly Division of Environmental Quality), Jefferson City Regional Office staff, under the direction of former Administrator Robert Hentges, for initial identification of water use problems and opportunities in the central Missouri area.

In addition, we acknowledge the contributions made by the Missouri Departments of Agriculture, Conservation, Economic Development, Health, and Public Safety, and the University of Missouri. In particular, we thank the following individuals who coordinated and contributed to the responses of their respective agencies: Marla Young and Don Yoest, Agriculture; Jim Czarnezki and Alan Buchanan, Conservation; Kevin Highfill and Sallie Hemenway, Economic Development; Stan Cowan, Randall Maley, and Karen Yates, Health; Capt. (formerly Sgt.) Hans Huenink, Public Safety; John Howland, Transportation; and Chris Barnett and David Hammer, University of Missouri - Columbia.

We appreciate the help of employees of the department's Public Drinking Water Program (PDWP) and Water Pollution Control Program (WPCP), for help with technical data in several topic areas.

We extend our thanks to Terry Barney and Tracey Wiggins of the Natural Resources Conservation Service, USDA state office, Columbia, for their help with 8-digit, 11-digit, and 14-digit Hydrologic Unit maps in Missouri.

We also express our appreciation to Susan Dunn (GSRAD) for preparing the illustrations and overall layout of this report, and coordinating the printing. The Water Resources Program staff members contributing to this State Water Plan project include Cynthia N. Brookshire, Sherry Chen, John D. Drew, Charles B. DuCharme, W. Terry Frueh, Richard M. Gaffney, Charles R. Hays, Paul R. Lenz, Bruce W. Netzler, and James E. Vandike. Mary Woodland provided clerical assistance. Steve McIntosh is the Director of the division's Water Resources Program, and served as Project Manager.

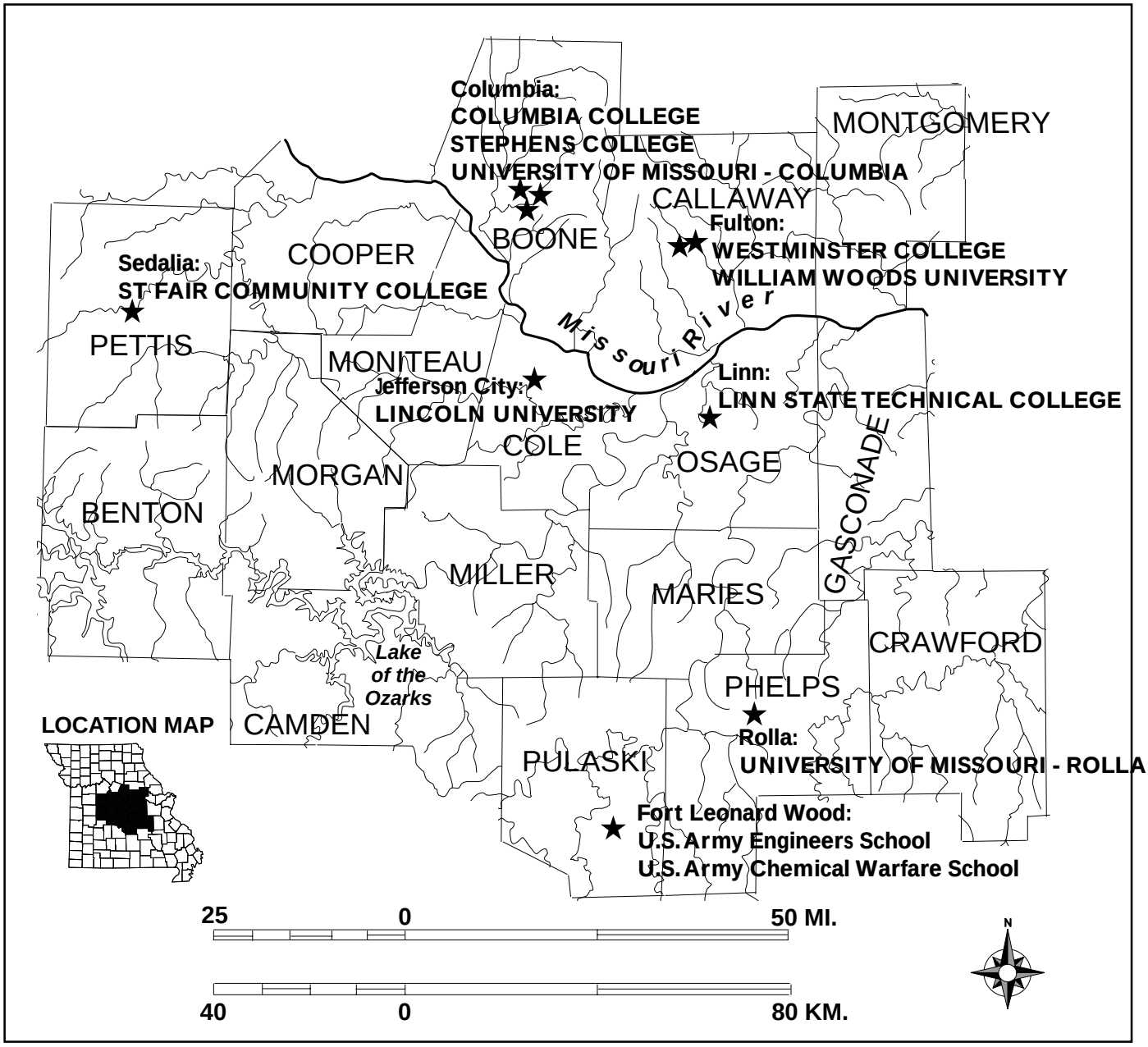

Figure 3. Locations of colleges and universities in central Missouri.

Regional Description

The Missouri Department of Natural Resources (the department), has six regional offices located throughout the state. These offices are designated by the area in which they are located and include the Kansas City, Southwest, Southeast, St. Louis, Jefferson City, and Northeast regional offices.

Within the boundaries of jurisdiction of the Jefferson City Regional Office are seventeen counties in central Missouri. These counties are Benton, Boone, Callaway, Camden, Cole, Cooper, Crawford, Gasconade, Maries, Miller, Moniteau, Montgomery, Morgan, Osage, Pettis, Phelps, and Pulaski (figure 1). Eight of the counties in this region are located along the Missouri River. Because of the region's location in central Missouri, it will alternately be referred to as the Jefferson City region or the central region.

Colleges and Universities

The seventeen counties in this region are home to several colleges. The list includes University of Missouri at Columbia (Boone County); University of Missouri at Rolla (Phelps County); Columbia College, Columbia (Boone County); Lincoln University, Jefferson City (Cole County); Linn State Technical College, Linn (Osage County); State Fair Community College, Sedalia (Pettis County); Stephens College, Columbia (Boone County); Westminster College, Fulton (Callaway County); and William Woods University, Fulton (Callaway County) (figure 3).

Regional Transportation

Motor vehicle transportation in the region is provided by two interstate highways and other federal and state highways. Interstate-70 trends east to west along the northern part of the region and I-44 trends generally northeast to southwest along the southern part of the region. Part of I-44 follows generally the northern segment of the 1839 Trail of Tears on which the Cherokee Nation was moved by the U.S. Army from their Appalachian Mountain homes to northeastern Indian Territory, now Oklahoma. This is a National Historic Trail, and is marked as an Auto Tour Route. In addition, I-44 follows closely the path of Historic U.S. Route 66. Several national highway routes also traverse the region. U.S. 65 and U.S. 63 run north to south across the area, and U.S. 50 and U.S. 54 each trend east to west, crossing each other at the Missouri River in Jefferson City (figure 4). Portions of highways 65, 54, 63, and 50 are divided, multilane roads with partially controlled access. The Missouri Department of Transportation (MoDOT) is presently converting additional sections of these roads to divided multilane highways. Missouri numbered highways, lettered state roads, and county roads complete the road and highway system. Another National Historic Trail, the Lewis and Clark Trail, parallels the Missouri River, using state and federal highways, and marked with special signs.

There are several freight railways crossing the area. Kansas City is a common western destination while Chicago and St. Louis are common eastern destinations. Gateway Western, a Missouri-based railroad company, runs freight through the northern part of Callaway County. Other freight railways are operated by Burlington Northern-Santa Fe and Union Pacific. A short line freight operation in Boone County is the Columbia Terminal Railway, nicknamed COLT. Railway passenger service is pro-

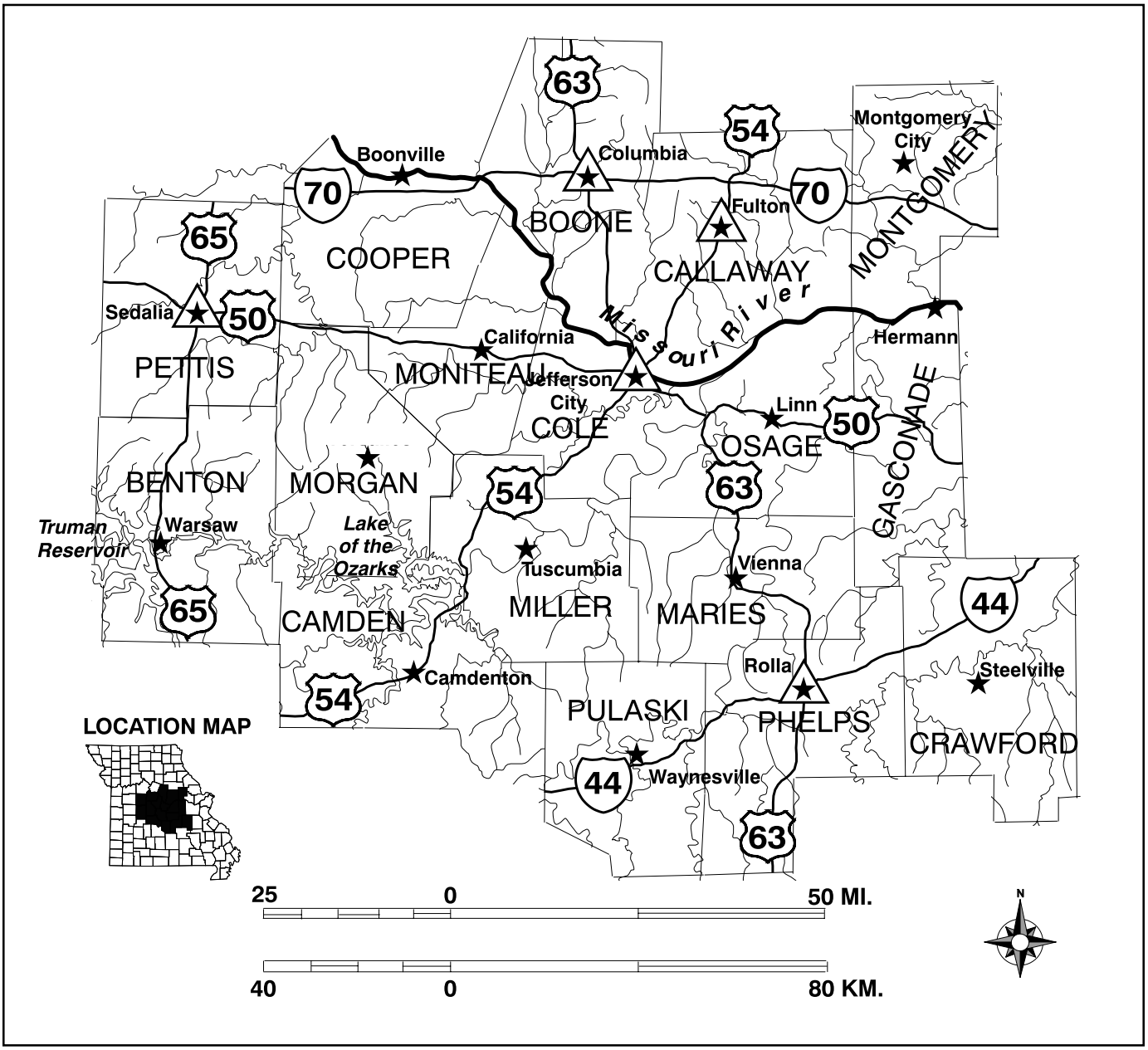

Figure 4. Major roads and cities in central Missouri. Stars indicate the county seat.

vided by an AMTRAK route that connects Kansas City and Chicago. The Kansas City to Chicago route has stations in the central Missouri region at Hermann (Gasconade County), Jefferson City (Cole County), and Sedalia (Pettis County) (figure 5). There are two trains in each direction, each day. These services are subsidized by MoDOT, and the number of riders has been increasing, annually.

The Missouri River provides commercial and recreational navigation in this region. Barge terminals are located at Rocheport (Boone County), Huntsdale (Boone County), Marion (Cole County), Jefferson City (Callaway County), Mokane (Callaway County), Chamois (Osage County), Gasconade (Gasconade County), and Hermann (Gasconade County) (figure 6). In addition, there are river access ramps provided by the Missouri Department of Conservation (MDC) at Blackwater Bridge, DeBourgmont Access, and Wooldridge Access (all in Cooper County), Providence Access on Perche Creek near McBaine (Boone

County), Marion Access (Cole County), Capitol View Access on Cedar Creek (Callaway County), North Jefferson City (Callaway County), the Moreau River-Route 50 ("Moreau 50 Access") (Cole County), Hartsburg (Boone County), Mokane (Callaway County), Chamois (Osage County), and Gasconade Park Access and Hermann Riverfront Park (both in Gasconade County).

Regional airports are located at Jefferson City, Sedalia, Columbia, Vichy, Rolla, Osage Beach, and Warsaw. Fort Leonard Wood near St. Robert in Pulaski County hosts a military airfield, and numerous small or private airfields are located across the seventeen-county area.

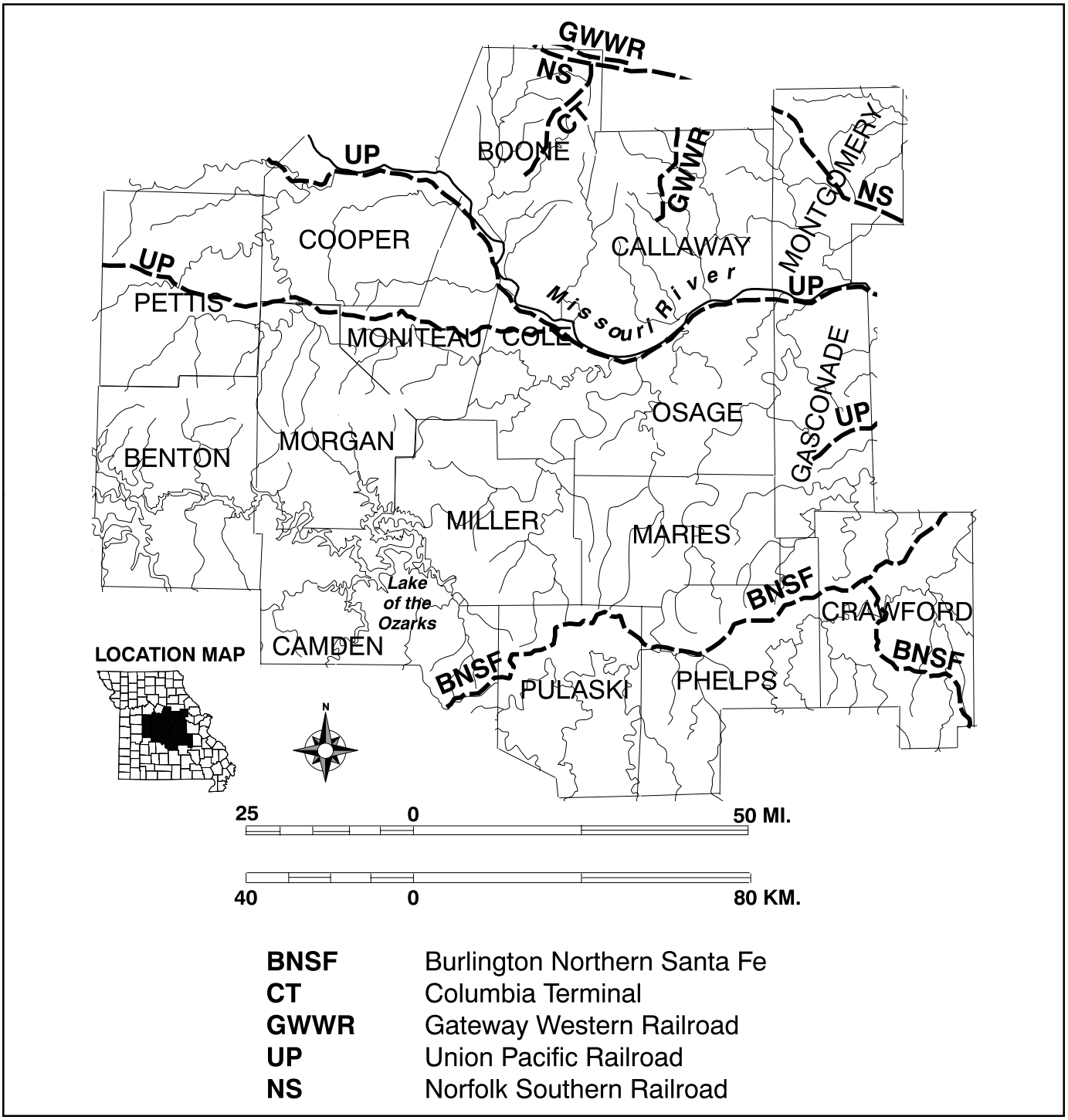

Figure 5. Railways in central Missouri.

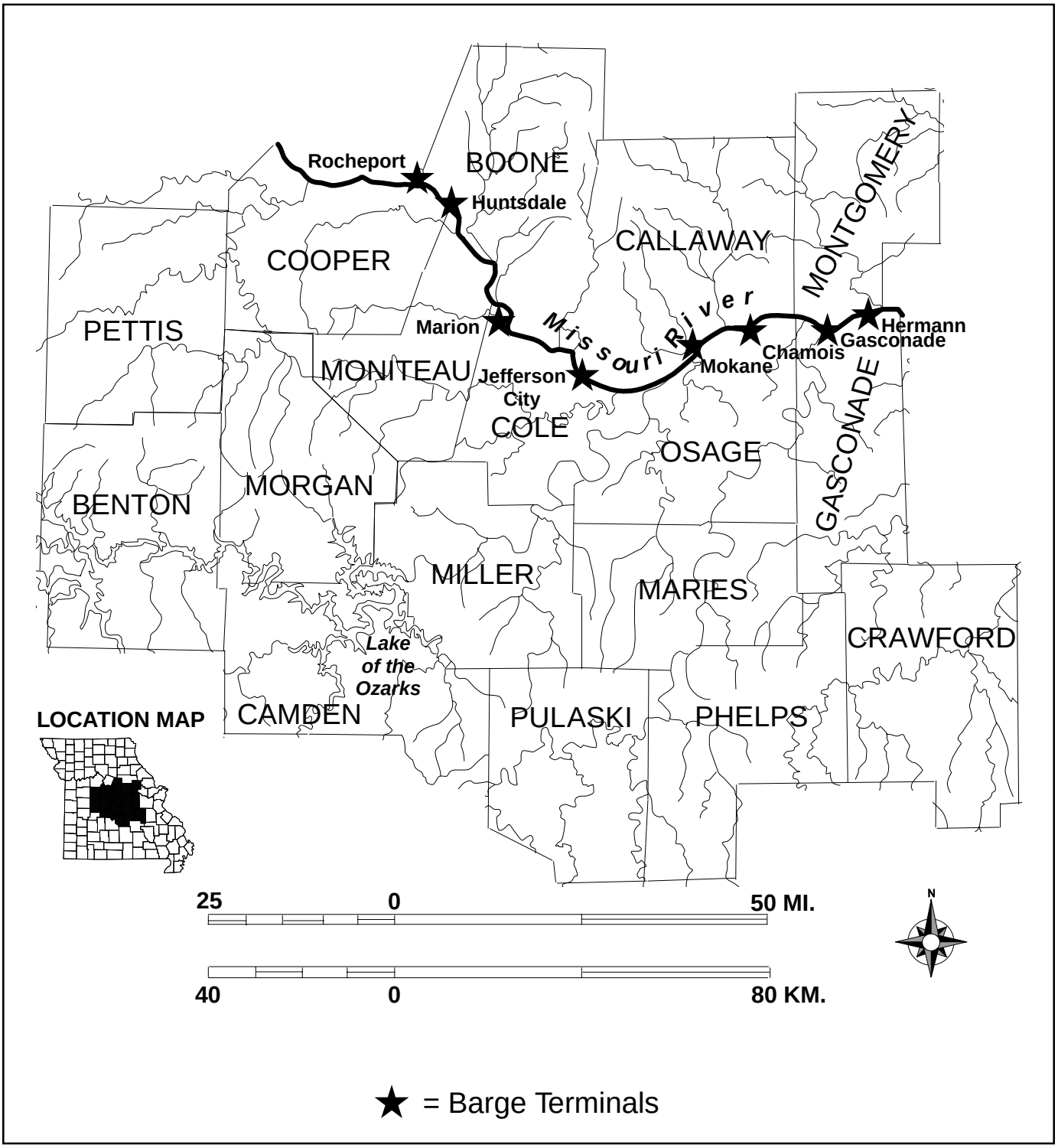

Figure 6. Barge terminals along the Missouri River in central Missouri.

Population Characteristics

Columbia, with 84,531 people, is the largest city in the region. The second largest city in the region is Jefferson City, in Cole County. Total population for the region, according to the 2000 census, was 568,858 (table 1). This represents an average of 55.3 persons per square mile. Fifty seven percent of the total population was rural residents. By age groups, 28.1 percent of the population is less than 20 years old, 37.1 percent is 20 to 44, 21.8 percent is 45 to 64, and 13 percent is 65 or older. The median age is 35.2. The 2000 census identified 264,814 housing units and 218,983 households within the region (Census Bureau, 2001).

Education statistics list 8.1 percent of the region's residents with less than a 9th grade education, 8.5 percent had greater than 9th grade but less than 12th, 21.3 percent had graduated from high school, 9.6 percent were college degreed and 4.3 percent held graduate degrees. Employment and income data show 10.6 percent of the population were managers/professionals, 13.3 percent held technical/sales/administrative positions, 6.5 percent were employed in a service industry, 1.9 percent farming and farm related, and 12.2 percent in "other" employment sectors. The average annual household income was $29,273 and the average home value was $52,496. The unemployment rate for the region was at 2.7 percent. Approximately 13.2 percent of the region's residents were at or below the poverty level (OSEDA, 1999) (table 2).

County Name	County Seat	Major Town(s)	River Port
Benton -17180	Warsaw-2,070	Cole Camp-1,028	
Boone-135,454	Columbia-84,531	Centralia-3,774	
		Ashland-1,869	
Callaway-40,766	Fulton-12,128	Holts Summit-2,935	Mokane-188
Camden-37,051	Camdenton-2,779	Osage Beach-3,662	
Cole-71,397	Jefferson City-39,636	Jefferson City-39,636	
Cooper-16,670	Boonville-8,202		
Crawford-22,804	Steelville-1,429	Cuba-3,230	
		Bourbon-1,348	
Gasconade-15,342	Hermann-2,674	Owensville-2,500	Hermann-2,674
Maries-8,903	Vienna-628	Belle-1,344	
Miller-23,564	Tuscumbia-218	Eldon-4,895	
		Osage Beach-3,662	
Moniteau-14,827	California-4,005	Tipton-3,261	
Montgomery-12,136	Montgomery City-2,442	Wellsville-1,423	
Morgan-19,309	Versailles-2,565		
Osage-13,062	Linn-1,354		
Pettis-39,403	Sedalia-20,339		
Phelps-39,825	Rolla-16,367	St. James-3,704	
Pulaski-41,165	Waynesville-3,507	Richland-1,805	
		St. Robert -2,760	
		Dixon-1,570	

Table 1. Central Missouri region counties and their population statistics (regional population = 568,858.) Source: Census Bureau Website: www.census.gov/, June 2001.

	1990		2000	
Population of region	490,048		568,858	
Population per square mile	47.6		55.3	
Number of rural residents	282,384			
Population younger than 20 years old	141,919	29.0%	159,608	28.1%
Population between 20 and 39 years old	162,271	33.1%	210,873	37.1%
Population between 40 and 64 years old	120,195	24.5%	124,064	21.8%
Population 65 years old or older	65,633	13.4%	73,755	13.0%
Median age	32 yrs, 11 months		35 yrs, 2 months	
Number of households	182,427		218,983	
Median household income	$29,273			
Number of people below poverty level	64,667			
Total persons aged 25+ with less than a 9th grade education	39,804			
Total persons aged 25+ with a 9th to 12th grade education	41,813			
Total persons aged 25+ with a high school diploma	104,533			
Total persons aged 25+ holding undergraduate degrees	47,244			
Total persons aged 25+ holding graduate degrees	21,229			
Unemployed	13,297	5.7%		
Population employed in management and professional occupations	51,831	22.4%		
Population employed in technical, sales or administrative occupations	65,401	28.3%		
Population employed in service occupations	31,783	13.7%		
Population employed in farming, forestry or fishing	9,206	4.0%		
Population employed in other occupations	59,784	25.8%		
Total available workforce	231,302			
Number of housing units	226,586		269,814	
Average home value	$ 52,496			

Note: At the time of publication, the complete census data for 2000 was not yet published.

[1]The age divisions for the 2000 census were: 18 years and younger, 19-44 years old, 44-65 years old, and over 65 years old.

Table 2. Summarized census data for central Missouri counties. Source: U.S. Department of Commerce, Bureau of the Census, www.census.gov/, October, 2001.

Industry, Commerce, and Agriculture

Industry in the central region is varied. Retail trade and service-oriented businesses top the list of industries in all counties, with retail-trade establishments equaling thirty percent or more of total businesses in Benton, Morgan, Camden, and Pulaski counties (U.S. Dept. of Commerce, 1994). Agricultural services are prevalent throughout the entire region but are somewhat concentrated in Pettis, Cooper, Boone, Callaway, Montgomery, Morgan, Moniteau, and Osage counties.

The central region of Missouri can be described as having mature, steep-sided deep valleys separated by more gently rolling uplands. Soils are typically thin except in the upland areas, where thick deposits of unconsolidated permeable residuum (weathered rock) exist. Additionally, some loess deposits (windblown silt) along the Missouri River have fairly high natural fertility and are favorable for intensive agriculture. The land farther from the river (upland) has soils that contain deep, organic-rich horizons that are also very favorable for crops. However, erosion control is required where steep slopes exist. Grain sorghum, soybeans, corn, wheat, and hay are the primary crops in the region. Tobacco, vegetables, and orchards round out the crop list. None of the counties in the central region were included in the 1997 top ten list for production of soybeans, corn, wheat, sorghum, or hay. However, Boone, was ranked seventh for production of tobacco (Missouri Agricultural Statistical Services, 1998). The floodplain north of the Missouri River, west of Jefferson City, is used for growing grass sod (largely for residential lawnscaping), and this crop is spray irrigated from shallow wells in the alluvial aquifer. Elsewhere in the Missouri River floodplain, corn, wheat, and soybeans are the primary crops grown in this central region. Because the water table in the floodplain is high, floodplain soils generally produce well, even in a drought period.

The success of livestock production in Missouri is influenced by several factors, including soil type, climate, terrain, location, and market availability. The moderate climate typical for this area is not associated with diseases and pests associated with higher temperatures, yet animals do not have to endure extremely harsh winters. Additionally, there are generally long growing seasons for pasture grasses. This could be the reason that all counties in this region except Montgomery County had higher livestock sales than crop sales in 1997 (OSEDA, 2001). Osage County ranked tenth for beef cattle raising and sales in 1997. The total of all top ten counties for beef cattle raising represents 20 percent of the state's total beef cow numbers. The region did not have any top ten counties for the following animal populations: milk cow, all cattle and calves, or hog. Pettis, Miller, and Morgan counties all had increases in total livestock sales in 1997, attributed to increased contract poultry operations. Prior to the War Between the States, Callaway County was noted for production of horses and mules. Today, there are numerous horse raising operations in the region.

Physical Characteristics

Climate

Central Missouri has a humid, continental climate with average annual temperatures from about 53^0 F to 55^0 F. Long-term annual precipitation averages from 35 to 41 inches throughout the region (figure 7). Rainfall amounts are generally highest in the spring and lowest in the fall and winter months. Evapotranspiration, the process of precipitation being returned to the air through direct evaporation or by transpiration of plants, consumes from 28 to 30 inches of the annual rainfall. Surface runoff of precipitation averages from 9 to 12 inches annually in the area.

Physiography

The northeastern and central areas of the central Missouri region (parts of Cooper, Moniteau, Boone, Callaway, and Montgomery Counties) are characterized by glaciated plains. These counties lie in the dissected till plains (dissected by streams flowing to the Missouri River)

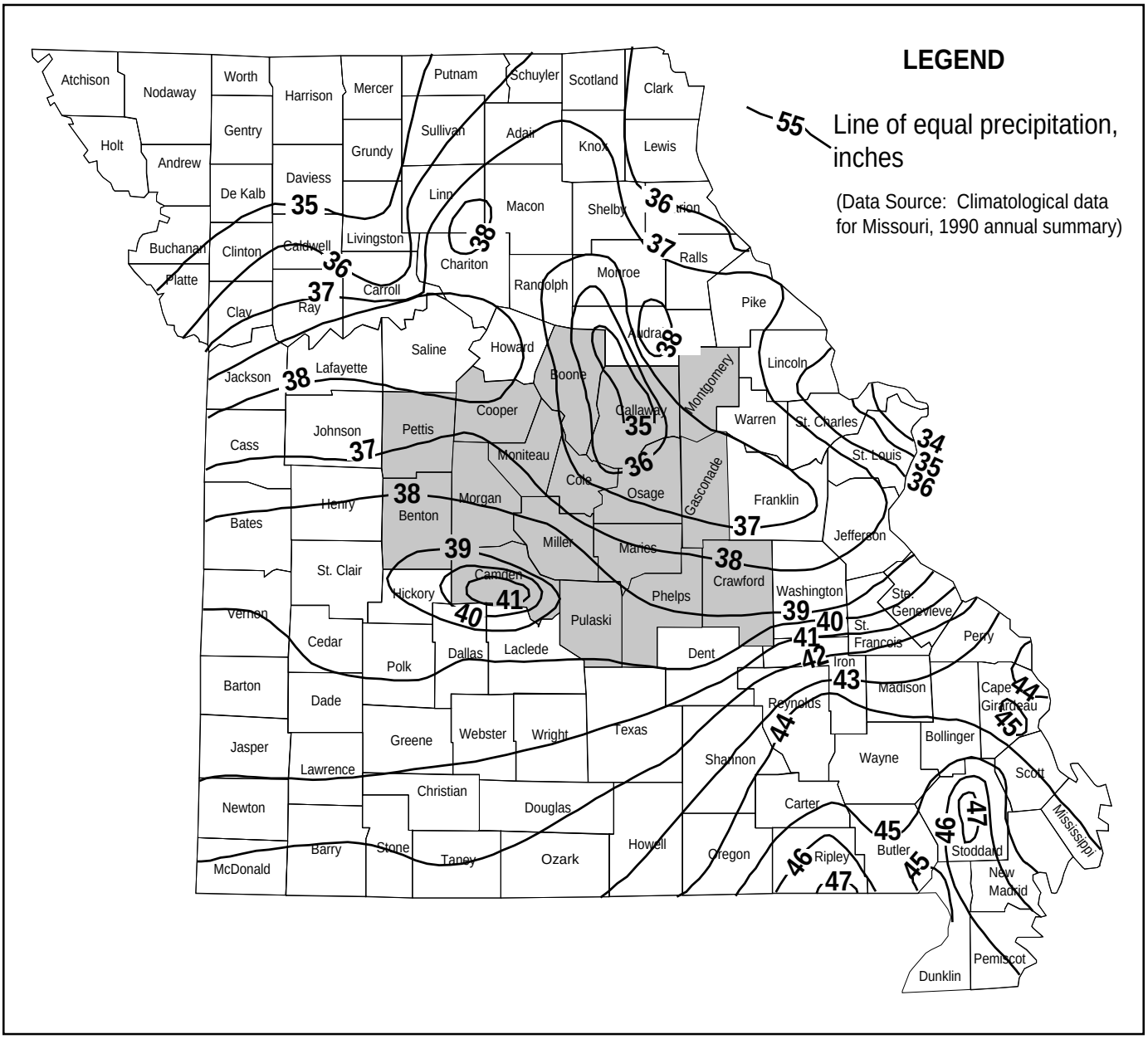

Figure 7. Average annual precipitation for Missouri.

subprovince of the Central Lowlands physiographic province (figure 8). These counties mark the southern extent of glaciation in Missouri, which roughly parallels the Missouri River. The Missouri River formed as a result of glacial meltwater runoff and Pleistocene Age stormwater runoff. The Missouri River carried sometimes blufftop-to-blufftop floods, together with their sediment, to the Mississippi River and the Gulf of Mexico, then located in the area we call the Bootheel region of the state. The advance and retreat of two great ice sheets laid down thick deposits of glacially derived sediments over the bedrock and earlier landscape of northern Missouri. The unconsolidated deposits left by glaciers consist of clay, silt, sand, gravel, and boulders derived from physical and chemical weathering of older rocks to the north. Soils in this area vary in depth and are erodible. Groundwater resources in this area differ, dependent on location with respect to the freshwater-salinewater transition zone. This zone is

an area that marks the transition from freshwater to salinewater in the subsurface (figure 9). Generally, aquifers on the north side of the transition zone contain water that is so highly mineralized it cannot be used without extensive treatment. Additionally, the deeper the aquifer, the higher its mineral content. However, aquifers on the south and east sides of the transition zone contain water that is of usable quality.

The present-day Missouri River runs in a channel the river has carved for itself in sediments (alluvium) that it has deposited over thousands of years. The sediment allows river water to be stored at high flows, and release water at low flows, thus keeping the Missouri River flowing even during a severe drought. Generally, the water table in the floodplain sediments (alluvium) is higher than the stage

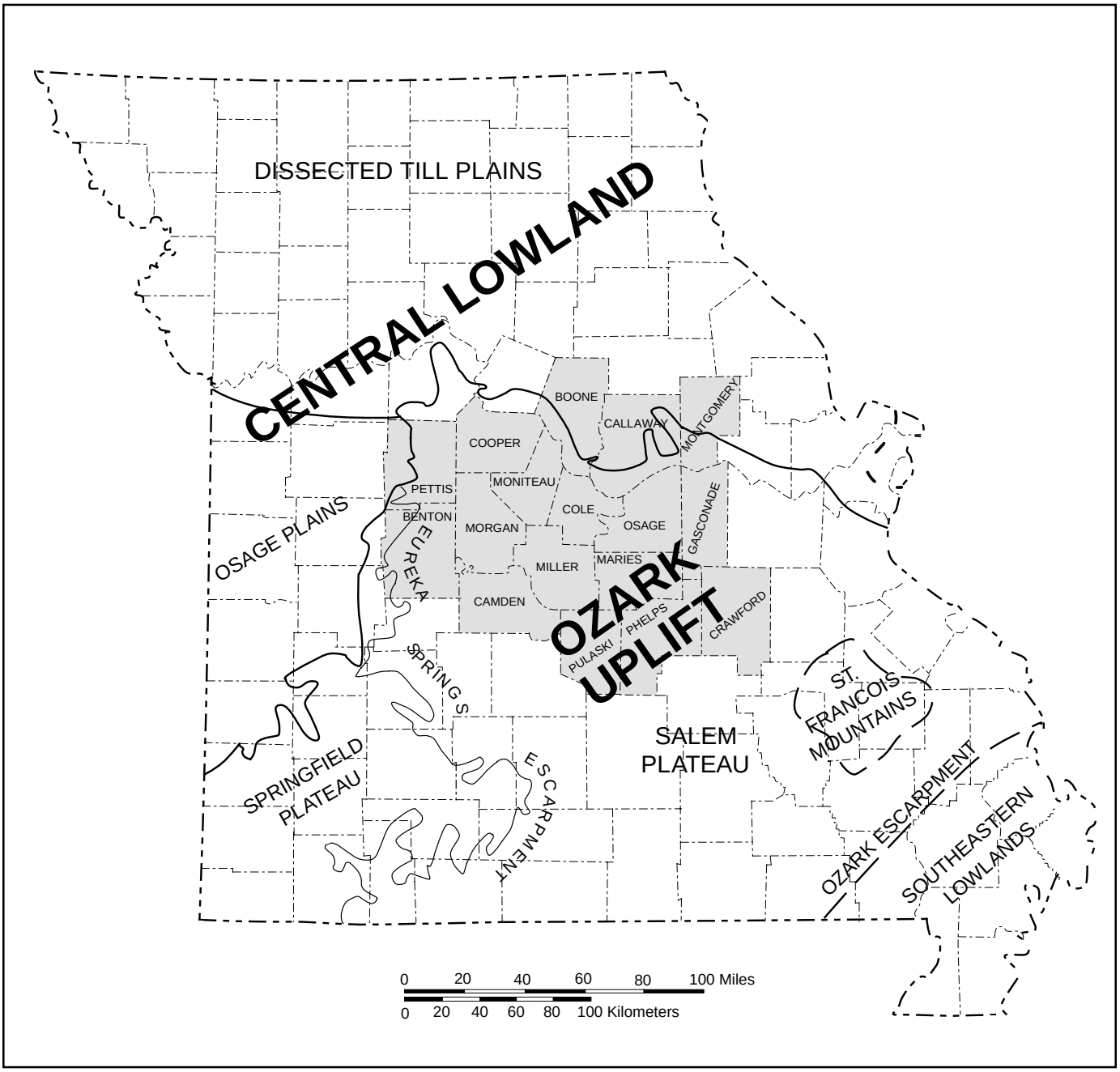

Figure 8. Physiographic provinces of Missouri. Source: Missouri Department of Natural Resources' Geological Survey and Resource Assessment Division.

of the river at any given time. The relatively high water table, combined with the natural capillary action of water in soil, makes the floodplain soils particularly productive. The water in the alluvial aquifer is used for drinking water supplies. Most notable among the cities of the central Missouri region, Columbia has numerous wells in the vicinity of Easley, south of the city.

The western one-third of Pettis County lies in the Osage Plains subprovince of the Central Lowlands physiographic province. These plains are unglaciated and have more gentle topography than the dissected till plains. This is generally because more competent Pennsylvanian-age shale, limestone, and sandstone underlie the area. As stated previously, this part of the central region coincides with the freshwater-

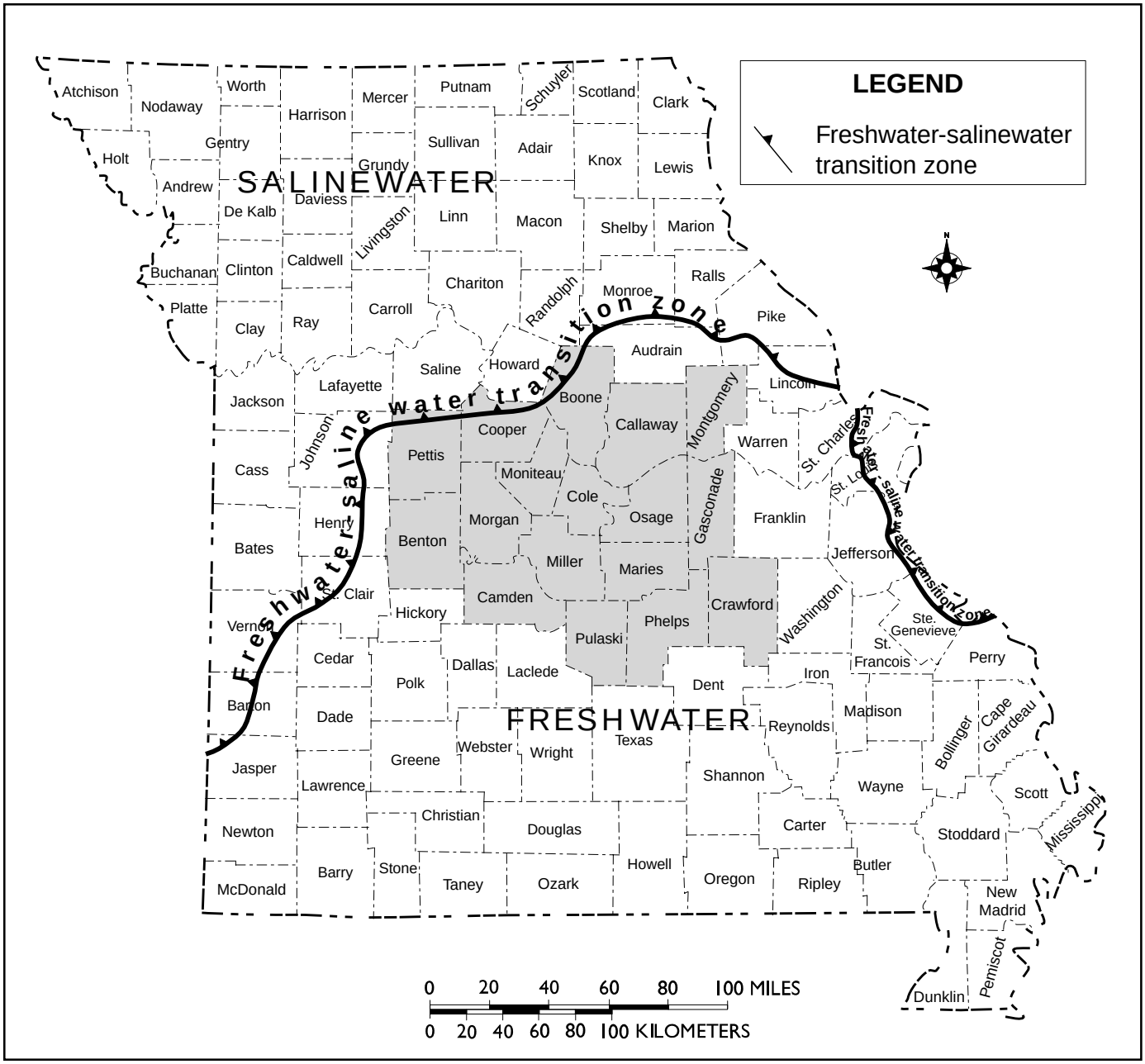

Figure 9. Freshwater-salinewater transition zone. Source: Missouri Department of Natural Resources' Geological Survey and Resource Assessment Division.

salinewater transition zone. Therefore, the deeper Springfield Plateau aquifer and the Ozark Aquifer contain water too highly mineralized for use. Nearer the surface, Pennsylvanian-age rocks locally are capable of yielding small amounts of marginal-quality water. Generally, the minerals with the highest concentration are sodium and chloride. This is the result of longer contact of the water with the surrounding bedrock due to poor circulation and long-term residence (Miller and Vandike, 1997).

The western one-third of Benton County is in the Springfield Plateau of the Ozark Plateau subprovince of the Interior Highlands Province. A thick sequence of Mississippian-age rocks overlies older Ordovician rocks. These formations are primarily limestone and are characterized by karst topography. The term "karst topography" refers to carbonate terrain that contains features such as sinkholes, caves, springs, and losing streams. The karst in the Springfield Plateau contains caves that are still active groundwater conduits with many cave entrances located in sinkholes (Miller and Vandike, 1997). Groundwater resources are generally good with some instances of localized contamination in the upper zones due to extreme weathering of the bedrock, which allows rapid infiltration, and movement of contaminants in the subsurface. Recharge to the aquifer is primarily from precipitation and the chemical quality of the groundwater is generally good.

The remainder of the central region is included in the Salem Plateau of the Ozark Plateau subprovince. This area is composed of mostly Ordovician- and Cambrian-age sedimentary rocks. The landscape is maturely dissected with steep-sided valleys separated by more gently rolling uplands. Modern soils are typically thin except for the upland areas. In those areas, bedrock is overlain by thick deposits of unconsolidated residuum (weathered rock), typically permeable, allowing high rates of groundwater recharge. Karst topography here is widespread, and on a larger scale than in the Springfield Plateau area. Water-supply wells in this area can yield large quantities of good-quality water. The aquifer in this area is known as the Ozark Aquifer, and is unconfined. It receives recharge primarily from precipitation and lateral movement of groundwater from outcropping bedrock.

Geology

The majority of the central Missouri region (central and south) includes Ordovician-age rock layers made up of shales, sandstones, dolomite, and limestone (all sedimentary rock). These formations are greatly affected by weathering. The action of water has created well-defined subsurface drainage systems that carry surface water underground, which then emerges in springs (Vandike, 1995). Sinkholes are common in this region. It is much more difficult to separate groundwater from surface water in this area, as compared to the northern part of the region, where groundwater and surface water are distinctly different.

The northern and east-central portion of the region includes the Mississippian, (limestone) Silurian-Devonian, and Pennsylvanian rock layers (Vandike, 1995) (figure 10, table 3).

The geology of the Missouri River alluvium has been greatly influenced by the Pleistocene glaciers. "As the glaciers advanced into Missouri, the ancestral Missouri River was blocked with ice. Water from the drainage upstream of the blockage was diverted to the south and west, forming new drainage channels. After the melting of the ice sheets, the original drainage patterns were not reoccupied.

"Melt water from glaciers during the Pleistocene generated tremendous volumes of runoff, carrying immense quantities of sediment that had to be transported by the Missouri River. In response, the river carved a much deeper and wider channel than the river occupies today. Glacially-derived sediments ranging in size from clay particles to boulders were transported in the melt water. A considerable thickness of the sediments was deposited within the river valley to form the Missouri River alluvial aquifer." (Miller and Vandike, 1997).

Water Resources

Surface waters and watercourses usually are discussed in terms of their watersheds. Watersheds are topographically defined areas, within which all apparent surface water runoff drains to a stream or other water body. In the U.S.A., larger watersheds usually are called "basins," such as the Missouri River Basin.

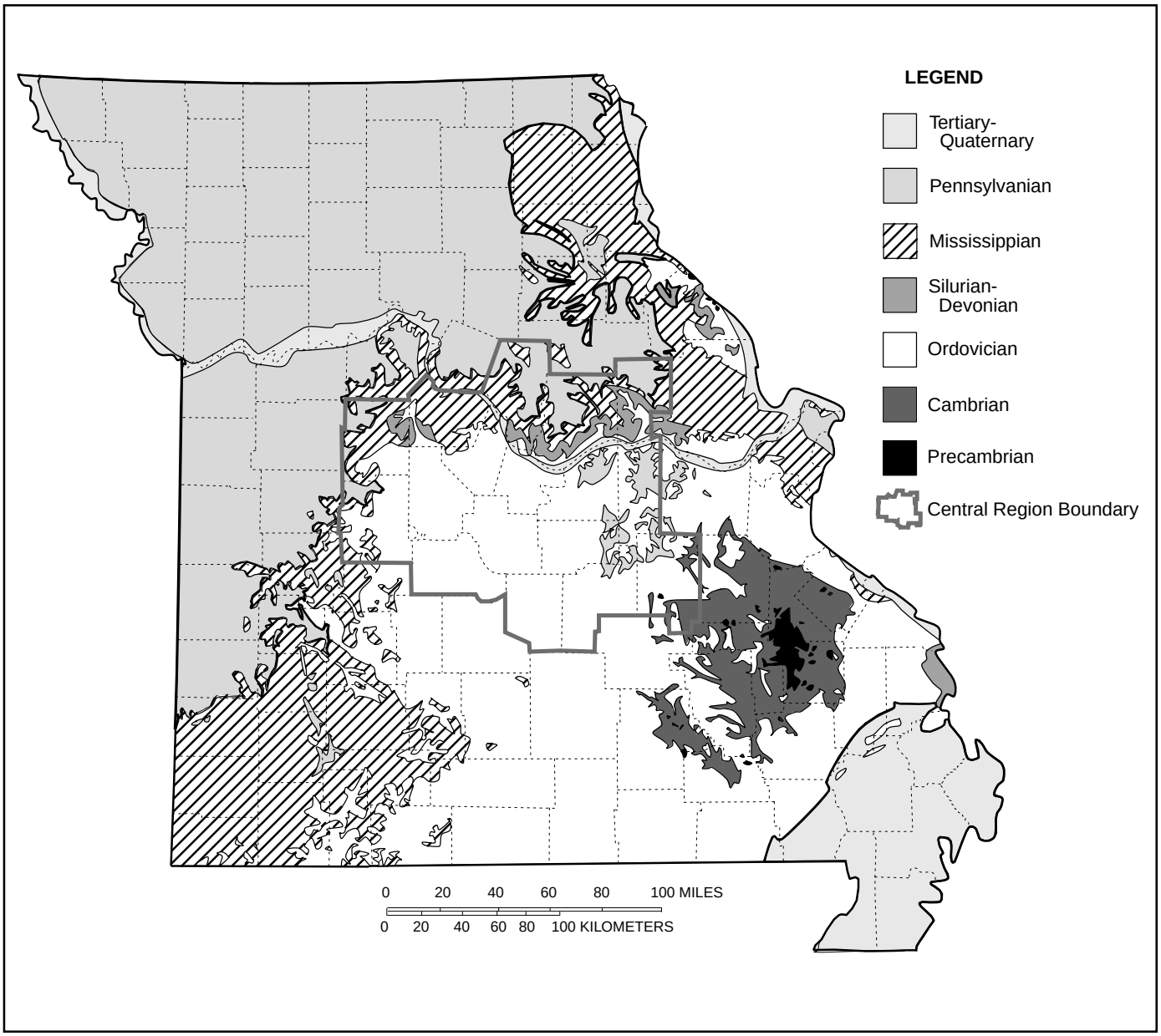

Figure 10. Generalized geologic map of Missouri. Source: Missouri Department of Natural Resources' Geological Survey and Resource Assessment Division.

Hydrologic Units (HUs) also are topographically defined drainage areas. These can be watersheds, or downstream segments of a watershed. The HU concept was developed by hydrologists to organize drainage areas across the United States into a hierarchical system of drainage areas of roughly equal size at any given level of the hierarchy. Because natural watersheds are of such varying sizes, and because comparisons and organization were important for some hydrological work, HUs fulfill certain needs. The HU concept assigns a unique hydrologic unit code (HUC) to each defined drainage area.

The standardized system of hydrologic units that we use was developed in the mid-1970s by the U.S. Geological Survey (USGS) under the sponsorship of the U.S. Water Resources Council. This system divides the country into Regions, Sub-regions, Accounting Units, and Cataloging Units. A hierarchical HUC consisting of

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT	HYDROGEOLOGIC UNIT
Quaternary	Holocene		Alluvium	Missouri and Mississippi rivers and in Mississippi embayment, 500-2000 gpm. Yields are less along smaller rivers
	Pleistocene		Loess, till, and other drift, sand and gravel	Drift and till typically yield 0-5 gpm. Drift-filled preglacial valleys typically yield 50-500 gpm.
Tertiary	(undifferentiated)			Wilcox Group (Mississippi embay-ment only), 50-400 gpm.
Cretaceous	(undifferentiated)			McNairy formation (Mississippi embayment only), 200-500 gpm.
Pennsylvanian	(undifferentiated)			Northern and west-central Missouri, 1-20 gpm, regionally forms a confining layer.
Mississippian	Chesterian		(undifferentiated)	
	Meramecian		(undifferentiated)	Springfield Plateau aquifer
	Osagean		Keokuk Limestone Burlington Limestone Grand Falls Formation Reeds Spring Formation Pierson formation	Southwest, central, and eastern Missouri, 5-30 gpm.
	Kinderhookian	Chouteau	Northview Formation Sedalia Formation Compton Formation	Ozark confining unit
			Hannibal Formation	
Devonian	(undifferentiated)			
Silurian	(undifferentiated)			
Ordovician	Cincinnatian		Orchard Creek shale Thebes Sandstone Maquoketa Shale Cape Limestone	
	Champlainian		Kimmswick Formation Decorah Formation Plattin Formation Joachim Dolomite Dutchtown Formation St. Peter Sandstone Everton Formation	Ozark aquifer (upper) Yield is greatest from St. Peter Sandstone Yields of 5 to 50 gpm are possible.
	Canadian		Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone Mbr.	Ozark aquifer (lower) Yields vary greatly with location and well depth. In Salem Plateau, yields are typically 50-500 gpm. In Springfield Plateau and central Missouri, yields are typically 500 to 1200 gpm.
Cambrian	Upper Cambrian		Eminence Dolomite Potosi Dolomite	
		Elvins	Derby-Doerun Dolomite Davis Formation	St. Francois confining unit.
			Bonneterre Formation Lamotte Sandstone	St. Francios aquifer Yields of 10 to 100 gpm are possible.
Precambrian	(undifferentiated)		Igneous, metasediments, and other metamorphic rock.	Not a significant aquifer

Table 3. Generalized section of Missouri's geologic units (after Vandike, 1995).

two digits for each level of the system is used to identify any HU of interest. The National Resource Conservation Service (NRCS) refers to the accounting unit areas (six digits) as "Basins" and the cataloging unit areas (eight digits) as "Sub-basins."

In the mid- to late-1970s, the NRCS followed with a fifth-level nationwide "watershed" coverage defined by three additional digits that resulted in an 11-digit hierarchy. In 1992, the NRCS released a draft National Instruction, 170-304, for mapping a sixth-level "sub-watershed" HU coverage, using a 14-digit coding scheme.

14-Digit Hydrologic Unit Hierarchy

Level 1 HUs (designated by two-digit codes) represent very large major drainage systems that the USGS refers to as Regions. At this level, the State of Missouri is part of four regions. Example: HU code 10 is the Missouri River Region (figure 11).

Level 2 HUs (designated by four-digit codes) represent large subdivisions of Regions, called Sub-Regions. At this level, Missouri has 12 sub-regions. Example: HU code 1030 is the Lower Missouri River Sub-Region (figure 12).

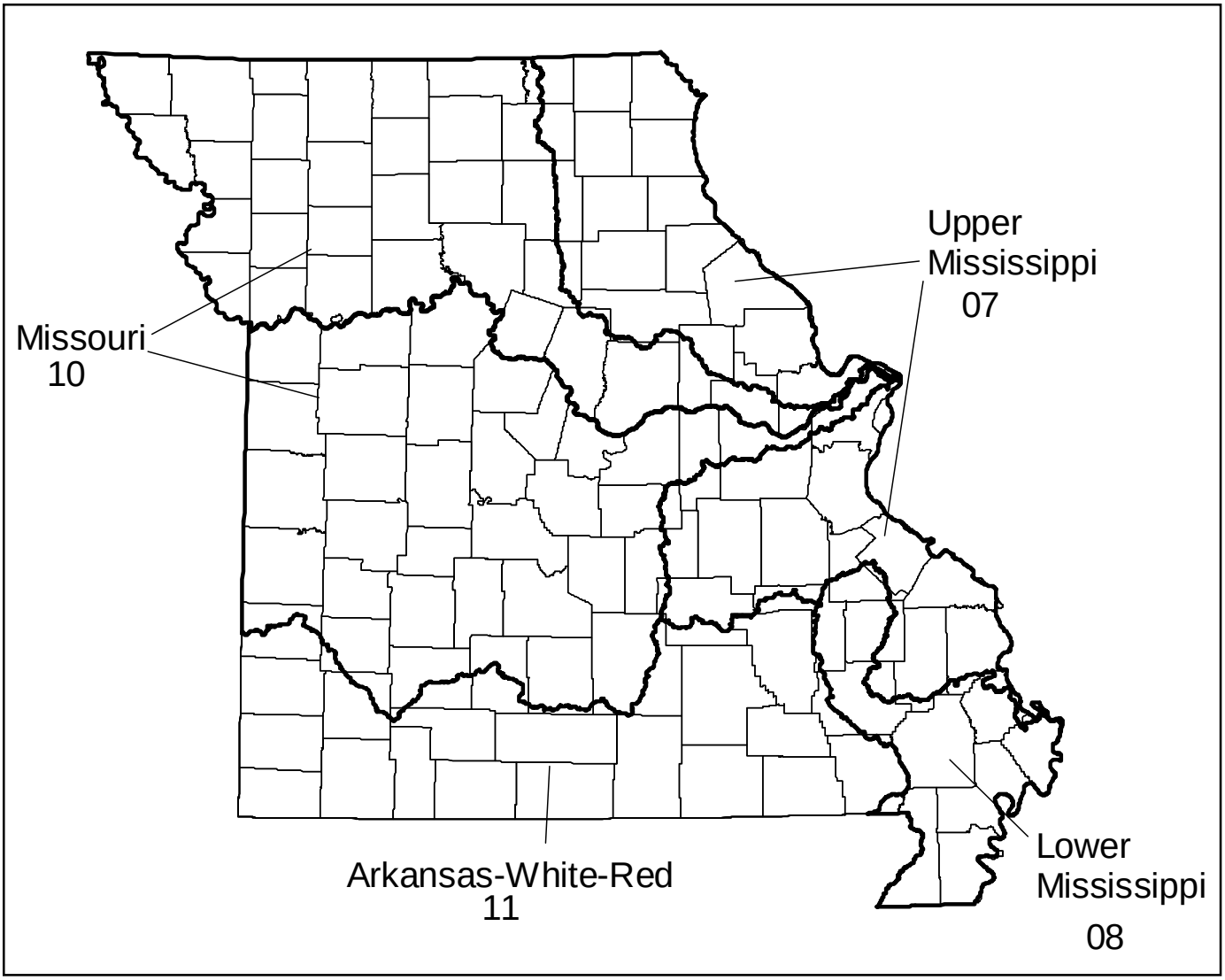

Figure 11. Two-digit hydrologic units of Missouri. Source: Missouri Department of Natural Resources.

Level 3 HUs (designated by six-digit codes) represent major river basins. These divisions are called accounting units by the USGS, and Basins by the NRCS. At this level, Missouri has 16 basins. Example: HU code 103001 is the Missouri River (Platte to Gasconade) Basin (Also called the "Lower Missouri-Blackwater HU"). This is a segment of the Missouri River (figure 13).

Level 4 HUs (denoted by eight-digit codes) are referred to as cataloging units by the USGS, and Sub-basins by the NRCS. At this level, Missouri has 66 sub-basins. Example: HU code 10300102 is the Missouri River Tributaries (Glasgow to Hermann) Sub-basin (or the Lower Missouri-Moreau HU") (figure 14).

Level 5 HUs (denoted by 11-digit codes) represent NRCS watersheds. Missouri has 500 11-digit "watershed" HUCs. Example: HU code 10300102190 is the Cedar Creek Watershed (Boone-Callaway counties) (figure 15).

Level 6 HUs (denoted by 14-digit codes) represent drainage units referred to as sub-watersheds. Missouri has 1,500 14-digit sub-watershed HUCs. Example: HU code 10300102190001 is the Cedar Creek Sub-watershed 1 (figure 16).

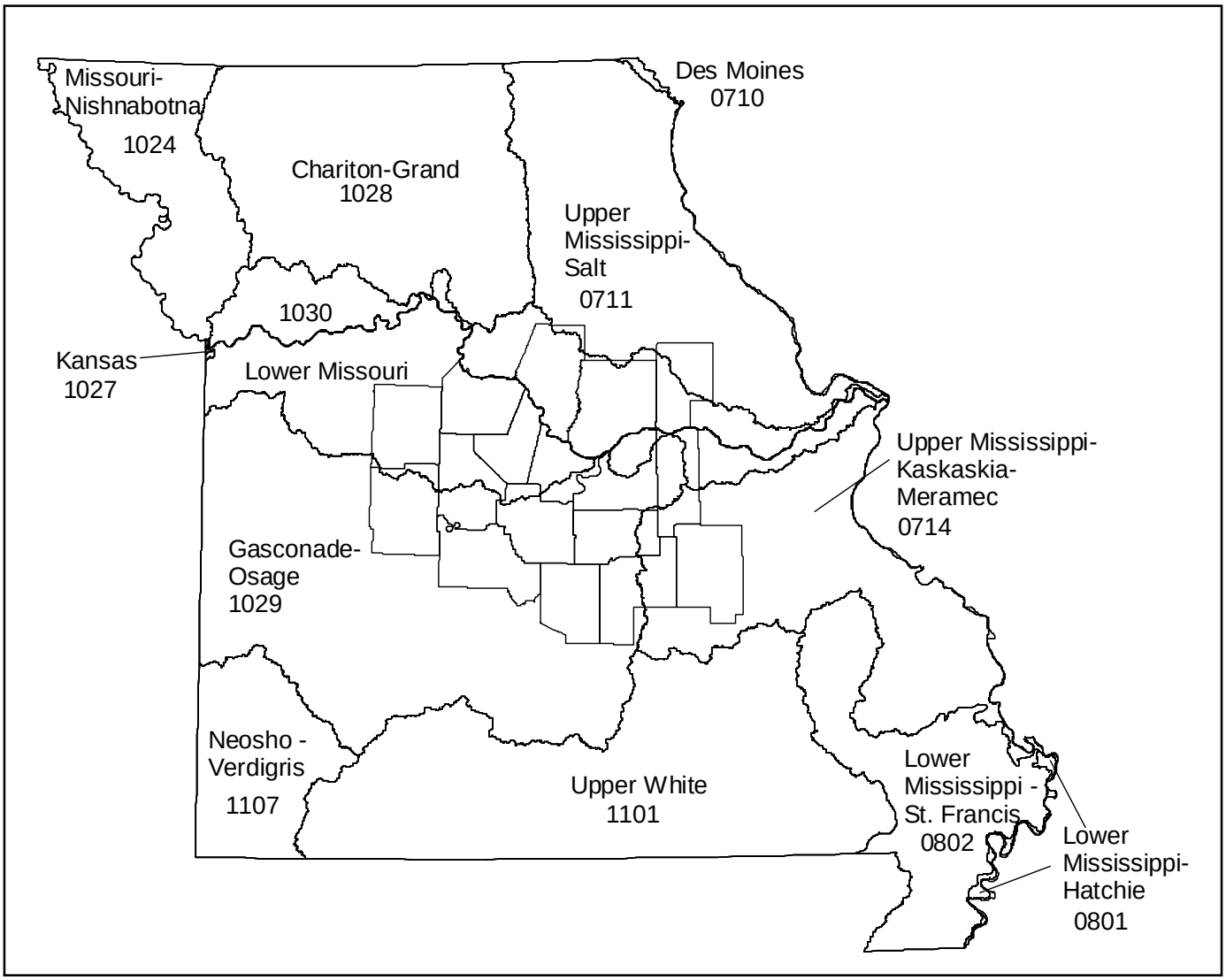

Figure 12. Four-digit hydrologic units of Missouri. Source: Missouri Department of Natural Resources.

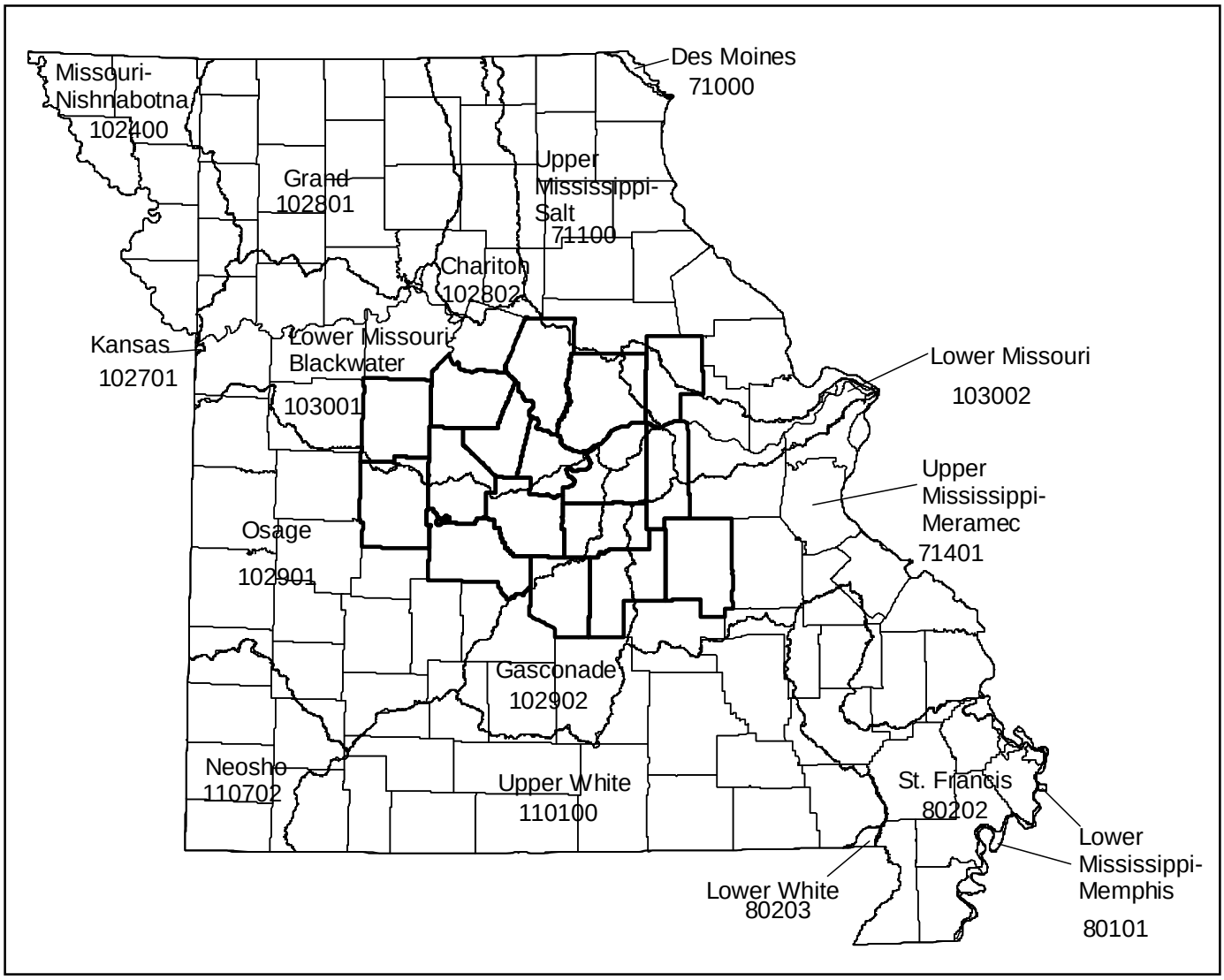

Figure 13. Six-digit hydrologic units of Missouri. Source: Missouri Department of Natural Resources.

Nearly all of central Missouri is drained directly or indirectly by the Missouri River. Within this basin, smaller streams and rivers provide drainage. All or part of the following river subbasins are located in the central region: Salt, Cuivre, Missouri, Blackwater, Lamine, Moreau, Bourbeuse, Meramec, Gasconade, Big Piney, Niangua, Pomme de Terre, Osage, and South Grand rivers, and Perche Creek. Flow characteristics of the central region differ from west to east in the region. The western edge, including parts of Pettis and Benton counties, experiences rapid runoff of precipitation due to the low permeability of the soils. Very little inflow of groundwater into the streams causes low flows or no flow during an extended drought. However, the eastern part of the area, which lies within the Ozarks physiographic province, has streams with well-sustained base flows provided by springs that discharge from the Springfield Plateau and Ozark aquifers. Surface water quality is generally very good, with slightly higher suspended solids in those streams in the western part of the region (Vandike, 1995). Major lakes in the region are the Lake of the Ozarks in Camden, Morgan, and Benton counties, and Harry S Truman Reservoir in Benton County. Truman Reservoir, covering 55,600 acres, is Missouri's largest reservoir.

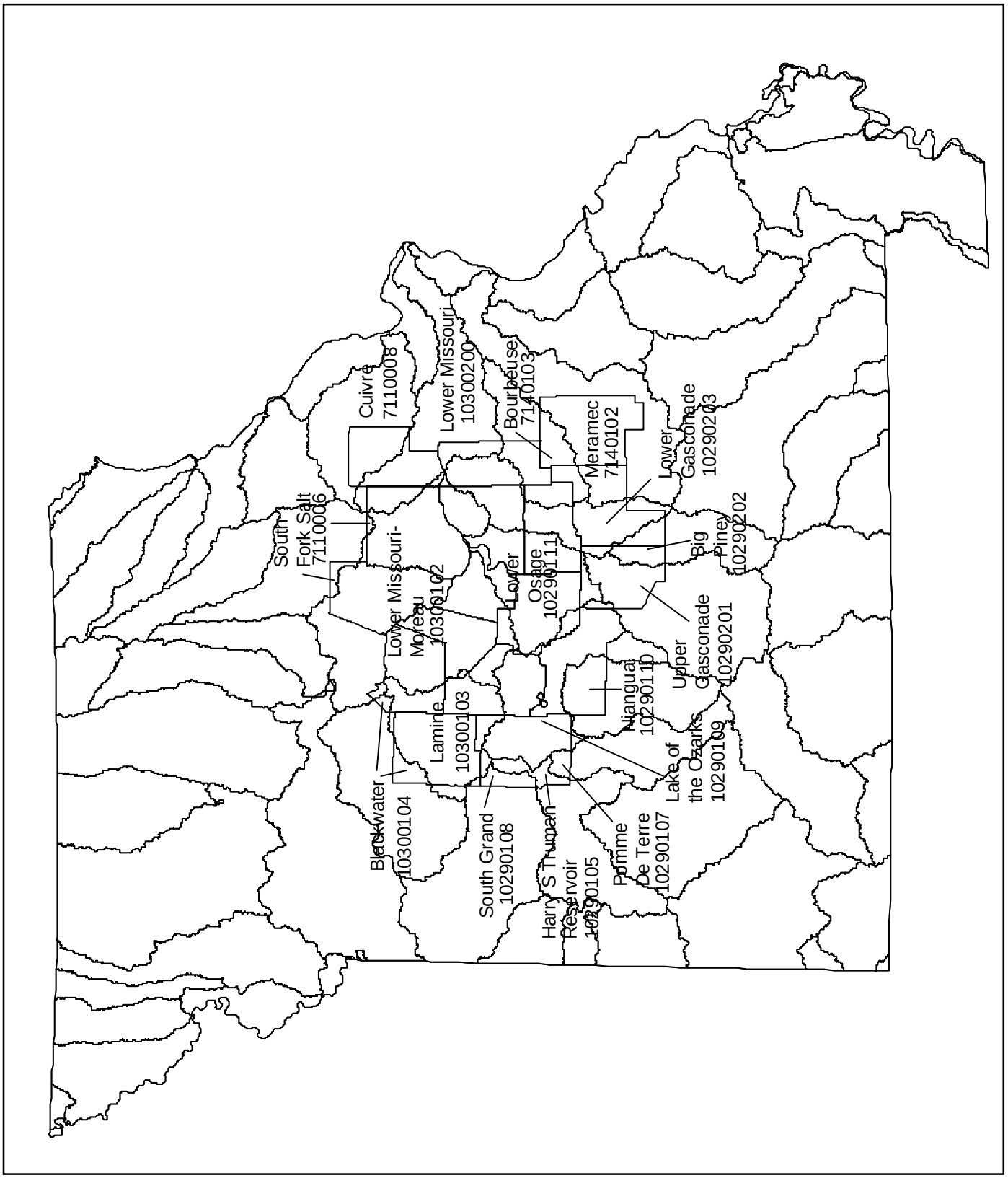

Figure 14. Eight-digit hydrologic units of Missouri. Source: Missouri Department of Natural Resources.

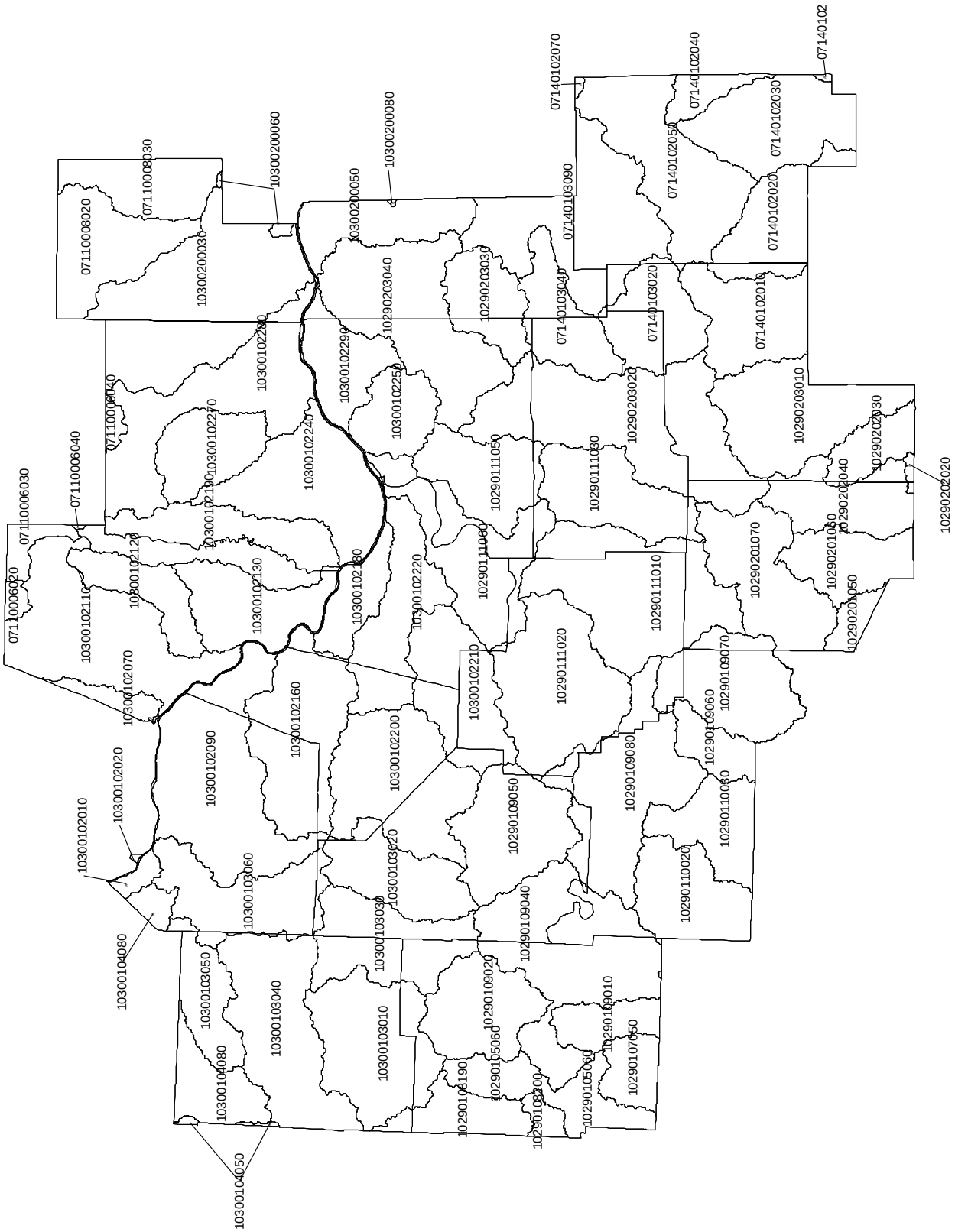

Figure 15. Eleven-digit hydrologic units of central Missouri. Source: Missouri Department of Natural Resources.

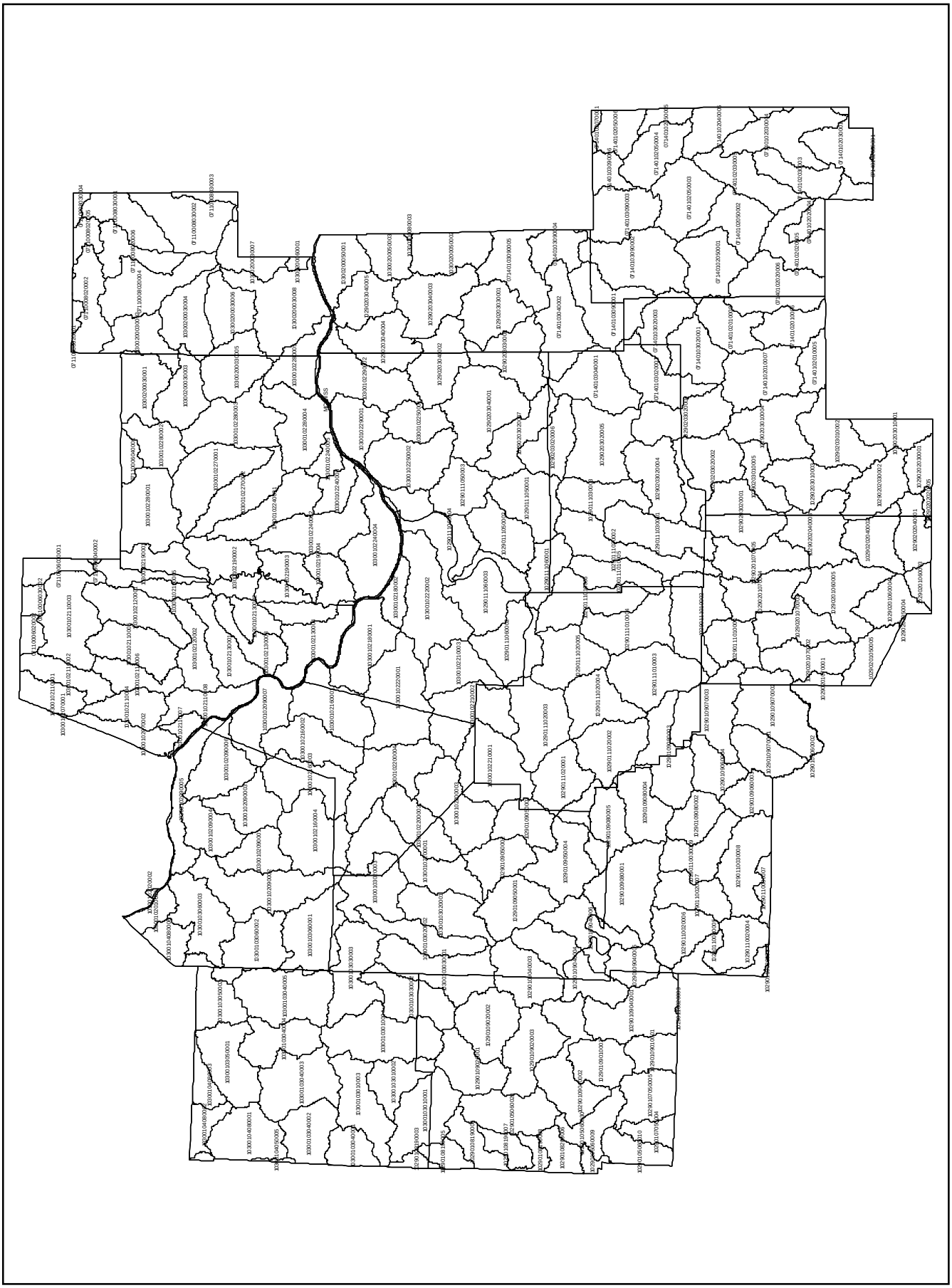

Figure 16. Fourteen-digit hydrologic units of central Missouri. Source: Missouri Department of Natural Resources.

Implications for Water Resources

Due to the different environmental settings within the region, water resources are affected differently. For example, in the northern area of the region, soil permeability is low which creates high rates of runoff. This may cause flash floods during large rain events. In addition, due to low permeability, streams that rely on groundwater to augment their flow during dry months (no rainfall) become very low or cease to flow in some instances. The glacial till that underlies much of the row crop fields is especially susceptible to erosion.

In the southern part of the region, the opposite conditions exist. Because soils are thinner, row cropping exists primarily along floodplains and not on steep slopes, therefore, soil erosion may be less of a problem. Many of the streams in the area receive groundwater from springs so even during drought periods, the streams remain flowing at static levels and cool temperatures.

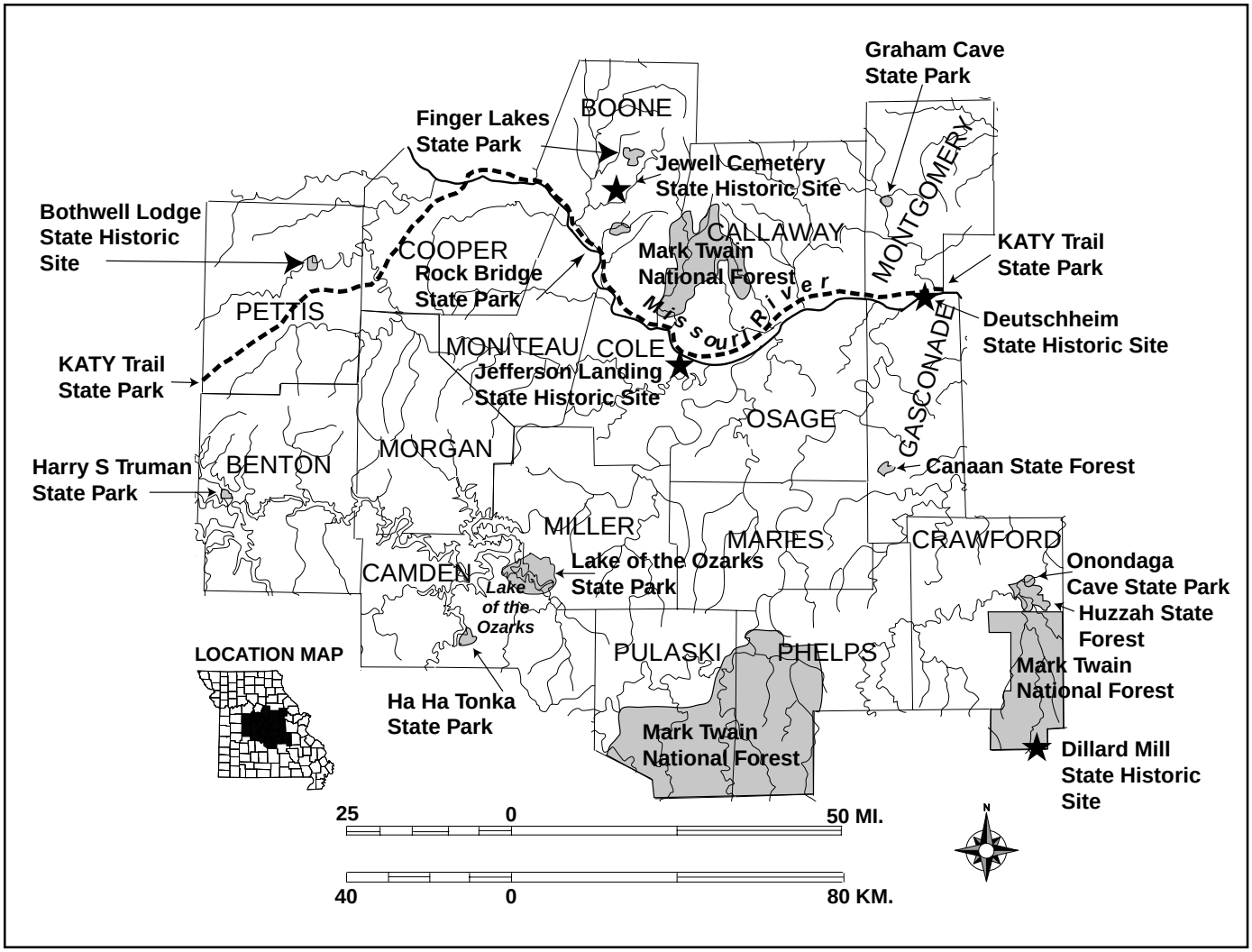

Figure 17. National and state forest lands, state parks and historic sites in the central Missouri region.

Recreation

The moderately rugged hills, and numerous rivers and lakes in central Missouri provide a scenic backdrop for eight state parks, five state historic sites (figure 17), and numerous conservation and wildlife areas (table 4). All types of water recreation, including fishing, sailing, swimming, canoeing, water-skiing, and motor boating are readily available at the area's rivers and lakes. Eight commercial caves located within the region provide windows to geological characteristics. They illuminate some of central Missouri's interesting history and demonstrate that portions of the central region is underlain by karst.

COUNTY	STATE PARKS[1]	MDC[2]	FEDERAL[3]
Benton	1	15	1
Boone	4	20	1
Callaway	1	10	1
Camden	2	8	0
Cole	1	13	0
Cooper	1	8	1
Crawford	2	12	1
Gasconade	1	7	0
Maries	0	7	0
Miller	1	9	0
Moniteau	0	5	0
Montgomery	2	7	0
Morgan	0	5	0
Osage	0	9	1
Pettis	3	9	0
Phelps	0	9	1
Pulaski	0	10	2

Table 4. Number of state and federal recreational facilities in central Missouri. (Sources: [1]www.dnr.state.mo.us/dsp/index.html; [2]www.conservation.state.mo.us; [3]www.fws.gov/; [3]www.fs.fed.us/; [3]www.usace.army.mil/; [3]www2.army.mil).

Sources:

Brookshire, Cynthia, 1997, Water Resources Report Number 47, Missouri water quality assessment, Missouri State Water Plan Series Volume III, Missouri Department of Natural Resources, Division of Geology and Land Survey.

Census Bureau Website: www.census.gov/, June 2001

Miller, Don E. and Vandike, James E., 1997, Water Resources Report Number 46, Groundwater resources of Missouri, Missouri State Water Plan Series Volume II, Missouri Department of Natural Resources, Division of Geology and Land Survey.

Missouri Agricultural Statistics Service, 1998, 1998 Missouri farm facts, Missouri Department of Agriculture.

Missouri Department of Natural Resources, 1996 Missouri's masterpieces, state parks and state historic sites, Department of Natural Resources, Division of State Parks.

Missouri Department of Transportation, Missouri official highway maps, biennial editions, Missouri Department of Transportation.

Missouri Division of Tourism, 1996. Missouri 1997 travel guide, Missouri Division of Tourism.

Office of Social and Economic Data Analysis (OSEDA), 1999, available online at http://www. oseda.missouri.edu/.

Office of Social and Economic Data Analysis (OSEDA), 2001, available online at http://www. oseda.missouri.edu/.

Office of Social and Economic Data Analysis, 1996, Northeast Missouri regional social and economic data, available online at http: //www.oseda.missouri.edu/profile/necnty.gif.

Office of Social and Economic Data Analysis, 1996, Northwest Missouri regional social and economic data, available online at http: //www.oseda.missouri.edu/profile/nwcnty.gif.

United States Department of Commerce, 1994, County business patterns, 1991 and 1992, Bureau of the Census, CD-ROM.

Vandike, James E., 1995, Water Resources Report Number 45, Surface water resources of Missouri, Missouri State Water Plan Series Volume I, Missouri Department of Natural Resources, Division of Geology and Land Survey.

4. Regional Water Use Overview

Problems with Water Resources Management

There are many issues that confront and hinder water resource managers. Watershed management has now become the preferred method for evaluating water resources and identifying problems and solutions. A watershed may be defined as the natural or disturbed unit of land on which all the water that falls (or emanates from springs or snowmelt), collects by gravity, and fails to evaporate, runs off via a common outlet (Gaffney and Hays, 2000). While these units are natural and logical boundaries, they seldom follow political boundaries. This creates a problem for planners who must now coordinate many agencies, municipalities, and varied interests. Cooperation among all stakeholders is usually needed to implement and manage an effective watershed management plan. This cooperation is often difficult, if not impossible. On the local level, municipalities may not have the funding, expertise, or political will to become involved in a regional or state plan.

On many water topics, there are organizational challenges to address. For example, the protection of wetlands involves many state and federal agencies. Some wetlands manipulations require federal permits while others do not, and this situation appears to change frequently in the wake of federal court decisions. There are federal and state guidance and executive orders, all of which back the concept of stopping the loss of wetlands. However, there are few formal means to prevent wetlands losses when many activities that destroy wetlands are beyond regulation. An understanding of the missions of each agency involved in the discussion, as well as what assistance each can lend, would be useful in solving the larger problem (Madras, 2001).

The state is working with the Corps of Engineers (COE) districts to unify the approaches to Section 404 permits and their corresponding Section 401 water quality certifications. Similarly, the state is working with parties that frequently obtain certifications so that the requirements of certifications can be accommodated within the design of the projects. A major initiative is to make these requirements known at an early stage of the process so the design can anticipate them (Madras, 2001).

Jurisdictional issues also arise in water resources planning and management. Most river basins are inter-state and therefore, fall under jurisdiction of the federal government. This is implicit in the United States Constitution, in which the federal government reserves the right to regulate commerce with foreign nations, and among the several states, and with the Indian tribes. In the early years of our country, commerce was carried out via waterways and navigation was an important issue. A stream is navigable if it can float a boat that can be involved in commerce. It was also deemed that the defense of our country was dependent in large part on the protection of navigable waters.

The COE is now involved with issuing wetland permits, granting permits for dredge and fill in navigable waters, flood control, water supply, dam safety, floodplain management, and more recently, environmental protection and restoration. The Environmental Protection Agency (EPA) is another agency involved in water resources. Created in 1970 by President Nixon, it is an arm of the executive branch and has risen to cabinet level. It is charged with administration of the Clean Water Act (CWA). It is in-

volved in water resource planning, research, and enforcement. In most cases, the EPA has delegated much authority to the states in regards to water resources protection and management. Recent court rulings may have both clouded and clarified the role of the COE in determining what wetland areas are and are not within their administrative jurisdiction to regulate under the CWA and other federal laws.

Because Missouri has 1,320,900 acres of National Forest, a brief discussion of the U.S. Forest Service is warranted (figure 17). One of the earliest mandates of the national forest service was to protect water supplies as well as timber resources. Today, forestry and logging activities take place on national forests, including those in Missouri. The forest service manages our forests under the concept of "multiple use" in which many activities such as recreation (hunting, fishing, biking, bird watching, etc), water protection, and logging are permitted. Recently, the Forest Service has begun to use an ecosystem management approach to guide forest policy. This also opened the policy-making process to public participation in which competing demands are often considered and evaluated. The way these forests are managed has important implications for water quality in our state.

The following description of water use in central Missouri is included to provide context for the water use problems identified in this report. The categories used below are the same as those used by the United States Geological Survey (USGS) in the National Water-Use Information Program. In addition, most of the water use data provided in this section was collected through this program. Many of the water use problems included in this report address environmental issues.

Public Water Supply

Central Missouri, home to a large segment of Missouri state government and the University of Missouri at Columbia, is more urban in nature than most parts of the state. This is reflected, to some extent, in the disposition of central Missouri's public water supplies. The percentage of publicly supplied water allocated to commercial and public uses is higher than statewide averages. Industrial water use, however, accounted for less than two percent of public water supply deliveries. The percentage of water delivered in 1995 for domestic use was approximately 85.5 percent compared to 65.2 percent for Missouri statewide (USGS, 2001).

Public water use is often defined as community-wide applications of water, such as firefighting and filling public swimming pools. Public water use also includes transmission losses- water lost from leaking pipes and joints while being delivered to domestic, commercial and industrial users. Nearly 28 percent of central Missouri's publicly supplied water was allocated to public uses in 1995 compared to 21.8 percent statewide (USGS, 2001).

Similarly, 1995 commercial use of public water supplies was slightly higher in mid-Missouri than for the state overall. Commercial water use is defined by the USGS as "water for motels, hotels, restaurants, office buildings, other commercial facilities, and institutions" (Solley, et. al., 1993). In 1995, approximately 12.6 percent of central Missouri's publicly supplied water was delivered to commercial water users compared to 10.3 percent statewide (USGS, 2001). Public water supply deliveries for industrial use in central Missouri, conversely, were exceptionally low in 1995. Compared to the statewide figure of 24.4 percent, industrial water users in mid-Missouri accounted for only 1.8 percent of total public water supply usage (USGS, 2001).

Two-thirds of the population of central Missouri receiving water from public water systems are supplied by groundwater wells (figure 18). The Missouri River and a number of small public water supply lakes supply the remaining third of the population. In central Missouri, two of every three citizens are connected to a public water supply.

Domestic Water Use

Domestic water use is often defined as "water used for household purposes," such as drinking, cooking, bathing, and washing clothes and dishes. Excluding thermoelectric and hydroelec-

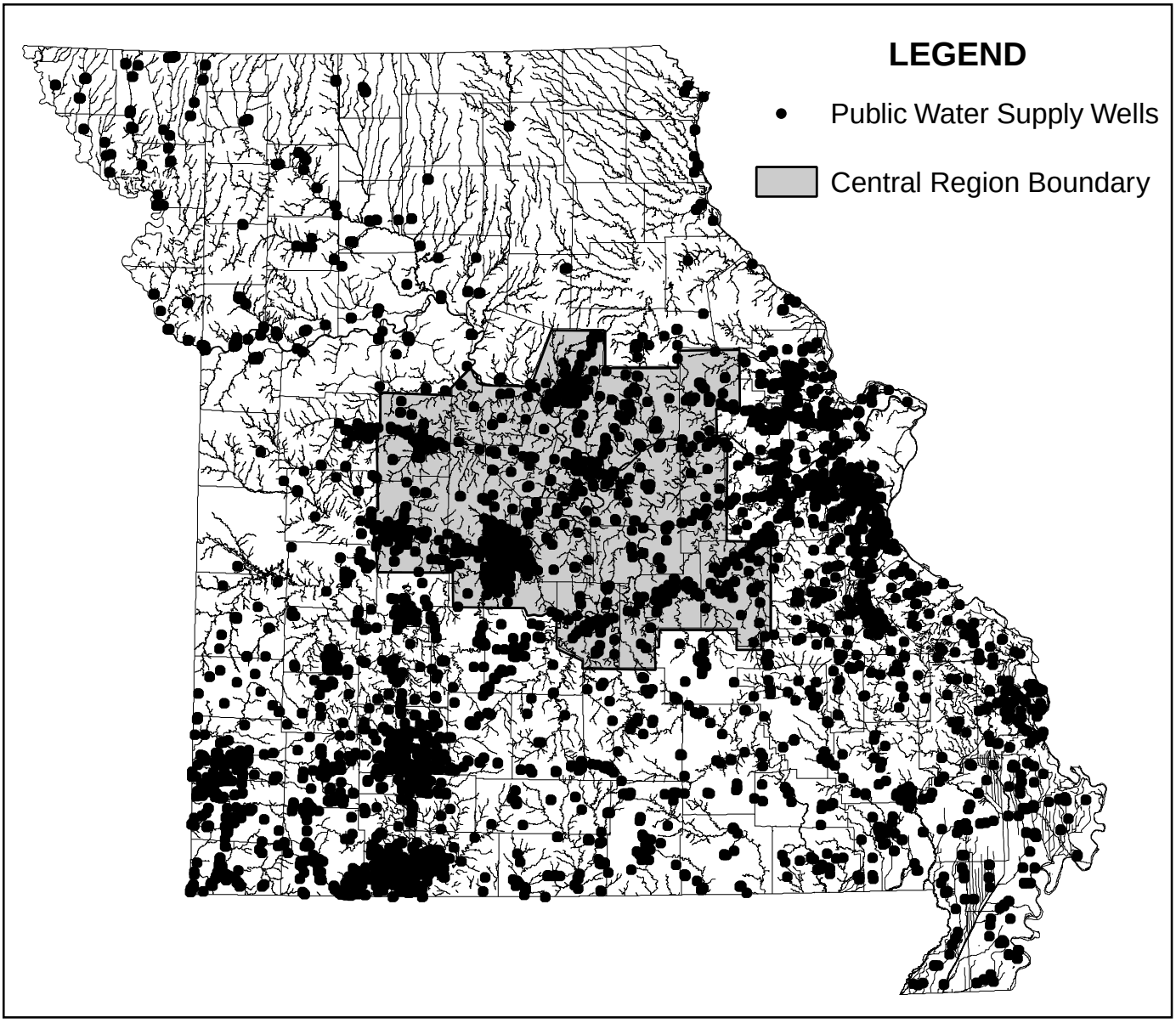

Figure 18. Locations of public water supply wells in Missouri. Source: Missouri Department of Natural Resources.

tric power generation, domestic water use is the predominant use of water in central Missouri. The National Water-Use Information Program of the United States Geological Survey (USGS) estimated 1995 domestic water use in mid-Missouri at 15.3 billion gallons of water. USGS figures indicate that per capita usage was approximately 61 gallons/day for domestic usage. While three-fourths of central Missouri's domestic water requirements are supplied by public water systems, private water supplies serve much of the area's population. Approximately 174,000 people in mid-Missouri drew water from private supplies in 1995 (USGS, 2001). USGS data from 1995 indicates that 100 percent of self-supplied domestic water withdrawals came from groundwater sources, although it is likely that a small percentage of users obtained water from surface water sources. In the 1990 U.S. Census of Population and Housing, approximately 3,200 housing units in central Missouri reported using "some other source" for water, a catch-all cat-

egory that the Census Bureau defines as "water obtained from springs, creeks, rivers, lakes, cisterns, etc."

Industrial and Commercial Water Use

Industrial water use in central Missouri is especially low, and accounts for less than two percent of public water supply deliveries. The USGS estimated 1995 industrial water withdrawals at only 321 million gallons throughout the year. Industrial water users across Missouri typically rely on public supplies rather than self-supplied water. In 1995, industrial water users in mid-Missouri received 251 million gallons of water from public water systems, approximately 80 percent of their total water use (USGS, 2001). In 1995, almost 100 percent of total self-supplied withdrawals for industrial use came from groundwater sources. USGS data indicates varying levels of industrial water use throughout central Missouri, with nine out of 17 counties showing no industrial water use at all.

In central Missouri, commercial water use far outweighs industrial water use. Commercial water use in mid-Missouri totaled nearly 3.2 billion gallons in 1995, ten times as much water as was withdrawn for industrial use. Commercial water use in central Missouri depends upon both public water supply deliveries and private supplies, with public water systems supplying approximately 53 percent of the region's commercial water requirements (USGS, 2001).

Agricultural Water Use

Farmers in central Missouri draw water both to irrigate farmlands and to water their livestock. Although irrigation water use far exceeds water used for livestock watering in statewide totals, water withdrawals for livestock watering surpass withdrawals for irrigation in central Missouri. Surface water sources account for most of central Missouri's agricultural water use. In 1995, 73 percent of the 6.3 billion gallons of water used for agricultural operations in central Missouri was taken from the region's lakes and streams (USGS, 2001).

Livestock water use in central Missouri surpassed irrigation withdrawals in 1995, with usage exceeding 4.3 billion gallons of water. Three-fourths of livestock water withdrawals were from surface water sources, consistent with the state as a whole. Livestock production is evenly distributed across central Missouri, with individual counties using up to 467 million gallons per year (USGS, 2001). A variety of livestock is raised in central Missouri, each of which must have access to water throughout the year. Farmers in central Missouri used slightly more than 2 billion gallons of water to irrigate their fields in 1995. Irrigation water use is widely distributed across central Missouri, with the three counties north of the Missouri River (Boone, Callaway and Montgomery counties) accounting for over 70 percent of the region's irrigation water use (USGS, 2001).

Approximately two-thirds of irrigation withdrawals in central Missouri came from surface water sources in 1995, in sharp contrast to the statewide value of 6 percent (USGS, 2001).

Water Use in Power Production

The Major Water Users Database of the Missouri Department of Natural Resources estimated total thermoelectric power generation withdrawals in central Missouri at approximately 31 billion gallons of water in 2000 (Missouri Department of Natural Resources, 2001). Withdrawals for thermoelectric power generation are used primarily for power plant cooling and come mainly from surface water sources. Although thermoelectric power generation requires vast amounts of water, very little of it is actually consumed. Statewide, more than 99 percent of all thermoelectric power withdrawals were returned to their source waters. In central Missouri, four facilities (the AmerenUE Callaway Nuclear Plant, the University of Missouri at Columbia, the City of Columbia, and Central Electric Power Cooperative in Osage County) account for the region's thermoelectric power generation. The two Columbia plants get all their water from wells. The other two plants get the majority of their water from the Missouri River.

Three hydroelectric power generation facilities operate in central Missouri: AmerenUE's Osage Plant at Bagnell Dam, Sho-Me Power Corporation's Tunnel Dam on the Niangua River, and the U.S. Army Corps of Engineers' Harry S Truman Dam and Reservoir. Together, these three facilities used approximately 3.2 trillion gallons of water to generate electricity in 1995. Hydroelectric power generation is generally considered a non-consumptive use of water, although some water is lost every year through evaporation.

Other Instream Flow Uses

Fish and other aquatic organisms in central Missouri's lakes and streams depend upon flowing water for survival and aquatic habitat preservation. Many municipalities in mid-Missouri rely upon flowing water to safely release wastewater back into the environment. River barges on the Missouri River require flows sufficient to permit safe navigation. Swimming areas and boat launches found on nearly every body of water within the region accommodate recreational activities throughout most of the year. Although no water is withdrawn, each of these is a "use" of water as well. Collectively, these are often referred to as "instream" uses.

Mid-Missouri's water resources are known across the state for the recreational opportunities they provide. The Lake of the Ozarks, constructed by Union Electric Co. (now AmerenUE) in the early 1930s, attracts visitors from throughout the Midwest. In addition to hydropower benefits, Truman Reservoir in Benton County provides numerous recreational opportunities as well, including fishing, boating and swimming. In 1994, the U.S. Army Corps of Engineers, recorded approximately 13 million visitor hours at Truman Reservoir. In addition, a number of state parks within central Missouri draw upon the region's water resources, including the Lake of the Ozarks State Park, Harry S Truman State Park, and Finger Lakes State Park in Boone County. Central Missouri's many rivers and streams (including the Missouri River) offer a variety of recreational opportunities, including fishing and canoeing.

Preservation of aquatic wildlife and habitat is another important "instream" use of water. Numerous conservation areas maintained by the Missouri Department of Conservation are located in central Missouri. Most of central Missouri falls within the Ozark Aquatic Faunal Region, although counties north of the Missouri River are part of the Prairie Aquatic Faunal Region (Pflieger, 1989). Although some upland drainages may become dry during drought conditions, most rivers and streams in central Missouri have permanent streamflow that supports fish and wildlife throughout the year.

Many communities in central Missouri release wastewater into nearby rivers and streams. In 1995, the USGS estimated that central Missouri's rivers and streams assimilated 28.8 billion gallons of wastewater.

Sources:

Gaffney, R.M.; and Hays, C.R.; 2000, Water Resources Report Number 51, A summary of Missouri water laws, Missouri State Water Plan Series Volume VII, Missouri Department of Natural Resources, Division of Geology and Land Survey, 50 p.

Madras, John, Planning Section Chief, Water Protection Control Program, Department of Natural Resources, Water Pollution and Soil Conservation Division, 2001 written communication.

Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division, Water Resources Program. Major water users database, 2001.

Missouri Department of Natural Resources, Division of Environmental Quality, Inventory of Missouri public water systems, 1996.

Pflieger, William L., 1989, Aquatic community classification system for Missouri, Missouri Department of Conservation, Aquatic Series Number 19, 70 p.

Solley, W.B.; Pierce R.R.; Perlman, H.A.; 1993, Estimated use of water in the United

States in 1990, United States Geological Survey Circular 1081, 76 p.

U.S. Bureau of the Census, Census of Population and Housing, 1990.

USGS water use; http://water.usgs.gov/watuse, 2001.

Vandike, James E., 1996, Water Resources Report Number 45, Surface water resources of Missouri, Missouri State Water Plan Series Volume 1, Missouri Department of Natural Resources, Division of Geology and Land Survey, 122 p.

Water Use Problems

Each description of a water use problem identified in this section follows a similar format. In each, a brief problem statement is followed by a short discussion in which background information is provided and the nature of the problem is established. It is important to note that the problem descriptions appearing in this section are not arranged according to priority or degree of severity. They are arranged in the following major categories: Drinking water use, agricultural water use, industrial water use, recreational water use, and environmental protection water use, as provided in the Water Resources Law.

Drinking Water Use

Overuse of Groundwater in Site Specific Areas

Problem:

There are several areas in Missouri where the overuse of groundwater has led to declining groundwater levels. When a well is pumped, the water level in the well is lowered, which induces water in the aquifer adjacent to the well to flow into the well. The difference between the static or non-pumping water level in a well, and the water level at the end of the pumping cycle, is called the drawdown. The drawdown depends on the pumping rate, the pumping period, and the hydrologic characteristics of the aquifer such as its thickness, hydraulic conductivity, and storage coefficient. The drawdown is greatest in the pumped well, and decreases with distance from the well. A well producing a large quantity of water for a long period of time can develop a substantial “cone of depression” or “drawdown cone” around the well. The cone of depression that forms around a high-yield well that is pumped for an extended period may extend several thousand feet or more from the well. The distance from the pumped well to the edge of the cone of depression is called the radius of influence (figure 19). When pumping ends, water level in the well begins to rise and the cone of depression begins to decrease in size. If there is ample time between pumping cycles, the well will fully recover and water level will return to its pre-pumping level.

Well interference results when the drawdown cones of multiple pumping wells merge. If drawdown cones of two wells overlap, the result is increased drawdown in both wells as compared to the drawdowns generated by the individual wells. Spacing wells as far apart as possible reduces well interference. Groundwater-level declines often occur where there are numerous high-yield wells producing within a relatively small area such as a municipal well field, industrial park, irrigation area or confined animal feeding operation. As long as the production wells are of similar depth, well interference typically is not an immediate or major problem. However, in areas where relatively shallow domestic wells are drilled into the same aquifer as deep high-yield wells, production by the high-yield wells may lower water levels to the point that the shallow wells will no longer function. There is no statute to assure that earlier users are not harmed by later users.

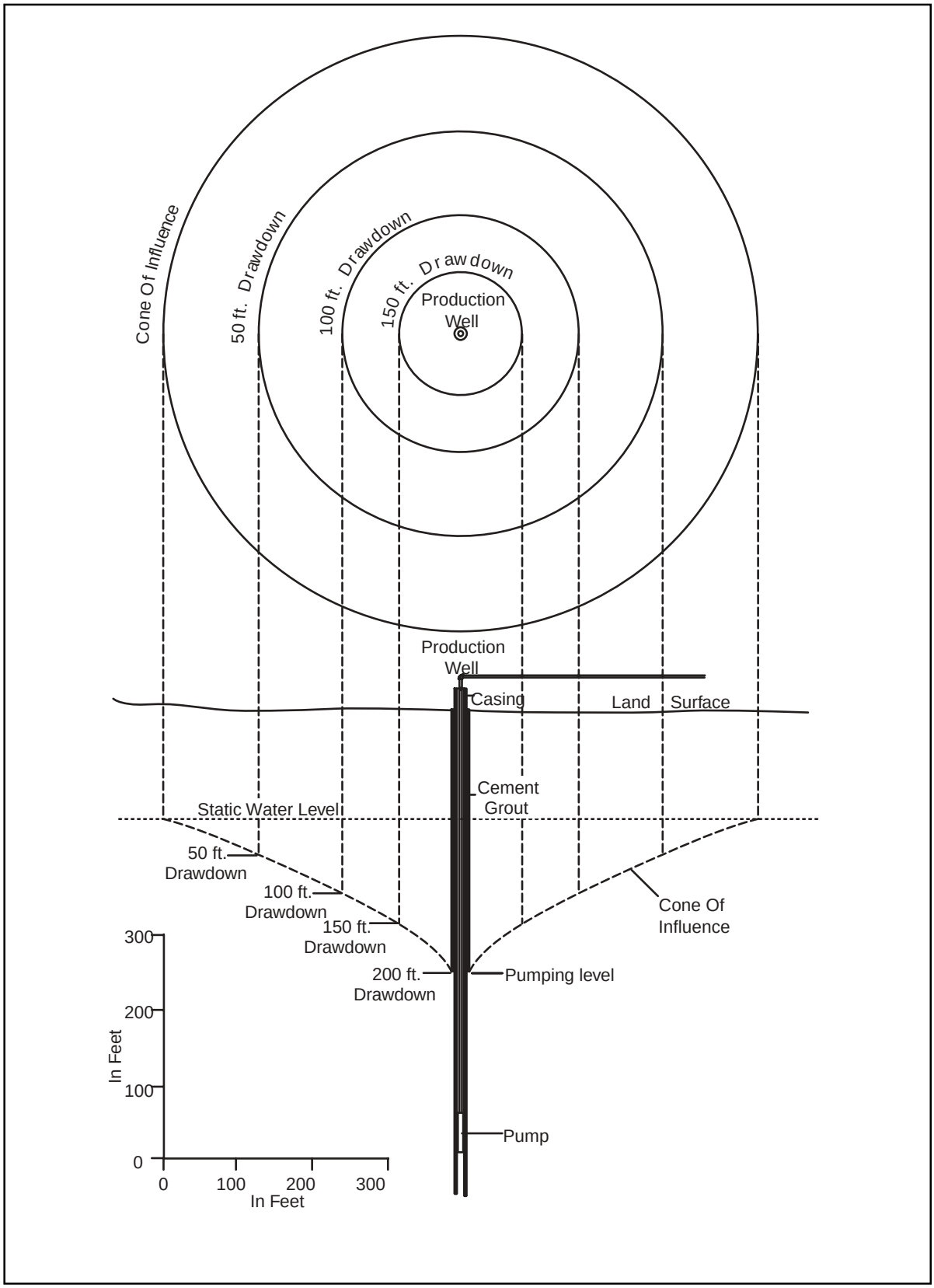

Figure 19. Idealized ìcone of depressionî from pumpage of a high-yield well. Source: Miller and Vandike, 1997.

Discussion:

Groundwater is water beneath the earth's surface within a zone of saturation. The upper surface of the zone of saturation in an unconfined aquifer is called the water table. Layers of rock and other geologic materials capable of transmitting and storing economically significant quantities of water are called aquifers. Groundwater is a finite resource that is ultimately replenished by precipitation soaking into the earth. Each water well has a source water area that supplies it. Depending on geology and well construction, some wells receive their recharge entirely from infiltration of precipitation into the earth within its source water area Others may not be appreciably affected by local rainfall, but rely on lateral movement of groundwater from a more substantial distance.

Although it is a finite resource, groundwater is also a renewable resource. However, groundwater recharge can be a slow process. The time it takes to replenish a given volume of groundwater in the earth depends on many factors including the porosity and hydraulic conductivity of the earth materials, aquifer depth, presence of confining units, precipitation, and area groundwater withdrawal rates. Relatively shallow unconfined aquifers are typically more readily recharged than deeper confined aquifers. In some cases, groundwater may take years to move only a few feet, while in the karst terrain of south-central Missouri, groundwater flowing through major spring systems may travel a mile or more per day through solution-enlarged openings in the carbonate bedrock. Recharge rates may be less than 1 inch of water per year (33 gallons per minute per square mile) in low-permeability glacial drift and Pennsylvanian-age bedrock north of the Missouri River, to more than 12 inches of water per year (400 gallons per minute per square mile) in the karst watersheds in the southwest part of the region. Where groundwater extraction exceeds recharge there is a net loss of water in storage and water level in the aquifer will decline proportionally. Groundwater recharge can also be decreased in urban areas due to pavement and buildings, which increase the amount of impervious surface area.

Groundwater availability and potability vary with location across the region. In some areas, such as extreme northern Boone County, groundwater resources are so meager that wells can produce, at best, only small quantities of marginal quality water that is suitable only for modest household or farm needs. In most other areas of the region, however, large quantities of high-quality groundwater is readily available and is sufficient to provide for municipal, agricultural, and industrial uses. Under certain conditions, such as in low groundwater yield areas or areas of high groundwater production, the rate that water is being extracted exceeds the recharge rate. This can lower groundwater levels and affect groundwater availability, especially in shallower wells. Excessively lowering groundwater levels will negatively affect water supply economics in the area. Pumping costs will increase, wells ultimately may need to be deepened or abandoned, or in extreme cases alternative water supplies may eventually need to be developed.

Some of the major aquifers in central Missouri serve private homes and public water supply districts, and supply water for agriculture and industry. Missouri usually has enough snow and rainfall to replenish the water supply in most aquifers, but during years of drought, water levels in many aquifers decline. Water conservation is common during droughts, and mandatory curtailment of water use sometimes becomes necessary in severe, persistent droughts. Mandatory curtailment of water use must be ordered by the governor, under state emergency declarations. Missouri has no statute that requires curtailment in certain circumstances. However, citizens can file suit under the "reasonable use" doctrine to curtail what is alleged to be unreasonable or excessive use.

During the 20th Century, per capita use of water rose. As populations grow in the 21st Century, parts of central Missouri could experience groundwater declines or shortages.

Site Specific Case Study of Groundwater-Level Declines in the Dresden Area, Pettis County, Missouri

Nearly continuous operation of several high-yield wells in west-central Pettis County that supply a large poultry processing facility has caused substantial local groundwater-level decline in the Ozark aquifer in and near the community of Dresden.

Dresden is an unincorporated community in Pettis County about 5 miles west-northwest of Sedalia. There is no centralized public water supply for the community or the rural area surrounding it. Individual residences and farms rely on privately owned domestic wells that vary in depth from less than 100 feet to more than 500 feet. Beginning in 1988, a series of five deep high-yield wells were constructed in and near Dresden to supply a poultry processing plant and ancillary facilities. Water-use information is available for the processing plant since September 1994. Monthly groundwater usage has increased steadily during the past 5 years from 10 to 15 million gallons per month in 1994 to a current usage averaging about 58 million gallons per month. In July 1996, the Geological Survey began receiving reports of well problems in the Dresden area. To help determine the extent and magnitude of the drawdown, the program installed a water-level recorder on an unused private domestic well that is located about one mile south of the main poultry processing facility. In 2000, the division constructed a second dedicated groundwater-level observation well near the Pettis Co. R-12 School in Dresden about one mile west of the main poultry processing facility.

Two aquifers that are commonly used in this area--the shallow Springfield Plateau aquifer and the deeper Ozark aquifer. The base of the Springfield Plateau aquifer in the Dresden area is, at most, about 200 feet below land surface. This relatively thin aquifer consisting of Mississippian-age limestone units yields modest quantities of water, generally less than 10 gallons per minute. The Ozark aquifer underlies the Springfield Plateau aquifer and is separated from it by relatively low-permeability strata. Lower Ordovician- and Cambrian-age strata comprise the Ozark aquifer and consist, in ascending order, of the Derby-Doerun dolomites, Potosi Dolomite, Eminence Dolomite, Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, and Cotter Dolomite. The Ozark aquifer's major water-producing zones are generally found in the Roubidoux Formation, lower Gasconade Dolomite, Gunter Sandstone Member of the Gasconade Dolomite, and Potosi Dolomite.

A third major aquifer, the St. Francois aquifer, underlies the Ozark aquifer, and consists of the Bonneterre Formation and the Reagan Sandstone. The top of the St. Francois aquifer is at a depth of about 1,450 feet in the Dresden area, and the aquifer is from about 150 to 350 feet thick. With the exception of the city of Sedalia, the St. Francois aquifer is not widely used in this area of west-central Missouri. Several wells that supply the City of Sedalia produce from both the Ozark and St. Francois aquifers.

All of the high-yield wells in the Dresden area are thought to produce from the Ozark aquifer. Residents in the Dresden area who are close to the poultry facility that have relatively shallow wells producing from the Springfield Plateau aquifer have not reported major problems with water-level decline. However, private wells that are deeper than about 200 feet have had some impact. The most adversely affected wells are probably those that produce from the very upper part of the Ozark aquifer, have relatively shallow pump settings, and are relatively close to the poultry facility. Water levels in some wells that produce from the upper part of the Ozark aquifer in the Dresden area have declined 30 feet or more since 1988.

The three largest-producing poultry processing plant wells are about 1,400 feet deep and contain about 350 feet of casing. They produce from the Ozark aquifer and are capable of supplying 500 to 900 gallons per minute. Water use by the facility has steadily increased from 1995 through 2000. Yearly reported water use for 1995 through 2000 was 398 million gallons, 426.4 million gallons, 590.2 million gallons, 679.2 million gallons, 692.7 million gallons, and 701.4 million gallons, respectively. There is another registered major water user in the Dresden vi-

cinity that has several high-yield wells capable of producing several hundred gallons per minute. However, that facility reported using only about 22 to 28 million gallons per year during the same period.

On August 30, 1996, the Missouri Department of Natural Resources' Water Resources Program installed a digital water-level recorder on an unused private domestic well that is located about a mile south of the poultry processing facility. The observation well is from about 0.7 miles to 1.2 miles from the poultry processing plant wells. The well is reportedly deeper than 200 feet and therefore should be open to the upper part of the Ozark aquifer. Data collected from the well during the past five years shows the groundwater level has declined about 25 feet during that period at that location. The water level in the well, when the recorder was installed, was about 156 feet. As of mid-July, 2001, water level was about 181 feet (figure 20). Unfortunately, the observation well is probably not cased through the Springfield Plateau aquifer, and as a result the water levels measured from it may reflect both aquifers rather than just the Ozark aquifer.

Because the Ozark aquifer is about 1,200 feet thick in this area, a water-level decline of 25 feet over a 5-year period a mile from the pumping center is not tremendous. Part of the village of Dresden is closer to the pumping center than the observation well, and may have experienced somewhat greater drawdown. However, water-level information collected by Pettis County R-12 School personnel in Dresden does not indicate that drawdown in Dresden has been excessive. In about 1996, the pump in the school's well was serviced. At that time equipment was installed to allow school officials to monitor water levels in the well. Weekly water-level fluctuations were noted, but after a year the water level in the well was nearly the same as the previous year (Don Stratton, 1999).

A preliminary report produced in November 1998 for the poultry processing facility by an independent consulting firm contained information gathered in a survey conducted in September 1998 by a local group of concerned citizens. The survey showed that of 54 wells listed in the survey, 32 reportedly experienced water quality problems, yield problems, or both. The report also indicated that water-level declines in the three high-capacity poultry processing facility wells were about 100 to 125 feet.

Information available at this time indicates that the water-level decline problem in the Dresden area is relatively local. Water-level decline in the Ozark aquifer is greatest near the three high-yield wells where it is at least 100 to 125 feet, and decreases to at least 25 feet about a mile from the pumping center. The facility's other two wells probably are not causing much additional drawdown. These wells also produce from the Ozark aquifer, but reportedly are not capable of pumping more than about 65 gallons per minute.

On June 6, 2000, the Water Resources Program had a permitted water well driller construct a dedicated groundwater level observation well immediately south of the Pettis Co. R-12 School in Dresden. This is the second well that is used to monitor the groundwater in this area. The well is 456 feet deep, and is cased through the Springfield Plateau aquifer to a depth of 200 feet. In August 2000, electronic equipment to measure and record water level changes was installed on the well. The data recorder also contains a radio transmitter that transmits the data to the program every 4 hours using the GOES weather satellite system. Data no older than 4 hours from both observation wells in and near Dresden, and 68 other locations around the state, can be viewed over the Internet (www.dnr.state.mo.us/water.htm, then click on "current groundwater conditions").

Water level in the Pettis Co. R-12 School observation well ranged from a high of about 223 feet below land surface to a low of about 245 feet below land surface between August 2000 and July 2001. The hydrograph of the well is strongly influenced by a weekly pumping cycle (figure 21). Water level in the well is generally closest to the surface early Monday morning, and decreases steadily throughout the week until late Friday afternoon when the trend begins to reverse. The weekly fluctuation is generally between 5 and 10 feet. The water level recovers somewhat over weekends, but average water level appears to have decreased approximately 10 feet during the 11-month period since the recorder was installed.

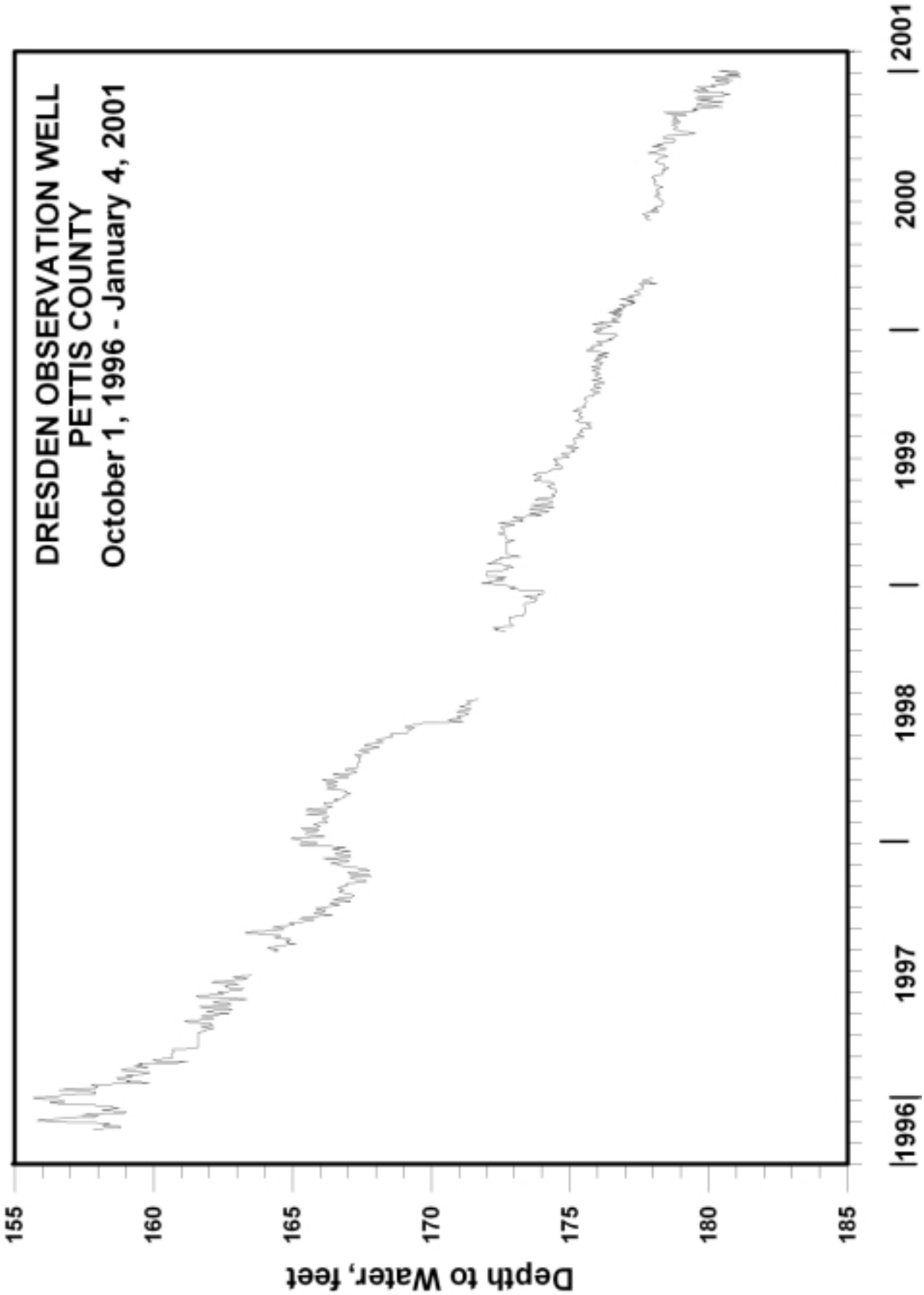

Figure 20. Graph of groundwater level decline in Dresden observation well. Source: Vandike, 2001.

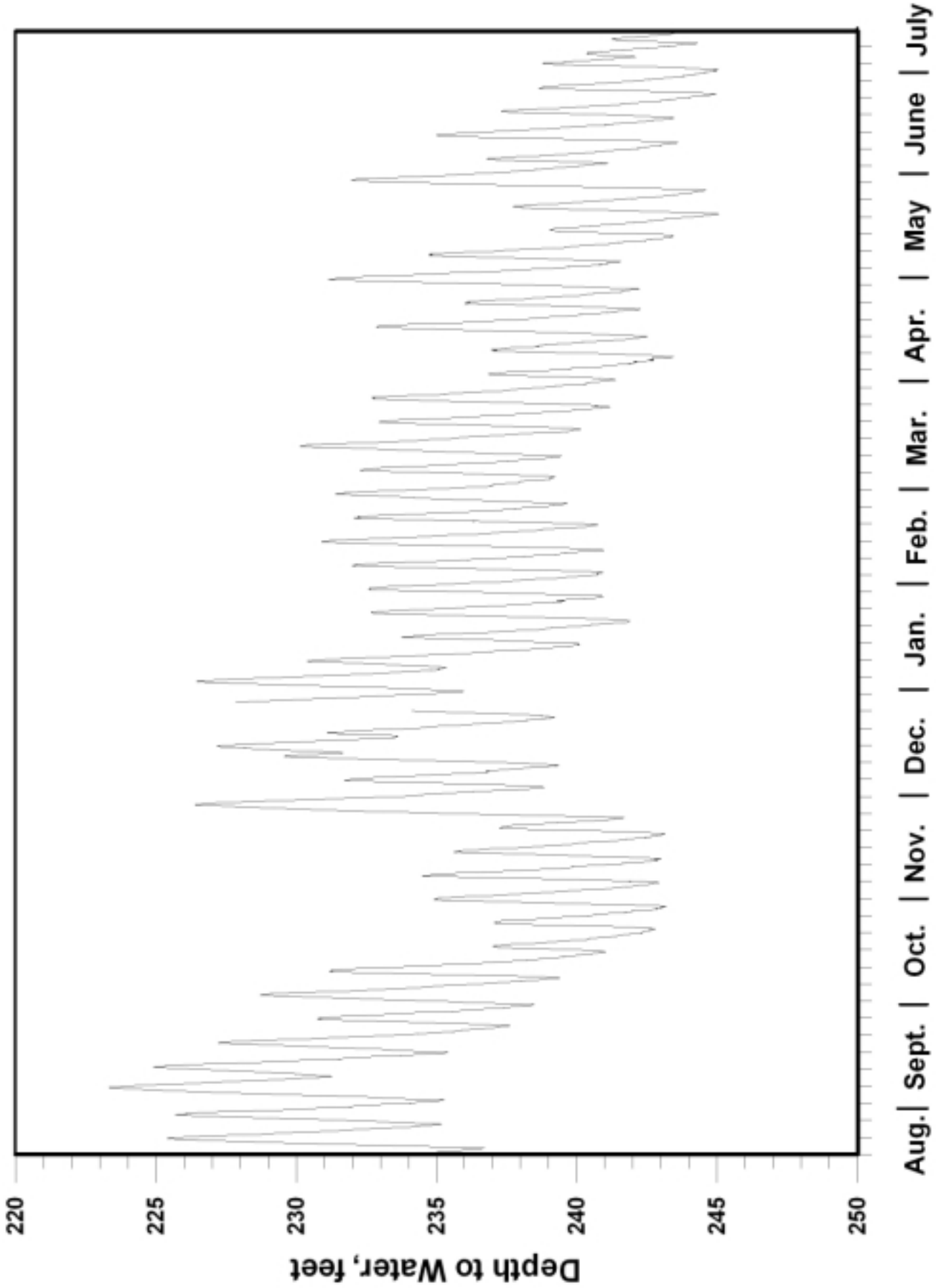

Figure 21. Graph of groundwater level in Pettis County R-12 school observation well. Source: Vandike, 2001.

It is interesting to note that although the Dresden observation well and the Pettis County R-12 School observation well are about the same distance from the poultry processing facility, and have very similar land surface elevations, water level in the well at the school is nearly 60 feet lower than that at the Dresden observation well. There are at least three possible explanations for this: First, the shallower Dresden observation well is not cased completely through the Springfield Plateau aquifer and is open to only a small part of the Ozark aquifer. Down-hole movement of water from the Springfield Plateau aquifer is likely affecting its water level. Second, carbonate-rock aquifers such as the Ozark aquifer commonly are anisotropic, meaning that the hydraulic conductivity is dependent on direction of groundwater movement. In anisotropic aquifers, drawdowns are not uniform in all directions from pumping wells. Third, there could be other wells near the Pettis Co. R-12 School observation well affecting its water level that are not affecting the Dresden observation well. The closest well to this observation well is the school's noncommunity public water supply well. It produces from the Ozark aquifer, but does not appear to greatly influence the observation well. The weekly water-level fluctuations measured at the observation well do not appear to increase when school is in session, or decrease when school is not in session. Compared to the volume of water produced by the poultry processing plant wells, the school well likely produces a relatively insignificant volume of water.

Because statutes in Missouri do not regulate groundwater production, there is little that the Department of Natural Resources can do to address water-level decline except gather information to accurately document it. Conflicts dealing with water use and water-level declines in Missouri must be adjudicated in the civil courts (Vandike, 2001).

Sources:

Miller, Don E.., and Vandike, James E.., 1997, Water Resources Report Number 46, *Groundwater resources of Missouri*, Missouri State Water Plan Series Volume II, Missouri Department of Natural Resources, Division of Geology and Land Survey, 210 p.

Stratton, Don, Pettis County R-12 School Superintendent, personal communication with James E. Vandike, Groundwater Section Chief, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, 1999.

Vandike, James E., Groundwater Section Chief, Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, written communication, 2001.

Lack of Spring Protection

Problem:

There is a lack of spring protection. The location and size of many springs are not known. Protecting spring quality is difficult because recharge areas are usually unknown and water from most springs is not routinely monitored for contamination.

Discussion:

Missouri's springs have received limited attention from resource managers. The scarcity of basic information on distribution, abundance and geologic structure makes protecting and managing springs difficult. Many springs appear to flow cold and clear from deep within the earth, providing a false impression of purity. In reality, springs are often directly linked to surface water, and are vulnerable to contamination from many sources.

Historically, agricultural, industrial and municipal developments have negatively impacted many springs. In November, 1981, a pipeline rupture resulted in liquid fertilizer entering the Dry Fork, a losing stream in southern Phelps County. The spill caused serious water quality problems in Maramec Spring, 12 miles away. Before the spill, it was not known that this losing stream was part of the recharge area for Maramec Spring (figure 22).

The Natural Resources Conservation Service (NRCS) of the United States Department

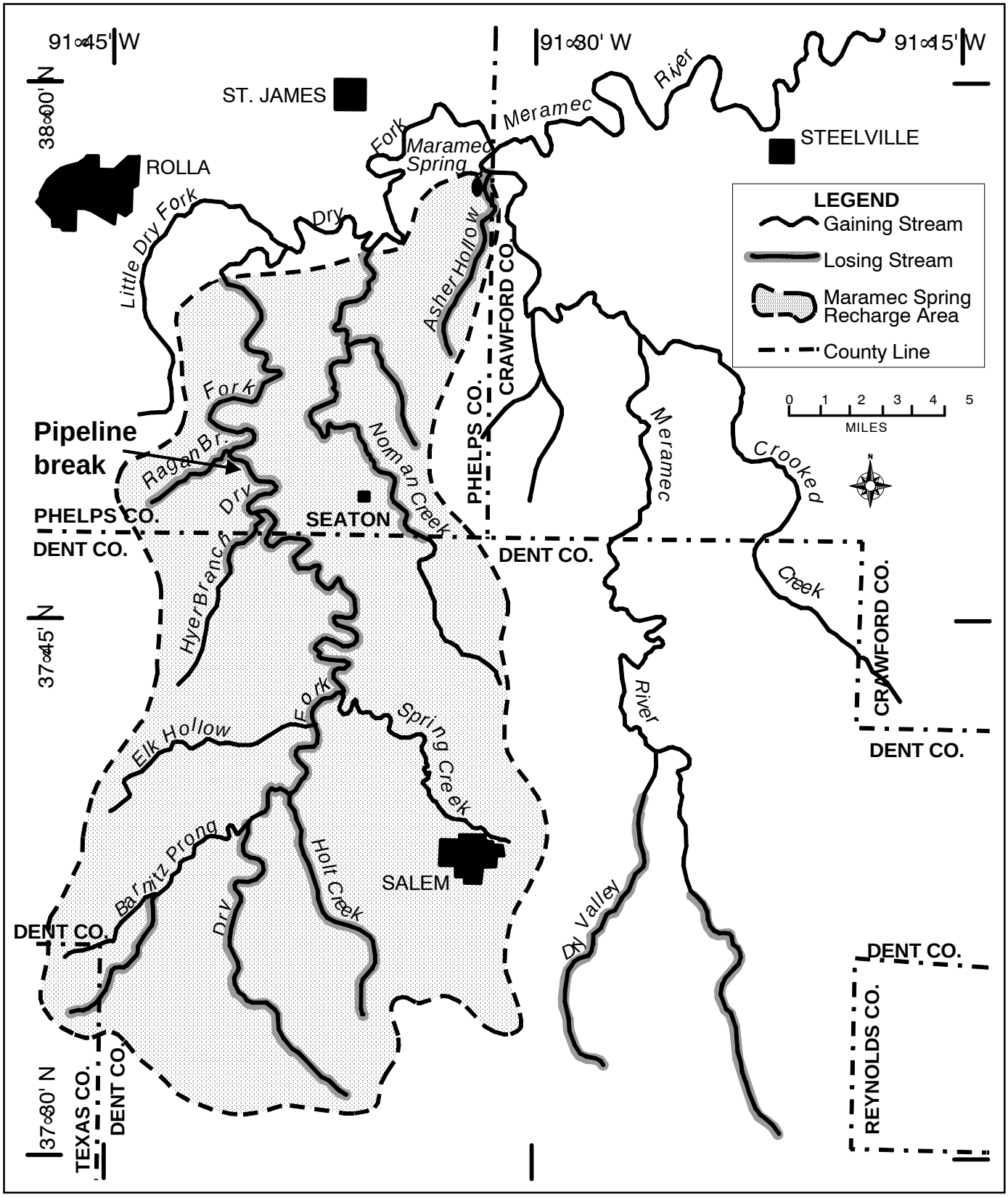

Figure 22. Recharge area of Maramec Spring. Source: after Vandike, 1996

of Agriculture does have Spring Development standards and specifications which address the surface impoundment of a spring. The purpose of these specifications is to provide guidance to improve the quality and quantity of water produced. A number of springs with exceptional ecological value are protected within Missouri's Natural Areas system. Other springs with significant ecological value, found on both public or private lands, are listed in the Missouri Natural Heritage Database. However, a complete inventory of springs in public ownership is not available. A complete inventory of Missouri's springs does not exist. An update of the "Springs of Missouri" publication is warranted.

The department's Geological Survey and Resource Assessment Division (GSRAD) has developed "The Springs Database." This is a Geographic Information System (GIS) coverage that incorporates all spring location and information available and represents the institutional knowledge that the division has developed since the First State Geological Survey was begun in 1853. This database is updated continually as new springs are documented. At the beginning of 2001, "The Springs Database" contained over 4,000 springs with improved locations due to the use of GIS and latitude and longitude.

Sources:

McPherson, J., et al., 1997, *Spring protection action plan.*, Fisheries Division, Missouri Department of Conservation, 20 p.

Miller, Don E. and Vandike, James E., 1997, Water Resources Report Number 46, *Groundwater resources of Missouri*, Missouri State Water Plan Series Volume II, Missouri Department of Natural Resources, Division of Geology and Land Survey, 210 p.

Vandike, James E., 1996, Water Resources Report Number 55, *The hydrology of Maramec Spring*, Missouri Department of Natural Resources, Division of Geology and Land Survey, 104 p.

Surface Water Quality Threats from Pollutants

Problem:

Some waters in Missouri are impacted by pollutants that may degrade water quality, harm fish and wildlife, and impact human health. Surface waters, the Missouri River in particular, are subject to increased contaminant levels during spring planting. For example, these include wastewater treatment/sewage plant bypasses during heavy spring rains, upstream from public water supply intakes, e.g. Wellsville, Sedalia, and Fort Leonard Wood. Also the run-off of chemicals from farms, golf courses, and playgrounds are other sources of surface water contamination.

Discussion

Surface waters most often come from precipitation, either rainfall or snowmelt, and as a result are susceptible to contamination from direct drainage or from diffused runoff. Surface waters in urban areas are especially susceptible to contamination from polluted runoff from hard surface and paved areas. Stormwater can wash contaminants from roads, paved areas and residential lawns and gardens into streams by way of storm drains. In rural areas, fertilizers, manure, pesticides, drainage from abandoned mines, and excessive soil erosion all contribute to the contamination of Missouri's water courses. These contaminants affect not only the aquatic habitat and wildlife that lives in or near the water, but also private and public drinking water supplies that are dependent on surface waters. In using chemicals on farm fields, the timing of the application is important. If a storm event occurs soon after application, much of the chemical may be washed into nearby streams and wetlands via surface runoff.

The Missouri River, as it enters our state, brings water that already has been changed by contamination of one kind or another, and to varying degrees. The U.S. Geological Survey

has chemistry monitoring gaging stations on the Missouri River at St. Joseph, Kansas City, and Hermann, Mo. Bacterial contamination in the river tends to rise, just below cities, and then fall off (due to dilution). Sulphate contamination of the river (from upstream) is diluted as it passes through Missouri. Runoff within the state adds to the river's contamination.

Herbicides are used by farmers and turf managers to control weeds in crop fields and on golf courses, school playing fields, city parks, and lawns. Herbicides are more economical to use in the short-term than mechanical cultivation of crops, and allow closer planting, to more efficiently use the available acreage. When rain falls soon after an application of a herbicide, the herbicide can be washed off the field and into streams. In many instances, the stream flows to a drinking water reservoir. This not only is wasteful of the herbicide product, but also contaminates the water, and forces the supplier to treat the water, which is sometimes a very expensive proposition. It is cheaper to avoid or prevent the contamination. The U.S. Environmental Protection Agency (EPA) has set maximum limits (MCLs) for those chemicals in a water supply used for human consumption.

Investigations by the U.S. Centers for Disease Control (CDC) and the EPA indicate that human illnesses related to contaminated drinking water may be more prevalent than thought (USGS, 1998). Research indicates that between 1971 and 1979, some 57,970 people in the U.S. suffered from waterborne diseases (Craun, 1986), and within that group, 45 percent were caused by groundwater (Gerba, 1988). Groundwater supplied from the deep bedrock aquifers in the Ozark Plateaus (most of the southern half of the state) has historically been found to be free of bacterial contamination. This area, however, is characterized by karst features, which have relatively free exchange of surface and groundwater, with limited geologic restriction of water movement. This makes the aquifers susceptible to surface water-transported contamination. Land use in the area primarily includes forest, pasture, cropland, and managed grazing and confined animal feeding operations. Private septic systems and municipal wastewater treatment plants are other sources of biological contaminants (USGS, 1998).

Sources:

Craun, G.F., 1986, Waterborne diseases in the United States, CRC Press.

Gerba, C.P., 1988, Methods for virus sampling and analysis of groundwater, ASTM STP 963, the American Society for Testing and Materials, 343-348 pp.

U.S. Geological Survey (USGS), March, 1998, USGS Fact Sheet 028-98.

Unplugged Abandoned Wells

Problem:

Historically, most abandoned wells have not been plugged. Abandoned wells are a hazard to people and livestock, and an entry point for surface waters that may carry contaminants into the groundwater. Rules requiring the plugging of wells were established in late 1987, and generally do not apply to wells abandoned before that time. Therefore, there are hundreds of thousands of wells, abandoned since Missouri was settled, that have not been properly plugged.

Discussion:

It has been estimated that Missouri has from 150,000 to 300,000 unplugged abandoned wells. This may be a conservative estimate. After looking into the origin of this estimate, it could easily be at least 500,000 unplugged wells and cisterns scattered across Missouri (Netzler, 2001). If the 500,000 number is used, then there could be approximately 66,000 unplugged wells in the region covered by this report. Each of these unplugged wells or cisterns is a danger either to the health, welfare and safety of Missourians, or to the groundwater that we rely on so heavily for our water resources.

Many things have changed since Missouri's early settlement days more than 200 years ago, but one thing that has not changed is the need for a dependable supply of water (Department of Natural Resources, 1988). If early settlers did not live near a river, spring, lake, or stream, they had to dig a well or cistern. Unlike wells that

produce water, cisterns simply store water, filled by runoff from roofs and channeled by gutters and downspouts.

The first wells were hand-dug, and many of them are still in existence today but are rarely used, and often forgotten. A hand-dug well is typically five to ten feet in diameter, and up to fifty feet deep. These wells were lined with local rock or brick and were covered with a concrete or wooden cap. (The biggest hand-dug well in the U.S. is located in southwestern Kansas in the town of Greensburg and is 32 feet in diameter and 109 feet deep.) These types of wells are considered a major danger to life and limb. People have died in Missouri by accidentally falling into one of these hand-dug wells. These types of tragedies can be avoided with a little preventive action--plugging the well.

Unplugged abandoned drilled wells are also a danger to personal safety and a potential conduit for surface-derived pollutants. The sizes of Missouri's drilled wells range from the normal six-inch diameter for a private domestic well, upwards to 36 inches in diameter. Many people do not realize that a well as small as eight inches in diameter can be a death trap to young children. Some people still remember the drama that played out on our television sets in October, 1987, about a little girl named Jessica McClure who was trapped in a well in Texas. The well was just eight inches in diameter. She was very lucky to have been rescued alive.

Many rural areas today are served by public water supply systems. Usually, when a water supply system is built in an area, people hook onto the system and the wells are abandoned but not properly plugged. There is a statute (Section 256.628, RSMo) that requires well owners, when they hook onto a public water supply, to report if they will be using their water well. If they are not going to use the well, then it must be plugged. Usually, the well owner states that they will use the well in the future, and therefore do not plug the well. In reality, many of these wells are never used again and over the years the well is forgotten and added to the number of unplugged abandoned wells. Follow-up and enforcement of this statute is extremely difficult.

Another example of wells not being plugged properly can be illustrated by the following scenario. A state employee was investigating a lakeside resort and discovered that the facility had been razed. Two water wells had served the resort. Remnants of one well remained, with a rock placed on top of the casing to block the opening. The other well was covered with soil, and it could not be determined from site examination if the well had been properly plugged. The statute requires that the well-plugging follow certain procedures, and be registered with the department's Geological Survey and Resource Assessment Division. Plugging abandoned wells is the responsibility of the landowner, who is liable for accidents.

The definition of an abandoned well, as it appears in Section 256.603 (1), RSMo,

"Abandoned well," a well shall be deemed abandoned which is in such a state of disrepair that continued use for the purpose of thermal recovery or obtaining groundwater is impractical and which has not been in use for a period of two years or more. The term "abandoned well" includes a test hole or a monitoring well which was drilled in exploration for minerals, or for geological, water quality or hydrologic data from the time that it is no longer used for exploratory purposes and that has not been plugged in accordance with the rules and regulations pursuant to sections 256.600 to 256.640, is ambiguous and seemingly open-ended, so it is extremely hard to determine when a well is technically abandoned. Also, if a landowner does not cooperate or "agree" to plug abandoned wells on owned property, the only enforcement that can be done is to refer the party to the Attorney General's Office for litigation. Litigating against large numbers of property owners who have abandoned wells on their property is not the most efficient or cost effective way to accomplish the goal of having all abandoned wells plugged.

Sources:

Missouri Department of Natural Resources, Division of Geology and Land Survey, 1998, Eliminating an unnecessary risk: abandoned wells and cisterns, Brochure 1.

Netzler, Bruce, (former Section Chief of the Wellhead Protection Section), Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication, 2001.

Private Water Well Construction and Water Quality

Problem:

Before enactment of the Water Well Drillers' Act (Sections 256.600 to 256.640, RSMo) and the Missouri Well Construction Rules in 1987, there were no set standards for private, domestic water well construction. Inadequate well construction could lead to water quality problems and could affect human health.

Discussion:

State statutes and rules establish water well construction standards for private water wells, with the goal of protecting both consumers and Missouri's groundwater. The natural quality and quantity of groundwater varies considerably across the state, ranging from abundant high quantity and quality to mineralized or muddy water of limited quantity. In some areas, past land uses have caused contamination of aquifers with pollutants. Because of these factors, statutes cannot guarantee water from a properly constructed well will be of high quality. The water well construction rules are designed to ensure that surface contamination does not enter the well, contaminating it and the aquifer (Department of Natural Resources Web Site, 2000).

The most important features concerning proper well construction are that enough casing is used in the well shaft, and that the annulus of the well is grouted. (The space between the outside of the casing and the drilled hole is called the annulus.) In the years prior to the well construction rules (pre-October, 1987), there were no requirements on the minimum amount or type of casing that must be used. It is not uncommon to encounter "old wells" that have ten feet of rusted-out "stove pipe casing" (Netzler, 2001). Generally speaking, the casing should seal out the soil and unconsolidated material, and be set into good, solid bedrock. In the central Missouri region, usually the minimum requirement of eighty feet of casing is sufficient. Additionally, if the well is located within a quarter mile of the Lake of the Ozarks or Harry S Truman Reservoir, then more casing is required to insure that lake water does not enter the well.

Grouting the annulus of a well is of utmost importance. When a private domestic well is drilled in this region, usually an eight and five-eighths inch (8 5/8") diameter hole is drilled to the casing point (at least eighty feet). Then the six-inch nominal casing is set into the hole. Since the casing has a smaller diameter than the drilled hole, the space left after the casing is installed must be sealed. This space, the annulus, must be grouted, according to the Missouri Well Construction Rules.

Whenever surface contamination (pesticides, septic tank effluent, animal waste, chemicals, petroleum products, solvents, etc.) finds an ungrouted annulus of a well, it can quickly bypass the natural filtering system of soil, unconsolidated material and rock, and directly contaminate the underground sources of water, the aquifers. Once an underground aquifer is contaminated, it is very difficult and very expensive to clean up. Prevention is always cheaper and more effective than remediation. For example, cases exist where septic tank effluent has come in contact with the ungrouted annulus of a well, and the next thing that happened was that the peoples' well water tested positive for fecal coliform bacteria (Netzler, 2001).

The quality of the drinking water produced by these wells is very dependent on how well the annulus has been grouted. A problem exists concerning enforcement of how these wells are grouted. The present regulatory system operates on an after-the-fact reporting requirement based on honesty. The permitted well driller has sixty days to report how the well was constructed. Since the regulatory agency, (the department's Geological Survey and Resource Assessment Division) does not know when and where a well is to be drilled, it cannot have staff present to insure that wells are grouted properly (Netzler, 2001).

Domestic water wells installed after 1987 must comply with Missouri statute (The Water Well Drillers' Act, Section 256.600 to 256.640, RSMo). However, once installed, there are no requirements for maintenance of these wells. The Centers for Disease Control (CDC) Nine-State Well Survey, completed in 1994, gives very good background information on the state of water quality produced from private wells. The CDC Survey was initiated after the Great Flood of 1993 (on the Missouri River) submerged many wells located in the flooded areas. Questions were raised about the impact of the flood of 1993 on water quality. This study was conceived because little background information existed on a statewide basis. Through the efforts of the nine flooded states (Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin) and the CDC, this study plan was presented to the U.S. Public Health Office, Office of Environmental Protection, and ultimately was funded by that organization.

The CDC Study systematically placed a grid of longitude/latitude intersections across the entire state of Missouri, with a minimum of eight sample sites for every county. Sampling personnel were to locate and obtain a sample from one private, domestic water well within a three-mile radius of each intersection. This sampling method provided a true cross-section of well type and construction. The only criterion was that each well had to be used for drinking water purposes. Each sample taken was tested for bacteria, nitrate, and atrazine contamination. Figure 23 shows the results of the bacteria tests for the counties in the central Missouri region.

The CDC Study tested for two types of bacteria. The first is a group of bacteria called Coliform. This type of bacteria is present in soils and at the surface of the ground. This is an indicator bacterium, which suggests that these bacteria have gone from the surface into the subsurface either by way of an ungrouted annulus, improper well cap, or an unplugged aban-

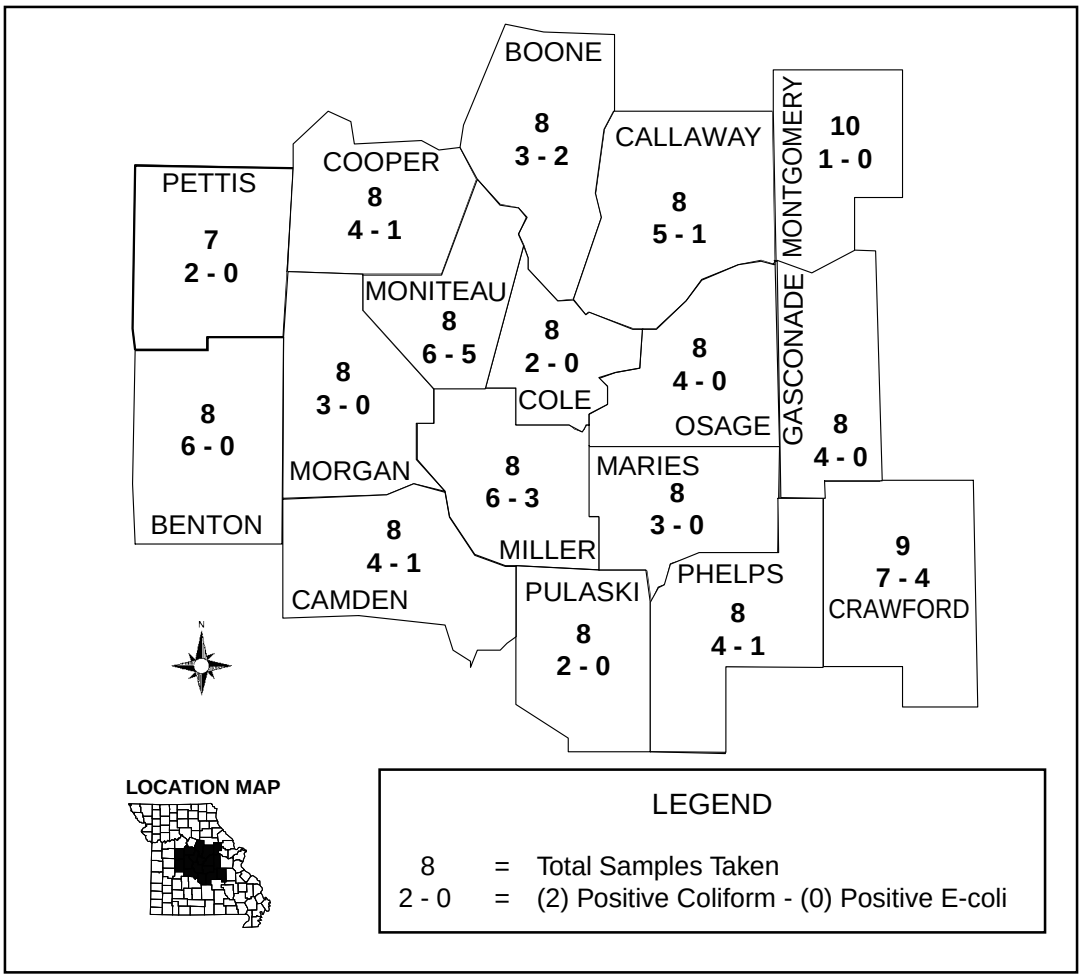

Figure 23. Private water well test results from U.S. Centers for Disease Control, 1994 study.

doned well. The second type of bacteria tested for was of the subgroup called Fecal Coliform, specifically the potential disease causing E-coli strain. Fecal Coliform bacteria represent a group of bacteria commonly found in the intestinal tract of warm-blooded animals.

Approximately 47 percent of the wells tested in the central Missouri region tested positive for coliform bacteria. The average age of these wells was 24 years, and the average depth was 314 feet, with 53 percent showing poor construction features. For drilled wells, a number of factors were significantly associated with coliform results--depth, age, diameter, type of casing, whether or not the well had a cap, type of pump installed with the well, and proximity to a septic tank leach field. Well depth over one hundred feet, age less than eight years (remember, this was done in 1994), and plastic or steel casing were associated with significantly lower positive coliform percentages. Additionally, well diameter less than nine inches, capped wells, submersible pumps, and location greater than one hundred feet from a lateral field were protective from coliform contamination (CDC Summary, 1994).

A concern with the construction of pre-1978 wells is the type of pump that may have been used. Specifically, the lubricating oil used in some pre-1978 wells may contain PCB's. The manufacture of PCB's ended in 1977 but before that time it was an additive to some lubricating oil utilized in well pumps. If these old pumps leaked while in use then a problem could occur. There is also a concern for proper disposal when pulling the pump during the plugging these wells (Netzler, 2001).

Sources:

Centers for Disease Control (CDC), Community Environmental Health, Summary, 1994.

Missouri Department of Natural Resources Web Site on line at: http://www.dnr.state.mo.us/dgls/geosrv/wellhead.htm

Netzler, Bruce, (former section chief of the Wellhead Protection Section), Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication, 2001.

Aging Infrastructure of Small Public Water Supply Systems

Problem:

The basic equipment, structures and installations that small public water suppliers use to provide services can become less efficient with age, and undersized with increasing demand. Economic issues concerning upgrading of small water supplies need to be addressed.

Discussion:

Small public water supply systems sometimes face water supply/water quality problems they are inadequately prepared to resolve. In many cases, existing rate structures do not cover the costs of capital improvements and maintenance, and managers of small water systems often are forced to focus upon daily operations rather than long term financial issues. Consequently, many small public systems are not able to maintain adequate cash reserves to repair, upgrade, or construct new facilities.

Many of central Missouri's public water suppliers serve small communities. Nearly 60 percent of the public water supply systems found within the region have service populations of 1,000 people or less. Many small municipal systems have been in operation for a half century or more; the median age of municipal systems serving 1000 people or fewer is 40 years, and 20 percent of them are more than 50 years old (Department of Natural Resources, 1996). Two-thirds of the population of central Missouri is served by a public water supply (Soley et al., 1993).

An adequate and fair rate structure is essential to the operation of any utility. This allows the utility to generate funds for proper management, operation and maintenance, and amortization of any outstanding loans. However, in many small (and very small) water supply systems, there is a lack of earnings to accomplish these responsibilities, resulting in the possibility of substandard service and poor water quality (U.S. EPA, 1991).

Substandard service can manifest itself in many ways. In some cases, a utility may not be able to provide new water supplies and addi-

tional infrastructure needed to support growth in the service area. Aging facilities and infrastructure may require upgrades or replacement, and a utility may lack the necessary funds. Water quality problems may call for new, improved treatment measures that a utility may be unable to provide. In much the same way, a utility may not be able to provide the level of treatment required by new, more stringent regulations. Problems in setting an appropriate rate structure may arise for several reasons. The managers of a small public water supply system may be so occupied with facility operations that they may have little time to address financial issues. Passing capital costs on to the service population is sometimes a concern. Many water systems wait too long before increasing user service charges for improvements because they fear adverse customer reaction (U.S. EPA, 1991). Operational costs, such as electricity, chemicals, payroll and training, must be accounted for in the rate structure as well. In some cases, community development block grants have been used to provide an alternative to rate restructuring to make capital improvements.

Some suppliers may find that their water sources, once pristine, have become contaminated, over time. New treatment technology may need to be purchased, and there is no reserve account to cover the costs. Under supervision of the U.S. Geological Survey, groundwater samples were collected and tested for biological contaminants in July, 1997. Findings included enteric viruses, coliphage, and fecal indicator bacteria at sample sites in Camden, Cole, Miller, and Osage Counties. [Phage are forms of viruses (from the Greek word, phagein, meaning “to eat”). Bacteriophage are viruses that infect bacteria. Bacteriophage that infect Escherichia coli (or E. coli) are coliphage. Coliphage are the most complex of all the viruses. Bacteriophage are not pathogenic, but may be useful as indicators of fecal contamination. (Phage, bacteriophage, and coliphage are plural words, of which there is no singular form.)] (USGS, 1998).

Contrary to what was expected, most of the enteric virus contamination was found outside karst areas. Coliphage and enteric viruses were present in two wells located in the alluvial aquifer along the Missouri River and fecal coliform bacterial indicators were also found in small densities in three public water supply wells. Until further testing can be completed, it is not possible to relate these initial findings to hydrogeology or land use nor does it appear that biological contamination is widespread or, where located, at significant levels (USGS, 1998).

Sources:

Missouri Department of Natural Resources, 1996, Inventory of Missouri public water systems, 204 p.

Solley, W.B.; Pierce, R.R.; Perlman, H.A.; 1993, Estimated use of water in the United States in 1990, United States Geological Survey Circular 1081, 76 p.

United States Environmental Protection Agency (USEPA), 1991, Manual of Small Public Water Supply Systems, 193 pp.

United States Geological Survey (USGS), March, 1998, Microbiological Quality of Public Water Supplies in the Ozark Plateaus Aquifer System, Missouri, Fact Sheet 028-98.

Untreated Residuals from the Production of Drinking Water

Problem:

There are several drinking water treatment plants along the Missouri River within the JCRO region that returns solids from the drinking water treatment process into the Missouri River. Post treatment solids have been handled in this fashion for years. There are many reasons for the situation. A big reason is that there are currently no facilities available for the treatment of the drinking water solids. The EPA urges Missouri River water treatment plants to discontinue the practice of returning solids from water treatment plants back to the river.

Discussion:

The main product produced at water treatment plants is clean water. However, there are some by-products produced through the water treatment process.

The quantity of solids generated from water treatment plants largely depends on the quality of the raw water. Generally, the harder and more turbid the raw water, the larger the volume of solids produced. The deposition of the solids downstream of drinking water treatment plants varies greatly depending on the quantity of the solids discharged, and stream flow. When the river is experiencing low flow, solids may accumulate in slower river reaches and may be flushed out of the river system during high flow periods.

Many drinking water treatment plants soften the water as part of the treatment process. In addition, a variety of chemicals are used to clarify or purify the water in water treatment processes. Lime and alum are two common additives used in the treatment process.

Missouri Effluent Regulations do not have effluent limitations set up for water treatment plants located along Missouri and Mississippi Rivers, though there are limitations set for those located along smaller rivers.

Some question whether the discharge of treatment chemicals and softening solids significantly alters the water chemistry of the Missouri River. One of the main concerns of the EPA is that the discharge of treatment chemicals and softening sludge may be unacceptable from the standpoint of creating harmful bottom deposits and will not meet applicable technology requirements. Currently there is little information published on the characteristics of solids generated from the Missouri River and little information available on possible impacts of water treatment solids discharges on river benthos or the natural river environment.

Further research is needed to determine if discharged solids have a negative impact to health or the environment. Other uses for the sludge may be found with further research.

Agricultural Water Use

Land Application of Animal Manure

Problem:

Improper disposal of animal manure can impair water quality.

Discussion:

Composted manure is a valuable component of topsoil, with nitrogen-phosphorous-potassium plant nutrients of about one percent each, however this varies with species. This often is expressed as N-P-K. While having typically less nitrogen than chemical fertilizer mixes, composted manure is also a rich source of organic matter, which helps build a healthy soil. Manure commonly is spread on corn, soybeans, pasture, and hay fields, where actively growing crops can take up the nutrients.

When animal manure is applied to cropland or pasture at rates greater than can be absorbed by the soil or used by growing plants, or when excessive rainfall causes applied amounts to wash off fields, direct runoff of manure is carried into watercourses.

The number of confined animal feeding operations (CAFOs) has increased rapidly in Missouri, as well as in this region of the state. Larger concentrations of livestock increase production efficiency by their economies of scale. Consequently, the trend toward larger, vertically integrated facilities is likely to increase (figure 24).

Excessive nutrient concentrations from manure runoff into streams can lead to enhanced growth of algae in the water, called algal blooms. Algal blooms eventually die and the decomposition of the algae uses oxygen that is dissolved in the water. This oxygen demand can rob fish and invertebrate creatures of the oxygen they need to live.

The loss in numbers of aquatic animals, and the reduction in the number of species of aquatic

life may be a result of excessive nutrients from manure in water bodies. High nutrient levels, especially high nitrate levels in the water, can make the water unfit for public water supply use (Brookshire, 1997). Over time, chronically high pollution levels have caused a serious decline in sensitive aquatic species.

Besides nutrients, there are other components in manure that also run off into streams and ponds--bacteria from the intestines of livestock can survive in raw manure. Growth enhancing substances and antibiotics fed to livestock as part of their rations also enter surface waters as part of runoff. These may create risks that scientists do not completely understand as yet, to humans, fish, and wildlife.

The many pathogens found in livestock manure can be harmful to human life, and it has been shown that some pathogens may have become resistant to antibiotics because of exposure and misuse of antibiotics used for livestock. Fecal coliforms and fecal streptococcus are among the pathogens found in manure and streams that are harmful to humans, and have built up a resistance to certain antibiotics (Edwards, et al., 1997).

Without thorough and adequate data, it is impossible to combat what is seen as a growing problem of antimicrobial resistance in human pathogens. A spokesman for the FDA says that the agency has drafted regulations that will call for the data on antibiotic use to be made available. The FDA's Center for Veterinary Medicine says that transmission of antimicrobial-resistant pathogens from animals to humans in the food supply is an established fact (Nature, 2001).

There are three predominant sources of manure in the region: poultry, swine, and cattle. Poultry manure combined with bedding is termed "litter" and is typically handled dry. Swine manure is handled both wet and dry, but swine manure from CAFOs usually is handled wet, as a "slurry." Slurry is commonly moved to a lagoon for stabilization. Slurry can be pumped, and can be applied to farm fields by spray irrigation, or by "injection-plowing," a technique that puts the slurry under the surface of the earth, avoiding both odors and runoff.

After the animal waste is flushed from the animal confinement buildings, the slurry is stored in large anaerobic lagoons. Operators are required to draw down these ponds from time to time, based on volume estimates.

Some 62 pollution incidents were attributed to livestock manure in the Central Region from 1990 to 1998. Twelve of these incidents occurred in 1998. Fifty-four involved hog manure, five involved cattle manure, and three involved poultry manure. Seventeen of the 62 incidents resulted in fish kills, where an estimated 83,997 fish died (Missouri Department of Conservation).

Sources:

Brookshire, Cynthia N., 1997, Water Resources Report Number 47, Missouri water quality assessment, Missouri State Water Plan Series Volume III, Missouri Department of Natural Resources, Division of Geology and Land Survey, 172 p.

Edwards, D.R.; Larson, B.T., and Lim, T.T., August, 2000, Runoff Nutrient and Fecal Coliform Content from Cattle Manure Application to Fescue Plots, in the Journal of the American Water Resources Association, Volume 36, Number 4, pp. 711 ff. See also Edwards, D.R., Coyne, M.S., Vendrell, P.F., Daniel, T.C., Moore, P.A., and Murdoch, J.F., April, 1997, Fecal Coliform and Streptococcus Concentrations in Runoff from Grazed Pastures in Northwest Arkansas, in the Journal of the American Water Resources Association, Volume 33, Number 2, 413-414 pp..

Environmental Defense Fund, 1999, online at http//www.scorecard.org.

Jefferson City Post Tribune, January 26, 2001.

Missouri Department of Conservation, files and database at 1110 S. College Ave., Columbia, MO 65201.

Nature, January 18, 2001, Volume 409, Number 6818, 273 p..

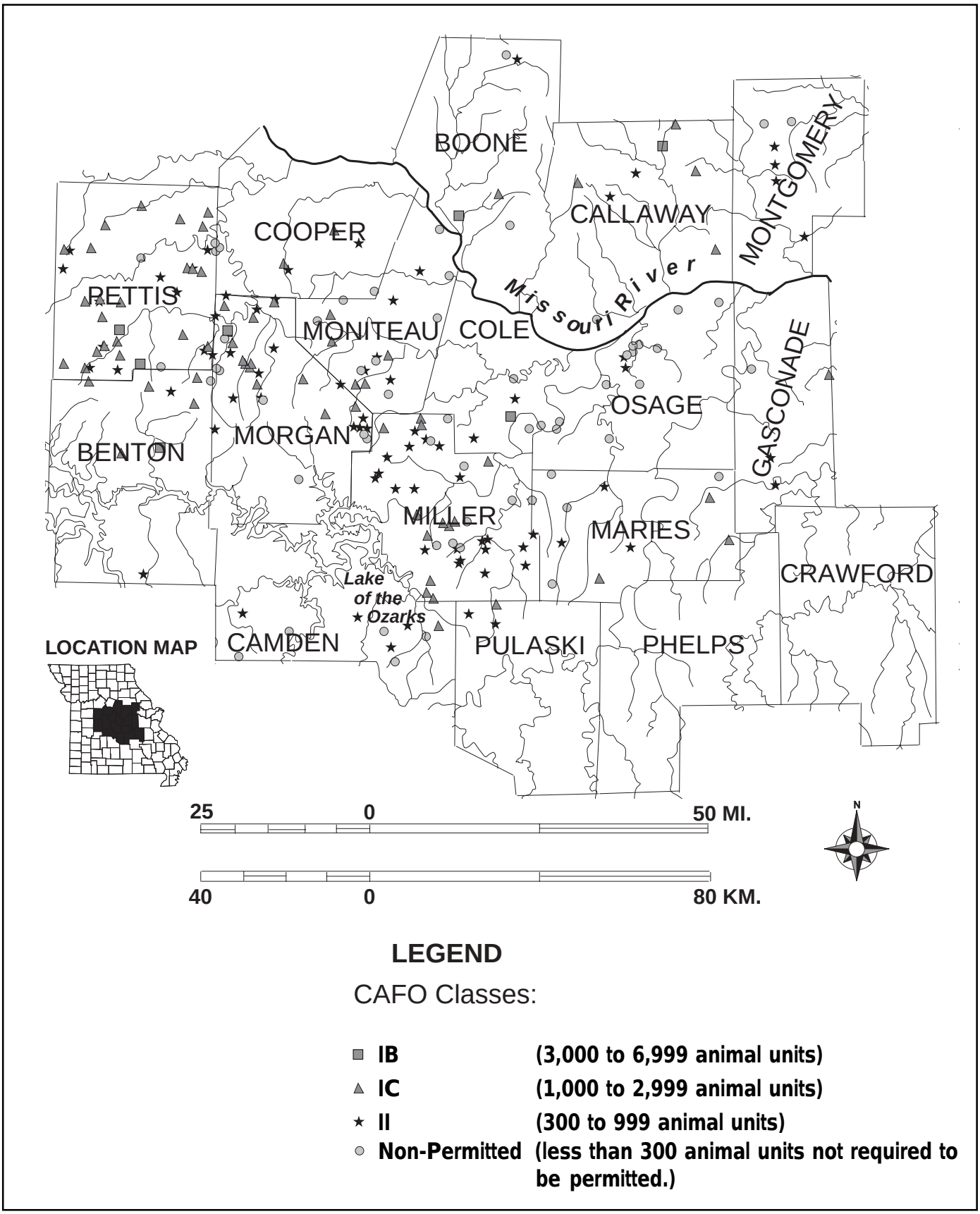

Figure 24. Locations of confined animal feeding operations (CAFOs) in central Missouri, 1988-1989. Source: Missouri Department of Natural Resources.

Lack of Coordination of Levee Construction

Problem:

Non-federal levees are not built to any consistent standard, and levees are not coordinated into any system of statewide protection.

Discussion:

Most existing levees along the Missouri River were first constructed during the era of flood control "common enemy doctrine." This was based on the concept that floodwaters were the common enemy of all, and each property owner had a right to protect his land from flooding as best he might. So, originally, when levees were built, it was with the goal of protecting the landowner's property, without consideration for the property of adjacent owners. Over the years, Missouri court rulings moved away from the harshest elements of this legal doctrine, into what then was called the "modified common enemy doctrine." In 1993, the Missouri Supreme Court ruled that the reasonable use doctrine has replaced the common enemy doctrine in this state (Gaffney and Hays, 2000).

While the reasonable use doctrine may have an effect upon the construction of new or higher levees in the future, it is not known how this legal doctrine may affect the repair or replacement of those currently in place. In Kansas and Illinois, a state levee permit is required for construction of a new or replacement levee (Funk, 1987). This assures that the levees permitted will be built to a construction standard, and will be designed to fit into a system of levee protection. There is no such system in Missouri.

Levee construction to protect real property in Missouri from flood damage is not coordinated. Levee heights (or levels of protection) are not systematic or coordinated along Missouri's rivers. Non-federal levee construction is not undertaken to any set standard. Environmental affects are not considered. The construction of levees in past centuries opened up additional lands for agriculture by reducing the frequency of flooding of floodplain fields.

Some levees have been built by the Corps of Engineers of the U.S. Army's Division of Civil Works. There are strict construction standards for Corps of Engineers' levees and floodwalls, so that they will not suffer construction failures. Many levees are not in the Corps of Engineers' Operation and Maintenance Program. Since the 1986 flood, the flood damage rehabilitation program of the Corps requires that only levees that are owned or sponsored by a legal entity that has the power to tax to support maintenance will be eligible for post-flood repairs at federal cost-share (now 80 percent federal, 20 percent levee district) (Engineering Regulations, 1987).

Cities and counties that participate in the National Flood Insurance Program have the power to permit floodplain development, including levee construction, within their jurisdictions. Sections 49.600 et seq., Revised Statutes of Missouri (RSMo), clearly indicate that levee and drainage districts (special purpose governments) are subordinate to county (general purpose) governments. This is reiterated at Section 64.001, RSMo. This law sets no standards.

The Missouri River, the principal river of the Central Missouri region, has been greatly changed from the river that Lewis and Clark explored as they passed through in 1804. The river then was a shallow, meandering river, with many islands. In its form, it had what is called a "braided channel" in which the river typically had two or more flow lines, with islands among them. The river moved within what is termed a "meander belt" across its floodplain, changing with every flood. There commonly were two floods a year, one in April, caused by spring rains and Great Plains snow melt; the second in late June or early July, caused by Rocky Mountain snow melt. Whenever there was high water, the flood would spread from bluff to bluff, in a shallow moving sea, altering the landscape, and causing considerable bank sloughing (pronounced "sluffing") and channel changes.

In the 20th Century, following a number of severe floods and droughts, and the start of the Great Depression, work began on a large dam on the upper Missouri River in Montana. This is called Fort Peck Dam. In 1944, the Pick-Sloan Plan for controlling flooding on the Mis-

souri River was authorized by Congress, following the 1943 flood of the Lower Missouri. This plan incorporated the already-built Fort Peck Dam into a series of dams to reduce flooding by storing excess water, and to augment flows in dry years by releasing stored water for irrigation and navigation on the Lower Missouri River. The Lower Missouri also was changed by construction of a series of "river training works" that closed certain channels of the river in favor of others, to straighten the river for the benefit of barge navigation, and to encourage the deepening of the channel by the construction of wing dikes. The water surface of the river, and the number of islands in the river, both have been greatly reduced by these efforts.

In addition, numerous levees and flood walls have been built by the Corps of Engineers to prevent the flooding of low areas along the river, chiefly areas of existing or planned urban and industrial development. The Corps uses stringent standards for levee construction to avoid failure. There is no such standard for the various private levee districts along the river. During the extensive flooding of 1993, most of the levees in Central Missouri were overtopped, with considerable land damages (scouring and deposition), as well as damages to homes and personal property, as a result. Some communities, such as Cedar City, no longer exist, while others carry on.

Sources:

Engineers, Chief of, U.S. Army, Corps of Engineers, 1987, *Engineering regulations*.

Funk, Bill, Kansas Water Board, 1987, personal communication to Richard M. Gaffney.

Gaffney, Richard M., and Hays, Charles, 2000, Missouri State Water Plan Series Volume VII, *A summary of Missouri water laws*, Water Resources Report Number 51, 292 pp., Missouri Department of Natural Resources, Division of Geology and Land Survey.

Loss of Riparian Corridor

Problem:

Loss of riparian corridor vegetation has negative water quality impacts and increases flood damage.

Discussion:

The "natural" condition of most river and stream banks in central Missouri is a forested riparian corridor, except where flooding has caused the bank to cave into the stream. Generally speaking, in pre-settlement times, the uplands consisted of tall-grass prairies, and the bottoms had trees, such as cottonwoods, silver maples, elms, sycamores, a few wet-soil tolerant oaks, and willows.

Early Euro-American settlers, using the rivers as arteries of travel and commerce, often settled on floodplain lands, cleared the trees for lumber, building materials, and fuel, and grew crops on the cleared land. In fact, early surveyed lot lines were laid out perpendicular to the rivers, so that each lot owner had access to the river for shipping and travelling (Brown, 1998).

The destruction of riparian corridor vegetation leaves stream banks exposed to the erosive force of moving water. But other effects can also be seen: lack of shading increases in-stream water temperatures, causing heat stress on organisms in the water, and there is less energy in the form of leaf litter that enters the stream and supports the food web. Conversely, healthy riparian corridors are usually vegetated, thereby having cooler in-stream water temperatures, more aquatic life, more fish, and more wildlife living near the stream, including birds, amphibians, reptiles, bats and other mammals.

Historically, riparian corridors have been viewed by some as areas of little land use value, except for farming. For purposes of increasing agricultural production, or perhaps increasing marketability, some property owners clear the land and build levees to protect the floodplain from frequent flooding. Some areas of central Missouri have experienced extensive land conversion, and sometimes, one can see crops

planted very close to the edge of the river bank.

Resulting conditions are extensive soil disturbance, including scouring and deposition during flood events, changing stream channels by accretion and erosion, and by avulsion (rapid channel change by cutting off river bends). According to staff of the Jefferson City Regional Office (JCRO), these types of changes can be seen in many parts of the region. Destabilized banks have high rates of erosion that lead to undesirable changes in channel morphology, excessive instream sedimentation, and loss of habitat for many aquatic organisms (Lyons, et al., 2000). Stream bends with unforested banks have a migration rate three times greater than stream bends with forested banks (Burckhardt, et al., 1998).

A healthy riparian corridor should have a 50- to 200-foot width of undisturbed vegetation back from the banks, depending on the size of the stream, in order to reduce damage from flooding. Studies performed along the Missouri River after the Great Flood of 1993 showed that a wide forested corridor between the river bank and the levee protected the levee from the flood's high energy flows. A forested corridor slows the flow of flood waters, reducing its erosive force (Dwyer, et al., 1997). The width of grassy riparian areas is also important. Maximum benefits are normally achieved with widths of 30 yards or more (Lyons, et al., 2000).

Both woody and grassy riparian vegetation can filter pollutants such as organic wastes, pesticides, heavy metals, and hydrocarbons from terrestrial runoff. Plant stalks and roots intercept and retain at least some of the contaminants, diminishing chemical pollution. Pollutants can become attached to soil particles in the riparian corridor, where they are held and degrade, preventing some of the pollutant from entering the water.

Sediment is considered a major pollutant when in excess of natural conditions, as it can clog the gills of fish and fill small spaces among cobbles and pebbles on the streambed, preventing their being used as living space by small invertebrates. Sediment is released into streams and rivers as a consequence of soil erosion, often a result of the clearing of riparian corridors. Plants and debris (downed tree branches and leaf litter), by slowing down any stormwater flow, cause sediment to drop out of suspension, settling on and into the soil of the corridor. The vegetation prevents the soil particles from reentering suspension in water and travelling downstream.

Vegetated riparian corridors help to: filter some contaminants to protect water quality, improve aquatic habitat, reduce soil erosion, limit flood damage, and provide for an overall healthier terrestrial habitat. These are positive environmental effects of vegetated riparian corridors.

Sources:

Brown, Norman, 1998, Land Survey Program (retired 2000), Geological Survey and Resource Assessment Division, Missouri Department of Natural Resources, personal communication..

Burckhardt, Jason C., and Todd, Brian L.; February, 1998, Riparian forest effect on lateral stream channel migration in the glacial till plains, in the AWRA Journal, Volume 34, Number 1, 179-184 p..

Dwyer, John P., Wallace, Douglas, and Larsen, David R., April, 1997, Value of woody river corridors in levee protection along the Missouri river in 1993, in the Journal of the American Water Resources Association, (AWRA) Volume 33, Number 2, pp. 481-489.

Lyons, John, Trimble, Stanley W., and Paine, Laura K., August, 2000, Grass versus trees: managing riparian areas to benefit streams of central north America, in the Journal of the American Water Resources Association, (AWRA), Volume 36, Number 4, 919-930 pp.

Pesticide Runoff

Problem:

Pesticides, when applied in combination with sufficiently heavy rainfall and other environmental factors, can leave their application sites and contaminate surface and groundwater.

Discussion:

There are more than 1,400 compounds found in various pesticide products used to control crop pests (insects, weeds, diseases) (Clarke, 1997). Many of these same chemicals are also used to control similar pests in the urban environment. Modern pesticides are typically more water-soluble than those used in the past. This can increase the likelihood that they will enter nearby water bodies. At the same time, modern pesticides are normally shorter lived in the environment reducing overall impact. Both agricultural and urban pesticide users want to keep pesticides where they have been applied. When pesticides move from their intended site, either by drift or runoff, they cannot perform the function for which they were intended (Andre, 2001).

Pesticides are designed to control specific types of pests. When pesticides are used improperly, they may have adverse effects on other organisms. Information about the proper selection and use of pesticides is available through University Extension and other outlets. The most critical piece of information about a particular pesticide is the label attached to the product container. By reading the pesticide label before purchasing, consumers can assure they are purchasing the product they need. By reading and following the pesticide label during use, consumers are able to minimize the impacts on non-target organisms.

As our base of scientific knowledge and analytical methods continues to grow, we gain more information about our environment and how pesticides impact it. This increased knowledge and understanding has led to the removal of some chemicals from the marketplace and a change in use patterns of others. At the same time, our new knowledge has led to the development of new chemicals that have a reduced impact on the environment while allowing us to continue to control pests that pose a threat to our health and economic well-being.

Sources:

Andre, Paul, 2001, Missouri Department of Agriculture, Pesticide Management Program, written communication.

Clarke, G.M., 1997, Occurrence and flux of selected pesticides in surface water of the upper Snake River basin, Idaho and western Wyoming, in the Soil and Water Conservation Journal, Volume 52, Number 5, 381-388 pp..

Excessive Instream Sedimentation

Problem:

One of the most widespread water quality and stream habitat issues in the region is excessive human-induced instream deposition of sediment. This results in water quality degradation and aquatic habitat loss.

Discussion:

Alteration of the land surface can enhance the natural forces of change in the environment. Wind and water naturally work to erode the surface of the land. The tendency is to wear away the hills and fill in the swales to create a plain surface. However, in the process, erosive forces create gullies, degrade some watercourses, widen some streams, and fill others. In the natural world, these forces work slowly on the land.

Since the 1930s era of severe drought and economic depression, thinking people have focused on the need to conserve soil and water for the long term sustainability of agriculture in this country and the world. One need only to look at the results of erosion in other countries to understand that wealth is produced by human energy working with natural resources. Where the soil resources have been lost, the economy is often less than desirable.

Row cropping leaves bare ground exposed to the erosive forces of stormwater, unless some

form of reduced tillage is practiced. A number of Best Management Practices (BMPs) have been devised and demonstrated in Missouri to reduce soil erosion. Still, there is excessive erosion, resulting in excessive deposition of sediment in the streams of central Missouri.

In some watersheds, particularly north of the Missouri River, and in the western part of the central region, soil sedimentation results in turbid water in the streams. The source of the sediment is by no means limited to soil erosion from traditional agriculture settings, but could come from a wide variety of construction sites, including single family homes, businesses, and road construction. This turbidity and excessive siltation has negative effects on aquatic life, including fishes and invertebrates like crustaceans and insect larvae. Too much sediment in a stream can fill pools and impede riffles, making them unsuitable for aquatic life that prefers these types of stream morphological characteristics. Too little sediment, on the other hand, prevents the formation of runs and flats, making the stream unsuitable for aquatic life that prefers these areas. Sediment fills ponds and reservoirs, reducing their useful life, water storage capacity and changing the habitat. Deposits in stream channels increases local flooding because of reduced channel capacity. In addition, because many chemicals and nutrients bond to soil particles, these may be flushed into water bodies, contaminating them.

To explain better what siltation does to aquatic habitat, some organisms, such as mayflies, stoneflies, and caddisflies, in their larval stages, live in the spaces (called interstices) between and beneath pebbles and cobbles in streams. When these spaces are filled with silt, or other fine sediment, these invertebrates disappear, and the fish or other organisms that depend on them also disappear.

Turbidity and siltation can also reduce or destroy fish populations, sometimes due to sublethal effects, such as respiratory impairment (silt clogs the gills of fish), reduced tolerance to disease, physiological stress, reduced reproductive success, reduced feeding and less growth. Sediment also fills the pools and riffles that fish use for feeding and cover. Deep pools are especially valuable during cold winter months, and during low flow periods in summer and autumn. Loss of these deep pool habitats concentrates fish in the few remaining suitable locations, and often increases the competition among species, especially the availability of prey to predator species.

Gravel sedimentation is typical of Ozark streams in the part of the region south of the Missouri River. Most affected seem to be the eastern Osage River and Niangua River watersheds. Increased sedimentation is one of the identified possible threats to the welfare of the Niangua darter, a threatened species (Mattingly, 1995).

Sources:

Brown, D.J., Dent, R.D., and Turner, W.M., 1992, Lamine river basin plan, Missouri Department of Conservation.

Mattingly, H.T., 1995, Factors affecting the distribution and abundance of the federally threatened Niangua Darter (Etheostoma nianguae), Unpublished Ph.D. dissertation, University of Missouri, Columbia, Misouri.

United States Department of Agriculture (USDA), 1997, Blackwater-Lamine river basin in Missouri.

INDUSTRIAL WATER USE

Low Flow in the Missouri River

Problem:

At times, there may not be enough water in the Missouri River to meet power generation and thermal dissipation needs for the water intakes or outflows from power plants.

Discussion:

River stages at power plant water intakes may fall below critical levels during low-flow periods, requiring plants to shut down or reduce the amount of energy they generate. Low water problems have been more of a concern

during winter when there is a great demand for power. In winter, when ice jams occur, they can dramatically decrease the amount of water in the river downstream. Ice can also cause localized problems at the intakes. The ice problems are coupled with the fact that there are lower releases from the Missouri River Main Stem Reservoirs located in Montana and the Dakotas. Since the completion of the Missouri River Main Stem Reservoirs in the early 1960s there has not been a major drought and so we have not tested the system with extreme low flows during times other than the winter.

An example of wintertime problems occurred during the winter of 2000-2001. Very cold weather in December and January caused the shutdown of the Nearman Creek Power Plant on the Kansas River in Kansas. This was due to ice jams that restricted water flow, and lowered the river stage below their intake pipes. Even though this event took place outside the central Missouri region, it is an example of what can happen.

Another issue is having enough water in the river so that thermal discharges made by the power plants do not cause environmental harm. Thermal discharges are regulated under the National Pollution Discharge Elimination System (NPDES). Temperature problems are not only a source of environmental concern but can cause a decrease in generating capacity.

Two power plants in central Missouri, the Callaway Nuclear Power Plant at Reform, and the Chamois Power Station (Associated Electric), Osage County, draw cooling water from the Missouri River.

Thermoelectric power plants use water in two important processes--steam generation and steam condensation. Steam generation uses high quality water to produce steam, which drives the turbines and generates electricity. Steam condensation uses cooling water to condense turbine exhaust steam. The condensation process increases plant efficiency by creating a vacuum, which reduces backpressure on the turbine blades. It also allows the recovery of high quality feedwater (Power, 1989).

The power plants use water from the Missouri River in the steam condensation process. The Callaway plant operates a cooling tower to reduce the temperature of used cooling water. This water is then returned to the cooling tower basin, where it is recirculated through the steam condensers. Although nearly all of the cooling water is reused, approximately 75 percent is lost from the top of the tower through evaporation. Another approximately 25 percent is used to flush suspended solids from the cooling tower basin, and then returned to the Missouri River (Union Electric, 1996).

The minimum streamflow required to supply cooling water for the Callaway and Chamois power plants is determined by the elevations of their water intakes rather than by their capacities. While the Callaway and Chamois water intakes do not draw large volumes of water relative to flow in the Missouri River, the intakes experience problems when water elevations are not adequate for the pumps to function. It has been estimated that the Callaway plant's water intake begins to become endangered of losing the ability to produce power at approximately 27,000 cubic feet per second of flow at the Hermann U.S. Geological Survey gage station (AmerenUE Services, 2001) (figure 25). Likewise, operations at the Chamois plant are at risk of losing the ability to produce at about 30,000 cubic feet per second, which corresponds to a gage height of 502.5 feet mean sea level (Associated Electric Cooperative, 2001). Note also that the river bottom (typically sandy) is changing constantly with the water flow in the river. Thus, for any given discharge, there can be a range of river stages.

The U.S. Geological Survey (USGS) operates a stream gaging station on the Missouri River at Hermann, located approximately 18 miles downstream of the Callaway and Chamois water intakes. Because of its proximity, the gaging station provides some indication of streamflow conditions at the water intake sites. Under most circumstances, streamflow at the intake sites is more than sufficient to meet water requirements at the Callaway and Chamois power plants.

During winter months, however, streamflow may conceivably fall below levels necessary to provide sufficient amounts of cooling water. The U.S. Army, Corps of Engineers' management of the Missouri River system normally does not

support navigation on the river from December through March (U.S. Army, Corps of Engineers, 1979). During these months, ice conditions throughout the main stem reservoir system may limit releases from Gavins Point Dam. This, in combination with ice damming, especially north of Sioux City, Iowa, below the reservoir system, and low inflows from downstream tributaries, can result in exceptionally low streamflow near the Callaway and Chamois water intakes. For the entire period of record for the USGS report cited, 1897 to 1996, the "instantaneous low flow" of the Missouri River at Hermann was only 4,200 cfs, January 10, 1940. Discharges of this size would, if applied to the upstream water intakes, stop operations at all the lower Missouri River power plants. There would also be appeals for help to get more water into the river, such as from increased releases from Bagnell Dam on the Osage River.

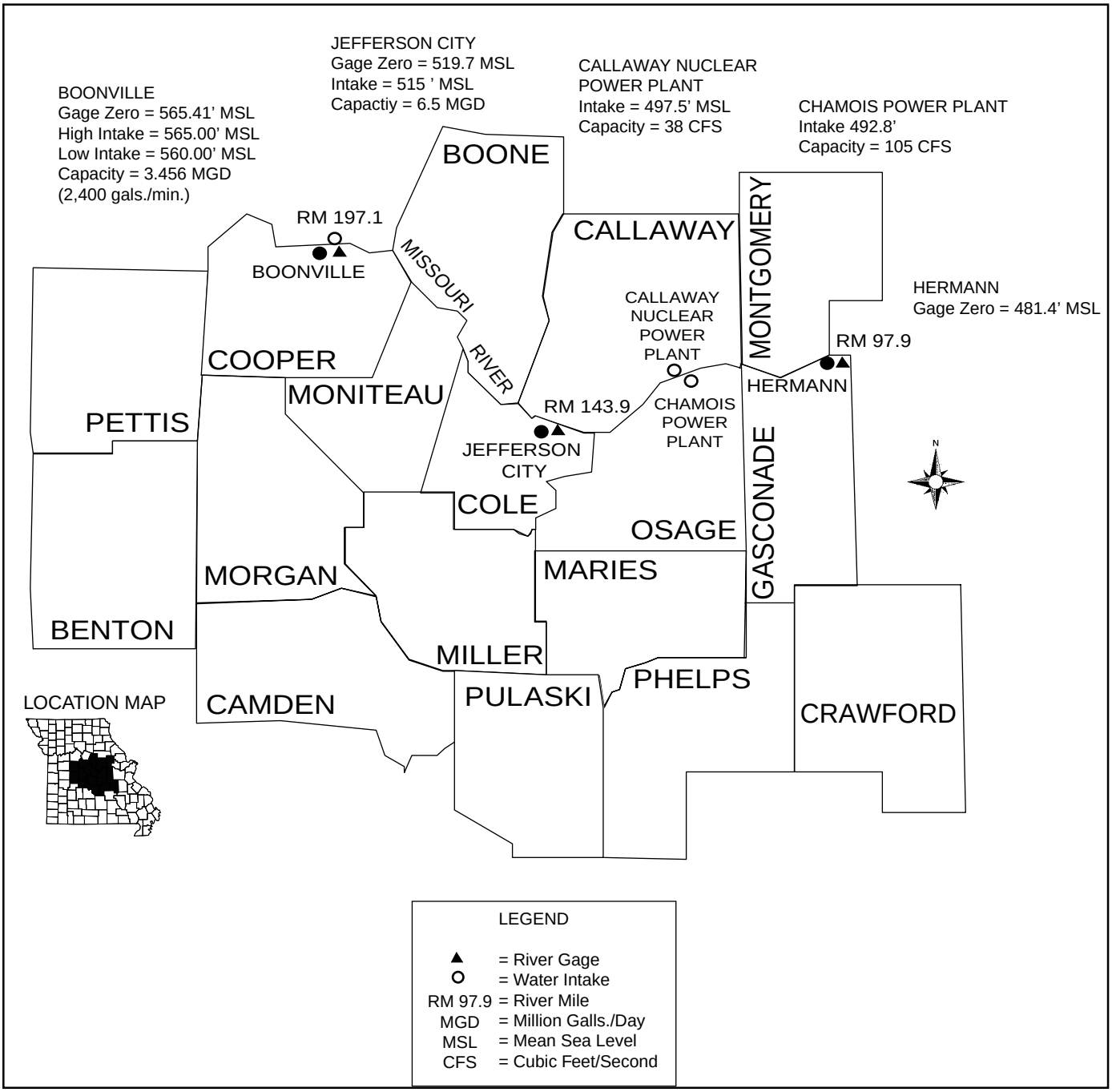

Figure 25. Location of Missouri River water intakes in central Missouri.

In December, 2000, and early January, 2001, there were very low flows in the Missouri River, especially noted in the central Missouri region and upstream. At this time, AmerenUE increased releases from Bagnell Dam for the purpose of raising the stage of the Missouri River. This lowered the water level at the Lake of the Ozarks.

Sources:

AmerenUE Services, John Pozzo, Supervisor of the Water Quality Section and Environmental Safety and Health, April 9, 2001, personal communication.

Associated Electric Cooperative, Jerry Bindle, April, 2001, personal communication.

Hauck, H.S., Huber, L.G., Nagel, C.D., 1997, Water resources data—Missouri, water year 1996, U.S. Geological Survey (USGS) Water-Data Report MO-96-1, 292 p.

Power Magazine, June, 1989, Cooling Systems.

U.S. Army, Corps of Engineers, 1994, Missouri River master water control manual, review and update study, Volume 3A: Low Flow Studies, Gavins Point Dam to St. Louis, Missouri, Missouri River Division.

U.S. Army, Corps of Engineers, 1979, Missouri River main stem reservoir system reservoir regulation manual, Volume 1: Master Manual.

Union Electric, 1996, Callaway plant key facts, [Online], Available at HTTP://www.ue.com/about-ue/power-plants/callaway.html

Vandike, James E., 1995, Water Resources Report Number 45, Surface waters of Missouri, Missouri State Water Plan Series Volume I, Missouri Department of Natural Resources, Division of Geology and Land Survey, 122 p.

Low Levels of Dissolved Oxygen

Problem:

Low levels of dissolved oxygen (D.O.) in water below dams.

Discussion:

Dams are built on rivers and streams to trap (impound) water behind them for flood control, generation of electricity, water power for industrial uses, and the release of water during low flows for some purpose such as navigation or to maintain minimum flows for surface water supplies or for the health of aquatic organisms (termed “low flow augmentation”), drinking water supply, and other purposes.

If a dam is built to provide water for generating electricity, an important consideration is what is called “head,” the vertical distance between the water surface and the turbines. The greater the head, the more efficient will be the flow of water through the turbine/dynamo that generates the electricity. Because the height of the column of water exerts pressure, the greater the head, the more energy is produced at the turbine. Under most conditions, the dam is designed so that water flows through the structure via a tube called a “penstock” at a low level. When the penstock takes water from the lower layer of the reservoir, there can be depleted oxygen levels in the water passing through the turbines, and immediately below the dam, following release.

Avoiding low D.O. in water bodies is a complex matter that touches on several aspects of water management, including dam design and operation, and nutrient management. Existing dams can be modified, or operated in such a way as to avoid or relieve the problem of low D.O.

Low D.O. in the water is not a pollution problem. The Missouri Supreme Court case of State ex rel. Ashcroft v. Union Electric Co., 559 S.W.2d 216 (1977) involved a charge of water pollution as a result of hydroelectric station depleting oxygen content of the water. This case concerned the conduct of an electric company in causing or permitting water flowing through

its dam and electric generating plants which was biologically devoid of or deficient in dissolved oxygen. The court found that "this action did not rise to the level of legislative intent or conduct proscribed by the Clean Water Law (CWL). The CWL makes it unlawful for any person to cause pollution, from an external source, of any waters of the state or to cause or permit to be placed any water contaminant in location where it is reasonably certain to cause pollution of any waters of the state" (Gaffney and Hays, 2000).

Sources:

Gaffney, R.M., and Hays, C.R., 2000, Water Resources Report Number 51, A summary of Missouri water laws, Missouri State Water Plan Series Volume VII, Missouri Department of Natural Resources, Division of Geology and Land Survey, 292 p.

Missouri River - Basin-wide Agreements

Problem:

There is no comprehensive basin-wide agreement that assures future uses of the lower Missouri River.

Discussion:

The Missouri River is a resource that is shared by many people and many uses. There are over 500,000 square miles in the basin, located above the central region. The basin drains part or all of 11 states and two Canadian provinces.

Not all uses are compatible and consequently there is competition for this resource. Currently there are no agreements among the states that assure the region that water will be available in the future. There are also no long-term assurances that the federal government, that manages flow and many other aspects of the river (i.e. channel maintenance), will continue to provide for any given use of the river.

Many Tribal water right issues have not been resolved. This presents an uncertain future about water in the Missouri River. Depletions upstream of this region will likely grow in the future. This will decrease the amount of water available in the central region. Out-of-basin transfer of water is a possibility. North Dakota has been developing the "Garrison Diversion" that would transfer water out of the Missouri River basin and into another basin, that of the Red River of the North. Removal of water from the Missouri River upstream of the main stem reservoirs would impact the amount of water in these reservoirs. Since the U.S. Army Corps of Engineers (Corps) bases releases on reservoir storage, less water would be released during a drought, affecting flow in this region.

Lack of assurances has long-term consequences for future use of the Missouri River. However, there may also be short-term consequences. The lack of long-term assurances can create short-term uncertainty; which could impact use of the river. An example is the Corps' review and update of the Missouri River Main Stem Reservoir, Master Water Control Manual (the document that guides the Corps' operation of the main stem reservoirs). This has been going on for over a decade. The pending changes have caused uncertainty about the future use of the Missouri River, especially for the navigation industry. This uncertainty has greatly curtailed capital investments and delayed improvements, hurting their industry. Other uses of the river potentially suffer from uncertainty also.

Sources:

Garrison Diversion Conservancy District web site http://www.garrisondiv.org/

Lui, Sylvia F., 1995, American Indian reserved water rights: the federal obligation to protect Tribal water resources and Tribal autonomy, in Environmental Law 25: 425-462 pp..

Solley, Wayne B., Pierce, Robert R., and Perlman, Howard A., 1993, Estimated use of water in the United States in 1990, U.S. Geological Survey Circular 1081, 71 p.

U.S. Army, Corps of Engineers, July, 1994, Missouri River Master Water Control Manual Review and Update: Volume

2: Reservoir Regulation Studies – Long Range Study Model.

Missouri River - Vision for the Future

Problem:

We do not have a "master plan" to guide the changes that are occurring on the Missouri River. A master plan (not to be confused with the Master Manual) is a comprehensive plan to address best or future uses of the resource and may exist at several scales; from local to basin-wide.

Discussion:

The Missouri River is a dominant water feature in the central region. It provides many uses. It is a waterway that transports goods, it is a source of recreation, it provides water for drinking, commercial and industrial use. The river provides benefits for fish and wildlife. The floodplain provides productive farmland.

Over the past several decades, use of the Missouri River has been shaped by the U.S. Army, Corps of Engineers through various programs. An example of how the Corps has changed use of the Missouri River is the construction of the Missouri River Main Stem Reservoirs, Bank Stabilization and Navigation Project.

Many have benefited from the changes that have occurred on the river and its floodplain. There have also been impacts. For example, there have been changes in and in some cases, decreases in, the abundance of native fauna and flora.

Use of the Missouri River and the way we manage it are going to continue to evolve. There are several factors that are leading to change. The Missouri River Master Water Control Manual guides the Corps of Engineers' operation of the Missouri River Main Stem Reservoirs. Impacts to the reservoir users located in Montana and the Dakotas during the drought of the late 1980s and early 1990s under the Corps' current management has caused the politicians of upper basin states to petition the Corps to consider changing the Master Manual. This may result in less support for some of the current uses of the River in the central region. The pallid sturgeon and other species that are at risk of extinction are causing us, due to the Endangered Species Act, to revise the way that the Missouri River is managed. This will likely also impact the way we use the Missouri River.

In the last decade, there have been major floods that have impacted the way we use the Missouri River and its floodplain. Towns that were devastated by the flood of 1993 no longer exist or have moved out of the floodplain. Farmland that was damaged by the floods was bought-out, or easements established, shifting use of the land away from agricultural. As public lands, they will provide habitat for fish and wildlife and may reduce the severity of future floods by reducing flood crests.

There has been a large increase in the amount of public lands along the Missouri River in this region. The Missouri Department of Conservation estimates that there now are 87,582 acres (approximately 8.5 percent of the Missouri River floodplain) in public ownership or private easements for fish, forest and wildlife within Missouri. Beyond this, there are authorized another 56,918 acres of public lands for these purposes. The public land will change the way the Missouri River and its floodplain are used. There are efforts ongoing to revitalize riverside communities.

All this is occurring without a master plan to help guide wise and future use of the resource. The Corps' review and update of the Master Manual focuses on how to manage the Missouri River based on current use, not a long range plan or vision. Some of the other shifts in public policy and management are also done without the benefit of a master plan.

Sources:

Missouri Department of Conservation, undated, Missouri River floodplain, fish, forest, and wildlife public lands and private easements, Missouri Department of Conservation.

U.S. Army, Corps of Engineers, Northwestern Division, August, 1998, Preliminary re-

vised draft environmental impact statement, review and update of the Missouri River master water control manual, U.S. Army, Corps of Engineers.

U.S. Fish and Wildlife Service, November 30, 2000, Biological opinion on the operation of the Missouri River main stem reservoir system, operation and maintenance of the Missouri River bank stabilization and navigation project, and operation of the Kansas River reservoir system, U.S. Department of the Interior.

Dam Discharges and Instream Flows

Problem:

Discharges from power generating dams do not follow the natural hydrology of a river, but rather have an unnatural flow regime which includes periods of extremely low flows (or no flow at all) followed by very high flows. These widely fluctuating flows impact aquatic organisms living in the tailwaters and increases stream bank erosion.

Discussion:

The discharges from power generating dams typically do not simulate the natural hydrology of a river. Instead, the flows are regulated according to the management plan for the use of the reservoir. The downstream flows are maintained at higher than normal levels when the reservoir is being drawn down to the desired level, or while power is being generated. When the desired level is reached or the peak period is over, the discharges are reduced, sometimes drastically, or curtailed completely. These large and rapid changes in dam discharge result in rapid changes in depth, width, velocity, water temperature and water quality of the downstream river. Many riverine fish and invertebrate species have a limited range of conditions to which they are adapted. Potential impacts of these recurring disturbances are reduced abundance, diversity, and productivity of these riverine organisms.

Fluctuating water levels below dams can also result in serious bank erosion. The fluctuating water levels do not allow vegetation to be established on the lower levels of the stream banks. These banks are susceptible to erosion during peak discharges and heavy rainfalls. When the water levels drop, the bare stream banks are left unprotected. These rapid drops in water level can cause the saturated and unvegetated bank to slump into the river. When water levels are high, water infiltrates into the riverbanks, and when water levels drop, water exfiltrates out of the riverbanks. Depending on the material (loam, silt, clay, sand, gravel, bedrock), the riverbanks may be susceptible to bank sloughing (pronounced “sluffing”).

Sources:

Cushman, Robert M., 1985, Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities, North American Journal of Fisheries Management, Volume 5: 330-339 pp.

RECREATIONAL WATER USE

Septic Systems and Lake of the Ozarks

Problem:

Water quality at the Lake of the Ozarks is threatened by wastewater releases from lakefront septic systems and public sewer systems. The impact of polluted lake waters on recreation and tourism could be damaging to the recreational economies of the communities surrounding the lake area.

Discussion:

Recent population growth at the Lake of the Ozarks has resulted in areas of lakeshore

degradation, with an associated impact on water quality and environmental aesthetics (Uhlenbrock, 1996). As a result of the degradation losses incurred, environmental mitigation opportunities are abundant in this area.

Some of the highest densities of septic systems in Missouri are found on land surrounding the Lake of the Ozarks. Although, when properly installed and sited, they are an effective means of treating domestic waste, plant nutrients (such as nitrates and phosphates) typically remain in treated wastewater. Until recently, on-site septic systems were virtually the only means of sewage disposal used by residents near the lake. Public sewer systems constructed in the 1980s could not support the rapidly growing tourist population, allowing raw sewage into the lake on several occasions (Uhlenbrock, 1996). Raw sewage, in addition to nutrients, can contain fecal coliform bacteria, viruses, parasites and other pathogens.

Phosphates and nitrates provide nutrients for plant growth in water bodies receiving wastewater discharges. Under certain conditions, concentrations of these compounds can cause a significant increase in plant growth, a process known as eutrophication. Most often, high levels of plant nutrients are linked to algae blooms, which can impair water quality in a number of ways. Algae blooms can discolor water and lead to undesirable tastes. When they die off, bacteria and other microbial organisms present in the water consume substantial amounts of dissolved oxygen decomposing the algae. The oxygen demand imposed by decomposition can deoxygenate the water (this condition is called hypoxia), causing fish kills and other problems (Leopold and Dunne, 1978). (See also Low Levels of Dissolved Oxygen topic in Industrial Water Use section).

The high number of septic systems built in the area is a component of nutrient loading in the Lake of the Ozarks. In 1990, approximately three of every four housing units located near the lake were equipped with septic systems. U.S. Census data indicate that the density of on-site septic systems in the eight-digit hydrologic unit encompassing the Lake of the Ozarks was the third highest in the state (DuCharme and Miller, 1997).

Even when functioning at maximum efficiency, septic systems may not remove all pollutants. Some pollutants, especially nitrates, may remain in wastewater even after they have passed though a system's filter field (Leopold and Dunne, 1978). Consequently, some nutrients may be entering the lake even when most septic systems in the area are functioning properly. The sheer number of septic systems in operation around the Lake of the Ozarks makes it likely that elevated nutrient levels exist in the lake. In backwater areas (such as coves), there may be limited mixing with the main body of water passing through the channel. Consequently, concentrations of nutrients may be especially high, intensifying the problems associated with nutrient build-up.

There are locations around the lake that are geologically or geographically unsuited for on-site sewage disposal. In addition, some septic systems may be located so close to the lake (or a tributary watercourse) that adequate filtering of effluent does not take place. These conditions can also contribute to nutrient loading and the perception that the lake is polluted.

In 1996, a state law was enacted that required a permit be secured for installing or repairing an onsite sewage system. With the karst and prevalence of small lots, area business and community leaders assembled the Lake Area Task Force to work toward creation of an entity that would develop cluster sewage systems where feasible and provide necessary and routine maintenance for onsite systems where necessary.

In recent years, the Lake of the Ozarks has had spills of raw sewage from faulty public sewers. With increasing tourism outstripping capacity, overflows of sewage sometimes spill directly into the lake. In addition to being undersized, some lines are fractured and allow stormwater to enter, overflowing the system (Uhlenbrock, 1996).

If left unchecked, increasing pollution in the lake could endanger its growing fishing industry, become a threat to human health, and discourage recreational water users from visiting the area. Communities surrounding the Lake of the Ozarks rely heavily on income from tourism to support their economies. In an area that relies so strongly on a clean, healthy lake, the economic damage stemming from unabated pollution could be substantial.

Sources:

DuCharme, Charles B., and Miller, Todd M., March 9-11, 1997, Using GIS to Summarize Water-related Information from the 1990 Census, With a Watershed Perspective, 2nd Annual Missouri GIS Conference, Jefferson City, Missouri.

Leopold, Luna B., and Dunne, T., 1978, Water in environmental planning, W.H. Freeman and Company, New York, 818 pp.

Uhlenbrock, T., 1996, Ozark sewer system bursts at the seams, St. Louis Post-Dispatch.

Missouri River Marinas

Problem:

Economic development opportunities for Missouri River marinas are hindered by the velocity of the river flow and fluctuation of water levels, location of railroads and supply of basic utilities.

Discussion:

The Missouri River flows downhill on a slope of approximately one foot per mile through Missouri. This gradient causes a “normal” velocity of flow of about two and a half miles per hour. This is about twice the slope and velocity of flow as that of the Mississippi River. The Missouri, with twice the gradient and twice the velocity, also has a narrower channel and more bends, so towboats are limited in the number of barges they can put together in a tow. The Missouri River, with its swifter current, is a more difficult river for commercial or recreational navigation than the Mississippi and some other rivers. Through 1997, there was no commercial passenger boat operating in the central Missouri reach of the Missouri River. However, excursion vessels between St. Charles and Kansas City were in operation in 1998 and 1999.

There is a large market for recreational vessels in North America. More than 17.2 million pleasure boats were used in 1996, and $17.8 billion was spent on those boats, according to the Marine Environmental Education Foundation (Nonpoint Source News-Notes, 1997). In the central Missouri region, a marina at Hermann is under development. There is no other marina on the Missouri River in this region.

The velocity of the river is not the only deterrent to the development of marinas on the Missouri River. Another consideration is that much of the riverbank or access to the riverbank in central Missouri is owned by the Union Pacific Railroad. The railroad faces a liability risk when automobiles or pedestrians cross the tracks to gain access to the river. At Hermann, a fence has been built between the tracks and the riverside park where the marina is under development. Access to the river where the tracks run alongside the river is difficult because of what is termed “exposure” to the risk of trains colliding with vehicles or people. Railroad officials are justly wary of risk exposure.

Another problem is utilities for those using a marina. Marinas must have potable water, gasoline, diesel fuel, sewage disposal, electricity, and telephone for their patrons. Sometimes these are available only at commercial ports along the river. To bring utilities into a new marina site would be costly, especially if railroad tracks must be crossed for installation. If a marina were to be built across the river from the railroad tracks, the river crossing then becomes the obstacle to use of the marina by those who are ashore (bridges across the Missouri River are far apart). Conversely, if the boaters want to come into town, there must be some means of conveyance, such as a shuttle bus or taxi.

There are environmental protection constraints, also. A gasoline tank in a floodplain

would float at times of high water. This has happened during floods, and it is dangerous. In addition, gasoline is a hazardous material, and storage tanks must be installed with a protective wall or earthwork around it, to contain the fluid in case of a leak. There are numerous design obstacles to overcome in building a marina today.

Another problem is the fact that the Missouri River is subject to flooding and occasional low flows. This has been mitigated to some extent by the building of six main stem dams on the upper Missouri River, to reduce flooding and augment low flows. Any docking or other facilities must be built with the fluctuation of the river in mind, and the facilities placed along the river must be made to accommodate low flows and flooding. Design for occasional flooding or low flows can help to overcome this problem.

Developers have been reluctant to put money into solving these problems, because the solutions are costly, and return on investment might be slow in coming. In addition, any marina would be seasonal, because of the climate, and this adds to the costs, and reduces the rate of return on investment. An organized effort to increase recreational use of the Missouri River would be needed to make investment more attractive to potential developers.

By having tours of the river, the environmental and ecological characteristics of the river could be explained to interested citizens. Tours could include explanations of the river's ecosystem, endangered species, and wetlands. Current habitat restoration projects (Big Muddy, Eagle Bluffs) could be highlighted to generate further interest in protecting and enhancing the river.

Interest in the river for recreational purposes has been rising in anticipation of the Bicentennial of the Lewis & Clark Expedition, known as the Voyage of Discovery (1804 -1806), on the Missouri River. The Bicentennial of that exploratory expedition will turn the Missouri River into a tourist destination in the years 2004 – 2006. It is expected that there will be a large number of recreational boaters who will want to travel the Missouri River, in the "footsteps" (figuratively) of Lewis and Clark. The availability of gasoline and diesel fuel for power boats, the availability of docking facilities for those wanting to view historic sites ashore, and the availability of riverbank restaurants and grocery stores is sorely lacking in the central Missouri region.

The Katy Trail State Park runs along the right-of-way of the Missouri-Kansas-Texas (MKT or Katy) Railway, through central Missouri. Highways, such as U.S. Route 63 in Callaway and Boone Counties, and Mo. Routes 94, 100, and 179 on both sides of the Missouri River, are designated the Lewis and Clark Trail, so that the motoring public can follow the route of the Voyage of Discovery. Numerous State Historic Sites and other significant locations and sights will be marked and promoted during the Bicentennial of the Lewis and Clark Expedition.

Sources:

Division of State Parks, Missouri Department of Natural Resources, Jefferson City, MO 65102-0176 (Dial 800-334-6946).

Missouri Department of Transportation, Multimodal Operations Division, Jefferson City, Missouri, John F. Hynes, Director, October 22, 1997.

Nonpoint Source News-Notes, August/September, 1997, Issue No. 49.

U.S. Army, Corps of Engineers, Jefferson City Project Office, Suite 103, 221 Bolivar Street, Jefferson City, MO 65101, Bob Meyer, Project Manager, October 24, 1997.

Washington Economic Development Office, Richard Oldenburg, Washington, Mo., October 22, 1997.

Competition for Water at Lake of the Ozarks

Problem:

Competition in lake level management between recreational and hydropower water uses at Lake of the Ozarks.

Discussion:

Bagnell Dam was built by the Union Electric Co. to provide hydropower generation. The dam created the Lake of the Ozarks. Unlike federal reservoirs, which are commonly operated for a variety of purposes, Bagnell Dam and the Lake of the Ozarks are owned and operated by private interests just for power generation. In the last several decades, intensive development has occurred around the lake, and a large recreational industry exists.

As an example of a recreational industry, it is said that the value of sport fishing at the Lake of the Ozarks is $80 million a year (Green, 2000).

For recreational use, a stable reservoir level is desired. This is for aesthetic reasons as well as physical reasons. An example of an aesthetic reason is unsightly low watermarks around the lakeshore and an example of a physical reason is inaccessibility of docks due to low water. With static lake levels, development (docks, bulkheads, marinas, homes, condominiums, etc.) along the lake is less risky and building can take place, right up to the water's edge.

Water management for hydropower is a balancing act between holding water in storage and releasing water. Water is held in storage to increase electric generating capacity and to reserve water for future generating needs. Water is released through the turbines to generate electricity. Maximizing hydropower benefits can result in fluctuating reservoir levels.

In recent years, AmerenUE has been able to generate hydropower while accommodating recreational interests. A change in hydrologic conditions, such as a major drought or a change in the demand for hydropower generation, could create a situation where AmerenUE is unable to accommodate recreational interests in their water level management. This kind of situation could affect public relations and long-term recreation at the Lake of the Ozarks.

Sources:

Green, Jeff, City Planner, Osage Beach, Mo., in an oral presentation, March, 2000.

Anderson Cove at Lake of the Ozarks

Problem:

Anderson Cove at Lake of the Ozarks is a focal point for people and boats. Although it brings in a lot of tourist dollars to the local economy, it also brings along water-related problems, such as pollution and recreational dangers.

Discussion:

Anderson Cove at Lake of the Ozarks is where large numbers of boaters congregate. It attracts people from all over the country, as evidenced by the numerous web sites advertising it. Tourists anchor boats next to each other, and enjoy themselves. Tourist dollars boost the local economy since they buy fuel, alcohol, food, etc. However, there are many potential and real water-related problems.

The primary problem is that of personal safety. The risk of accidents occurring is greatly increased with the concentration of a large number of individuals driving motorboats when they have been consuming alcohol. When there is a serious accident, the emergency response crews have a hard time getting in because of the high density of the boats in the cove.

These people contribute a lot of pollution (human waste and garbage) to the area. This dramatically increases the levels of fecal coliform (Phillips, 2001), which in turn can endanger the health of anyone who might accidentally consume the water by swimming or falling overboard.

Sources:

Huenink, Capt. Hans, Missouri State Water Patrol, Missouri Department of Public Safety, June, 2001, personal communication.

Phillips, Pat, Ph.D., Epidemiologist, Missouri Department of Health, June, 2001, personal communication.

ENVIRONMENTAL WATER USE

Flora and Fauna

Problem:

Endangered and threatened aquatic species in central Missouri: establishing a balance between natural resource development and environmental protection.

Discussion:

One of the results of land development has been aquatic environmental degradation. Some aquatic species are more sensitive to environmental changes than others. There are many arguments for and against environmental protection. This extends to the topic of endangered species. Arguments for increased environmental protection include the need to maintain biodiversity, social reasons such as aesthetics, and economics. Some argue that the economics of an activity should be viewed on a macro scale so that the loss of resources and any impacts that an activity causes would be weighed as costs against the economic gain of individuals benefiting from the activity.

The arguments against environmental protection measures include economic reasons (such as inhibiting growth or increased cost related to environmental review and environmental protection measures), and landowner rights. In many cases, there is a lack of decisive scientific evidence that certain environmental protection measures are effective. There are many environmental regulations that address environmental protection. Still, there is no clear indication what the correct balance is between environmental protection and development. What should be done to save endangered species? What is the proper balance between developing our resources and environmental protection? What are the cumulative impacts of incremental changes? What is the balance between landowner rights and environmental protection?

Sources:

Missouri Department of Conservation, undated, Endangered species guide sheet.

How the ESA has impacted people, National Endangered Species Act Reform Coalition (http://www.nesarc.org)

What is the ESA? National Endangered Species Act Reform Coalition (http://www.nesarc.org)

Aquatic Species Loss

Problem:

Loss of sensitive aquatic species.

Discussion:

Degradation of land and stream habitats are causing the range of sensitive aquatic species to be drastically reduced in central Missouri. This degradation is resulting in the reduction and/or loss of many sensitive species of fish from entire basins in central Missouri.

Because of their unique reproductive process, whereby their larval stage (glochidia) is released into the water column where it must contact, encyst upon, and metamorphose on native fish, mussels are particularly susceptible to changes in water quality. Not only are the larvae extremely sensitive to water quality changes, any change in habitat which impacts a particular species of fish can impact mussel species that rely on that species for reproduction.

Several fish and mussel species that are found with limited range in central Missouri, which also have disjunct populations, are in danger of further decline. Several federally threatened or endangered species are known to occur in the west central portion (Benton, Camden, Miller, Morgan, and Pettis counties) of central Missouri. These include the Niangua darter (federally threatened, state ranked S2 from Benton, Camden, and Miller counties); Topeka shiner (federally threatened, state ranked S1 from Morgan and Pettis counties); and the pink mucket pearly

mussel (federally endangered, state ranked S2 from Miller County).

In addition to these, there are six species of conservation concern in Missouri. These include: Blacknose shiner (state ranked S2 from Benton and Pettis counties); Plains topminnow (state ranked S3 from Miller and Morgan counties); Highfin carpsucker (state ranked S2 from Miller County); Paddlefish (state ranked S3 from Benton, Camden, Miller, Morgan, and Pettis counties); Rock-pocketbook mussel (state ranked S3 from Miller County); and Elephant ear mussel (state ranked S1 from Miller County) (MDC, 1998) (table 5).

Stream habitat degradation is fairly widespread throughout central Missouri, probably more so in the prairie-type streams to the north and less so in the Ozark-type streams of the south. This degradation is due to sedimentation and nutrient enrichment from poor land management practices. Agricultural practices, like cattle degrading streams, row cropping of erodible land, and concentrated animal feeding operations, are causing accelerated rates of erosion or result in high levels of ammonia and other pollutants entering streams. These pollutants are seriously degrading the steam habitat of sensitive aquatic species.

The major threats to Niangua darters in the above-mentioned counties include construction of large reservoirs within the fish's historical habitat. Reservoir construction has inundated habitat and fragmented former populations, making the remaining disjunct populations more vulnerable to local extinctions. Other major threats to long-term survival of the species include destabilization of stream channels by gravel removal and riparian corridor clearing, and nutrient enrichment of streams from livestock manure (Pflieger, 1997).

A numeric rank (S1 through S5) of relative endangerment based primarily on the number of occurrences of the element (i.e., species, subspecies, or variety) within the state. Other factors considered when assigning a rank include: abundance, population trends, distribution, number of protected sites, degree of threat, suitable habitat trends, level of survey effort and live history. Thus, the number of occurrences suggested for each numeric rank below are not absolute guidelines. Missouri species of conservation concern typically do not fall within the range of S4-S5.

S1 = Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state (typically 5 or fewer occurrences or very few remaining individuals).

S2 = Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state (6 to 20 occurrences or few remaining individuals or acres).

S3 = Rare and uncommon in the state (21 to 100 occurrences).

S4 = Widespread, abundant, and apparently secure in state, with many occurrences, but the species is of long-term concern (usually more than 100 occurrences).

S5 = Demonstrably widespread, abundant, and secure in the state, and essentially ineradicable under present conditions.

Table 5. Missouri endangered species ranking system. Source: www.conservation.state.mo.us/nathis/endangered/

Topeka shiners were last collected from Heath's Creek in Pettis County in 1993. A recent sampling effort in the fish's former range in Pettis and Morgan counties has failed to turn up any remaining populations. The loss of this species is attributed to agricultural land management practices in the past, mainly row cropping on highly erodible land and the subsequent sedimentation and pollution delivered to streams. Concentrated animal feeding operations in the region may now pose the largest threat to remaining populations (Bonneau, 2001).

Mussel populations are declining in the Bourbeuse, Meramec, and Gasconade Rivers due to declines in water quality, increased sediment loads, and destabilization of stream banks and channels.

Sources:

Bonneau, J, Fisheries Management Biologist, Missouri Department of Conservation, St. Joseph, Missouri, June 12, 2001, personal conversation with Jim Czarnezki.

Missouri Department of Conservation (MDC), June, 1998, Missouri species of conservation concern checklist.

Pflieger, Wm. L., 1997, The fishes of Missouri, Missouri Department of Conservation.

Exotic Species Infestation

Problem:

Infestation of Mid-Missouri lakes and rivers by zebra mussels and other exotic species could create numerous water use problems.

Discussion:

Numerous non-native species have become naturalized in Missouri and other states. Among these are the zebra mussel, which probably came to the Great Lakes in the ballast tanks of ocean-going vessels, then by way of the Illinois River to the Missouri River; the purple loosestrife, or lythrum, a magenta-blossomed wetland plant that was imported from Europe as a horticultural specimen.; the round goby, a little (5- to 6-inch) pug-nosed fish with big eyes, that is also thought to have arrived in the Great Lakes in the ballast tanks of ocean-going vessels; various kinds of carp, an Asian fish related to the aquarium goldfish, including the black carp and the grass carp, have been introduced for various reasons; Eurasian water milfoil, a pond plant that spreads from cuttings and can "hitch-hike" on boats, outboard motors, or boat trailers, from one water body to another. This plant was used in home aquaria.

The tiny zebra mussels are prolific; producing 30,000 to 1,000,000 eggs a year. The swimming larvae, called veligers, move with water currents. The young adults attach themselves to objects in the water, such as rocks, buoys, boats, or water pipes. They also have been spread by "hitch-hiking" on boats, either by the water or by road trailers. Adult zebra mussels can live up to two weeks out of water, and be carried on boat hulls or motors to new bodies of water. Recently, it was also discovered that microscopic zebra mussel fry are also transported in ballast water, live wells, and outboard/inboard boat motors. There is also discussion in the scientific community on zebra mussels being transported by migrating waterfowl. This greatly enhances the mussel's ability to be spread (hitch-hike) and makes enforcement programs difficult, if not impossible.

Zebra mussels have certain environmental requirements that limit their spread. They require alkaline waters (a pH higher than 7.3) with adequate calcium (more than 20 mg/L) to support shell formation and growth (Effler, 1996). They require solid objects on which to build colonies. Rock surfaces can support particularly dense populations. High levels of dissolved oxygen and an abundance of organic materials (like phytoplankton) to feed upon also are needed (Effler, 1996). The calcium-rich rock-bottomed streams of Missouri provide at least some of their requirements.

Damage to aquatic species and to aquatic habitat is part of the problem. Upkeep of water and sewer pipes and water supply structures, and of boats and motors is another (they clog the cooling systems of boat motors, causing them

to overheat). Sharp-edged shells and rotting dead mussels are a clean-up problem. Cities and power companies have spent many millions of dollars in the Great Lakes states to control the creatures. Feeding on plankton and microscopic plants and animals that form the base of the aquatic food chain, zebra mussels are in direct competition with native mussels, forage fish, and young bass, bluegill, and other popular game fish (MDC, 1993).

The conclusion to be drawn from the research findings presently available is that zebra mussel infestation is to be expected in the temperate, alkaline, hard water systems of central Missouri. The zebra mussel would be challenging enough if it were the only aquatic species that is or could be a nuisance in Missouri waters. In fact, the problem has become serious enough, nationally, that the U.S. Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA) in response to invasions of numerous exotic species (Kabler, 1996).

The other examples of nuisance exotic species, mentioned above, include the round goby, a little fish that eats zebra mussels, but the two species seem to be thriving together, and the goby also eats native species and fish eggs (Dickson, 1997); the purple loosestrife, a wetland plant occasionally found chiefly in northeastern Missouri counties, and the Eurasian water milfoil, an exotic water plant found dispersed across Missouri (Bassett, 1993). Like the zebra mussel, the water milfoil can be spread from one water body to another by pieces of the plant caught on or attached to the hull or motor, or even the hauling trailer.

The purple loosestrife (lythrum) is a European plant that has invaded large tracts of wetland areas in the northeastern states. As of 1985, Missouri had over 40 wild populations of the plant. This species is a prolific reproducer, with just one plant producing over 300,000 seeds. The plant has little wildlife food or shelter value and quickly crowds out native species. The plant prefers sunny wetlands, ditches, farm ponds, and other disturbed areas. It has been spread to Missouri in large part due to importation for landscape and flower garden plantings. As wetland areas are disturbed due to construction, development, and agriculture, seeds may be able to start germinating and rapidly spread throughout large wetland tracts. A Department of Natural Resources employee observed two suspected purple loosestrife plants at the Eagle Bluffs Conservation Area in August, 1999. It must be chemically controlled, as cutting tends to spread the seeds, and not kill the roots.

Sources:

Bassett, Barbara, et al., 1993, Nuisance aquatic plants in Missouri ponds and lakes, in Missouri Conservationist, Missouri Department of Conservation.

Dickson, Tom, October, 1997, Can electric shocks stop Goby advance? in Mississippi Monitor, Volume 1, Number 8, 16 p.

Effler, Steven W., et. al., March/April, 1996, Impact of Zebra mussel invasion on river water quality, in Water Environment Research, Volume 68, Number 2, 205-214 pp.

Freshwater Foundation, 1995 and 1996, Aquatic nuisance species digest.

Hydata News and Views, July, 1997, American Water Resources Association, Volume 16, Number 4, 4-5 pp.

Kabler, L.U., March, 1996, Ballast water invaders, in Aquatic Nuisance Species Digest, Volume 1, Number 3, p. 1.

Missouri Conservationist, April, 2000, Lake Ozark marina puts Zebra mussels in dry dock, Volume 61, Issue 4, 29 p.

Missouri Department of Conservation (MDC), 1993, Zebra mussels come to Missouri.

Http://conservation.state.mo.us/nathis/flora/purple.html.

Sea Grant Institute, 1997, Zebra Mussel Update.

Stream Bank Erosion

Problem:

Stream Bank Stabilization.

Discussion:

Landowners with stream bank erosion problems along gravel-bed streams often attempt to stabilize their eroding stream banks. The first method involves using heavy equipment to push gravel from a point bar onto the toe and face of the opposite eroding bank. The second method is the removal of colonizing sycamores or willows from the point bar opposite of an eroding stream bank.

Pushing gravel from a low velocity area (depositional) to a high velocity area (erosional) tends to change aquatic habitat by destabilizing gravel deposits and allowing excessive amounts of gravel to be eroded and deposited in the downstream aquatic habitats. Removing in-channel vegetation also increases stream velocities and may result in undesirable habitat changes downstream.

Bank erosion, whether natural or accelerated by man-made disturbances, increases the cross-sectional area of the channel. The larger cross-sectional area reduces water velocities and allows subsequent deposition of gravel on the point bar. Often, this deposit is colonized by sycamores or willows. If the true causes of bank erosion are not addressed, the stream bank continues to erode, more gravel is deposited on the opposite point bar, more vegetation colonizes the point bar, and landowners perceive that the point bar and/or vegetation is causing the bank to erode. Woody vegetation actually slows overall stream velocities (when inundated) and stabilizes gravel deposits; both processes contribute to overall system stability. However, meandering will continue.

Sources:

Roell, M.J., June, 1999, Gravel and sand extraction in Missouri stream systems: potential effects and proposed actions, Missouri Department of Conservation.

Stream Channelization

Problem:

Channelization, channel incision and sedimentation of streams within the Blackwater River watershed.

Discussion:

Channel incision is the deepening and associated widening of stream channels as a result of channelization. Channelization is a name for channel straightening, and was often performed by a dredge. The cutting off of channel bends shortens the river's length, thereby making the channel gradient or slope steeper. The steeper slope imparts a greater velocity to stream flow through the straightened reach of the river. The faster flow of the river increases the rate of erosion from the streambed and banks.

The sediment eroded and deposited from channel incision negatively impacts water use through increased turbidity. Excessive sedimentation in channels causes localized flooding, fills pools, embeds riffles and decreases capacities of reservoirs. The loss of pools and riffles is a direct loss of aquatic habitat. It actually takes decades for the affected river to regain the hydraulic equilibrium it once had achieved by meandering and passing over small riffles.

Channelization was a widespread federal government-supported or condoned stream management practice from 1908 to the 1970s. Stream channelization has been common in some watersheds in west central Missouri and has occurred only sporadically throughout others. The Blackwater River watershed in northwestern Pettis County is the most highly channelized system in the region. Forty-seven of the original one-hundred and three miles of main stem North and South Fork Blackwater Rivers, the main stem Blackwater River, and Davis Creek have been channelized. The Lamine River and Flat Creek have an estimated 8 percent of the total main stem length channelized (Missouri Department of Natural Resources, 1986). Most other watersheds in the region have small channelized areas associated with bridge and road construction, or single landowner projects.

When a channelized reach of a river is upstream of a reach that has not been changed, the lower reach of the river also suffers from the work done upstream. In channelized reaches, the channel continues to erode and channel capacity increases. In downstream reaches, the channel capacity remains small, and the slower velocity of water movement results in the stream "dropping its load" of sediment in the bottom. Channel capacity continues to decrease, resulting in more flooding and sediment deposition. "Headcutting," a phenomenon associated with channelization, occurs upstream, as a result of the higher flow velocities generated in the reach where the work was done. This headcutting becomes an ever-present problem in upstream tributaries of the channelized river.

Flooding is responsible for major economic losses to agriculture, roads, bridges, and buildings in the Lower Blackwater – Lamine River valley (USDA, 1977). Channelized reaches of streams are also less aquatically productive than unchannelized reaches. A study on the Platte River in northwest Missouri found an 85 percent reduction of fish biomass from a channelized to an unchannelized reach. The study also found a 77 percent reduction in the number of harvestable size (>10 inches) fish and a 90 percent reduction in the pounds of harvestable size fish from channelized to unchannelized reaches (Michaelson, 1971).

The pilot (earliest straightened) channels in the Blackwater watershed have created problems that continue today. United States Geological Survey (USGS) records show that the stream bottom at the Blue Lick gage station has aggraded six feet from 1922 to 1975. During this same period, the upper reaches of Davis Creek and the Blackwater River have degraded 30 feet or more. Consequently, the fall of the stream has been reduced 36 feet from an original 85 feet to the present 49 feet in a distance of 50 miles (USDA, 1977).

Sources:

DuCharme, Charles B. and Miller, Todd M., 1996, Water Resources Report Number 48, Water use of Missouri, Missouri State Water Plan Series Volume IV, Missouri Department of Natural Resources, Division of Geology and Land Survey, 150 p.

Michaelson, S.M., 1971, Fish population in channelized and unchannelized sections of the Platte River, Missouri, Presentation at the 33rd Annual Midwest Fish and Wildlife Conference (Missouri Department of Conservation internal document).

Missouri Department of Natural Resources, 1986, Missouri water atlas, 97 p.

Missouri Department of Natural Resources, Division of Geology and Land Survey, 1993, [Diskette] Major water users database.

Missouri Department of Natural Resources, 1996, Inventory of Missouri public water systems.

United States Department of Agriculture (USDA), 1977, Blackwater-Lamine river basin in Missouri, United States Department of Agriculture.

Solley, W.B., Pierce R.R., Perlman, H.A., 1993, Estimated use of water in the United States in 1990, United States Geological Survey Circular 1081, 76 p.

U. S. Bureau of the Census, 1992, 1990 Census of Population and Housing.

United State Geological Survey, 1997, National water use data [Online]. Available HTTP: water.usgs.gov Directory: public/watuse/data/ascii/ w8data_bystate Filename: mo90w8.

Vandike, James E., 1995, Water Resources Report Number 45, Surface water resources of Missouri, Missouri State Water Plan Series Volume I, Missouri Department of Natural Resources, Division of Geology and Land Survey, 122 p.

Sand and Gravel Mining

Problem:

In-stream sand and gravel mining can affect stream hydraulics and hydrology, and can damage aquatic flora and fauna.

Discussion:

Many central Missouri stream channels are a convenient source of sand and gravel for construction projects, gravel road maintenance, and other purposes. While most central Missouri streams situated north of the Missouri River run on bedrock, most of this region's streams situated south of the Missouri River are Ozark-type gravel-bottom streams.

Sand and gravel removal from, and adjacent to, stream channels can alter stream channel form, may increase sedimentation and turbidity, and can have negative impacts at, below, and above the removal location. Research in sand and gravel bed streams of the United States and elsewhere has indicated that in-channel extraction of sand and gravel destabilizes the bed and banks of stream systems. This is similar to the effects noted, above, in the topics on erosion and channelization.

Extraction can cause aquatic habitats to be degraded and aquatic species to be reduced in number or eliminated (Roell, 1999). The central Missouri region contains several federally listed species that have the potential to be negatively impacted by sand and gravel removal.

Gravel removal is a common practice in many Ozark streams in central Missouri. Gravel is used for building construction and roads. It is in high demand, especially in regions near the Lake of the Ozarks. Gravel is taken directly from stream channels, often in large quantities. Stream gravel is an industrial natural resource. It is used in several ways. For example, gravel is used as an aggregate in Portland cement concrete, as a porous fill material around drainage tile, as a backfill material in some kinds of on-site sewage disposal systems, as a fill material when laying water pipes, and as a surface material in unpaved roads and driveways. Stream gravel can be graded to size. In this region, it usually is an attractive light tan color, and is popular for driveways. Sand and gravel are valuable economic commodities.

Gravel occurs naturally in streambeds in the Ozarks. During the past century, soil erosion in the Ozarks has caused streambed aggradation. Other articles in this report deal with the causes of gravel deposition in Ozark streams.

The most widespread effects of in-channel gravel mining on aquatic habitats are bed degradation and sedimentation. Several studies have documented the bed degradation that occurs during in-stream gravel mining. Two general forms of in-stream mining occur--pit excavation (trenching) and gravel bar skimming (scalping) (Kondolf, 1997). Bed degradation is manifested in two ways. First, excavation of gravel mining pits in the active channel causes a local lowering of the stream bed, creating a so-called "nickpoint" that locally increases channel slope and therefore flow energy. During high flows, nickpoints are a location of vertical bed erosion that gradually moves upstream in a process called headcutting (Bull and Scott, 1974; Kondolf, 1997), which mobilizes significant quantities of stream bed materials that are then transported downstream to refill the excavated area. Headcuts often move well upstream and into tributaries (Scott, 1973; Harvey and Schumm, 1987; Kondolf, 1997), in some locations as far as headwaters or until halted by non-erodible surfaces in the stream channel such as bedrock or man-made structures.

A form of mining-induced bed degradation occurs when gravel removal creates a local sediment deficit either at a bar-skimming site or an in-channel pit (Kondolf, 1997). A sediment deficit exists when there is not enough sediment being carried by the stream. Any stream has the ability to carry sediment, depending on factors such as the availability of sediment, velocity of flow, volume of water in the stream, and the temperature of the water. A skimming operation locally increases channel flow capacity and a pit operation locally increases flow depth; both operation types result in decreased flow energy, causing heavier sediment arriving from upstream to deposit at the mine site. As stream flow moves beyond the site and flow energies increase in response to the "normal" channel slope down-

stream, the amount of transported sediment leaving the site is now below the sediment carrying capacity of the flow. This "hungry water" therefore picks up more sediment from the stream reach below the mine site, furthering the bed degradation process (Kondolf, 1997). This degradation is also due to the flow energy increasing as it leaves the mine site.

Channel incision not only causes vertical instability in the channel bed, but also causes lateral instability, in the form of stream bank erosion, followed by channel widening (Heede and Rinne, 1990). Incision increases stream bank heights, which cause bank failure when the mechanical properties of the bank material cannot sustain the material weight. This instability increases the mobility of channel sediments and their transport downstream (Parker and Klingeman, 1982).

Diverse physical habitats of alluvial gravel streambeds provide resources for diverse communities of fish and other creatures, for example, benthic invertebrates such as crayfish, and macrophytes such as algae. Disturbed streambeds have more homogenous habitats than those occurring in a pre-mined state and are therefore less capable of supporting diverse flora and fauna. Pools below gravel removal sites tend to be longer and shallower than undisturbed areas, and riffles occur less frequently than would be expected. In most cases, channel widths also increase at, and downstream of, gravel removal sites. Different species of fish require unique spawning, rearing, and feeding areas, as do different species of macro invertebrates (Brown, 1992).

The United States Army, Corps of Engineers (USACE), reported that as of November 19, 1998, there were 159 permitted gravel removal sites in the five counties making up the west central portion of the central Missouri region. The breakdown of gravel removal sites by county is: Benton and Miller counties (52 sites each); Camden County (30 sites); Morgan County (19 sites); and Pettis County (6 sites) (USACE, 1998).

Two Osage River sand and gravel operations dredge within the known distribution of the pink mucket pearly mussel, a federally listed endangered species, and the spectacle case mussel, considered rare in Missouri. In-stream gravel mining is also thought to be a threat to Niangua darters, a federally listed threatened species (Mattingly, 1995). In addition, severe problems with stream bank erosion caused by headcutting and channel reaming are evident in Gravois Creek in Morgan County, and in Tavern Creek in Miller County. Repeated problems with gravel operators are also pronounced in Cole Camp Creek, Lake Creek, Haw Creek, and Turkey Creek, all in Benton County.

Sources:

Brown, A., 1992, Impacts of gravel mining on Ozark stream ecosystems, Arkansas Game and Fish Commission.

Bull, W.B., and K.M. Scott, 1974, Impact of mining gravel from urban stream beds in the Southwestern United States, Geology, 2:171-174.

Harvey, M.D., and Schumm, S.A., August, 1987, Response of Dry Creek, California, to land use change, gravel mining and dam closure, in Erosion and Sedimentation in the Pacific Rim, proceedings of the Corvallis symposium (International Association of Hydrological Sciences Publication 165) Pages 451-460.

Heede, B.H., and Rinne, J.N. 1990, Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research, North American Journal of Fisheries Management, 10:249-268.

Kondolf, G.M., 1997, Hungry water: effects of dams and gravel mining on river channels, Environmental Management, 21:533-551.

Mattingly, H.T., 1995, Factors affecting the distribution and abundance of the federally threatened Niangua Darter (Etheostoma nianguae), Unpublished Ph.D. dissertation, University of Missouri, Columbia, Missouri.

Parker, G., and Klingeman, P.C., 1982, On why gravel bed streams are paved, Water Resources Research, 18:1409-1423.

Roell, M.J., June, 1999, Gravel and sand extraction in Missouri stream systems: potential effects and proposed actions, Missouri Department of Conservation.

Scott, K.M., 1973, Scour and fill in Tujunga Wash - a Fanhead Valley in urban southern California – 1969, U.S. Geological Survey Professional Paper 732-B.

United States Army, Corps of Engineers (USACE), 1998, General Permit 34M (GP34M) database, United States Army, Corps of Engineers, Kansas City District.

Stream Sedimentation Problems

Problem:

Instream deposition of soil and gravel can cause water quality and habitat loss problems.

Discussion:

One of the most widespread environmental water quality and stream habitat issues in the region is instream deposition of soil, in the northern portion of the region, and gravel in the southern. Soil erosion and sedimentation from row cropping, downcutting, widening of channelized streams, highway and residential construction and stormwater runoff, is a water quality and habitat loss problem especially in the Blackwater and Lamine river watersheds. Sedimentation of gravel in the Ozark type streams of the region and the subsequent loss of habitats to these systems is a major problem in the East Osage, Pomme de Terre, and Niangua watersheds.

Soil sedimentation negatively impacts environmentally oriented water use through increased turbidity, which negatively affects aquatic biota. For example, the Topeka shiner must have clear water not only to live, but for the development and hatching of its eggs. Sedimentation within its range is believed to be responsible for the Topeka shiner's dramatic decline. Sediment fills pools and embeds riffles, making them less desirable or unsuitable for aquatic life. Sediment fills reservoirs and ponds, which reduces habitat for aquatic life. Also, sediment in reservoirs and ponds decreases capacity, and thus, the "life expectancy" of the usefulness of them. Excessive sedimentation in stream channels increases the likelihood of localized flooding because the channel has less capacity to carry flood water.

Sedimentation reduces the number and kinds of aquatic invertebrates found in streams. Sensitive organisms like mayflies, stoneflies, and caddisflies disappear and are replaced by invertebrates that are more tolerant. The deposition of fine sediment has reduced the biotic diversity of animals that require deep pools or riffles. Many sensitive invertebrates inhabit the surface of stones and the interstial spaces between and beneath large substrate particles such as pebbles and cobbles. When these spaces are filled with fine sediment, the original invertebrates disappear, and are replaced with fewer tolerant ones.

Turbidity and siltation can result in the reduction or loss of fish populations. This is usually not the result of direct mortality but instead caused by sublethal effects like reduced feeding and growth, respiratory impairment, reduced tolerance to disease, physiological stress, and reduced reproductive success. Fine sediment fills the interstial spaces of riffles, which reduces or eliminates these spaces essential to fish eggs, and fish fry, and reduces the water depth in pools.

Deposition of gravel fills pools. As pools lose the ability to hold water, more pressure is put on stream banks and an increase in bank erosion is possible. Deep pools are critical refuges to fish during low flow periods in fall and summer, and during winter. Loss of these deep habitats concentrates fish in the remaining suitable habitats and competition among and between species increases. This also increases the availability of prey species to predator species. Water quality problems in pools may also become magnified, as less deep-water habitat becomes available.

SITE SPECIFIC DATA: Gross erosion amounts in the Lamine-Blackwater watersheds

combined total 21,000,000 tons of displaced soil annually. About 5,500,000 tons (one-fourth) of this displaced soil arrive in suspension at the mouth of the Missouri River. Erosion and sediment yields have increased as woodlands on private land have been converted to cropland (Brown et al., 1992).

Soil erosion and deposition is considered to be one of the top two nonpoint source pollution problems for the Lamine River watershed (Mattingly, 1995). Increased sedimentation has also been identified as a possible threat to the welfare of the Niangua darter (USDA, 1997).

Sources:

Brown, D.J., Dent, R.D., and Turner, W.M., 1992, Lamine River basin plan, Missouri Department of Conservation.

Mattingly, H.T., 1995, Factors affecting the distribution and abundance of the federally threatened Niangua Darter (Etheostoma nianguae), Unpublished Ph.D. dissertation, University of Missouri, Columbia, Missouri.

United States Department of Agriculture (USDA), 1997, Blackwater-Lamine river basin in Missouri, United States Department of Agriculture.

Urbanization and Roadway Construction

Problem:

As land is cleared and altered for "developed uses," the way in which water travels across the land and is absorbed by the soil is changed. Urbanization creates increased stormwater concerns.

Discussion:

The ambiguity in the application and enforcement of sediment control on construction sites has led to practices which allow excessive sediment to leave construction sites and degrade the environment.

Land disturbance associated with construction projects, such as roadways or buildings, create a source for sediment. Runoff from rainfall events flushes this sediment downstream. Uncontrolled, this sediment can be excessive and cause environmental degradation. For example, highway construction at the Lake Ozark bridge and at least four other areas in central Missouri have created sediment problems.

Storm water runoff is rainwater that has not infiltrated into the ground, (usually due to impervious surfaces such as parking lots, roofs, and compacted soils) and flows over the surface. In a natural setting, surface flow is less common and voluminous as much of the rain is intercepted by trees, shrubs, or grass. The force of the rain is diminished by surface litter, or the rain water infiltrates rapidly into the soil. When the landscape is changed into an impermeable surface, precipitation quickly runs off, often in ditches or culverts, to the nearest water body. The problem is that this rapid pulse of water often overwhelms small streams, and in the case of a large urban area, can cause flooding. In a forested watershed, rainwater from different locations takes a long time to reach a stream and often arrives at different times. In an urban setting, rainwater in different parts of the watershed from a storm event may reach the stream at approximately the same time, causing increased peak flood flows.

A further problem with storm water is that as the rainwater travels over an impervious surface, it picks up chemicals, oxygen-demanding nutrients, toxic substances, litter, pathogens, and sediment. Sources for this material include pavement, spilled substances, motor vehicles, anti-skid compounds (salt, sand), construction sites, lawns, and storm sewers (NYSDEC, 1992). Another issue is that as water travels over the heated surfaces of a parking lot, the water warms and may contribute to thermal pollution of local streams. Since most of the water is swept off the surface, there is little left to replenish soil moisture and recharge groundwater. This can have consequences in areas that rely on ground water sources for drinking water or base flow for streams during low flow periods. It has been shown that even small changes within a watershed can lead to dramatic increases of pollution and flooding.

A Roubidoux Creek development is an example of hillside clearing resulting in erosion and deposit of sediment. The clearing was about one mile away from Roubidoux Creek, a notable trout stream near Waynesville. Fort Leonard Wood expansions may cause future stormwater runoff/erosion compliance problems and make regulation difficult. Trout fishing is a major local recreational attraction.

There are ways to reduce the amount of sediment leaving construction projects. These measures include practices such as diverting water away from the disturbed area, and installation of sediment filters (i.e. sediment fencing). When implemented properly, sediment control measures greatly reduce the amount of sediment leaving a site. However, improper design, installation or maintenance can nullify their effectiveness.

Sources:

New York State Department of Environmental Conservation (NYSDEC), 1992, Reducing the impacts of stormwater runoff from new development, 178 p.

Missouri River Habitat Loss

Problem:

Loss of wildlife habitat in the Missouri River.

Discussion:

The Missouri River has been leveed and channelized. As a result of the changes that have been made, many of the river/floodplain processes have been disrupted and fish and wildlife habitats impacted. The pallid sturgeon, which exists in this reach, is listed as endangered. There are also other aquatic species at risk listed under the State's listing of species of concern. The Missouri River is listed on the State's Clean Water Act, 303d list of impaired waters (for habitat degradation). This includes the entire 550 miles of the Missouri River in Missouri; 91 miles are located in the Central Region.

The Missouri River now exists as a fairly continuous single controlled channel as a result of the Missouri River Bank Stabilization and Navigation Project. Officially completed in 1981, 735 miles of the Missouri River from Sioux City, Iowa, to St. Louis, Missouri have been stabilized by the project. The project has enhanced urban and agricultural development of the floodplain as well as more secure placement of public infrastructure (i.e. bridges, wastewater treatment plants, etc.). The Army Corps of Engineers (Corps) narrowed the channel, built dikes, and armored the river's banks. In the process, the Corps eliminated most all of the river's braided side channels, and many wetlands, islands and sandbars. Attached is an illustration that demonstrates the types of the changes that occurred (pictures from Indian Cave Bend in Northwest Region).

A Mitigation Program was established to help compensate for some the impacts of the Missouri River Bank Stabilization and Mitigation Program. Authorized by Congress in the Water Resources Development Act of 1986, the Corps began implementation in 1991. Under this program 48,100 acres of terrestrial and aquatic habitat were authorized from Sioux City to the mouth. This acreage was expanded to 166,750 acres under the Water Resources Development Act of 1999. Habitat projects have included establishment of constructed wetlands, prairies, side channel habitats, shallow water fish nursery, protection of cave habitat used by the endangered Indiana bat, and other projects.

In addition to the Corps' Mitigation Project, the Big Muddy National Fish and Wildlife Refuge, managed by the U.S. Fish and Wildlife Service, is located on the Missouri River and includes locations in the Central Region. About one-fifth of the 60,000 acres authorized are in place. The Missouri Department of Conservation manages several Conservation Areas for fish and wildlife habitat in this reach of the Missouri River. The Missouri Department of Natural Resources manages the Katy Trail State Park, which is also located along this river reach.

The Army Corps of Engineers expanded Mitigation Program, the Fish and Wildlife Service Big Muddy Wildlife Refuge, and state managed lands, create tremendous potential to re-

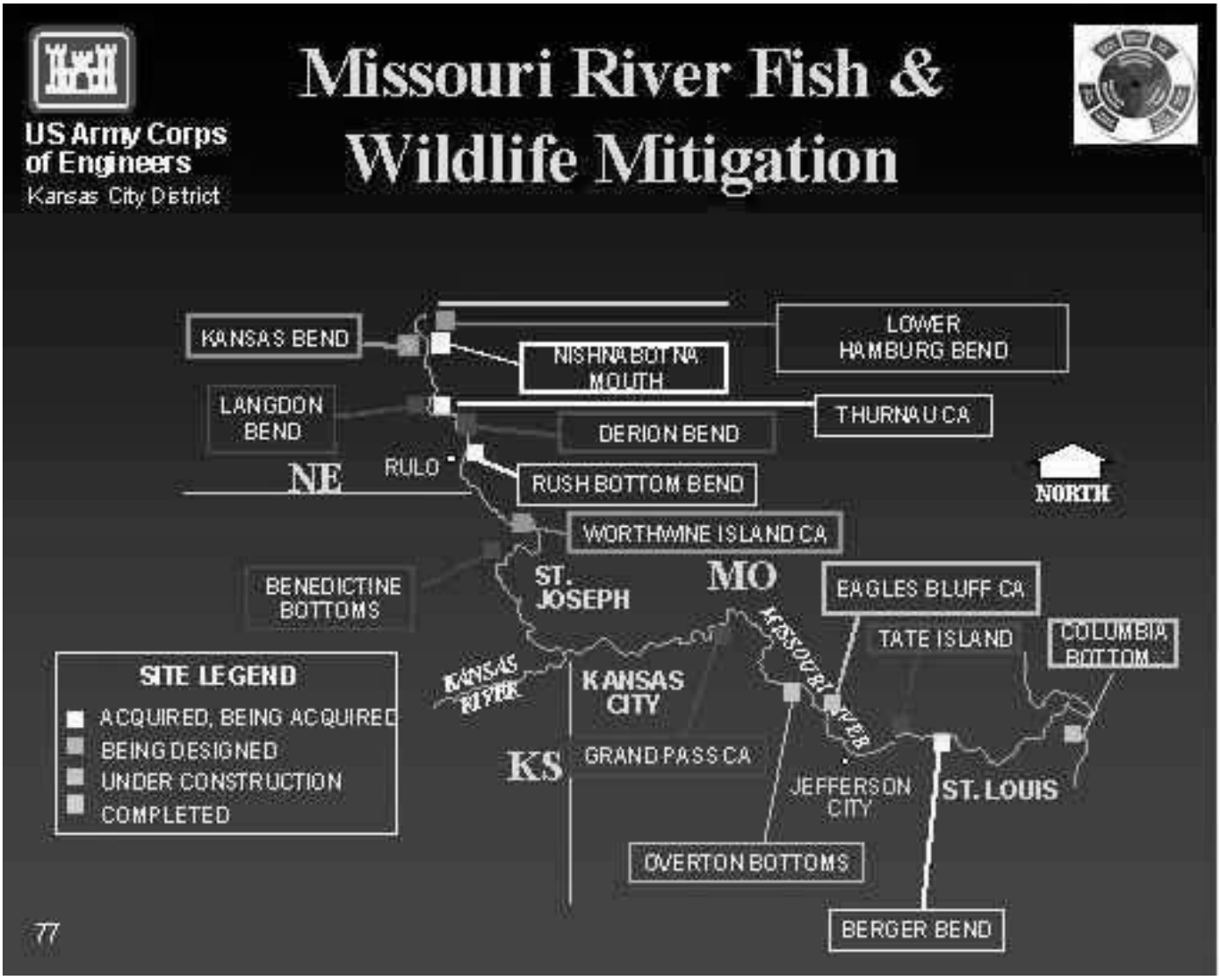

Figure 26. Missouri River Fish and Wildlife Mitigation. Source: Illustration extracted from the U.S. Corps of Engineers, Missouri River Mitigation web page, http://www.nwk.usace.army.mil/projects/mitigation/).

cover and rehabilitate some of the lost wildlife habitat throughout the Central Region and other reaches along the Missouri River. However, because many of these projects are in their infancy, and there is much to be learned about regaining some of the fish and wildlife values that have been lost on the Missouri River, habitat loss and species impacts are still a problem.

Sources:

Missouri Department of Conservation, 1995, Missouri's Conservation Atlas, A Guide to Exploring your Conservation Lands.

Missouri Department of Conservation, Eagle Bluffs Conservation Area, Undated.

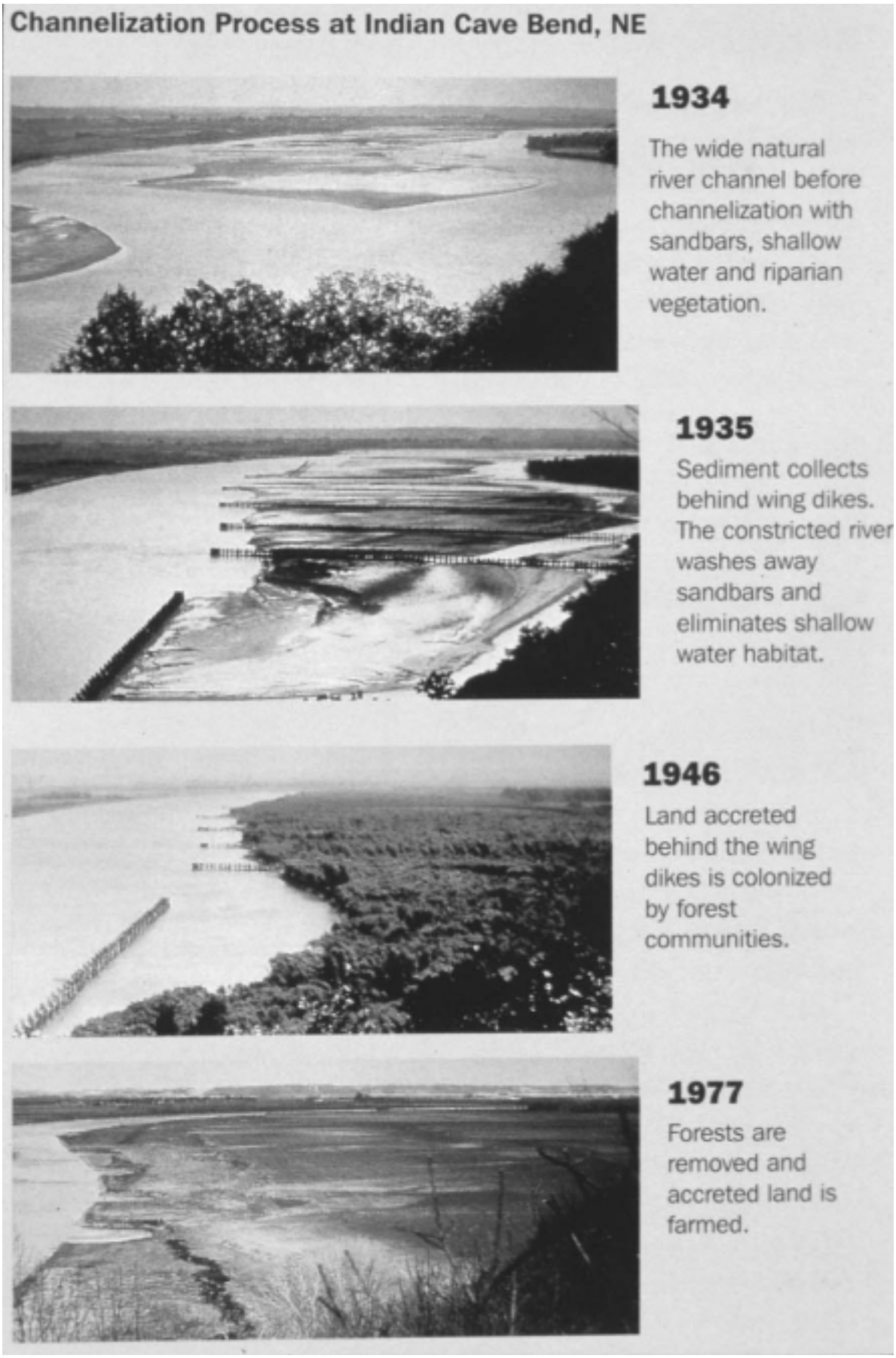

Figure 27. Channelization process at Indian Cave Bend, Nebraska. Source: US ACE, 1994.

Missouri Department of Natural Resources, Katy Trail State Park, Undated.

Missouri Department of Natural Resources, September 23, 1998, Section 303d List of Impaired Waters of the Federal Clean Water Act. http://www.dnr.state.mo.us/wpscd/wpcp/tmdl/tmdl_list.pdf

U.S. Army Corps of Engineers, May 1981, Missouri River Bank Stabilization and Navigation Project Final Feasibility Report and Final EIS for the Fish and Wildlife Mitigation Plan.

U.S. Army Corps of Engineers (USACE), 1994, Interagency Floodplain Management Review Committee, Sharing the Challenge, Floodplain Management in the 21st Century, Part 5, SAST Report, Washington, D.C.

U.S. Army Corps of Engineers, January 2002, Missouri River Bank Stabilization and Navigation Project, Fish and Wildlife Mitigation Project, Annual Implementation Report.

U.S. Fish and Wildlife Service, November 30, 2000, Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.

Habitat Loss, Osage and Blackwater River Systems

Problem:

Numerous free flowing stream miles have been lost to the impoundment of two major reservoirs in the west central region, Lake of the Ozarks and Truman Reservoir. The Blackwater River system has been heavily channelized, accounting for a direct loss of stream miles and the associated habitat.

Discussion:

Bagnell Dam was completed in 1931 and the Lake of the Ozarks impounds the lower 21 miles of the Niangua River, the lower 10 miles of the Little Niangua River (Schulz, 1997), and 94 miles of the Osage River, upstream to Truman Dam (Stoner, 2001). Truman Dam was completed in 1977 and impounds 90 percent of the remaining Osage River watershed (in Missouri) above the Lake of the Ozarks (Dent, et al., 1997). The two large dams in the watershed are responsible for several types of habitat degradation that negatively affect aquatic populations.

The frequent wetting and drying of the bank, associated with dam operation, and water released from the dam, make for massive bank failing and severely eroded vertical banks are a common feature (Dent, 2001). Frequent fluctuation of the water level on Truman Lake kills trees and other riparian vegetation, and has prevented their re-establishment. Increased flooding on the lower portion of streams by Truman Lake has contributed to increased bank erosion caused by saturated soils, loss of riparian corridors, and decreased channel capacity caused by increased sedimentation when streams enter backwaters of the lake.

Other impacts of these two impoundments include: Inundation of numerous tributaries, alteration or elimination of spawning areas, competition of lake fishes with stream species, separations of disjunct populations of fish and other aquatic organisms, and frequent fluctuations of the reservoirs' pool sizes and depths (Dent, et al., 1997).

Forty-seven stream miles have been channelized in the Blackwater River watershed with an undetermined amount of stream miles and associated habitat having been lost (Missouri Department of Natural Resources,1986). Channelized streams do not support the diversity or amounts of fish as do non-channelized streams in the same or similar watersheds (Michaelson, 1971). Problems of increased deposition and flooding downstream and increased streambed and bank erosion upstream are common in channelized systems.

Personnel from the MDC have worked closely with personnel from AmerenUE to formulate a plan to increase and sustain dissolved oxygen levels in water released through Bagnell Dam. AmerenUE staff testifies to the marked improvement in levels of D.O. resulting from implementing the plan (AmerenUE, 2000).

Sources:

AmerenUE, 3/22/00, 4th Stakeholders' Meeting on Bagnell Dam Relicensing, Holiday Inn, Lake Ozark, Mo., recorded by Richard M. Gaffney, Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division.

Dent, R.J., Missouri Department of Conservation, personal communication to Jim Czarnezki, June 13, 2001.

Dent, R.J., Fantz, D.K., Heatherly, W.G., and Yasger, P.A., 1997, West Osage River basin inventory and management plan, Missouri Department of Conservation.

Michaelson, S.M., 1971, Fish population in channelized and unchannelized sections of the Platte River, Missouri, Presentation at the 33rd Annual Midwest Fish and Wildlife Conference (Missouri Department of Conservation internal document).

Missouri Department of Natural Resources, 1985, Missouri water quality basin plan, Volume 4, Missouri Department of Natural Resources, Water Protection and Soil Conservation Division, Water Pollution Control Program.

Schulz, R.G., 1997, Niangua River basin inventory and management plan, Missouri Department of Conservation.

Stoner, G., Missouri Department of Conservation, personal communication to Jim Czarnezki, June 13, 2001.

Missouri Department of Natural Resources, Water Protection and Soil Conservation Division, Water Pollution Control Program, Missouri water quality basin plan, Volume 2, 1986.

Water Use Opportunities and Regional Observations

This report documents water use problems that have been identified in central Missouri. In the process of creating this report, several "success stories" and opportunities in water use have been recognized as well. Although the goal of this series is to identify problems rather than offer solutions, some of these findings are described below. By taking note of successes (and opportunities for success), we recognize approaches that work, and can use them as stepping stones to problem resolution. Water use opportunities are presented in this section to stimulate further thought and discussion, without endorsement of feasibility or merit.

Missouri River

The Missouri River is the dominant water feature in the central Missouri region. The average daily flow at Boonville is 69,600 cfs and 88,750 cfs at Hermann (Hauck and Nagel, 2000). This equates to, on average, approximately 50 and 64 million-acre feet of water, respectively, which passes by these locations each year. The Missouri River flows through eight of the 17 counties in the central Missouri region and drains 501,700 sq. miles and 524,200 sq. miles, at these two cities, respectively. In reference, Bagnell Dam stores around 2 million-acre feet of water at normal maximum water surface elevation at 660 feet above mean sea level (AmerenUE, 2001). Average annual discharge out of Lake of the Ozarks is approximately 10,370 cfs or approximately 7.5 million acre-feet per year and drains approximately 14,000 sq. miles (Hauck and Nagel, 2000). Due to these and other surface waters, the Central Missouri region has much potential for expanded and enhanced economic, environmental and societal water use opportunities.

Sources:

Hauck, H.S. and Nagel, C.D., 2000, Water Resources Data, Missouri, Water Year 1999, United States Geological Survey, Water-Data Report MO-99-1, 390 p.

AmerenUE, Osage Project (FERC No. 458) Initial Consultation Document, January, 2001, prepared by AmerenUE and Duke Engineering & Services, Inc.

Missouri River Master Manual Review

The review and update of the Missouri River Master Water Control Manual is currently under way. The Master Manual guides the Corps of Engineers' operation of the Missouri River Main Stem Reservoirs. The controversy over this manual and the management of the Missouri River Main Stem Reservoirs emerged in the drought that began in 1987. At the urging of the states of Montana and the Dakotas, the Corps agreed to study and reevaluate the Master Manual. Since this time, Missouri River basin states and several federal agencies have been engaged in trying to find the best outcome for the endangered species and the various states' interests. This open review process as to how the flows on the river are managed is an opportunity for central Missouri and the state of Missouri to express their opinions and institute

changes that are environmentally, socially and economically beneficial to the citizens of the region and state.

Development of Commercial Navigation Facilities on the Missouri River

With over 100 miles (Hermann being located at river mile 98 and Boonville at river mile 197) of commercially navigable river in central Missouri, extensive road and rail interlinks, several medium sized towns and an available work force, the central Missouri stretch of the Missouri River is an ideal location for development of commercial navigation facilities. Barge transport of bulk commodities is often more economical than transport by truck or rail. With Omaha, St. Joseph, and Kansas City upstream from the central Missouri region and St. Louis and the Mississippi waterway system downstream, there is an opportunity for development of commercial navigation facilities in this region.

Missouri River - Potential Water Supply for Large Quantity Users

Many industries are dependent upon continuous supplies of large quantities of water. At an average flow in excess of 30 million gallons per minute, the central Missouri reach of the Missouri River has the capacity to meet the needs of large quantity users. Power generation and certain food processing industries are examples of some large quantity water users. Agricultural irrigation is also a user of large quantities of water, however central Missouri generally receives enough precipitation to support the typical crops, corn, wheat, and soybeans, that are grown on bottomlands along the river. Missouri River water could be used to support the growing of fresh fruits and vegetables in new and expanded truck farming enterprises in the Missouri River bottomlands, which are some of the most fertile soils in the state. The region has a natural propensity, because of its water, transportation, and human resources, for population, business and industrial growth. The comparatively plentiful underground and surface water supplies in the area help to naturally reduce the detrimental effects of drought on consumptive uses.

Recreation and Habitat Restoration

Since the Flood of 1993, numerous locations along the Missouri River have been altered or adapted for recreational uses and environmental benefits. The Missouri Department of Conservation has numerous boat launches and access points on the river and on tributaries to the Missouri River. The U.S. Fish and Wildlife Service's Big Muddy Fish and Wildlife Refuge at Overton Bottoms and Marion Bottoms are examples of premier fish and wildlife areas. These areas were developed with the goal to restore and preserve both terrestrial and aquatic habitat and provide excellent resources for nature watchers and sportsmen. In addition, there have been hundreds of acres of floodplain land placed in the Wetland Reserve Program by private land owners, for recreational and habitat restoration purposes.

Hermann and Rocheport are examples of towns that utilize their locations adjacent to the river and the Katy Trail State Park to enhance available recreational opportunities. These two locations, as well as others along the river should figure prominently into the Lewis and Clark bicentennial celebration. There have been efforts in the past to develop an I-70 tourist center at Rocheport and a riverfront park on Adrian Island at Jefferson City. Riverboat excursions, dinner cruises, and gaming cruises intermittently utilize the central Missouri portion of the Missouri River, as do boaters, canoers and kayakers. Recreational boaters and sportsmen heavily use the Gasconade, Osage, Big Piney, Meramec and Niangua Rivers.

Economic, environmental and social enhancement opportunities exist at Lake Ozark and along the Osage River from Bagnell Dam to the Missouri River. These opportunities include the benefits for fish and wildlife, agricultural and landowner interests.

Best Land Use Practices

Opportunities exist at local governmental levels to utilize best land use practices around growing suburban areas to maintain and to improve the overall health of watersheds and the quality of runoff. Minimal economic investments now could realize big dividends later due to improved water quality, improved water supplies, less non-point source pollution, and increased land value for agriculture and housing development, as well as recreational opportunities and set-aside undeveloped areas. The western-northwestern and northeastern areas of the Central Missouri region are primarily agricultural. As such, modified farming practices in these areas can help to improve water quality and quantity in streams and to decrease the amounts of pesticide and nitrogen run-off to area streams. Housing construction and land development in and around Columbia, Jefferson City, Rolla and the Lake of the Ozarks change runoff rates, and have the potential for increased erosion, sedimentation and pollution of adjacent streams and groundwater aquifers. Active watershed planning and management can help to lessen or prevent this from occurring.

Riparian Corridors Protection

Set-aside riparian corridors along rivers and streams have many benefits, such as flood attenuation, fish and wildlife habitat, decreased soil erosion from croplands and suburbs, and helping to prevent contaminants from entering waterways. The region has varied topography and soil types with both silt/clay bottom and sand/gravel bottom streams. It is a crossroads region with predominately agricultural cropland north of the river and forests and pastures in the south. As much as half of the region is karst, with sinkholes and springs. Karst areas are especially vulnerable to contamination, due to the direct interchange of surface and groundwater. Private land owners, local governments and state and federal agencies have the opportunity to improve and protect the health of the region's watersheds and waterways by identifying particularly vulnerable land areas and watercourses with the placement of vegetated riparian corridors in key locations.

Missouri Water Law

An opportunity exists for Missouri to legislate certain aspects of the Missouri water law that are more appropriately statutory in nature rather than judicially mandated. Missouri riparian water law, with the exceptions of water pollution statutes, is predominantly based on court decisions, rather than legislated statutes. Statutes are typically written with consideration to broad-based guidance that can be applied to a variety of real world situations. Case law, on the other hand, is most often highly specific to a single issue, in a highly detailed set of circumstances. The public is, under our present system of water laws, left on its own to sort out how much water can be withdrawn from a stream or well, where and how it can be used, and what is and is not acceptable. More often, it is ultimately decided after the fact by a law suit, and the expense and liability which goes with it, what can and can not be legally done by a landowner. With a basic structure of statutory water laws in place, the landowner and water user would at least have minimal guidance as to what is and is not legally allowable and as a result, be relieved from some legal liabilities. By clarifying Missouri's water laws it would provide users with a legally tangible guarantee to the present and future quantities of water available for use, and in-turn, help to spur economic, environmental and social endeavors.

Comments Received

The Central Missouri report was reviewed at several stages of preparation. Ultimately, the report was added to the Department of Natural Resources' Internet home page for access and comment by the public. The department sought public review of this report. Although the report was accessed by many people, no public comments were received.