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SOUTHERN PLAINS RIVERS

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INTRODUCTION

Two large, separate river basins, the Arkansas and the Red, drain the southern Great Plains region of the United States south of the Kansas River and north of the Texas–Gulf coastal drainages (Fig. 7.2). All major rivers in the region drain generally from northwest to southeast and are tributaries of the Mississippi River. The Southern Plains region includes all of Oklahoma, much of western and central Arkansas, and parts of eastern New Mexico, Colorado, Kansas, north Texas, and western and central Louisiana. The region is characterized by shortgrass prairie in the west, mixed or tallgrass prairie in the midsection, and forests in the east. A general description of rivers in the southern Great Plains is in Matthews (1988), Matthews and Zimmerman (1990), and Brown and Matthews (1995).

The largest rivers (Arkansas, Canadian, Red, Washita, Cimarron) all have upper main stems that lack flow at times and mid- and downstream reaches that are wide, shallow, and sand or mud bottomed. They are some of the hottest and harshest aquatic habitats on Earth, with water temperatures reaching near 40°C when exposed to full sun under low flow conditions. Hefley (1937), describing the South Canadian River near Norman, Oklahoma, wrote, "Probably no more ecologically dynamic region exists: the seasonal, diurnal, and yearly fluctuations of meteorological factors are great and sudden; the course of the river changes with each succeeding rain and the shifting sand . . . is constantly being moved by wind and water." Adding to this the intense summer heat and winter cold of the region, organisms of these rivers are challenged by harsh, rapidly changing environmental conditions (Matthews and Hill 1979, Matthews 1987, Matthews and Zimmerman 1990).

People occupied the Arkansas and Red basins 11,500 to 10,000 years ago as hunters of the last ice age large animals (mammoths, mastodons, and big horned bison), roaming from central Texas, where they apparently spent winters fashioning and refurbishing tools from cherts of the region. By 10,500 years ago, the Ouachita Mountain parts of the Arkansas and Red basins were primarily grasslands, with sparse, riparian woodlands of oak and pine. Hunter-gatherers there and in the Ozarks focused on deer, turkey, small game, and wild plant foods. By 7500 years ago the Ozarks and Ouachitas were denuded of most woodlands, as a hot, dry Altithermal climate prevailed until about 4500 years ago. Recovery from the adverse effects of the Altithermal climatic regime was slow. Substantial numbers of

← **FIGURE 7.1** Red River, Oklahoma (PHOTO BY W. J. MATTHEWS).

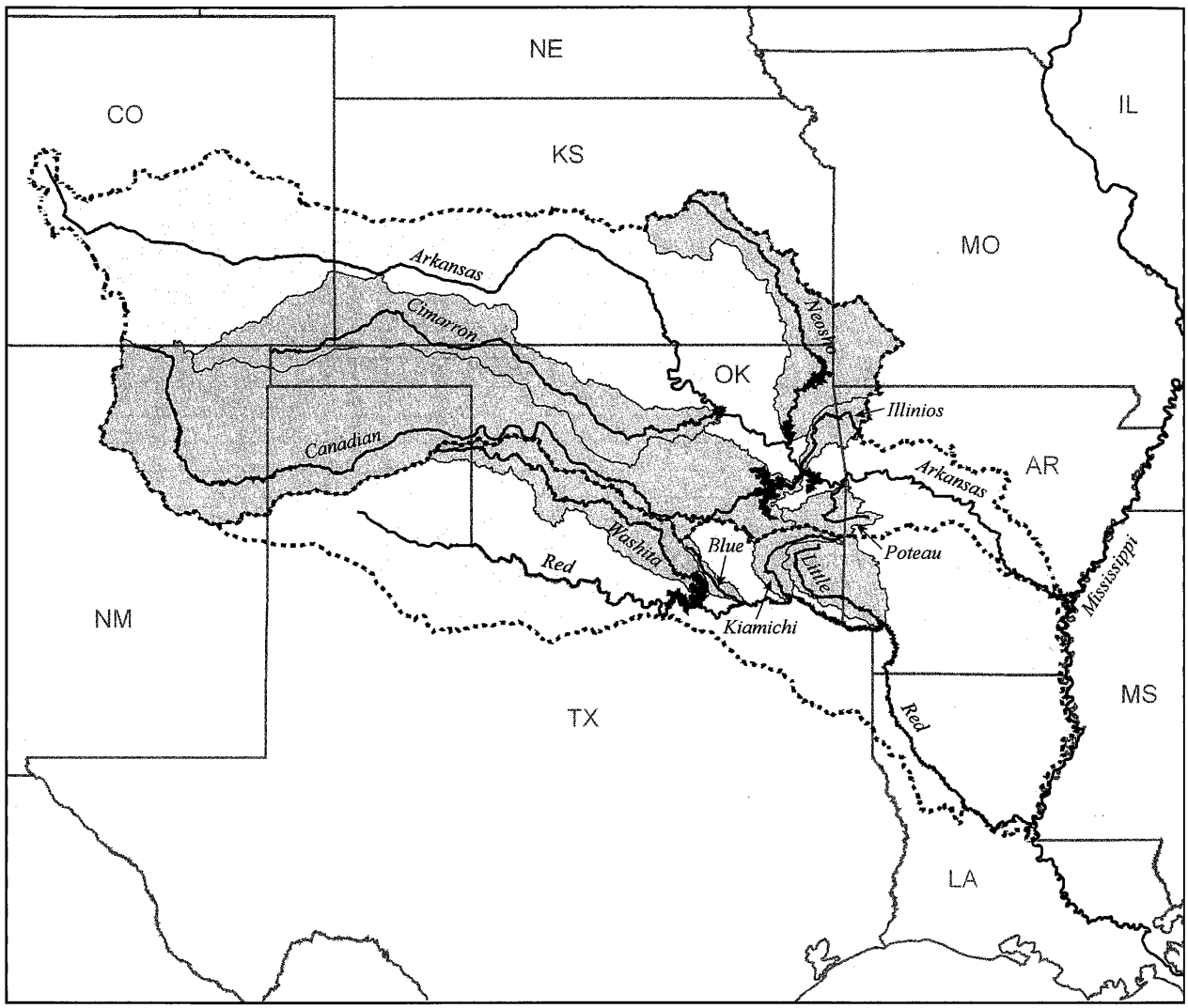

FIGURE 7.2 Southern Plains rivers covered in this chapter.

hunter-gatherers came to occupy the eastern parts of the Arkansas and Red basins, and by 2000 years ago they were adopting the bow and arrow and manufacturing pottery. By 1500 years ago these people were becoming farmers of corn, beans, and squash, and by 900 years ago major populations of these people occupied the fertile valleys along the Grand, Arkansas, Poteau, Little, and Red rivers in eastern Oklahoma and adjacent Arkansas. Meanwhile, to the west, sizeable societies of part-time bison hunters and farmers were spreading along the Washita River in Oklahoma, the South Canadian River in the Texas panhandle, and the Beaver (North Canadian) River in the Oklahoma panhandle (D. Wyckoff, personal communication).

By 500 years ago these people were undertaking major migrations and social change as climatic fluctuations adversely affected farming and other native societies moved into the plains from the Mississippi Valley and the Great Basin. It was during this transitional period that French and Spanish explorers began recording native inhabitants and lifeways in the basins of the Red and Arkansas rivers (D. Wyckoff, personal communication). The Arkansas and Red basins first came under European control under the claims of Spanish explorers like Coronado and de Soto. By the early 1700s many French explorers, trappers, and traders came into the region, making contact with and in many cases marrying native people. Spain was recognized by other European nations as the owner of the region in treaties of 1762–1763 (Morris et al. 1986), but transferred ownership of "Louisiana" to France in negotiations in 1800–1802. The United States purchased

"Louisiana" for $15,000,000 in 1803, by which most of the Red and Arkansas river basins, along with the Missouri and western Mississippi basins, became permanently owned by the United States. Following this purchase, numerous military expeditions throughout the West provided the first records of natural history of the region, and the stage was set for European dominance of the Red and Arkansas river basins.

In spite of similarities among the larger rivers, the streams of the region are so diverse overall that they represent many of the types of rivers in North America, ranging from shallow, unstable sand-bed rivers, to tumultuous montaine headwaters, to small rivers in upland valleys of modest gradient. We selected four focus rivers in the region, including the Arkansas, Canadian, Red, and Little rivers. The Canadian and Little river systems are substantial tributaries of the Arkansas and Red rivers, respectively, but their dominance of the landscape or their unique faunas cause us to give them special attention. Of the many lesser rivers in the southern Great Plains, seven best represent the wide range of diverse physical, hydraulic, and floral–faunal characteristics of streams of the southern Great Plains: the Cimarron, Neosho (Grand), Illinois, and Poteau in the Arkansas River basin and the Washita, Blue, and Kiamichi in the Red River basin. Some of these smaller rivers differ substantially from most other streams in the region (e.g., the calcareous, marl-depositing Blue River), and we included them for their unique features.

Physiography and Climate

Physiographic provinces included in the region are Southern Rocky Mountains, Great Plains, Osage Plains section of the Central Lowland province, Coastal Plain, Ozark Plateaus, and Ouachita Province (Hunt 1974). The latter two provinces are known collectively as the "Interior Highlands" in many treatments of fauna, particularly fishes. The region is quite diverse (Brown and Matthews 1995) and includes some of the highest mountains in the conterminous United States, vast expanses of flat plains, parts of the Gulf Coastal Plain, the highly eroded Ozark Mountains, the ridge and valley structures of the Ouachita Mountains, and numerous smaller but important uplifted areas, including the Flint Hills in Kansas and the Wichita and Arbuckle mountains in Oklahoma. Outside the mountainous areas the landscape of the region appears relatively flat, but the plains drop from an elevation exceeding 1200 m at the base of the Rocky Mountains to 50 m asl or less in the east. A major feature of the western part of the region is the Llano Estacado or "Staked Plain," which rises abruptly along a long north–south line in the Texas and Oklahoma panhandles, forming a high level plain of immense proportions.

Geologically, the region is complex (Hunt 1974). It was not glaciated in the Pleistocene, but glaciation to the north had strong influence on river courses and connectivity in the southern plains (Cross et al. 1986) and likely on distributions of aquatic organisms. The Arkansas and Canadian rivers arise in granitic-volcanic terrain as high-gradient, turbulent streams over boulder-strewn channels, with the upper Arkansas River sufficiently large and high gradient to support a white-water rafting industry.

Thus, at the extreme western edge of the region are mixed volcanic and metamorphic rock and Tertiary or Mesozoic sedimentary deposits, mostly of marine origin. Dominance of marine sedimentary deposits continues east onto the Great Plains, with streambeds also characterized by outwash from the Rocky Mountains (Hunt 1974, Brown and Matthews 1995). Much of the region in eastern Kansas, most of Oklahoma, and western Arkansas includes marine and continental sediments of Mississippian, Pennsylvanian, and Permian age, with sedimentary Cretaceous formations in southeast Oklahoma and southwest Arkansas. The Red River from south-central Oklahoma through Louisiana passes mostly over Quaternary sedimentary deposits of fluvial origins, as does the Arkansas River after it drops off the Fall Line onto the Mississippi Delta of the Coastal Plain (Hunt 1974). As a consequence of geologic diversity between and within the river drainages, the physical structure of rivers in the southern Great Plains ranges from high-gradient riffle–pool headwaters to wide, shallow, sandy river main stems, with substrates varying from boulder and bedrock to fine river sands.

Extensive geological and podological research near the Great Bend of the Arkansas River documents soil development and surface stability about 36,000 years ago, followed by wind and water erosion until some 22,000 years ago. The region was a C_4 dominated grassland, where horses, camels, and mammoths were the prevalent large herbivores. By 21,000 years ago the Wisconsinan glaciation was nearing its maximum. Silt from the glacial front was deposited in the Arkansas basin, and macrofossil finds indicate that at least scattered stands of spruce woodlands were present along the middle Arkansas River during full glacial times. To the east, in the

Grand (Neosho) watershed, spruce and pine woodlands persisted until at least 12,000 years ago. During full glacial times the High Plains and their eroded eastern margins in the Red and Arkansas basins were lush grasslands where mammoth, camel, and big horned bison were common (D. Wyckoff, personal communication).

Total rainfall and its temporal distribution has long been the bane of settlers in the western parts of the region. Thornthwaite (1941) noted about the Great Plains, "Men have been badly fooled by the semiarid regions because they are sometimes humid, sometimes desert, and sometimes a cross between the two." The Llano Estacado of eastern New Mexico and west Texas, through which the Red River, Canadian River, and southern tributaries of the Arkansas River pass, is so lacking in surface water that a patrol of "Buffalo Soldiers" of the 10th Cavalry, somewhere near the headwaters of the Red River in 1877, drank the blood and urine of their horses in an attempt to survive (Leckie 1967).

Climate differs markedly from southeast to northwest. Louisiana and eastern Arkansas are in a region of hot summers (daily average temperature about 28°C in July) and moderate winters. In the western part of these river basins, summers are also hot, but winters can have extended periods of cold and true blizzard conditions. Snow cover is not persistent, however, except at high elevations in the mountainous westernmost parts of the Arkansas and Canadian rivers. Air temperatures in the headwaters of the Canadian and Arkansas rivers in Colorado–New Mexico are cold, influenced by elevation, but even on the lower-altitude western plains in the upper parts of these basins mean air temperature in January is below freezing. Mean annual precipitation decreases from >120 cm in Arkansas or Louisiana to about 20 cm in the west, in the rain shadow of the Rocky Mountains (Brown and Matthews 1995). Because of its central location in the North American continent, air masses from the Pacific Ocean, Gulf of Mexico, and Canada converge in the region, resulting in some of the most violent weather on Earth (e.g., central Oklahoma averages more tornados per year than any other location, and the most powerful tornado ever recorded hit Oklahoma City on May 3, 1999).

Basin Landscape and Land Use

Biomes within the southern Great Plains region include Temperate Mountain Forest, Temperate Grasslands, and Temperate Deciduous Forest. Terrestrial ecoregions in the southern Great Plains include, roughly from west to east, the Colorado Rockies Forests, Western Short Grasslands, Central and Southern Mixed Grasslands, Flint Hills Tall Grasslands, Central Forest/Grassland Transition Zone, Ozark Mountain Forests, Piney Woods Forests, and Mississippi Lowland Forests (Ricketts et al. 1999). Major rivers like the Red, Canadian, and Arkansas flow through and cut across the terrestrially defined ecoregions but have such distinctive faunas that some states (e.g., Oklahoma) have officially recognized an additional "Big Rivers Ecoregion" that represents these unique large rivers and their associated riparian zones. A prominent feature within the Central Forest/Grassland Transition Zone is the "Crosstimbers," a mosaic of forest, woodland, savanna, and prairie vegetation dominated by post oak and blackjack oak (Hoagland et al. 1999) about 100 km wide east to west and extending from southern Kansas to north Texas.

Before European settlement many river main stems in the east flowed through vast forests, and even in the western part of the region riparian forests of cottonwood, willow, or chinaberry existed before they fell to the axes of early settlers in need of timber and firewood. One enormous cottonwood near the Canadian River in present-day north Texas was reported by Capt. Randolph Marcy as being 19.5 feet (almost 6 m) in circumference. Historically, vast forests covered the Interior Highlands and unbroken grasslands extended to the west. Forests of the Ozark Mountains remain relatively like the original oak–hickory forest and probably have had the least cultural modification overall. The Ouachita Mountains in south Arkansas and eastern Oklahoma were dominated in presettlement times by relatively open parkland of large pine trees interspersed with grasses.

Beyond the immediate proximity of the rivers, much of the western part of the region was covered in presettlement times by seemingly endless plains of short grasses. Near the headwaters of the Red and Canadian rivers, Marcy described "the elevated plateau of the Staked Plain, where the eye rests upon no object of relief within the scope of vision," and that "the grass upon the Staked Plain is generally a very short variety of misquite [*sic*], called buffalo-grass, from one to two inches in length, and gives the plains the appearance of an interminable meadow that has been recently mown very close to the earth" (Foreman 1937).

Rivers have played major roles in the European human history of the region. In 1806, Capt. Zebulon Pike's expedition followed the Arkansas River from Great Bend west to the Rocky Mountains, but a

detachment under Lt. James Wilkerson turned downstream at Great Bend to follow the Arkansas past the present site of Webbers Falls, Oklahoma, thence to New Orleans. These explorations provided some of the earliest accounts of the landscape and natural history of the Arkansas River region. Other pre–Civil War explorations of the Arkansas River region in Kansas–Colorado were by parties under command of or including Maj. Stephen Long, Thomas Say, Jacob Fowler, Jedediah Smith, John C. Fremont, and Washington Irving. Further south, substantial explorations and descriptions of natural history were by Col. George Sibley (Chikaskia River and Salt Fork of the Arkansas), Maj. Stephen Long (Red River, Kiamichi River, Mountain Fork, Poteau River), Thomas Nuttall (botanical descriptions of streams and mountains in southeast Oklahoma, then the Arkansas, Grand, Verdigris, Canadian, North Canadian, Deep Fork, and Cimarron rivers, and native peoples encountered therein), and a variety of other military or trading expeditions (Morris et al. 1986). Highly significant in knowledge of natural history of the region were the "Pacific Railroad Surveys" westward across the region under the command of Whipple, Marcy, and others, completed by the War Department in the 1850s.

In the mid-1800s, military expeditions under Marcy and Whipple followed the major east–west rivers like the Canadian and Red to seek routes for railroads, trade and commerce, or westward settlement. Steamboats navigated the Arkansas and Red rivers upstream to eastern Oklahoma by the early 1800s, and rivers became corridors along which movements of settlers and military were common. Throughout the 1800s, native peoples from elsewhere in the United States were displaced from their homelands and moved to the region that would become Oklahoma. The major original native people in the Red and Arkansas basins prior to the European-mediated displacements of the 1800s were the Kichai and Caddo in Louisiana, eastern Oklahoma, and southwest Arkansas; the Quapaw and Osage in southern Oklahoma, northeast Oklahoma, Arkansas, and Kansas; the Wichita along the Red River; and the Comanche, Kiowa-Apache, and Apache on the high plains to the west. Arapaho and Cheyenne lands were generally north of the Arkansas River basin (Socolofsky and Self 1988), but these nomadic peoples of the high plains no doubt were also present in the Southern Plains region at times.

European settlement of the Arkansas or Red River basin was advanced by establishment of military forts throughout the region from about 1820 onward, by the existence of federal wagon roads after 1849, by stage routes through the region after 1850, by cattle trails from Texas that crisscrossed the region from about 1840 to 1897, by sheep trails up the Arkansas River from the 1870s to 1900, and by establishment of railroads with access to commerce in western Kansas and eastern Colorado after 1865, followed by rail lines throughout the region by the 1870s and 1880s. Statehood promoted settlement by the establishment of permanent governments, with the states in the Southern Plains region granted statehood as follows: Louisiana (1812), Arkansas (1836), Texas (1845), Kansas (1861), Colorado (1876), and Oklahoma (1907).

Europeans dramatically changed the region by plowing the prairies, cutting forests, mining, altering patterns of stream flow, and extracting oil and natural gas. The region is now a mosaic of private timber production, large areas of forest under federal ownership and management, row-crop production, and cattle ranching, with only a few large cities and very limited heavy manufacturing. In recent decades, large-scale swine and poultry production has sharply increased, threatening water quality. Feedlots for cattle also cause local water-quality problems. Plowing of native prairie caused increases in silt and associated losses of some fish species in streams (Cross and Moss 1987). Fire suppression on former prairies allowed encroachment of trees, and the introduced cattle imposed grazing patterns very different from those of the wide-ranging native bison they replaced. The last "virgin forest" in the central United States (in the Ouachita Mountains) was harvested for timber before 1950 (Smith 1986) and replaced by pine monoculture, now cut mostly for pulp, particle board, and similar products.

As the vast southern bison herd was annihilated in the late 1800s, open ranging of cattle began, followed by huge privately owned cattle ranches hundreds of square kilometers in size or larger (e.g., in the upper Red River region). Where water was available, row crops of wheat, corn, sorghum, milo, cotton, and, more recently, peanuts came to dominate the landscape. Center-pivot irrigation allowed extension of row crops farther west than formerly possible, but decimated important aquifers like the Ogallalah, which formerly recharged many prairie streams but now is reduced and imperiled. A dramatic example of irrigation and aquifer depletion is in the Oklahoma Panhandle. There, a sharp increase in numbers of high-capacity irrigation wells (since about 1960) coincided with a dramatic increase in the number of "no-flow" days per year in the Beaver

(upper North Canadian) River. No-flow days increased from fewer than 20 before 1960 to almost 100 in many of the years from 1980 to the present (http://nwis.waterdata.usgs.gov/ok/nwis/discharge).

Discovery of oil and gas resulted in further changes to the landscape in the 1900s, with negative impacts on some streams from salt water and other byproducts of drilling. In some areas, mining for zinc, lead, or other minerals contaminated large terrestrial areas and polluted streams like Tar Creek in northeast Oklahoma. Limited coal mining in the east and some gold mining in the west has had local impacts on streams. However, the region largely lacks raw materials, such as iron, copper, or coal, that support heavy manufacturing, so rivers here escaped some of the pollution problems. An increasing lack of water relative to demands, siltation from agriculture, local sewage or agricultural pollution due to large agribusinesses, impacts of impoundments, and generally poor water quality or physical conditions for biota in western parts of the region remain the most serious challenges to streams in the region. Rivers to the east, including the Little, Kiamichi, Neosho (Grand), and Illinois, may be some of the "best" in North America in retaining much of their original presettlement biodiversity and aesthetic quality. However, some, like the Blue River, are under increasing user pressure and erosion of overall quality.

Ultimately, the largest cities in the region grew on or near major rivers, including Little Rock and Fort Smith, Arkansas; Shreveport, Louisiana; Tulsa and Oklahoma City, Oklahoma; and Wichita, Kansas. With construction of the Kerr-McClellan navigation system from 1957 to 1970 widening and modifying the Arkansas and Verdigris rivers, Tulsa, Muskogee, and Little Rock became major barge ports, linking those inland cities to overseas commerce. The construction of numerous locks and dams along that system, in addition to the large dams and reservoirs on most river systems in the region, have changed irreversibly the channel configurations and flow schedules of these systems (although not necessarily altering overall annual discharge for river basins).

The Rivers

Rivers of the region flow through the Southern Plains, Central Prairie, Ozark Highlands, Ouachita Highlands, and Mississippi Embayment "freshwater ecoregions" (Abell et al. 2000). However, these freshwater ecoregions are very large and therefore generalized, and there is great diversity of streams within any one ecoregion. The rivers included in this chapter fall into two rather different groups on the basis of their upland versus lowland characteristics. The group including the Arkansas, Canadian, Red, Washita, and Cimarron rivers represents typical large to medium-size low-gradient prairie main stems with wide, shallow, braided, unstable sand-bed channels, often carrying heavy loads of large wood snags washed in by floods. These form massive brush piles around bridge abutments, requiring regular removal in some rivers (e.g., Washita River in southern Oklahoma). These rivers are highly distinctive as habitats or "ecoregions" within the region, containing animals and plants (e.g., some fishes and riparian vegetation) not found elsewhere. The other rivers, including the Little, Kiamichi, Blue, Illinois, Neosho (Grand), and Poteau, arise in upland areas as stony-bottomed streams and are typified in their upper reaches by relatively clear water, differentiation into swift riffles and deep pools, and relatively diverse and stable structural features. As streams of this latter group leave the uplands they become more turbid, sluggish, and incised but lack the braided sand-bed channels that typify rivers of the other group.

However, even within these groups each river has unique features of topography and biota, hence their inclusion here to provide a cross-section of rivers typical of the southern Great Plains region. The main-stem Red River arises in the Texas Panhandle near Amarillo, Texas, and lacks any montaine snowmelt influence. The Arkansas River and the Canadian River originate in the Rocky Mountains, and thus are influenced by snowmelt in their upper reaches. However, as they emerge from the mountains onto the dry western plains they lose water from evaporation or agricultural withdrawals and become small streams in western Oklahoma and Kansas.

In sharp contrast to low-gradient rivers flowing eastward across the prairies and grasslands, other rivers in the region arise in heavily forested, uplifted areas like the Ozark and Ouachita mountains in Oklahoma–Arkansas, the Arbuckle Mountains of Oklahoma, and the Flint Hills of Kansas. The Neosho (Grand), Illinois, Blue, Kiamichi, and Little rivers are strongly influenced in physiognomy by the uplifted areas where they arise and through which they flow for much of their length. Streams originating in these uplands typically have high-gradient headwaters with strong base flow (in spite of some dramatic drought conditions in recent years), more benign environmental conditions, clear water, and stony bottoms with much more well-defined riffle–pool configurations than for prairie streams.

Large to modest-size springs dominate base flow in the Ozarks and Arbuckles, whereas the Ouachita uplands have fewer large springs and their streams arise from runoff and more gradual influx of subsurface water. Rivers in the eastern mesic part of the region generally have more reliable flow, complex physical structure, and diverse faunas than rivers further west.

Late-summer drying of streams in the region is a function of both evapotranspiration and lowered rainfall. Shallow river main stems in the midportion of the region can enter winter under drought conditions if autumn rains are lacking, and under those conditions icing can be substantial in main channels. To the southeast, icing of river main stems typically does not occur. In most of the region spates can occur in any month of the year, and flow patterns are unpredictable (Resh et al. 1988, Brown and Matthews 1995). The rivers influenced by snowmelt may have more predictable seasonal patterns, but their flow also becomes erratic after entering the plains.

Extreme rainfall events result in annual or more frequent bankfull spates and streambed scouring in many of the smaller tributaries to the main rivers. For example, in October 1981, approximately 43 cm of rain fell in a two-day period in parts of south Oklahoma, resulting in massive flooding of small streams and alteration and complete scouring and reshaping of their physical structure. Such events also cause widespread flooding of main rivers, rearrangement of their sand-bed substrates and braided flow patterns, and extreme water-level fluctuations in main-stem reservoirs. Conversely, severe drought years have occurred in the region in recent decades (e.g., 1977–1979, 1981, 1991, 1998, and 2000), with long reaches of streams dewatered or reduced to small, isolated pools and reservoirs reaching very low levels. Under such conditions temperature and oxygen stress can be extreme, and animals crowded into shrinking habitats may experience density-dependent as well as density-independent constraints on their growth, survival, or population sizes (Matthews et al. 2001). Although the fauna is largely resistant to or adapted for physical stress, some evidence now suggests that recurrent drought may be having impacts on stream fishes (W. J. Matthews, unpublished data) and mussels (D. Spooner and C. C. Vaughn, unpublished data).

The rivers that originate in the Rocky Mountains (Canadian, Arkansas) arise as retentive, debris-regulated channels that become alluvial gravel beds with fluvially formed riffle–pool structure farther downstream and wide, braided sandbed channels after entering the plains (Brown and Matthews 1995). Other streams originating in the region arise as alluvial gravel riffle–pool channels or sand-bed or mud-bottomed streams. In the prairie portions of rivers like the upper Arkansas, Red, Canadian, Cimarron, and Washita, harsh physical conditions owing to solar heating, extreme and extended winter cold, and unpredictable drought or flooding limit development of the biota and may disrupt the transitions in flora and fauna hypothesized for more stable systems. Rivers in the prairie may be characterized by local patchiness of habitat and physicochemical conditions (e.g., local refugia formed at mouths of creeks entering river main stems). There, deeper shaded refugia, compared to the shallow exposed main stems, may provide less harsh thermal, oxygen, or other physical conditions (Matthews and Hill 1979). Sources of energy for streams in the western and central parts of the southern Great Plains likely differ from those in mesic forested regions in that headwaters of many systems lack riparian forest, and energy may come directly from autochthonous production (periphyton, biofilms) or from prairie grasses as allochthonous inputs.

In rivers arising in the mesic uplands to the east (including the Little, Kiamichi, Blue, Illinois, Neosho [Grand], and Poteau rivers) base flow (often spring fed) is more reliable, harsh physical conditions are less common, and a more predictable longitudinal zonation or continuum of biota and ecosystem processes may exist. However, most of these rivers are interrupted by dams, ranging from very large flood-control/hydropower structures to local low-head dams for municipal water supply or other uses, all potentially disrupting natural transitions of organisms and processes from headwaters to lower rivers. Finally, modern distribution of some aquatic organisms may be influenced by a large "Pre-Glacial Plains Stream" (Metcalf 1966, Cross et al. 1986) that hypothetically cut across present-day east–west river systems, draining into the lower Mississippi River or Gulf of Mexico, thus providing an avenue of north–south movement for stream fishes in the Pleistocene.

All large rivers and most small ones in the region have been dammed, resulting in reaches below dams in which physical conditions are markedly altered (e.g., increased water clarity due to trapping of silt in the reservoir; increased stony substrates in some cases). Rivers have been altered by clearing and snagging rivers for boat passage, contamination by salt water from oil production, and interbasin water

transfers (Red to Trinity river basins). However, many physical features of main stems in the central part of the region remain similar to presettlement/ first explorer reports (Matthews 1988).

ARKANSAS RIVER

The Arkansas River basin is the largest in the lower Great Plains, draining the western Mississippi River basin south of the Missouri River basin (Fig. 7.7). It originates in central Colorado near some of the tallest peaks in North America. Denver may be the "Mile High" City, but the Arkansas River could claim the title of "two mile" river because it drops almost exactly two miles in elevation from its headwaters to its confluence with the Mississippi River. In its course it passes through highly changing terrain, climate, and land use. It has strong flow in the Rocky Mountains, loses water to evaporation and withdrawal in eastern Colorado and western Kansas (Ferrington 1993), then recharges to be a major plains river through the rest of its path to the Mississippi River. In Oklahoma, the main-stem Arkansas River is joined by the Salt Fork, Cimarron, Verdigris, Neosho (Grand), Illinois, and Canadian rivers. The Arkansas becomes a 7th order river at the confluence of the Verdigris, at which it remains to its confluence with the Mississippi River. Some old maps show the large White River of north Arkansas and southern Missouri as joining the Arkansas River before the latter enters the Mississippi River, but at present the White River flows directly into the Mississippi River and there is no direct connection of the White and Arkansas rivers (except perhaps during periods of major flooding).

The lower Arkansas River basin was occupied from 10,000 to 2000 years ago by Paleo-Indians similar to those of known bluff-dwelling sites in the Ozarks and Ouachita mountains, who produced characteristic projectile points and stone tools (Hanson and Moneyhon 1989). In the "formative period" of Paleo-Indian culture in the lower Arkansas basin, permanent villages appeared, and major mound-building cities arose. For example, the Spiro Mound, near the Arkansas River in eastern Oklahoma, produced a rich treasure of detailed and intricate artifacts, making clear that this was a major center of prehistoric culture. By the mid 1500s the Spanish explorer de Soto reported large native populations along the Arkansas River, with substantial fortified villages (Hanson and Moneyhon 1989). In the western Arkansas basin nomadic peoples like the Kiowa, Comanche, Arapaho, and Cheyenne roamed the plains, with their mobility vastly increased and lifeways highly altered by dispersion of European horse onto the plains in the 1600s to early 1700s (Beck and Haase 1989). The upper Arkansas River basin was first explored with an eye toward permanent settlement beginning in about 1806, after the Louisiana Purchase, and during the next 50 years a substantial number of military and private expeditions used the upper Arkansas River as a conduit to the west.

Physiography, Climate, and Land Use

The Arkansas River basin flows primarily in an east-southeasterly direction, from latitude 39°N to latitude 34°N, passing through six physiographic provinces, including Southern Rocky Mountains (SR), Great Plains (GP), Central Lowland (CL), Ozark Plateaus (OZ), Ouachita Province (OP), and Coastal Plain (CP). This area includes the Western Short Grasslands, Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone, Ozark Mountain Forests, and Mississippi Lowland Forests terrestrial ecoregions (Ricketts et al. 1999). There is a wide range of vegetation, including coniferous uplands in the Rocky Mountains, short native grasses in the west, mixed to tallgrass prairie in the east, slopes covered with deciduous forests in the Ozarks, and dense Coastal Plain forest downstream in eastern Arkansas.

Climate varies greatly along the Arkansas River from central Colorado to eastern Arkansas. Near its headwaters in Colorado, mean monthly air temperatures typically range from –8°C in January to 13°C in July, with average annual rainfall about 51 cm. Overall, precipitation is greatest in May or June and lowest from December to February (Fig. 7.8). Mean temperatures are hottest in July and August and lowest in January. To the east, the climate is warm-subtropical, with generally hot, humid summers and mild winters and only occasional extreme cold events. At Pine Bluff, Arkansas, near the far eastern end of the basin, mean January temperature is 7°C, mean July temperature is 29°C, and rainfall exceeds 100 cm per year. In much of Colorado and western Kansas, January daily average temperatures are below freezing, but in eastern Oklahoma and Arkansas, January temperatures average well above freezing. From Colorado through western Kansas there is too little rainfall (<50 cm/yr) for farming without irrigation. As the river passes through Kansas and Oklahoma it traverses sharp increases in

rainfall, passing the 100 cm/yr isopleth in northeast Oklahoma.

Land use in the Arkansas basin varies with climate. In arid lands to the west, rangelands and grazing of cattle dominate, with row-crop agriculture, particularly wheat, increasing with rainfall to dominate the landscape through much of Kansas. In Oklahoma and Arkansas, row crops and livestock dominate the immediate river valleys, but the surrounding hills and mountains are heavily wooded. The entire region, with the exception of major cities like Pine Bluff, Little Rock, Fort Smith, Muskogee, Tulsa, and Wichita, is predominantly rural; oil and gas production is a major industry. There is little heavy manufacturing in the region; hard-mineral extraction is limited or localized and has no substantial impact on the river. Estimated percentages of land use outside of cities are, from U.S. Department of Agriculture maps, 50% rangeland and 50% cropland in the western parts of the basin, compared to 50% forest, 15% cropland, and 25% pasture further to the east.

River Geomorphology, Hydrology, and Chemistry

The Arkansas River is formed by creeks near Leadville, Colorado, at 3010 m asl, 30 km north of Mt. Elbert, the highest mountain in the state (and in the Arkansas River basin) at 4370 m asl. The Rocky Mountains in central Colorado are volcanic and metamorphic rock interspersed with sedimentary marine deposits; thus, the upper Arkansas River main stem flows through steep and rugged terrain en route to the plains. Near Canyon City, Colorado, it flows through the Royal Gorge, where one of the highest suspension bridges in the world passes over the turbulent main stem 320 meters below.

Downstream, it leaves the Rocky Mountains and flows near Pueblo, Colorado, onto the plains of east-central Colorado, becoming a low-gradient river through grazing and agricultural lands. Crossing Kansas, Oklahoma, and western Arkansas, the river traverses marine and continental sediments of Mississippian, Pennsylvanian, and Permian age, bisecting the formerly continuous Interior Highland (Ozark and Ouachita mountains) and finally reaching Quaternary sediments of the Mississippi Embayment. Before leaving Colorado the Arkansas is joined by the Purgatoire River, which drains very arid lands of southeastern Colorado, and forms John Martin Reservoir, the first large reservoir on the main stem. Eastward in Kansas, it passes Garden City and Dodge City, losing water to become ephemeral upriver of Great Bend. The most severe dewatering has been in a reach from Syracuse to Great Bend, Kansas, where complete loss of surface flow has occurred in several places for as much as a year (Ferrington 1993). Serious declines in surface flow coincided with increases in groundwater withdrawal in the early 1970s (Ferrington 1993). Near Great Bend it receives water from the Pawnee River and passes near the famous Cheyenne Bottoms Wildlife Area, which is a critical wetland for waterfowl and a wide variety of birds in the Central Flyway. Downstream from Great Bend the Arkansas thus is again a "river," about 20 m to more than 100 m wide in places, with moderate to swift current over coarse gravel and cobble in riffles and sand-bottomed pools to nearly a meter deep. Flowing through Wichita, Kansas, it has a braided, sandy channel, and beyond Wichita it is joined by the sandy Ninnescah River and the turbid Walnut River and is a sizeable stream as it crosses into Oklahoma. Immediately below the Kansas–Oklahoma border it becomes Kaw Lake, gains the Salt Fork of the Arkansas, and flows into Keystone Lake, impounded at the juncture of the Cimarron and Arkansas rivers.

Below Keystone Lake the Arkansas River flows through downtown Tulsa, Oklahoma, where it has a sand-bottomed, braided channel hundreds of meters wide, with flow strongly controlled by releases from the reservoir. Near Muskogee, Oklahoma, it is joined by the channelized Verdigris River and becomes the Kerr-McClellan Navigation System. The river passes through locks and dams and the Robert S. Kerr reservoir, exiting Oklahoma near Ft. Smith, Arkansas. At Ft. Smith the stream is a large, deep river several hundred meters wide, with mostly sand banks, and the channel is controlled by wing dikes and other navigational developments. Near Russellville, Arkansas, the river enters Dardanelle Reservoir, the last large man-made impoundment on the river. In central Arkansas the river gains more barge traffic at the port of Little Rock, then flows southeast through the large forests and rich farmlands of the Mississippi Delta to its confluence with the Mississippi River. From Little Rock downstream the river is low gradient, with broad meanders, backwater bays and sloughs, and flooded riparian forests, but is frequently interrupted by locks and dams of the Kerr-McClellan Navigation System. In its total course from headwaters in the Rocky Mountains to its confluence with the Mississippi River the Arkansas River has a mean overall slope of 185 cm/km.

Virgin discharge (1928 to 1939, before large dams) averaged 1004 m^3/s downstream in the basin at Little Rock, Arkansas. For the entire period of record at Little Rock the mean annual discharge "prior to regulation" (1928 to 1969) was 1118 m^3/s, whereas after upstream regulation by locks and dams, the mean annual discharge from 1970 to 2000 was 1389 m^3/s (ranging from 360 to 2711 m^3/s). Thus, overall flow statistics show that in spite of water withdrawal in Colorado and west Kansas and the highly regulated nature of the system, as much water is delivered downstream at Little Rock as during virgin flow conditions. Slightly upstream, near Van Buren, Arkansas, mean annual discharge only decreased from 885 to 826 m^3/s after regulation by Lake Eufaula (on the Canadian River, a large tributary), further evidence of only modest changes in discharge relative to virgin flow conditions. Runoff (0.3 to 1.5 cm/mo) is low in the Arkansas River basin because it includes arid lands, with most of the precipitation lost as evapotranspiration before it ever reaches the mouth (see Fig. 7.8).

The headwaters near Leadville, Colorado, are cold even in summer (e.g., 10°C) and low in ion concentrations. Typical values at three USGS headwater sites include conductivity of 85 to 150 µS/cm, pH of 6.3, hardness of 30 to 50 mg/L as $CaCO_3$, and calcium, magnesium, sodium, and chloride all <10 mg/L. Crossing the plains, the river changes chemically so that below Great Bend, Kansas, the main stem is characterized by pH typically >8.0, conductivity of 1000 to 3000 µS/cm, total hardness of 300 to 500 mg/L as $CaCO_3$, alkalinity of 150 to 300 mg/L as $CaCO_3$, and ions dominated by sodium (300 to 500 mg/L) and chloride (200 to 800 mg/L), but with substantial magnesium (20 to 40 mg/L), calcium (100 to 130 mg/L), and sulfate (150 to 250 mg/L). From Ft. Smith downstream the main stem typically has pH of 7.5 to 8.3, conductivity of about 400 to 900 µS/cm, total hardness of 100 to 200 mg/L as $CaCO_3$, alkalinity of 80 to 130 mg/L as $CaCO_3$, sodium of 30 to 80 mg/L, chloride of 40 to 150 mg/L, magnesium of 10 to 15 mg/L, calcium of 30 to 50 mg/L, and sulfate of 40 to 90 mg/L. In the lower river in east Arkansas, where there is much row-crop agriculture, nutrients are high: Total organic nitrogen is typically 0.5 to 2.0 mg/L and sometimes as high as 4.0 mg/L, and total phosphorus is about 0.05 to 0.20 mg/L. Water temperatures of the main river in eastern Arkansas have reached 32°C in some summers and as low as 4°C in winter. Average year-round water temperature for the basin is estimated at about 18°C.

River Biodiversity and Ecology

As mentioned, the Arkansas changes greatly along its course, and in so doing passes through four freshwater ecoregions: Southern Plains, Central Prairie, Ozark Highlands, and Mississippi Embayment (Abell et al. 2000). The Ozark Highlands ecoregion is largely defined by its high-gradient tributaries that drain into the Arkansas River; the main stem remains a low-gradient river that does not itself pass through the Ozark Mountains before entering the Mississippi Embayment. There are no comprehensive, basinwide studies of the flora and fauna of the Arkansas River. Sections of the river are treated in appropriate "state" floral and faunal guides, and there have been substantial studies of fishes in Kansas and Colorado by the University of Kansas, Fort Hays State University, and Colorado State University.

Algae

Relatively little is known about algal communities of the Arkansas River. Wilhm et al. (1978), however, reported that phytoplankton was dominated by diatoms (109 of 128 taxa), with *Cyclotella* and *Melosira* the most abundant genera. Benthic diatoms included *Navicula*, *Surirella*, *Nitzschia*, *Synedra*, *Cocconeis*, *Amphiprora*, and *Gomphonema*.

Plants

Riparian areas are dominated by silver maple, box elder, bur oak, and red oak. Sugarberry is common. Cottonwood–willow woodlands are common on floodplains throughout the watershed. Cattails and American bulrush occur in temporarily flooded sloughs. Within-channel macrophytes are not a noteworthy feature of the main-stem Arkansas River.

Invertebrates

The Arkansas River supports a diverse array of macroinvertebrates. Hard substrates (clear, rocky areas of the upper river and woody snags throughout) support grazing mayflies such as *Stenonema* and *Heptagenia*, filtering caddisflies such as *Cheumatopsyche* and *Hydropsyche*, the stonefly *Neoperla*, and black flies (*Simulium*). Further downstream the mayflies *Caenis* and *Hexagenia* (a burrower) become more common. Chironomid midges associated with hard substrates include *Polypedilum*, *Rheotanytarsus*, and *Glyptotendipes* (Wilhm et al. 1978). Crayfishes include *Orconectes palmeri*,

O. virilis, *O. nais*, *Procambarus simulans*, and *P. acutus* (Reimer 1969, E. A. Bergey, personal communication). Goldhammer and Ferrington (1992) demonstrated the importance of "epirheic" zones of capillary water fringe habitats as sources of secondary production of aquatic invertebrates in the Cimarron River, a tributary of the Arkansas River.

Lower reaches of the Arkansas River contain a diverse "big-river" mussel assemblage dominated by the commercially important washboard mussel, threeridge, and mapleleaf. Other common mussels include pink papershell, bleufer, plain pocketbook, fluted shell, fragile papershell, pimpleback, fawnsfoot, and pondhorn (Branson 1982, 1983, 1984, C. C. Vaughn, unpublished data). Two nonnative bivalves have invaded the Arkansas River: the Asian clam and the zebra mussel. Zebra mussels were introduced via barges in the early 1990s and are common in several main-stem impoundments, particularly Kerr Reservoir.

Vertebrates

The Arkansas River basin has 141 known species of native fishes and about 30 nonnative species. The number of native species occurring in the lower, middle, and upper river are 117, 111, and 64, respectively (Cross et al. 1986), with the fewest species in the far western reaches. Some species like longear sunfish occur widely in habitats from main stem to small tributaries, but others, like the river shiner or river darter, are mostly in the main channel. Native trout occur in the Arkansas River headwaters. The Arkansas River shiner, a federally threatened species, occurs in the main channel of the lower Arkansas River. Other main-stem-limited taxa of special interest are small minnows of the speckled chub complex, with the peppered chub (now rare or extinct) known from middle and upper portions of the system, and the shoal chub present in middle and lower parts of the drainage (Eisenhour 1999). The speckled chubs and Arkansas River shiner thus are unique faunal elements of the main stem. Collections made with small-meshed seines produced 7 and 9 species at a single site in the main stem of the upper Arkansas River at Great Bend, Kansas, compared to 16 and 17 species with about the same effort in shallow edges at a middle main-stem site at Webers Falls, Oklahoma. Below Ft. Smith in western Arkansas, T. M. Buchanan (personal communication) typically finds 18 to 20 species in similar seining samples in the main stem. The Arkansas River main stem in the lower parts of the basin is occupied by game fish like largemouth bass and spotted bass and the introduced striped bass, whereas upriver, where the main stem is smaller and shallower, white bass are more common piscivores. Channel catfish and blue catfish are also common in the main river. Formerly present anadromous species like American eel may persist lower in the basin, but their upstream passage through high dams is unlikely, so they would now be rare in the system upstream. Gars of the genus *Lepisosteus* are common in the lower main channel and associated backwaters or oxbow lakes.

Major aquatic amphibians or reptiles of the upper Arkansas River main stem and associated habitats (Colorado or Kansas) include plains leopard frog, American bullfrog (introduced in Colorado), snapping turtle, yellow mud turtle, common slider, midland smooth softshell turtle, western spiny softshell turtle, and northern water snake. Farther downstream (Oklahoma or Arkansas) are common snapping turtle, false map turtle, red-eared turtles, and several species or subspecies of water snakes. Cottonmouth are found from east Oklahoma downstream through Arkansas. Major riparian birds and mammals include white pelican (which sometimes overwinters), great blue heron, green heron, belted kingfisher, beaver (which are broadly increasing), and muskrat. River otter is an Oklahoma state species of special concern in the Arkansas River system, whose populations may be increasing due to stocking programs. River otter are increasing in Arkansas (Sealander and Heidt 1990), as are the nonnative nutria. Nonvegetated beaches and sandbars of the Arkansas River support breeding populations of the federally endangered interior least tern, including a protected population within the city of Tulsa.

Ecosystem Processes

The structure and function of Arkansas River ecosystems, from montaine headwaters to confluence with the Mississippi River, have not been studied comprehensively. Productivity in the headwaters is probably dominated by availability of coarse rock substrates and relatively clear water and perhaps nutrient limited, whereas far downstream the main river is sufficiently large and turbid that photosynthesis is probably restricted to upper parts of the water column and hard substrate processes are probably of minimal importance. The river downstream in Arkansas and Oklahoma is too deep in midchannel for substantial development of large snag piles, although wood is probably biologically important in backwaters or side channels. Comprehensive studies

of such processes for the lower main stem are lacking. Capillary fringe habitats (Goldhammer and Ferrington 1992), which have become scarcer since European settlement, may nonetheless be important sites of secondary production.

Many upland tributaries are stony bottomed, with algal communities forming thick coatings on substrates. In these tributaries, large standing crops of central stonerollers, other algae-eating minnows (Ozark minnow, southern redbelly dace), crayfishes, and snails likely have a strong influence on benthic algae and autochthonous primary productivity. In contrast, tributaries in prairie regions are typically muddy, with shifting mud–sand bottoms and a poorly developed benthic algal flora.

Human Impacts and Special Features

Within the southern Great Plains the Arkansas River is unique as the river most likely influenced by snowmelt from the Rocky Mountains and probably crossing more diverse landscapes than any other in the region. Its headwaters are high in the Rocky Mountains, followed by its passage as substantial rapids through rock-bound canyons, thence out onto the plains, where its loss and gain of water is dramatic. Crossing Kansas, what was a brawling mountain river is reduced to such a small size that one can literally step across it in places; then, to the east it again gains water to become a major river and a watercourse famous in European history, now dotted with large dams and their associated reservoirs.

Military posts were present on the Arkansas River by the early 1800s, and steamboats traveled upriver to Muskogee by that time. Throughout most of the history of European settlement the main Arkansas River remained largely unaltered, but the latter half of the 1900s saw marked changes, with modification by the Kerr-McClellan Navigation System upstream to Tulsa, addition of numerous large dams, and withdrawal of water in the western half of the basin. As previously noted, loss of water from the main channel of the river in western Kansas is extreme, owing to depletion of aquifers and removal of water for irrigation. This devastation of the main river channel must have had tremendous, albeit unknowable, impacts on the animals and plants that depended on the river in that reach of the plains in pre-European times. In addition, the channel has been modified by wing dikes and other navigation-control structures. Major impacts in the middle and lower river are locks and dams for boat passage, conversion of much of the midreach into the Kerr-McClellan Navigation Channel, and construction of major on-channel reservoirs (Lake Dardanelle, Arkansas; Keystone Lake, Oklahoma). Major cities on the main-stem river include Wichita, Kansas, and Tulsa, Oklahoma, where major oil refineries are alongside the river. Zebra mussels have invaded the river via barges in the navigation channel.

CANADIAN RIVER

The Canadian River, with the North Canadian River (Beaver River in the Oklahoma Panhandle), is the longest tributary of the Arkansas River (Fig. 7.9). The main stem of the Canadian River is the "south" Canadian River, which flows eastward between 37°N and 35°N latitude and is joined by the North Canadian River and the Deep Fork River in Lake Eufaula in eastern Oklahoma just before the system joins the Arkansas River. We focus on the "south" Canadian River in this description. The Canadian, like the Arkansas, originates as a high-gradient stream in the southern Rocky Mountains, crosses vast, arid plains, where it courses through earthen-walled canyons or past steep bluffs, and then becomes a wide, sand-bed river through western and central Oklahoma. Through much of its midreach the river is shallow, flowing over mobile sand-bed substrates and exposed to intense solar heating in summer (Fig. 7.3). It is possible that no large river on Earth has a harsher or more rapidly changing thermal environment to challenge the existence of fishes and aquatic invertebrates (Hefley 1937, Matthews and Hill 1979).

Human history in the Canadian River basin is similar in many ways to that of the geographically parallel Arkansas and Red rivers. The same Paleo-Indians that roamed the upper Arkansas and Red rivers no doubt also included the Canadian in their journeys, as did many early European explorers. In recent presettlement history, the Kiowa, Kiowa-Apache, and Comanche dominated the upper Canadian basin. As some of the original native peoples were displaced by tribes from the east, nations like the Sac and Fox, Shawnee, Seminole, Creek, Choctaw, Kickapoo, and Iowa were established in the eastern Canadian basin, and the western Canadian basin became territory of the Wichita, Caddo, Cheyenne, and Arapaho. Important early forts in the Canadian basin were Fort Holmes and Camp Arbuckle on the Canadian River and Fort Reno and Camp Supply on the North Canadian River. Military roads connecting these forts helped promote movement of people and goods. The

FIGURE 7.3 South Canadian River, Oklahoma (PHOTO BY W. J. MATTHEWS).

California Road, from Fort Smith on the Arkansas–Oklahoma border, followed the Canadian River through Oklahoma and westward, retracing the route initially followed by Whipple's expedition as part of the Pacific Railroad Surveys. The western Canadian River basin became permanently settled as open-range cattle herding gave way to farming and fencing of the plains in the late 1800s.

Physiography, Climate, and Land Use

The Canadian River passes through four physiographic provinces (Southern Rocky Mountains [SR], Great Plains [GP], Central Lowland [CL], Ouachita Province [OP]) and three terrestrial ecoregions (Western Short Grasslands, Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone) (see Fig. 7.9). The Canadian River basin originates in northeastern New Mexico and southern Colorado in a region of mixed Cretaceous sedimentary deposits and rocks of volcanic origin. It crosses a broad belt of Tertiary sedimentary rock in the Oklahoma–Texas panhandle region, Quaternary sedimentary deposits in western Oklahoma, a broad region of Upper Paleozoic unmetamorphosed sedimentary deposits in central Oklahoma, and then metamorphic rock related to the Ouachita uplift en route to its confluence with the Arkansas River (Hunt 1974). Soils in the western half of the Canadian basin are mostly alkaline red or red-brown prairie soils, whereas the eastern part of the basin flows through a region of neutral prairie soils (Hunt 1974). Original vegetation varied from short grasses in the west to mixed and tallgrass prairie in central Oklahoma, intermixed with the Crosstimbers region, which is dominated by low-growth form oak forests.

Like the upper Arkansas River, the Canadian River initially flows through a very arid region, with rainfall less than 40 cm/yr and high rates of evaporation. Summers are hot, with low humidity, and winters cold, with snow and blizzard conditions common. In eastern Oklahoma the Canadian River flows through more mesic country, with annual rainfall averaging 100 to 120 cm/yr. On average for the entire basin, rainfall is greatest in May, declining through the summer and autumn to winter low precipitation in December and January (Fig. 7.10). The upper Canadian system averages only about 175

to 180 frost-free days per year, whereas in east Oklahoma 210 to 220 days per year are without killing frost. Air temperatures in most of the Canadian River basin average about 2°C in January and 27°C in August (see Fig. 7.10).

Land use in the upper Canadian (New Mexico and Texas) is dominated by grazing and short grasslands, with Amarillo, Texas, the only major city near the river. Its course through Oklahoma is mostly rural, in landscapes dominated by cattle ranching, some oil production, and wooded bluffs or terraces. From central Oklahoma eastward, farms and ranches are common, with grazing land, wheat, cotton, milo, and substantial wooded areas. Land use overall is about 50% rangeland or pasture and 30% cropland but can be up to 55% forested in the eastern part of the basin.

River Geomorphology, Hydrology, and Chemistry

The Canadian River arises at about 1970 m asl near Raton, New Mexico, and is joined within the mountains by the Mora River, which arises south of Taos, New Mexico. The average slope of the entire Canadian River main stem from the headwaters to its confluence is 2.8 m/km. After exiting the mountains it crosses an arid, short-grass region and flows into Conchas Reservoir, a relatively small impoundment. Below Conchas Reservoir the river runs through steep-walled canyons, and Revuelto Creek adds water from the south before the river enters the Texas Panhandle. Crossing the Texas Panhandle north of Amarillo, it flows within about 50 km of the headwaters of the Red River, and early explorers were sometimes confused about which river they were on. Lake Meredith, near Borger, Texas, regulates flow of the river, which becomes a modestly wide, shallow, sand-bed river downstream through Texas and into western Oklahoma. In west Oklahoma the river makes three major loops, passing the Antelope Hills and the Black Kettle national grasslands, then flowing almost directly southeast for about 250 km past Norman, Oklahoma. In west Oklahoma it is a widening, sand-bedded river, with steep earthen-bluff banks that are 20 to 30 meters high in places. In central Oklahoma the Canadian flows through a riverbed several kilometers wide, with an actual sand bed half a kilometer or more wide in places and with flow highly variable and braided.

This is the area described by Helfley (1937) and the site of studies on fish habitat selection and tolerance as a function of physical stressors (Matthews and Hill 1979, 1980, Matthews 1987). Hefley (1937) described flood formation of terraces of the Canadian River and the physical dynamics of the unstable floodplain. This condition remains in spite of upstream dams built since Hefley's writing. The main-channel Canadian River in central Oklahoma still shrinks in hot summers to be so narrow that a child can step across, but occasional rains convert the Canadian at the same locality into a raging river with standing waves of a meter high or more, running "full" from bank to bank. The same aeolian processes described by Hefley dominate the architecture of the sand bed outside the wetted channel, leaving wide expanses of sand bars sculpted by the wind.

Near Ada, Oklahoma, the Canadian turns to flow slightly northeast to its confluence with the Arkansas River. En route it remains a wide, shallow, sand-bed river, characterized by an unstable and shifting sand bed, with relatively steep, incised bluffs on the outside of bends in the river and wide expanses of sand bars and flat floodplain with willow and small cottonwoods on the inside of bends. It is joined from the north by the Little River, which originates in Norman, Oklahoma (a different "Little River" than the one in southeast Oklahoma), then joins the North Canadian River and Deep Fork River in forming Lake Eufaula, the largest man-made impoundment in Oklahoma. After leaving Lake Eufaula, the Canadian, now carrying water from all its major tributaries, flows a few kilometers across the Arkansas River floodplain and joins that main stem in Robert S. Kerr Lake, near Webbers Falls, Oklahoma.

The system is fed by snowmelt in New Mexico, with flow controlled by Conchas Lake, New Mexico, and Lake Meredith, Texas, and, in its lowest reaches in east Oklahoma, by Lake Eufaula. Flow is highly variable through most of Oklahoma because of the occurrence of extreme rainfall events, at any time of year, that create river flooding, and summer desiccation, which in some years reduces the main stem to not more than a meter wide (W. J. Matthews, personal observation). In its headwaters near Logan, New Mexico, the Canadian River has a recent (since dam construction upriver) 30-year (1970 to 1999) mean discharge of about 1.3 m^3/s, with a few high discharge years (four years in the series had average discharge >2.8 m^3/s). In sharp contrast, virgin flow in that reach from 1927 to 1947 had annual mean stream flow an order of magnitude higher, averaging 12.1 m^3/s (http://waterdata.usgs.gov/nwis/sw). Downstream, near Whitefield, Oklahoma, mean

annual discharge of the Canadian River before regulation by Eufaula Lake (1939 to 1963) averaged 174 m^3/s, compared to 120 m^3/s from 1964 to 1984, after the lake was built. Basinwide runoff in this mostly arid area is extremely low, ranging from only 0.15 cm/mo in August to 1.04 cm/mo in May (see Fig. 7.10), due to high evapotranspiration.

With the exception of its headwaters in the Rocky Mountains, the Canadian River flows mostly over very unstable sand and mud substrates with a braided channel that changes continually. Each stage rise changes the patterns of flow and sandbars in the river bed, and stable habitats are largely nonexistent (Matthews and Hill 1980). The Canadian River has a highly shifting channel in its lower portions, often eroding away or depositing new farmlands. Oklahoma law allows a landowner with "new" land deposited by the river to use it, but the landowner on the other side, whose land is washed away, is merely "out of luck." The main stem in central Oklahoma has a bed several hundred meters wide, but flow over these sandy beds is often reduced to a few meters wide by late summer (Hefley 1937, Matthews and Hill 1979), with flow as little as 1 to 2 m^3/s. During extreme drought in the early 1950s, many kilometers of the main stem in central Oklahoma were reported by local residents to be completely dewatered. After rains the channel can run full, with swift and turbulent waters bank to bank over the sand bed, but by late summer the Canadian River near Norman is often reduced to a series of pools connected by scant flow in shallow channels 1 to 2 m wide. Under those conditions, solar heating is extreme, and the biota is impacted by high water temperatures and low oxygen alternating with supersaturation in backwaters. These conditions apparently have strong influence on the distribution of fishes, which sometimes are concentrated in huge numbers in microhabitats that offer slight survival advantages (Matthews and Hill 1979, 1980).

At Logan, New Mexico, the Canadian has occasional high specific conductance (1200 to >9000 µS/cm, depending on flow), pH ranging from 8.0 to 8.3, and is dominated chemically by sodium and chloride (150 to 1900 mg/L and 60 to 2800 mg/L, respectively) but with high concentrations of sulfate (300 to 500 mg/L). Hardness ranges from about 300 to 600 mg/L as $CaCO_3$, and alkalinity is about 200 to 330 mg/L as $CaCO_3$. By Amarillo, Texas, values remain approximately in those ranges. Alkalinity remains high and the river is well-buffered through central Oklahoma, with values at Calvin, Oklahoma, approximating specific conductance of 600 to 1200 µS/cm, pH 8.2 to 8.5, total hardness about 300 mg/L as $CaCO_3$, alkalinity about 200 mg/L as $CaCO_3$, and ions like calcium, magnesium, sodium, and chloride ranging from 20 to 150 mg/L. At this site nutrients in recent years have ranged from 0.1 to 0.5 mg/L total nitrogen and 0.04 to as high as 0.49 mg/L total phosphorus. In central Oklahoma, water temperature in the main channel regularly reaches or exceeds 36°C on summer afternoons, when direct sunlight strongly heats the shallow waters (less than 1 m deep) of the exposed sand-bed channel. The river in central Oklahoma ices along the shore in some winters, with main-channel water temperatures measured at 0°C to 1°C (W. J. Matthews, unpublished data).

River Biodiversity and Ecology

Unlike the Arkansas River, which traverses four freshwater ecoregions, the Canadian River passes only through the Southern Plains freshwater ecoregion (Abell et al. 2000), and, not surprisingly, its overall biological diversity is substantially less than the main river. Not only is its western portion even harsher than the main-stem Arkansas, but it does not flow as far into the more mesic east. Ecological studies of the Canadian are limited, with the most information available on the fish community.

Plants

The Canadian River basin has a distinct vegetation gradient from east to west. To the east, patches of silver maple and box elder occur on stream banks. An elm–hackberry–ash association is common in lower reaches of the river in Oklahoma. From the central to the western parts of the basin mixed grasses are common along the rivers edge, with cottonwood–willow woodlands common on floodplains, as well as patches of salt-cedar and sandbar willow. Salt-cedar, a major invader upstream, becomes limited downstream. Oak forest occurs on the upper terraces.

Invertebrates

The sand and clay sediments of the Canadian River support a limited invertebrate fauna, and most invertebrates are associated with snag habitats. Oligochaetes worms (*Limnodrilus*) and midges (e.g., *Bezzia*, *Chironomus*, *Cryptochironomus*, *Paratendipes*) are abundant. The most common mayflies are *Tricorythodes* and *Caenis*. The caddisfly fauna is dominated by filter-feeding *Cheumatopsyche* and *Hydropsyche* (Bass and Walker 1992, Wilhm et al. 1978). Crayfishes include *Orconectes nais*, *Procam-*

barus simulans, and *P. acutus* (Reimer 1969, E. A. Bergey, personal communication). Mollusks include *Physa* and the fingernail clams *Sphaerium* and *Pisidium*. At least 11 unionid species are known from the river, including pink papershell, fragile papershell, yellow sandshell, and white heelsplitter (Branson 1982, 1983, 1984). The introduced Asian clam is common.

Vertebrates

Cross et al. (1986) considered about 63 species of fishes to be native to the Canadian River system. Fish distribution in this system changes more gradually from west to east than in the Red River, with its salt gradients. One federally threatened fish species (the Arkansas River shiner) in the South Canadian River is now much reduced from its former range, but it was common in 1978 at least as far upstream as Revulito Creek, New Mexico (W. J. Matthews, personal observations). Marked differences exist in distribution of some fish species between North and "south" Canadian rivers (e.g., no Arkansas River shiners in the North Canadian). Like the Red and Arkansas rivers, there is a main-stem "big-river" fish fauna in the wide, shallow, sandy main-channel Canadian River that differs from that in tributary creeks (Matthews and Hill 1979, 1980). Typical and abundant (at least formerly) main-stem species include red shiners (also common in creeks), Arkansas River shiner, plains minnow, bullhead minnow, and emerald shiner.

Fish habitat use is strongly influenced by high temperatures and other physical stressors in summer, as temperatures in the main channel approach lethal limits for all species (Matthews and Hill 1979, Matthews 1987, Matthews and Zimmerman 1990). Important fish habitat is found at or near creek inflows, where pools typically are deeper and more stable than in the shallow main stem. These edge habitats also support fathead minnows in backwaters, longear and green sunfishes, and a limited number of channel catfish, largemouth bass, and gizzard shad. The Red River pupfish, formerly restricted in Oklahoma to the Red River basin, was introduced to the Canadian River in central Oklahoma. However, numbers of species at any site reflect the lower number of species in this basin compared to other main rivers, with typically only about a dozen species taken at any one seining site.

River otter, an Oklahoma state species of special concern, is found in eastern parts of the Canadian River. Nonvegetated beaches and sandbars of the Canadian River support breeding populations of the federally endangered interior least tern (Byre 2000). Smooth softshell turtles are commonly found burrowing into the sand bed, and snapping turtle, common slider, yellow mud turtle, and stinkpot turtle are found. Water snakes are common. Beavers are common in tributary creeks near their confluence with the main river channel, and beaver cuttings are commonly seen along the main stem as well. Great blue herons (sometimes in large numbers), green herons, and little blue herons occur along the river. Nesting colonies of great blue herons occur in large trees on upper terraces of the river at Norman, Oklahoma.

Ecosystem Processes

There are no comprehensive studies of ecosystem processes in the Canadian River or its large tributaries. However, in that much of this river flows through grasslands or former prairie, we would suspect that ecosystem processes are dominated by inputs of grasses or smaller amounts of tree-derived vegetation, combined with periodic high primary productivity within the streambed. For example, in autumn of some years, major portions of the streambed can become encrusted with a thick layer of algae that appears to be highly productive and is, in fact, directly eaten by some of the common fishes (W. J. Matthews, personal observations). An additional important organic input to the river itself is probably derived from the encroachment of seedlings of cottonwood and other woody plants, which rapidly grow on the dried portions of the streambed at low water. Upon the next flooding, this material is uprooted and washed into the river, where it no doubt provides substantial nutrients by its decomposition (W. J. Matthews, personal observations). However, retention of particulate carbon is probably low, in that stage rises substantially move the easily shifted sand bed.

Human Impacts and Special Features

The Canadian River was described by Hefley (1937) as one of the harshest environments on Earth, and heating of water can be extreme in summer (W. J. Matthews, unpublished data). The Canadian is probably one of the most dynamic and variable river environments anywhere in the world, ranging from a mere trickle in late summer to a boldly flooding river following rains. This natural flow cycle apparently was important as a stimulus to reproduction by some of the common fishes, which are now substantially

reduced in number as a result of flow moderation by upstream dams.

Two dams influence flow, and there is a strong influence of agriculture and oil production on the river. Near Norman the riverbed is extensively disturbed by commercial sand mining, but it also is protected in numerous places by private landowners and The Nature Conservancy, with nesting refuges on sandbars for the federally endangered interior least tern. No major cities are on the primary main stem, but the North Canadian River flows through Oklahoma City, where it recently has been dammed in several places to provide water for a new tourist canal system in the refurbished downtown. Lake Overholser is an "off-channel" impoundment on the North Canadian River near Oklahoma City, and an artificially heated power plant lake northeast of Oklahoma City apparently allowed establishment of a population of nonnative blue tilapia (Pigg 1978), which reproduce and invade the North Canadian River in large numbers in some years, as far as 50 to 75 km downstream to near Seminole (Matthews and Gelwick 1990). The Canadian River and its drainage generate controversy between the states of Texas and Oklahoma, with Oklahoma officials alleging that Texas is wrongfully storing water in a reservoir on a Canadian basin tributary in the Texas Panhandle (*Daily Oklahoman*, August 26, 2002).

RED RIVER

The Red River is the 2nd largest river basin in the southern Great Plains (169,890 km^2), arising at about 1050 m asl as mostly dry or ephemeral creeks converging in Palo Duro Canyon in the Texas Panhandle, and joining the Mississippi River (and/or the Atchafalaya River) in eastern Louisiana at about 25 m asl (Fig. 7.11). The Red River drains some of the driest areas of the Southern Plains, consisting of the western portion of the Texas Panhandle, where surface water is scarce, playa lakes appear and disappear, and permanent water in streams is rare. It is in or near this area that troopers of the U.S. 10^{th} Cavalry died of thirst in the 1870s. From Eastern Oklahoma through Arkansas and Louisiana, the Red enters a more mesic climate and is joined by a large tributary, the Ouachita River (see Chapter 6), just before it reaches the Mississippi River.

There has been considerable debate over whether North Fork or Prairie Dog Town Fork in western Oklahoma is the true main stem of the Red River. Prairie Dog Town Fork was followed by Marcy's military expedition of 1852 to find the source of the Red River, and, on the basis of lengthy congressional and judicial findings (Tyson 1981), is considered the main fork of the Red River. On the other hand, North Fork is nearly as long and typically carries more water (9.6 m^3/s for North Fork at Headrick; 3.2 m^3/s for Prairie Dog Town Fork near Childress), but legal decisions have agreed with Marcy's determination that the Prairie Dog Town Fork is "the river."

Native peoples along the Red River basin had sharply differing cultures even before Europeans entered the region. To the east were cultures of the eastern Piney Woods, dominated by tribes of the Caddoan Confederacy and characterized by a sedentary lifestyle in an area of plentiful game and favorable conditions for growing crops. In the middle Red River region, the Wichita and Tonkawa tribes roamed the prairies, living in skin tepees or pole and brush structures, with seasonal hunting and limited farming. In the western Red River basin, the Lipan Apache were the originally dominant native peoples but were displaced by the Comanche from the north in the 1700s, after which the upper Red basin was dominated by the Comanche until Europeans took control of the region in the late 1800s.

During European settlement after the American Civil War the upper Red River area in Oklahoma and the Texas Panhandle was a region of war or lawlessness involving Comanches, the U.S. Calvary "Buffalo Soldiers" of Fort Sill and other frontier forts, infamous outlaws and outlaw towns, cattle barons with huge holdings, and lawmen of legendary proportions. Perhaps no other region in the southern Great Plains so epitomizes the "Wild West" in all its inglorious forms. It has been immortalized in popular historical novels by Larry McMurtry (*Lonesome Dove*) and Elmer Kelton (*The Far Canyon*), in songs ("Panhandle Wind" by Bill Staines), and in films (*Red River*, starring John Wayne). However, despite wishes to the contrary by some residents, the plaintive love song "Red River Valley" was actually written about a cowboy at the "Red River of the North" in Minnesota.

The Red River forms the long-debated boundary between Oklahoma and Texas, with a long history of legislative and judicial arguments, a U.S. Supreme Court judgment to legally identify the main fork, and a recent agreement by the states setting the southern border of Oklahoma at the vegetated edge of the water line on the south bank. The focus of this debate was also on Greer County, Oklahoma, between the two main forks of the Red River in southwest Oklahoma, whose ownership was bitterly contested

by Texas versus "the United States" for decades, and which was known as the "Empire of Greer" in some early documents and now is referred to locally as "Old Greer County." As recently as 1931, National Guard units of the two states risked armed hostilities over ownership of the river and its oil-bearing riverbed, culminating in the peacefully ended "Red River Bridge War" (Fugate and Fugate 1991) over the right to establish toll fees for crossing.

Physiography, Climate, and Land Use

The Red River passes through four physiographic provinces (Great Plains [GP], Central Lowland [CL], Ouachita Province [OP], and Coastal Plain [CP]) and four terrestrial ecoregions (Western Short Grasslands, Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone, Piney Woods Forests) (see Fig. 7.11). The upper Red River originates at about 35°N latitude on the elevated plain known as the Llano Estacado in the Texas Panhandle at the eastern edge of primarily Tertiary deposits of sedimentary and mostly marine origin (Hunt 1974). In the eastern Texas Panhandle and western Oklahoma to about Lake Texoma, the Red River passes mostly through nonmetamorphosed marine and continental sedimentary deposits of Mississippian, Pennsylvanian, and Permian age. In western and central Oklahoma, the basin also drains streams from large granitic uplifted areas in the Wichita Mountains and other smaller and isolated granitic areas such as the locally important Tishomingo Granite. East of Lake Texoma, the Red River drains Cretaceous formations that abound in ammonites and "sea biscuit" echinoderm fossils, but the river main stem soon enters Quaternary sedimentary deposits, through which it flows to its mouth in eastern Louisiana at about 31°N (Hunt 1974).

The Red River basin in Texas and western Oklahoma is characterized by generally red to red-brown alkaline soils (Hunt 1974). In central Oklahoma and north Texas the basin drains generally neutral prairie soils, then drains mostly acidic red or yellow podzol soils in east Oklahoma and much of Louisiana and crosses alluvial soil in extreme eastern Louisiana. Vegetation generally reflects the major terrestrial ecoregions drained by the basin, with short and mixed grasses in the west, a transitional zone of short deciduous oak forest ("Cross-timbers") and taller native grasses, and the heavily forested mixed coniferous and deciduous regions of eastern Oklahoma and Louisiana.

Climatologically, the Red River flows from arid grasslands in the Texas Panhandle, receiving less than 50 cm/yr of rainfall on average with frequent blizzard conditions in winter, to areas in Louisiana that receive more than 140 cm/yr of rain and average about 250 frost-free days per year, with snow a rarity. The region as a whole has generally mild to cold continental winters, but summers are very hot, with July and August monthly means near 30°C (Fig. 7.12). In the upper Red River basin, average daily temperatures in January are about 2°C, in contrast to about 8°C in the lower basin in Louisiana. From April through autumn the middle and eastern Red River basin often has massive rain fronts coming in from the Gulf of Mexico or near daily afternoon thundershowers, some of which reach violent mesocyclone proportions. Greatest average monthly precipitation is in the month of May (see Fig. 7.12).

The Red River now flows mostly through cattle ranching or row-crop farming areas, with Shreveport, Louisiana, and Alexandria, Louisiana, the only large cities directly on the river. Oil and gas production are prominent features of land use near the river, with some large oil fields in southwest Oklahoma. The region is mostly rural, with many small municipalities in counties adjoining the river, plus the moderately sized cities of Wichita Falls and Sherman-Denison, Texas, and Texarkana, Arkansas–Texas. In the west, land use is about 40% to 60% rangeland and 30% cropland, whereas to the east it is about 50% forested, 20% cropland, and 10% pasture.

River Geomorphology, Hydrology, and Chemistry

Originating outside the Rocky Mountains, the Red River has no substantial influence of snowmelt and lacks montaine outwash in its sandy riverbed. The channel form throughout essentially all of the basin is a gently sloping floodplain a kilometer or more wide, bordered in some reaches by moderately sloping, rounded bluffs 20 to 30 m in height (Fig. 7.1). The exception is the steep-walled Palo Duro Canyon, through which the headwaters of the Prairie Dog Town Fork of the river flows. Beyond Palo Duro the river is essentially low gradient for its entire course, lacking waterfalls or any steep drops in elevation.

The main-stem Red River (Prairie Dog Town Fork) originates in Palo Duro Canyon in the Llano Estacado (High Plains) south of Amarillo, Texas,

flows eastward through the relatively arid Texas Panhandle to the western border of Oklahoma, then forms the southern border of Oklahoma with Texas. The river flows almost entirely through terrain of relatively low relief, resulting in a mean slope for the entire main stem of only 65 cm/km. In the Oklahoma–Texas reach it is joined by the North Fork and Salt Fork from Oklahoma and the Wichita River from Texas. Flow in even the largest of these forks remains uncertain in dry years, "pooling up" in some summers as far downstream as Burkburnett, Texas. Further downstream, where at least some flow persists in most years, it remains a sandy-muddy river, the crossing of which has vexed Europeans since Marcy's expedition in the 1850s and the first cattle drives. The Red becomes a substantial river from about Wichita Falls, Texas, downstream to Lake Texoma, a major on-channel impoundment at the junction of the Washita and Red rivers (see Fig. 7.11). Only below Lake Texoma, in the mesic region from eastern Oklahoma through Louisiana, does the river take on a more consistent flow in a defined channel, bordered by large deciduous forests and, in some places, oxbow lakes and overflow swamps. Below Lake Texoma the river is joined by the Blue, Boggy, and Kiamichi rivers from the north in Oklahoma, by the Little River in Arkansas, and by the Sulfur River and Cypress Bayou–Caddo Lake systems that originate in Texas. En route east, the main-stem Red River flows from arid grasslands to increasingly mesic forests, but throughout most of its length it has a sand-bed channel with massive bars and navigation hazards. The Cypress Bayou system, a substantial tributary in northeast Texas, has one of the largest remaining cypress forests in the region, with huge old trees in vast, winding river channels and overflow fringing swamps.

The Red River in eastern Oklahoma–north Texas and deep into Louisiana was the location of the incredible "Great Raft" or "Red River Raft" of drift logs and mud that existed before European settlement and was reported by early explorers (1806) to be as much as 240 km long and 30 km wide, blocking the channel and causing the river to spill over into countless oxbow and side-channel shallow lakes. A channel through the Great Raft as far as present-day Shreveport was first opened between 1833 and 1836 by the "snag steamboat" invented by Capt. Henry Shreve, but by 1839 the river had rebuilt and closed the raft. The Great Raft defied all attempts to remove it until intensive efforts were resumed in 1872 employing snag boats, "saw boats," "crane boats," and nitroglycerin. The Great Raft finally was cleared by about 1900, and the river remained permanently open thereafter (Tyson 1981).

Mean virgin discharge of the Red River (1928 to 1944) was 852 m^3/s, with basinwide runoff varying from very low in late summer (about 0.3 cm/mo) to about 2.5 cm/mo in late spring (see Fig. 7.12). A relatively high fraction of precipitation is lost as evapotranspiration. For the Red River downstream of Lake Texoma, in east Oklahoma, mean annual discharge was about 260 m^3/s before regulation by the dam, but from 1945 to 2000, mean annual discharge was identical, at 260 m^3/s. Drastic variation has, however, been observed in that period, from a low of 77 m^3/s in 1964 to a maximum of 652 m^3/s in 1990.

Upper portions of all forks have unpredictable flow. The main stem as far downstream as Wichita Falls, Texas, is subject to extended periods of "no-flow" and pooling up. Downstream of the forks it is a perennial, wide, shallow, sand–mud bed river, with discharge that varies greatly. The most likely months for storm-induced spates in tributaries are April, May, and midautumn. The Red River main stem can rise rapidly after heavy rains in the basin and can produce extreme flooding and turbidity in Lake Texoma, with strong effects on fishes and zooplankton.

Water chemistry reflects the harsh arid country through which the river flows. Marcy's 1852 expedition to the headwaters in Palo Duro Canyon was forced to endure bad water conditions, with the chemically charged Prairie Dog Town Fork causing severe gastrointestinal distress for army troopers who attempted to drink it. In the eastern Texas Panhandle, north Texas west of Wichita Falls, and extreme southwest Oklahoma, this river has (for "freshwater") extremely high salinity, approaching or exceeding that of seawater, because of a dozen or more brine springs from Permian strata. Downstream in Oklahoma, tributaries of the Red River flow through a large gypsum region, resulting in inputs of sulfates to the river.

Typical chemical values in the Prairie Dog Town Fork near Childress, Texas, include pH 7.7 to 8.2, alkalinity 75 to 110 mg/L as $CaCO_3$, total hardness 1800 to 5200 mg/L as $CaCO_3$, specific conductance 16,000 to 72,000 µS/cm, sodium 12,000 to 17,000 mg/L and chloride 17,000 to 28,000 mg/L (greater, overall, than for seawater), and calcium 600 to 1500 mg/L and magnesium 100 to 360 mg/L, suggesting the laxative properties of the water discovered by Marcy's army troops. In contrast, below Lake Texoma the main-stem Red River near DeKalb, Texas, has calcium and magnesium ranging around only about 25 to 70 mg/L and 5 to 25 mg/L,

respectively, sodium and chloride values of only 10 to 100 mg/L and 10 to 140 mg/L, respectively, and specific conductance about 200 to 950 µS/cm, depending on flow and discharge. The Red River near DeKalb, Texas, has typical nutrient concentrations ranging 0.1 to 0.3 mg/L total nitrogen, and 0.03 to 0.13 mg/L total phosphorus. Water temperatures in the main channel of the Red River regularly exceed 36°C in late summer and have been recorded as high as 39°C, making it one of the hottest large rivers on Earth, because of intense solar heating of the shallow water in the unshaded channel (Matthews and Zimmerman 1990).

River Biodiversity and Ecology

The Red River flows primarily through three freshwater ecoregions, the Southern Plains, the Ouachita Highlands, and the Mississippi Embayment (Abell et al. 2000). The Red River does not actually pass through the Ouachita Highlands, but several of its tributaries drain the highlands before entering the Coastal Plain and subsequently joining the main stem. Thus, the main stem remains a low-gradient river throughout its length as it enters the Mississippi Embayment ecoregion before joining with the Atchafalaya–Mississippi rivers. The overriding ecological feature of the upper Red River (in the Southern Plains above Lake Texoma) is strong structuring of biota by salinity gradients produced in the Permian Redbeds, with high fish diversity downstream reduced to as few as only two very hardy and salt-tolerant fish species in some of the headwaters (Echelle et al. 1972). Below Lake Texoma the river has relatively consistent flow, essentially never pools up or goes dry, and salinity gradients that would structure biota are lacking.

Plants

The basin as a whole has a gradient from high plains vegetation in the west to southern bottomland hardwood in the east. Cottonwood–willow woodlands are common on floodplains throughout the watershed. Stream banks contain patches of box elder and silver maple. Second growth slippery elm, sweetgum, black oak, and post oak are common. Eastern oxbows support swamp oak. Second growth loblolly pine, both naturally occurring and in plantations, occurs in the lower watershed.

Invertebrates

The shifting clay and sand sediments of the main-stem Red River, coupled with the high conductivities, create a harsh environment for many benthic invertebrates, and there have been few comprehensive studies of the benthic fauna. Oligochaetes, burrowing mayflies (*Hexagenia*), and chironomid midges (*Chironomus*) are common in sediments. Most other invertebrates are associated with snag habitats, including the chironomids *Glyptotendipes*, *Dicrotendipes*, and *Rheotanytarsus* (Sublette 1953, Vaughn 1982). Mayflies include *Caenis* and *Stenonema*, and the caddisflies *Chimarra*, *Cyrnellus*, *Hydropsyche*, *Cheumatopsyche*, *Oecetis*, *Hydroptila*, and *Triaenodes* are common (Resh et al. 1978). Crayfishes include *Orconectes palmeri*, *O. nais*, *O. virilis*, and *Procambarus simulans* (Reimer 1969, E. A. Bergey, personal communication). The Red River contains a large population of the Mississippi grass shrimp (Cheper 1988), an omnivore that thrives in the high-conductivity water. Upper reaches of the Red River are fed by hypersaline (43 ppm) springs that contain grapsoid crabs, *Hemigrapsus estellinensis* (Creel 1964).

The mussel fauna of the main-stem Red River is depauperate for a river of its size, largely because many species do not fare well in the shifting sediments. The fauna is dominated by pink papershell, fragile papershell, and bleufer. Other mussel species known from the main-stem Red River include white heelsplitter, yellow sandshell, threehorn wartyback, giant floater, maple leaf, pimpleback, lilliput, pistolgrip, and paper pondshell (Branson 1982, 1983, 1984; W. J. Matthews et al. unpublished data; Valentine and Stansbery 1971; Vaughn 2000). The nonnative Asian clam occurs throughout the river. In contrast to the main-stem Red River, tributaries to the river contain a diverse mussel fauna that has been well studied (Isely 1924, Valentine and Stansbery 1971, Vaughn 1997). The easternmost tributaries arising in the Ouachita uplands are particularly diverse. For example, 31 species of mussels are known from the Little River (Vaughn and Taylor 1999) and 29 from the Kiamichi River (Vaughn et al. 1996). Two federally endangered mussels, the Ouachita rock pocketbook and the scaleshell mussel, occur in Red River tributaries (Vaughn and Pyron 1995, ONHI 2001).

Vertebrates

A total of 171 fish species, 152 of them native, was reported by Cross et al. (1986), and additional introduced species are now present. A sharp contrast exists between the 133 native fish species in the lower Red River and the 56 in the upper Red River above Lake Texoma (Cross et al. 1986). The upper reaches that dry often or have very high salt loads have

environmental conditions so harsh that only two species (Red River pupfish and plains killifish) occur in some headwater reaches. Farther downstream, as salt concentrations are diluted by tributaries, a more speciose fish assemblage develops, with upstream limits to many species set by salinity gradients (Echelle et al. 1972). Below the highest salinity, upper reaches of the Red River are dominated by a recognizable "big-river" fish fauna, notably minnows like red shiner, chub shiner, plains minnow, silver chub, and the endemic Red River shiner. Main-channel members of the speckled chub complex include the prairie chub in the upper river and the shoal chub in the lower river, with the species sympatric near Wichita Falls (D. Eisenhour, personal communication). Nearing Lake Texoma additional minnow species like bullhead minnow and emerald shiner become more common, as do gizzard shad, channel catfish, introduced inland silversides, various sunfish species, white crappie, largemouth bass, white bass, and the introduced striped bass. In addition, gars are common above Lake Texoma, and paddlefish have been reintroduced above the reservoir.

Lake Texoma has a relatively stable fish assemblage (Gido et al. 2000) dominated both by native species like red shiners, blacktail shiners, gizzard shad, blue catfish, channel catfish, black bass, and various sunfishes, and abundant introduced species like striped bass, threadfin shad, and inland silversides. Lake Texoma and Keystone Reservoir on the Arkansas–Cimarron rivers are two of very few artificial impoundments with reproducing populations of the prized striped bass. Here, for unknown reasons likely related to salinity, striped bass exhibit spawning runs, resulting for Lake Texoma in a strong, naturally reproducing striped bass fishery with an economic value to the local economy estimated at $26 million per year.

Downstream from Lake Texoma the river remains dominated by unstable sand substrates and fishes tolerant of those conditions, with shads, catfishes, minnows, sunfishes, gars, and suckers (Catostomidae) common. The majority of the habitat is shifting sand-bottom, which supports numerous minnows (red shiner, blacktail shiner, speckled chub, emerald shiner, ghost shiner, and bullhead minnow), inland silversides, western mosquitofish, longear sunfish, bluegill, largemouth bass, and several darter species like western sand darter, Johnny darter, and bigscale logperch. Larger-bodied fishes that occur in the deeper portions of the main channel include shovelnose sturgeon, blue sucker, river carpsucker, and golden redhorse. In addition, there are low-velocity backwater or deep pool habitats that contain several gar species (shortnose, longnose, spotted), gizzard and threadfin shad, smallmouth and bigmouth buffalo, and common carp. After passing the Arkansas–Louisiana border, the river winds southeast through Louisiana, with a fish fauna typical of lowland streams of the Gulf Coastal Plain but still dominated by many of the same groups. The separation of the river into an upper and lower reach by Cross et al. (1986) not only reflects the general geography of the river, but the features of its native fish communities as well.

Lake Texoma is home to numerous visitors, such as gulls and shorebirds from the Gulf Coast, and bald eagles are very common during winter. Osprey are seen year-round at this impoundment. White pelicans are common in autumn, as they use Lake Texoma as a stopover, and sometimes overwinter. Many great blue herons and green herons, and an increasing number of cormorants, occur at Lake Texoma. Beaver are becoming very abundant around Lake Texoma, and nutria and muskrat are commonly associated with the river in Louisiana. Amphibians and reptiles associated with Red River in Oklahoma and eastward include snapping turtles, occasional alligator snapping turtles (from Lake Texoma eastward), plain-bellied water snake, false map turtle, yellow mud turtle, and cottonmouth from below Lake Texoma and eastward. We have never observed a cottonmouth in Lake Texoma, but they are common in the Blue River, the first substantial tributary east of the reservoir.

Ecosystem Processes

Relatively little is known about ecosystem processes in the main-stem Red River. However, in the Little Washita River (tributary to Washita River, thence to Red River) of south-central Oklahoma, riparian cover upstream was directly related to availability of whole leaves in the stream, and long reach lengths served as sources of detrital input at a given point (Johnson and Covich 1997). Johnson and Covich (1997) also found that organic content of benthic materials declined from headwaters to lower in the Little Washita River, and that floods reduced coarse POM in headwaters and increased the amount of fine organic material (10 to 360 μm) that were in suspension downstream.

Ecosystem factors like amounts and kinds of periphyton, primary productivity, ash-free dry mass (AFDM) and percentage of organic material in the substrate, size fractions of particulate organic matter, bacteria, and invertebrate standing crops, and

carbon–nitrogen ratios in Brier Creek, Marshall County, Oklahoma, a tributary of the Red River (in Lake Texoma), are strongly influenced by presence of the algae-grazing stoneroller minnows (Power et al. 1985, Matthews et al. 1987, Gelwick and Matthews 1992). A trophic cascade involving piscivorous black bass, central stoneroller minnows, and algal density and composition has been shown to influence primary productivity in pools (Power et al. 1985). Red shiners from the Washita River enhanced benthic primary productivity in experimental streams (Gido and Matthews 2001). In addition, another dozen fish species from several trophic or functional groups from Red River tributaries have been found to alter benthic primary productivity (C. Hargrave, K. Gido, W. Matthews, unpublished data.). Gido (1999) found in experimental pens in Lake Texoma that large-bodied, benthic-feeding fishes like river carpsucker and gizzard shad changed densities of chironomid larvae in benthic substrates, and that excretion by these fishes can be in sufficient amounts to account for substantial nutrient inputs to the reservoir.

Human Impacts and Special Features

Notable human impacts include the influence of agriculture (wheat, cattle) and of oil production in headwaters, and the construction of Lake Texoma, a 36,000 ha reservoir, at the juncture of the Washita and Red rivers. Interbasin water transfer from Lake Texoma to a reservoir of the upper Trinity River, Texas, is possible via a conveyance system completed in 1993. The largest city on the main stem is Shreveport, Louisiana, but the growing cities of Sherman-Denison and Wichita Falls, Texas, have a growing desire for Red River water for municipal uses. The Dallas–Ft. Worth metropolis also has increasing potential to use Red River water via interbasin transfer.

The mussel fauna of the Red River drainage has been significantly impacted by human activity. Vaughn (2000) resampled 19 sites in the drainage in Oklahoma and Texas that had been sampled in the 1910s and in some cases in the 1960s. Species richness declined at 89% of the sites. Local extinction rates were significantly greater than local colonization rates, indicating that mortality of mussels is significantly exceeding recruitment in the region.

In spite of all the human-induced changes, the Red River still retains many of its characteristics from presettlement times. The upper river, in its wide, shallow, and sandy nature, still reflects conditions first described by Marcy in the 1850s, although many small creeks and tributaries no longer flow freely or as clear as Marcy found them. Downriver, Lake Texoma blocks upstream migration of anadromous fish like American eel and traps huge loads of silt and woody debris borne by the upper river on flood flows. Further downstream, in spite of removal of the Great Raft, which formerly blocked human passage on the river, the river remains relatively unstable, and navigation of the river for commercial purposes is impractical along the Oklahoma–Texas border. From Lake Texoma onward, the river flows almost entirely through rural regions with small populations (with the exception of Shreveport and Alexandria, Louisiana), and it still overflows into oxbows and swamps throughout much of its lower course. Some of the remaining largest cypress forests and swamps in Texas remain along the Cypress Bayou system, which is a major tributary of the Red basin in northeast Texas. The Red River has thus resisted most efforts of humans to tame its unruly nature. Lake Texoma minimizes flood losses downstream when massive hurricane-derived rain fronts stall over the basin, but otherwise much of the river remains much as it was as seen by the first explorers—a relatively "wild" place where human impacts seem rather small. However, the Army Corps of Engineers has begun a massive program to reduce chlorides in the upper basin, which, if ever completed, will threaten the existing, natural salinity gradient that is the template for much of the distribution of flora and fauna in the upper river. In addition, if the waters of the upper Red River were lower in salinity such that they could be directly used for irrigation, water withdrawals would no doubt increase, and hydrological estimates suggest that "no flow" days in the upper basin might be tripled annually.

LITTLE RIVER

The Little River, a major tributary of the Red River, drains 10,720 km^2 in southeastern Oklahoma and southwestern Arkansas (Fig. 7.13). This system is the antithesis of many of the other rivers in the region, with the upper main stem or larger tributaries representing mostly high-quality habitat flowing from rocky uplands of the southern slopes of the Ouachita Mountains. Outside the uplands the Little River becomes a low-gradient stream, with large gravel riffles interspersed with long, deep pools. Biodiversity of this system is some of the highest in the southern Great Plains, and in some reaches it contains highly diverse local aquatic faunas at the ecotone

between upland and lowlands. Highly diverse fish, benthic invertebrate, and mussel faunas exist, and numerous species (e.g., about 15 fish species) reach their westward range limits in the Little River basin. The Little River and some of its tributaries are noteworthy for their remaining native mussel fauna, including some federally endangered species and several fish species of concern or with federal protection are in these streams.

Early human history of the region was dominated in prehistoric times by groups of woodlands cultures, with a mixture of hunting and gathering and planting of crops like corn, squash, beans, pumpkins, and sunflowers. The Kichai, Caddo, and Kadohadacho peoples dominated recent prehistory, when as many as 8000 Caddo, many in permanent settlements, lived in the region. As native peoples from the east were displaced, the Little River basin was eventually dominated by the Choctaw Nation, with establishment of early settlements like Eagletown and a prosperous culture dominated by farming and ownership of plantation-style homes and lifeways. During the 1900s native forest gave way to major pine plantations, and the Little River basin has a later history dominated more by the major land-holding timber companies, as well as national forests maintained by the federal government.

Physiography, Climate, and Land Use

The Little River passes through two physiographic provinces (Ouachita Province [OP], Coastal Plain [CP]) and three terrestrial ecoregions (Ozark Mountain Forests, Central Forest Grassland Transition Zone, Piney Woods Forests), flowing between about 35°N and 34°N (see Fig. 7.13). Geology of the region is dominated by the Ouachita uplift, in which all major tributaries (Glover, Mountain Fork, Rolling Fork, Cossatot, and Saline rivers), as well as the Little River proper, originate. The Ouachita Mountains exhibit "ridge and valley" structure, with long (as much as 50 km), steep, but narrow (only a few kilometers wide in most places) mountain ridges, with rivers flowing through the valley floors between the ridges. Rock is mostly sedimentary, of marine origin, but much is metamorphosed to form shales, quartzites, and similar noncalcareous bedrock. After flowing generally southward out of the Ouachita uplift, the Little River crosses Cretaceous sedimentary deposits and then enters Quaternary sedimentary deposits in the lowlands before flowing into the Red River. Soils of the basin are typically acidic red or yellow podzol (Hunt 1974). Dominant vegetation of the Ouachita Mountain uplands is conifer forest, apparently mixed in presettlement times with tall grasses in relatively open parkland. Downstream in the lowland parts of the basin, Coastal Plain deciduous forests mixed with conifer dominate the landscape.

Climate in the Little River basin is hot and humid in summer, with influence from Gulf Coastal weather patterns, and winters are milder than in most of the Great Plains. In the Little River basin, rainfall averages in excess of 100 cm/yr, and there are about 220 to 240 frost-free days per year. Mean monthly precipitation is highest in May (16 cm), with lows in January and August (7 cm) (Fig. 7.14). Air temperature in the Little River basin averages about 4°C in January and 26°C in August.

Land use in the uplands is almost entirely commercial timber, National Forest, or cattle ranching, and there are extensive cattle ranching, small farms, and some timber in the lowlands. Commercial poultry houses have increased in recent decades, and there is a major processing plant near the Little River south of Broken Bow, Oklahoma, that has locally polluted the Little River at times. There are few row crops, and the region largely lacks impacts of oil production. The lower main-stem Little River in Oklahoma is in the Little River Wildlife Refuge (U.S. Fish and Wildlife Service), but threats to the system continue from plans to transfer water out of state or to channelize some main-stem reaches. There are no large cities in the Little River basin; the region remains almost completely rural or in commercial timber, and the streams are prized by fishermen, hunters, and recreationists. Land use in the Little River basin is about 75% forest, 10% cropland, and 15% pasture, with no large urban areas.

River Geomorphology, Hydrology, and Chemistry

All major tributaries and the main-stem Little River originate in steep uplands of the Ouachita Mountains of Oklahoma or Arkansas, with typically rocky (boulder/bedrock) riffles and large pools with boulder-strewn bottoms. Here, the water is sufficiently clear that underwater observation of fishes is a useful study method. Upon exiting the uplands, the Little River flows onto the Coastal Plain, where it becomes deeply incised into sandy or clay soils, with highly developed floodplain/riparian forests and long, wide riffles separating pools often as much as a kilometer or more long. Overflow ponds or oxbow lakes, as well as fringing swamps, formerly

dominated the landscape of the lower Little River, although vast, large swamps are now drowned under Millwood Reservoir (see Fig. 7.13).

The main-stem Little River originates on the southern slopes of the Kiamichi and Winding Stair mountains at about 460 m asl in remote, rugged uplands in southeast Oklahoma near Honobia, then flows southwest and eventually eastward in a wide arc (see Fig. 7.13). Its headwaters are boulder-cobble and gravel, with well-developed pools and swift rapids until the main stem forms Pine Creek Reservoir. Below the reservoir the river retains pool–riffle structure over a mostly gravel bed, with water willow a common structural feature in the shallows. The Little River then turns eastward, widening and deepening, flowing through cypress riparian forest, and entering the Little River Wildlife Refuge near Idabel, Oklahoma. It flows parallel to and north of the Red River to the Arkansas border and gains major tributaries, including (west to east) the Glover, Mountain Fork, Rolling Fork, Cossatot, and Saline rivers (see Fig. 7.13). The entire system flows into and forms Millwood Reservoir northeast of Ashdown, Arkansas, inundating formerly huge swamplands. Below Millwood Reservoir the Little River enters the Red River about 2 km west of Fulton, Arkansas, at an elevation of 70 m. Mean slope for the entire Little River main stem is 2.1 m/km.

Although arising in uplands, headwaters are not fed by any large springs; thus, flows in upper reaches can be tenuous in late summer. In spite of this, the location of these streams in a relatively mesic area makes the Little River a large tributary of the Red River. Mean annual virgin discharge at Idabel, Oklahoma, from 1930 to 1968 (before closure of the upstream Pine Creek Reservoir) was about 45 m^3/s. Average annual discharge at Idabel from 1971 to 2000 was 53 m^3/s, suggesting no major change of discharge as a result of regulation. The highest annual mean discharge at Idabel was 89 m^3/s, whereas the lowest, during the worst drought on record in 2000, was only 18 m^3/s. Average annual discharge for the entire basin, measured at Millwood Dam, Arkansas, is 183 m^3/s. Monthly runoff for the entire basin ranges from only 0.8 cm/mo in late summer (apparently due to high summer evapotranspiration) to more than 8 cm/mo in spring (see Fig. 7.14).

Water chemistry at one site on the main-stem Little River included pH 7.2, alkalinity 24 mg/L as $CaCO_3$, and NO_3-N 0.33 mg/L. Total phosphorus can be as high as 0.36 mg/L, but typically ranges from 0.06 to 0.09 mg/L. The lower pH and alkalinity of the Little River or its major tributaries compared to other rivers of the Southern Plains is due to its origin in noncalcareous uplands, with subsequent passage through conifer forest and the Coastal Plain. For example, a large tributary, the Cossatot River, has pH values as low as 5.9, hardness ranging from 9 to 16 mg/L as $CaCO_3$, and low concentrations of ions like calcium, magnesium, sodium, and chloride, with specific conductance only 48 µS/cm. Measured water temperatures in the main channel near Idabel, Oklahoma, have ranged in recent decades from 0°C to 33°C, so this is clearly a "warmwater" river despite its origins in the Ouachita Mountains.

River Biodiversity and Ecology

The Little River is part of the Ouachita Highlands freshwater ecoregion (Abell et al. 2000). The river is known for its high aquatic biodiversity and was identified by The Nature Conservancy as a critical watershed for protecting freshwater biodiversity based on its diverse and healthy fish and mussel fauna (Master et al. 1998). It is one of the better-known river ecosystems in the Southern Plains, with extensive surveys of fishes, mussels, and other invertebrates by C. C. Vaughn and collaborators.

Plants

Common riparian corridor species include river birch, sycamore, smooth alder, sugar maple, and box elder (Hoagland 2000). Lower portions of the river flow through bottomland hardwood forest characterized by willow oak and blue beech (Hoagland et al. 1996). Sloughs and swamps along the river contain bald cypress. Extensive growths of water willow develop in shallow areas of low flow throughout the river.

Invertebrates

The Little River harbors 31 species of mussels, including regional endemics such as the Ouachita kidneyshell and the Ouachita creekshell and nationally declining species such as the rabbitsfoot and butterfly (Vaughn and Taylor 1999). Comparisons of historical mussel distributions (Isely 1924, Valentine and Stansbery 1971) with current distributions reveal no species extirpations from the river (Vaughn 2000), although populations below impoundments have been severely impacted (see the Human Impacts and Special Features section for this river). A small population of the federally endangered Ouachita rock pocketbook mussel occurs in the river (C. C. Vaughn, unpublished data).

Upper portions of the Little River are rocky, and cobble–gravel riffles occur throughout the river, so snags are not as important a habitat for invertebrates as in sandy-bottomed southern plains rivers. Limpets (*Ferrissia*) and snails (*Physa*, *Elimia*, *Helisoma*) are common throughout the river. Crayfishes include *Orconectes palmeri* and *Procambarus acutus* (Reimer 1969, E. A. Bergey, personal communication). The Little River contains an abundant and diverse insect fauna, including beetles (*Stenelmis*, *Psephenus*), mayflies (*Pseudocleon*, *Ephemerella*, *Heptagenia*, *Leucrocuta*, *Stenacron*, *Stenonema*, *Paraleptophlebia*, *Isonychia*), damselflies (*Argia*), stoneflies (*Neoperla*, *Acroneuria*), and caddisflies (*Cheumatopsyche*, *Helicopsyche*, *Chimarra*, and *Polycentropus*). (C. C. Vaughn, unpublished data).

Vertebrates

The fish fauna of the Little River is quite diverse for a system of such small size, with many small-bodied insectivore–omnivore species. Jenkins (1956) reported 87 species from the preimpounded basin, and a count of species from the "Fish Atlas" (Lee et al. 1980) and our own collections shows about 110 native species in the drainage. This unusually high number of fish species for such a small drainage reflects its geographic position, with headwaters in high-gradient stony streams of the Ouachita Mountains, its passage onto the low-gradient, soft-bottomed substrates, and eventual entry to the Gulf Coastal Plain. Thus, the headwaters have typical high-gradient upland fish species such as Ouachita Mountain shiner, steelcolor shiner, and orangebelly darter. In the midreach of the Little River, redfin shiner, harlequin darter, and numerous other darters were formerly common. The dominant game fish of the uplands is native smallmouth bass. After entering the Coastal Plain, upland species drop out and a largely different suite of species occurs, including, in the river or its swampy backwaters, taxa such as the rare bluehead shiner, pirate perch, pygmy sunfish, Blair's starheaded topminnow, redhorse suckers of the genus *Moxostoma*, grass pickerel, flier, bantam sunfish, and dollar sunfish. Downstream, dominant predaceous or game fishes include largemouth bass and gars. However, some species, like steelcolor shiner and orangebelly darter, are common throughout most of the system. In some off-channel habitats like overflow ponds, pirate perch and pygmy sunfish dominate and are extremely abundant. The main channel can yield very diverse local assemblages. Eight darter (*Etheostoma*, *Percina*) species were taken in a single gravel riffle, and as many as 29 species were in some individual seining collections (W. J. Matthews and C. C. Vaughn, personal observations).

One federally threatened fish species (leopard darter) is endemic to this system, as is the Ouachita Mountain shiner. Several other fish species, such as peppered shiner and orangebelly darter, although not endemic, are of very limited ranges geographically, with strongholds in this drainage. The crystal darter, now becoming uncommon throughout its range, has a substantial population in the Little River near Idabel. Other species of particular interest known from the Little River drainage include the southern brook lamprey, taillight shiner, and blackside darter, all state species of special concern in Oklahoma.

Aquatic and riparian areas of the Little River also support alligator snapping turtle and mole salamander, considered species of special concern in Oklahoma. Swamp rabbits are present in the riparian zone. Snapping turtle, common slider, razor-backed musk turtle, diamondback and northern water snakes, and cottonmouth, occur in the river proper. As elsewhere in the southern Great Plains, beaver are common, and American alligator could occur in the easternmost parts of Little River. Herons and kingfisher can be expected. Large vulture roosts are found on gravel bar islands in the river from below Pine Creek Reservoir to the Arkansas state line.

Ecosystem Processes

Ecosystem processes in the main-stem Little River have not been studied. In some tributaries, mussel beds (Spooner 2002, C. C. Vaughn et al. unpublished data) and abundant central stoneroller minnows may alter nutrients, primary productivity, standing crops of invertebrates, or ecosystem processes, but studies of those effects have not been made in this system. Headwaters in this river system are typically clear, and where riparian canopy is open, stones are coated with a rich algal covering, and autochthonous primary productivity appears high. Farther downstream, outside the uplands, the Little River becomes an incised, more turbid stream, with less potential for autochthonous primary productivity.

Human Impacts and Special Features

The Little River system, including the main stem and its array of large tributaries, collectively represent one of the most diverse riverscapes in North America relative to their short length. All major branches of the system arise on steep slopes of the Ouachita uplands, then drain long valley floors until they

emerge from the mountains to flow across the low-gradient, historically swampy Coastal Plain. Thus, in their relatively short distances, the branches of the Little River system mimic the headwater to lower river differences that are often seen in river systems over distances of thousands of miles, and also show clearly the biological phenomenon of a sharp ecotone between uplands and lowlands. As a result, these rivers, including the Little River main stem, depict strong longitudinal differentiation of taxa very well. In addition, they harbor rare or at-risk species, including some federally threatened and endangered fishes or invertebrates, and are marked by very high diversity of some groups, like darters.

The greatest human impacts in the region include dams on the main stem and all main tributaries except the Glover River (which remains one of the few free-flowing rivers in the region) and effects of the timber industry. Following final clearing of the last major old-growth forest in the central United States early in the twentieth century, vast tracts of the region were converted under timber company ownership to pine monoculture, replacing the original large pine-savannah and mixed deciduous forest with grow-and-cut forests. In some of the streams where timber is harvested, there has been a noticeable increase in silt on streambed surfaces in the last three decades (W. J. Matthews, personal observations). Large areas also are managed by the USDA Forest Service, and there have been recent land trades between private holders and the Forest Service that now place more of the rivers under federal authority. In some reaches, forest industries create pollutants, such as an outfall from a large mill near Wright City, Oklahoma, that apparently reduced native fish assemblages between the 1970s and 1990s (W. J. Matthews, personal observations). Additional pollutants can come from poultry processing effluents.

The Little River basin is most influenced by the three largest impoundments (see Fig. 7.13). The main stem of the river is impounded by 1644 km^2 Pine Creek Reservoir, used for flood control, water supply, and recreation. A major tributary of the Little River, the Mountain Fork River, is impounded by 1952 km^2 Broken Bow Reservoir, used for generation of hydropower, flood control, water supply, and recreation. Outflow from Broken Bow Reservoir enters the Little River via the Mountain Fork River, 64 km downstream of Pine Creek dam. Vaughn and Taylor (1999) examined the distribution and abundance of mussels at 37 sites along a 240 km length of the river. They observed an extinction gradient downstream from the two impoundments, with a gradual, linear increase in mussel species richness and abundance with increasing distance from the reservoirs. Mussel species distributions were significantly nested, with only sites furthest from the reservoirs containing rare species. The extreme downstream portion of the basin is now impounded by Millwood Reservoir, which drowned vast shallow swamplands of southwest Arkansas. This chapter's senior author vividly recalls as a child crossing those "spooky" swamps late at night on the old highway from Nashville to Ashdown, Arkansas, across what seemed like interminable wooden bridges, while his parents talked in hushed tones in the front seat of the old Nash Rambler station wagon and glanced nervously about, probably hoping the tubes in the tires wouldn't fail.

ADDITIONAL RIVERS

The Cimarron River is a large, shallow, low-gradient prairie tributary to the Arkansas River, interesting for its harsh physical conditions and desiccation of substantial reaches in the upper river in most summers. It arises in the Great Plains and flows through the Central Lowland before terminating in Keystone Lake (Fig. 7.15). It is representative of medium-size southern plains rivers, with an unstable, braided sand bed and highly fluctuating physical conditions. The Cimarron River has low basinwide runoff (<1 cm/mo year-round) due to very high evapotranspiration (Fig. 7.16). There has been widespread introduction of the Red River shiner from outside the drainage, coincident with dramatic loss of the native Arkansas River shiner. Red River pupfish has become abundant in at least one tributary to the Cimarron (D. McNeely, personal communication).

The Neosho (Grand) system also is a large tributary of the Arkansas River, arising in the Flint Hills of Kansas (Fig. 7.17). Endemic fish species and isolated or relict populations of other formerly widespread species exist in the drainage, such as the Topeka shiner, isolated populations of cardinal shiner and southern redbelly dace, and the endemic and federally threatened Neosho madtom. The lower main stem of the Neosho (Grand) system is dominated by three large tailwater-to-headwater reservoirs, with little free-flowing river remaining.

The Illinois River, with its major tributary, the Baron Fork, is a large Ozark river system in the Arkansas River basin (Fig. 7.19). It arises in karst topography, with many spring-fed tributaries, caves, and gravel-bottomed riffle–pool reaches. The Illinois River contains some of the highest-quality stream

FIGURE 7.4 Illinois River, Oklahoma (PHOTO BY C. C. VAUGHN).

habitat in the region and is the only major tributary flowing into the Arkansas River that represents an Ozark uplift, calcareous stream type (Fig. 7.4). Tenkiller Reservoir is a major on-river impoundment on the lower Illinois River. There is a particularly diverse (101 species) fish fauna (Moore and Paden 1950) for such a small basin, with many Ozark-limited fish species like the Ozark minnow, cardinal shiner, banded sculpin, slender madtom, greenside darter, and banded darter as prominent members of the fauna.

The Poteau River is a substantial southern tributary to the Arkansas River in east Oklahoma and west Arkansas. It arises in the steep Ouachita Mountains and feeds, along with other large upland tributaries, into the impounded Lake Wister, after which there is a long portion of low-gradient river and densely wooded riparian habitat before it enters the Arkansas River (Fig. 7.21). Numerous locally restricted fish species exist, like the relatively rare blackside darter and longnose darter. The Poteau River exhibits extremes of seasonal runoff, from an average as low as 0.25 cm/mo in August to more than 6 cm/mo in winter (Fig. 7.22).

The Washita River is the largest low-gradient, western tributary of the Red River that flows into Lake Texoma (Fig. 7.23). An unstable mud–sand riverbed and steeply incised, erosive red earth banks makes this one of the most turbid, silt-laden streams in North America (Fig. 7.5). The Washita River basin is heavily affected by agriculture, with cattle farming and row crops dominating the landscape, along with oil and gas operations. The native fish fauna historically was somewhat limited even before human impacts, with gaps in distribution of some minnow species. However, it has an excellent sports fishery for native flathead catfish and channel catfish.

The Blue River is a relatively short but faunally important tributary of the Red River, fed by large springs in south-central Oklahoma (Fig. 7.25). The upper portion of the river is strongly marl-depositing, and marl dikes form pools and small waterfalls throughout much of the upper main stem. There are no major dams on this system. Two locally unique forms of fishes (orangebelly darter and striped shiner) are distinctive morphologically or genetically from those taxa elsewhere in their range and warrant species-level recognition. Also, the redspot

FIGURE 7.5 Washita River, Oklahoma (PHOTO BY W. J. MATTHEWS).

chub is found only here and in the Ozarks. A reach of several kilometers is owned by the state conservation department for public access, particularly a stocked trout fishery. The latter results in heavy vehicle traffic in and near this part of the river. Mussels (24 species) have been extirpated from 75% of the Blue River over the last 30 years, probably primarily due to siltation from riparian clearing and agriculture (Vaughn 1997).

The Kiamichi River is an upland tributary of the Red River. It arises just east of the Arkansas–Oklahoma border, flows westward into Oklahoma, then south to join the Red River near Antlers, Oklahoma (Fig. 7.27, Fig. 7.6). It flows through a narrow river valley floor, bordered on both sides by steep slopes of long ridge-and-valley mountains. Its flow is altered about halfway down the main stem by the off-channel Sardis Reservoir, which controls inflow from a large tributary creek, and the lower main stem is altered by Hugo Reservoir. The Kiamichi River arises as a clear stream with riffles and long wide pools flowing over stony cobble–boulder substrate or well-developed gravel bars. Water willow is a prominent feature of shallow riffles and pool edges throughout the upper two-thirds of the river. It possesses an important native fish and mussel fauna, with two federally protected mussel species. The Kiamichi River has been particularly hard hit by drought in recent summers, with long reaches of typically flowing headwaters badly dewatered, which has had impacts on native mussel beds.

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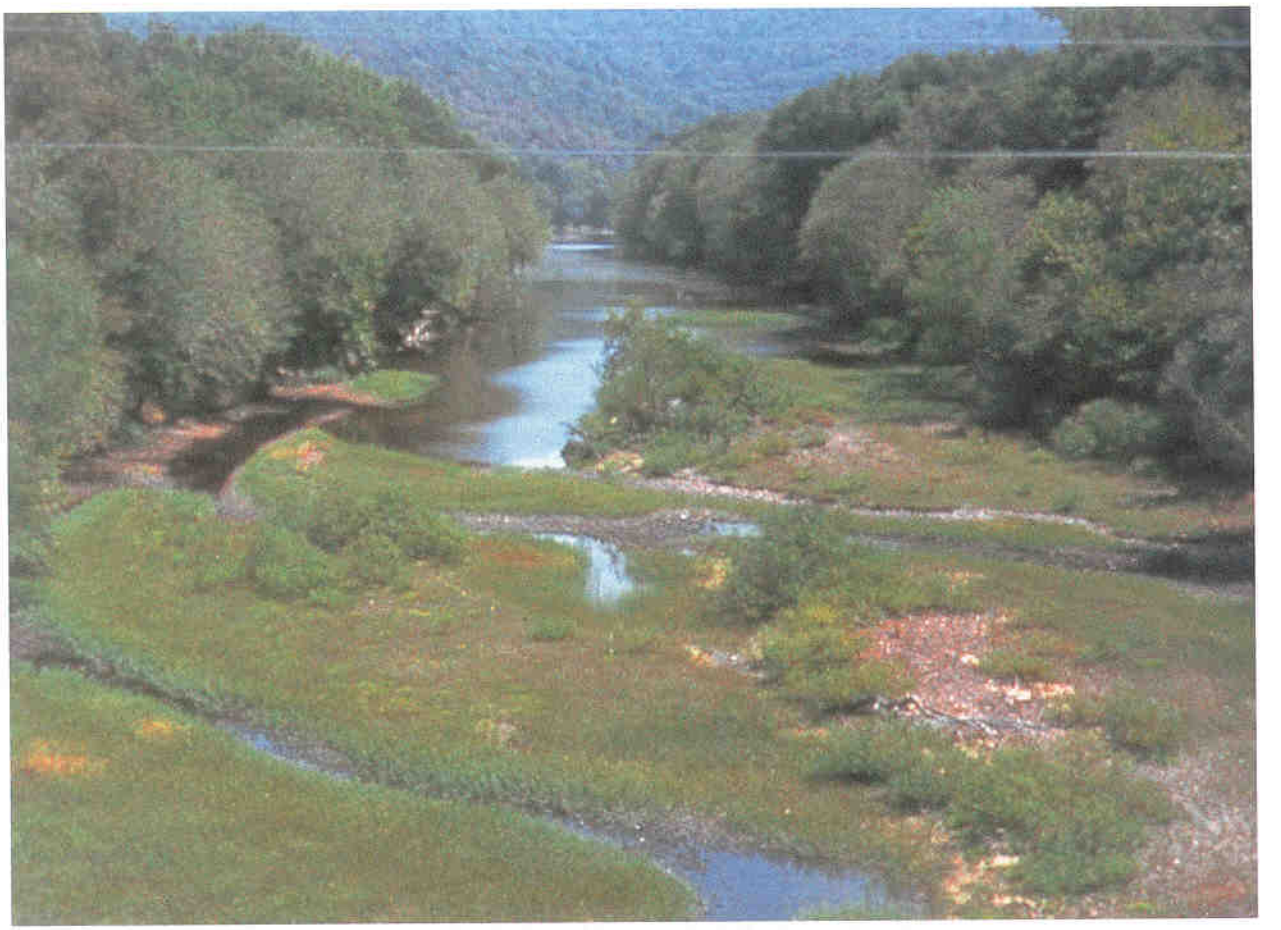

FIGURE 7.6 Kiamichi River, Oklahoma (PHOTO BY C. C. VAUGHN).

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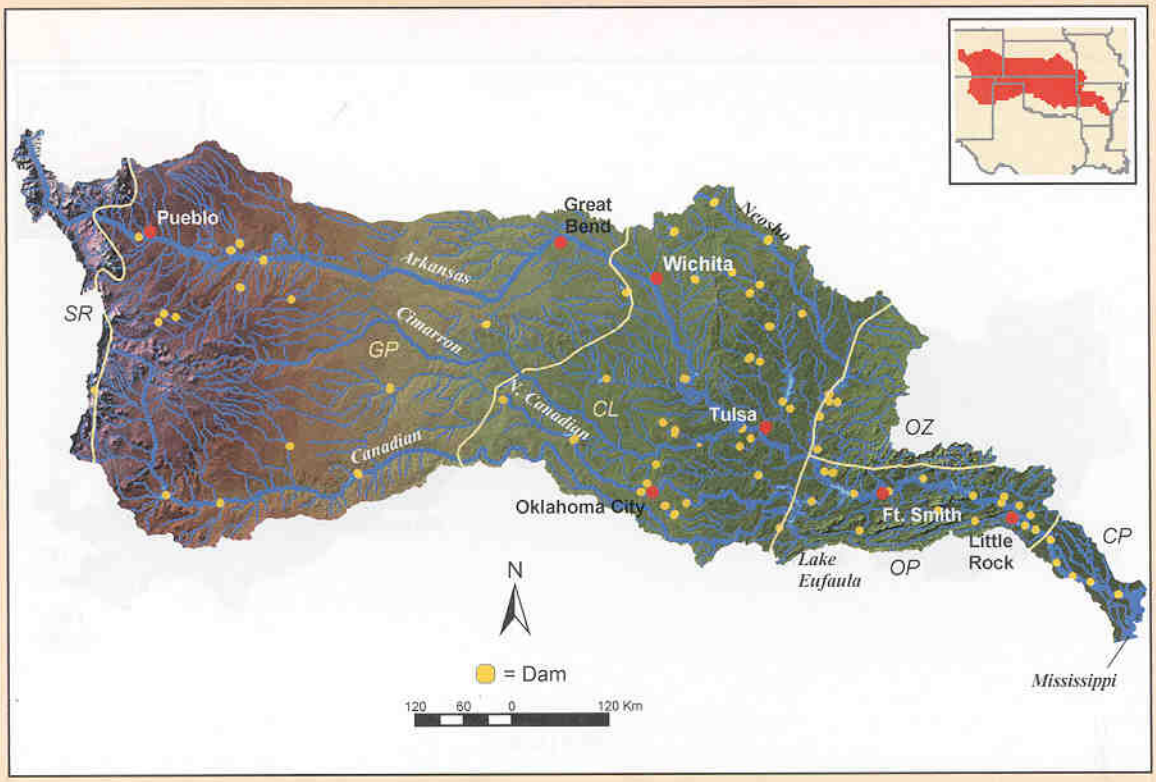

FIGURE 7.7 Map of the Arkansas River basin. Physiographic provinces are separated by yellow lines.

ARKANSAS RIVER

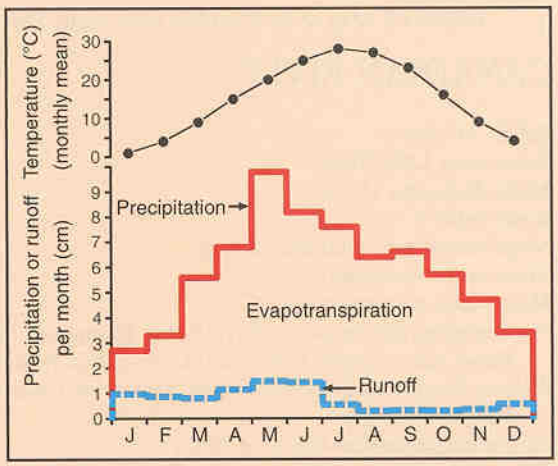

FIGURE 7.8 Mean monthly air temperature, precipitation, and runoff for the Arkansas River basin.

Relief: 4340 m
Basin area: 414,910 km^2
Mean discharge: 1004 m^3/s
River order: 7
Mean annual precipitation: 70.8 cm
Mean air temperature: 15°C
Mean water temperature: 17.9°C
Physiographic provinces: Southern Rocky Mountains (SR), Great Plains (GP), Central Lowland (CL), Ozark Plateaus (OZ), Ouachita Province (OP), Coastal Plain (CP)
Biomes: Temperate Mountain Forest, Temperate Grasslands, Temperate Deciduous Forest
Freshwater ecoregions: Southern Plains, Central Prairie, Ozark Highlands, Mississippi Embayment
Terrestrial ecoregions: 6 ecoregions (see text)
Number of fish species: 171 (141 native)
Number of endangered species: 1 fish, 1 bird
Major fishes: paddlefish, gars, gizzard shad, red shiner, river shiner, emerald shiner, plains minnow, smallmouth buffalo, bigmouth buffalo, river carpsucker, channel catfish, flathead catfish, plains killifish, western mosquitofish, white bass, largemouth bass, spotted bass, sunfishes, river darter
Major other aquatic vertebrates: plains leopard frog, American bullfrog, Blanchard's cricket frog, snapping turtle, spiny softshell turtle, smooth softshell turtle, yellow mud turtle, common slider, false map turtle, painted turtle, northern water snake, diamondback water snake, American white pelican, great blue heron, belted kingfisher, beaver, muskrat
Major benthic invertebrates: mayflies (*Caenis*, *Hexagenia*, *Stenonema*), caddisflies (*Cheumatopsyche*, *Hydropsyche*), chironomid midges (*Polypedilum*, *Glyptotendipes*), crayfishes (*Orconectes palmeri*, *Procambarus simulans*), mussels (washboard, threeridge, mapleleaf, pink papershell)
Nonnative species: Asian clam, zebra mussel, ~30 fish species (common carp, grass carp, striped bass), nutria in Arkansas
Major riparian plants: silver maple, box elder, hackberry, cottonwood, willow, cattails, American bulrush
Special features: arises as strongly flowing mountain river, almost disappears in western Kansas due to water withdrawal and evaporation; recharged near Great Bend, Kansas
Fragmentation: five major reservoirs on main stem, plus 17 locks and dams; part of the Kerr-McClellan Navigation System
Water quality: pH = 7.4, alkalinity = 52 mg/L as $CaCO_3$, NO_3-N = 0.25 mg/L, PO_4-P = 0.02 mg/L, but with wide range of values from headwaters to lower main river
Land use: western basin: mining, oil and gas production, 50% rangeland, 50% cropland; eastern basin: 50% forest, 15% cropland, 25% pasture; urban in Wichita, Tulsa, Little Rock
Population density: 14.6 people/km^2
Major information sources: Branson 1982, 1983, 1984; Cross et al. 1986; Reimer 1969; Sealander and Heidt 1990; Solley et al. 1998

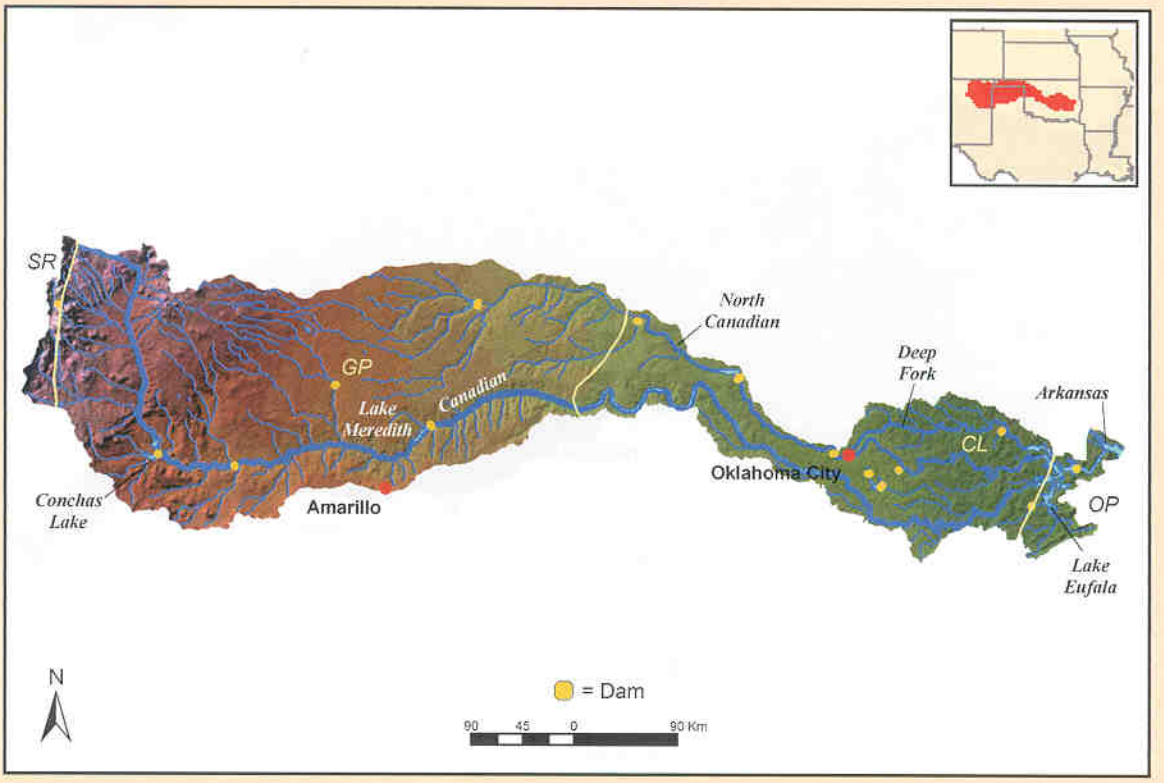

FIGURE 7.9 Map of the Canadian River basin. Physiographic provinces are separated by yellow lines.

CANADIAN RIVER

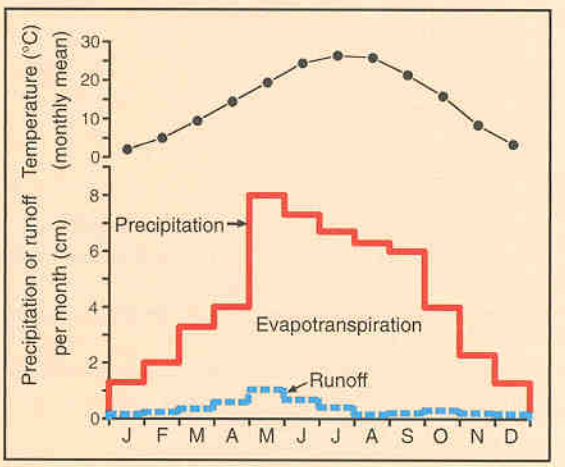

FIGURE 7.10 Mean monthly air temperature, precipitation, and runoff for the Canadian River basin.

Relief: 4132 m
Basin area: 122,070 km^2
Mean discharge: 174 m^3/s
River order: 6
Mean annual precipitation: 52.5 cm
Mean air temperature: 15°C
Mean water temperature: 18°C
Physiographic provinces: Southern Rocky Mountains (SR), Great Plains (GP), Central Lowland (SL), Ouachita Province (OP)
Biomes: Temperate Mountain Forest, Temperate Grasslands, Temperate Deciduous Forest
Freshwater ecoregion: Southern Plains
Terrestrial ecoregions: Western Short Grasslands, Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone
Number of fish species: 63 (native)
Number of endangered species: 1 fish, 1 bird
Major fishes: gizzard shad, red shiner, Arkansas River shiner, emerald shiner, plains minnow, bluntnose minnow, fathead minnow, plains killifish, western mosquitofish, river carpsucker, channel catfish, white bass, largemouth bass, longear sunfish, green sunfish
Major other aquatic vertebrates: snapping turtle, yellow mud turtle, stinkpot turtle, smooth softshell turtle, beaver
Major benthic invertebrates: oligochaetes, midges (*Bezzia*, *Chironomus*, *Cryptochironomus*), mayflies (*Tricorythodes*, *Caenis*), caddisflies (*Cheumatopsyche*), crayfish (*Orconectes nais*), fingernail clams (*Sphaerium*, *Pisidium*), mussels (pink papershell, fragile papershell, yellow sandshell, white heelsplitter)
Nonnative species: Asian clam, Red River pupfish, inland silversides, common carp, blue tilapia, saltcedar
Major riparian plants: silver maple, box elder, American elm, hackberry, sandbar willow, ash, cottonwood, saltcedar
Special features: crosses arid grasslands in west, sometimes desiccating, mesic forest in east; shallow, shifting "sand bed" rivers create harsh environments, limiting richness and persistence of fauna
Fragmentation: four impoundments on main stem
Water quality: pH = 8.2, alkalinity = 156 mg/L as $CaCO_3$, NO_3-N = 0.46 mg/L, total phosphorus = 0.32 mg/L
Land use: 50% rangeland or pasture, 30% cropland; up to 55% forested in east
Population density: 9.1 people/km^2
Major information sources: Branson 1982, 1983, 1984, Byre 2000, Cross et al. 1986, Matthews and Hill 1979, 1980, Solley et al. 1998, Reimer 1969

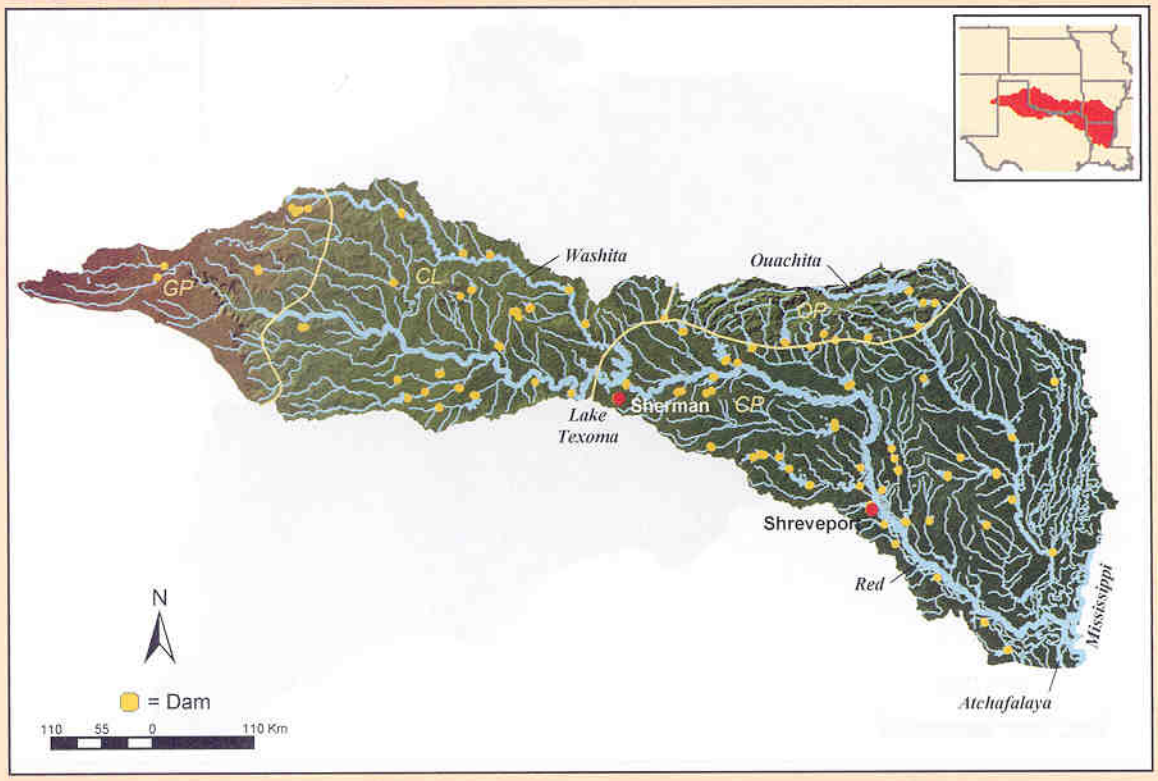

FIGURE 7.11 Map of the Red River basin. Physiographic provinces are separated by yellow lines.

RED RIVER

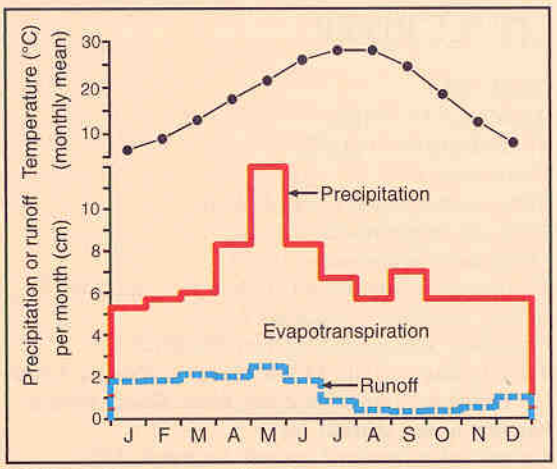

FIGURE 7.12 Mean monthly air temperature, precipitation, and runoff for the Red River basin.

Relief: 1347 m
Basin area: 169,890 km^2
Mean discharge: 852 m^3/s
River order: 7
Mean annual precipitation: 82 cm
Mean air temperature: 18°C
Mean water temperature: 19.3°C
Physiographic provinces: Great Plains (GP), Central Lowland (CL), Ouachita Province (OP), Coastal Plain (CP)
Biomes: Temperate Grasslands, Temperate Deciduous Forest
Freshwater ecoregions: Southern Plains, Ouachita Highlands, Mississippi Embayment
Terrestrial ecoregions: Western Short Grasslands, Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone, Piney Woods Forests
Number of fish species: 171 (152 native)
Number of endangered species: 1 bird
Major fishes: alligator gar, longnose gar, gizzard shad, red shiner, emerald shiner, Red River shiner, chub shiner, emerald shiner, blacktail shiner, bluntnose minnow, plains minnow, blue sucker, smallmouth buffalo, river carpsucker, channel catfish, blue catfish, plains killifish, Red River pupfish, sunfishes, white bass, largemouth bass, bigscale logperch
Major other aquatic vertebrates: alligator snapping turtle, common slider, spiny softshell turtle, false map turtle, yellow mud turtle, plain-bellied water snake, cottonmouth, American alligator, great blue heron, beaver, muskrat, nutria
Major benthic invertebrates: Chironomid midges (*Glyptotendipes*, *Dicrotendipes*, *Chironomus*), mayflies (*Hexagenia*, *Caenis*, *Stenonema*), caddisflies (*Cyrnellus*, *Hydropsyche*), crayfishes (*Orconectes palmeri*, *O. nais*, *Procambarus simulans*), mussels (pink papershell, fragile papershell, bleufer)
Nonnative species: Asian clam, nutria, striped bass, walleye, threadfin shad, inland silversides, common carp, grass carp
Major riparian plants: cottonwood, willows, box elder, silver maple, slippery elm, sweetgum, post oak
Special features: spans gradient from driest to some of wettest climatic conditions in North America; high salinity in headwaters, frequently drying; Great Raft, once a logjam of gigantic proportions upstream from Shreveport
Fragmentation: one major impoundment (Lake Texoma) on main stem; four locks and dams in Louisiana
Water quality: pH = 8.0, alkalinity = 131 mg/L as $CaCO_3$, NO_3-N = 0.18 mg/L, PO_4-P = 0.11 mg/L, total phosphorus = 0.12 mg/L; chloride extremely high in headwaters, conductivity to 35 µS/cm, decreasing to about 2 µS/cm near Lake Texoma
Land use: 40% to 60% rangeland and 30 % cropland in west; 50% forest, 20% cropland, and 10% pasture in east
Population density: 9.1 people/km^2
Major information sources: Branson 1982, 1983, 1984, Creel 1964, Cross et al. 1986, Echelle et al. 1972, Hoagland 2000, Valentine and Stansbery 1971

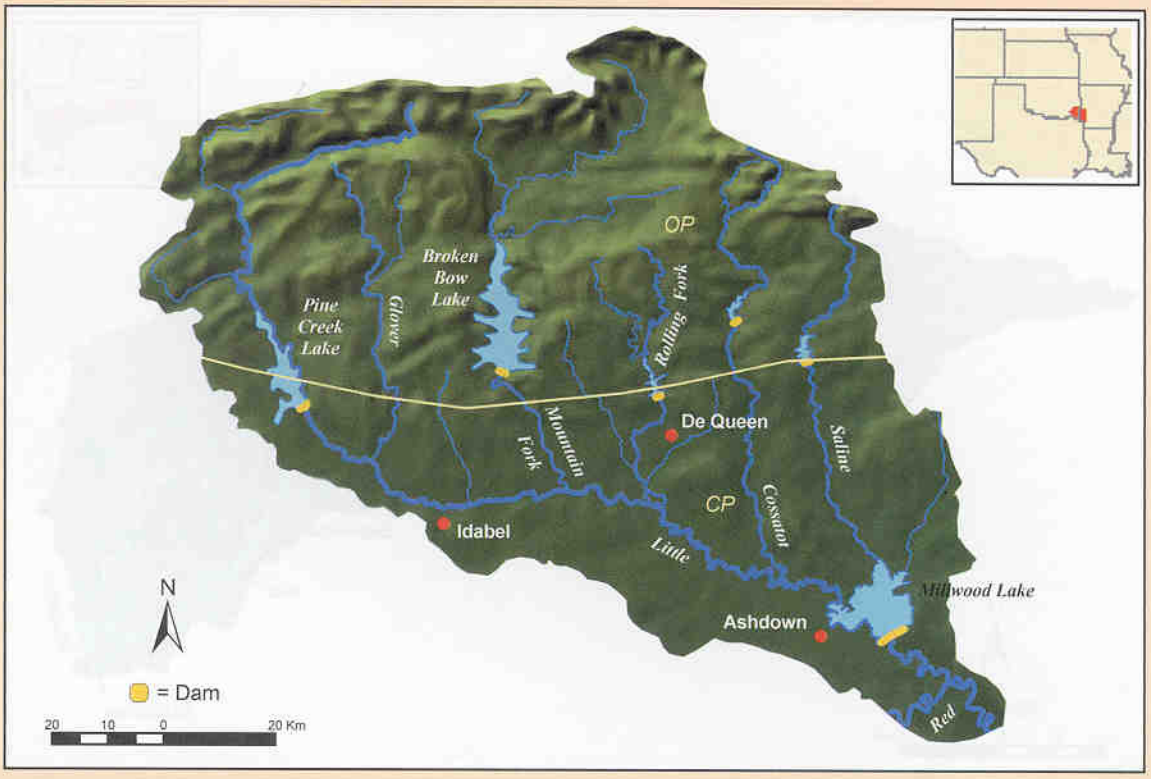

FIGURE 7.13 Map of the Little River basin. Physiographic provinces are separated by a yellow line.

LITTLE RIVER

Relief: 741 m
Basin area: 10,720 km^2
Mean discharge: 183 m^3/s
River order: 6
Mean annual precipitation: 123 cm
Mean air temperature: 16°C
Mean water temperature: 16.5°C
Physiographic provinces: Ouachita Province (OP), Coastal Plain (CP)
Biome: Temperate Deciduous Forest
Freshwater ecoregion: Ouachita Highlands
Terrestrial ecoregions: Ozark Mountain Forests, Central Forest Grassland Transition Zone, Piney Woods Forests
Number of fish species: 110
Number of endangered species: 2 mussels, 1 fish
Major fishes: gars, rocky shiner, blacktail shiner, central stoneroller, river redhorse, golden redhorse, blackstriped topminnow, grass pickerel, flier, bantam sunfish, pirate perch, dusky darter, crystal darter, orangethroat darter, orangebelly darter, largemouth bass, spotted bass, sunfishes, leopard darter

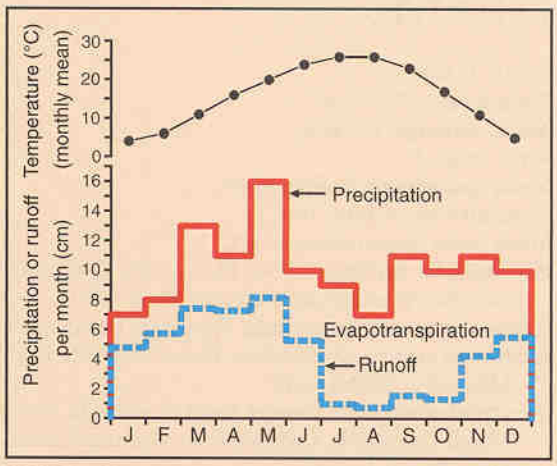

FIGURE 7.14 Mean monthly air temperature, precipitation, and runoff for the Little River basin.

Major other aquatic vertebrates: snapping turtle, common slider, razor-backed musk turtle, diamondback water snake, northern water snake, cottonmouth, swamp rabbit, beaver, river otter, mink
Major benthic invertebrates: mussels (threeridge, mucket, pimpleback), limpets (*Ferrissia*), snails (*Elimia*, *Heliosoma*), crayfishes (*Orconectes palmeri*, *Procambarus acutus*), mayflies (*Stenonema*, *Ephemerella*, *Heptagenia*, *Isonychia*), beetles (*Stenelmis*, *Psephenus*), stoneflies (*Acroneuria*, *Neoperla*), caddisflies (*Cheumatopsyche*, *Helicopsyche*, *Chimarra*)
Nonnative species: Asian clam, brown trout, rainbow trout, common carp; grass carp and striped bass likely
Major riparian plants: river birch, sycamore, smooth alder, sugar maple, box elder, willow oak, blue beech, bald cypress
Special features: some of last well-preserved upland rivers in central United States; regional "hot spot" of biodiversity
Fragmentation: two reservoirs on main stem (Pine Creek and Millwood); four large reservoirs on main tributaries
Water quality: pH = 7.2, alkalinity = 24 mg/L as $CaCO_3$, NO_3-N = 0.33 mg/L, PO_4-P = 0.06 to 0.09 mg/L
Land use: 75% forest, 10% cropland, 15% pasture; no urban areas
Population density: 3.2 people/km^2
Major information sources: Hoagland 2000, Hoagland et al. 1996, Jenkins 1956, Reimer 1969, Shackelford and Whitaker 1997, Solley et al. 1998, Vaughn 2000, Vaughn and Taylor 1999

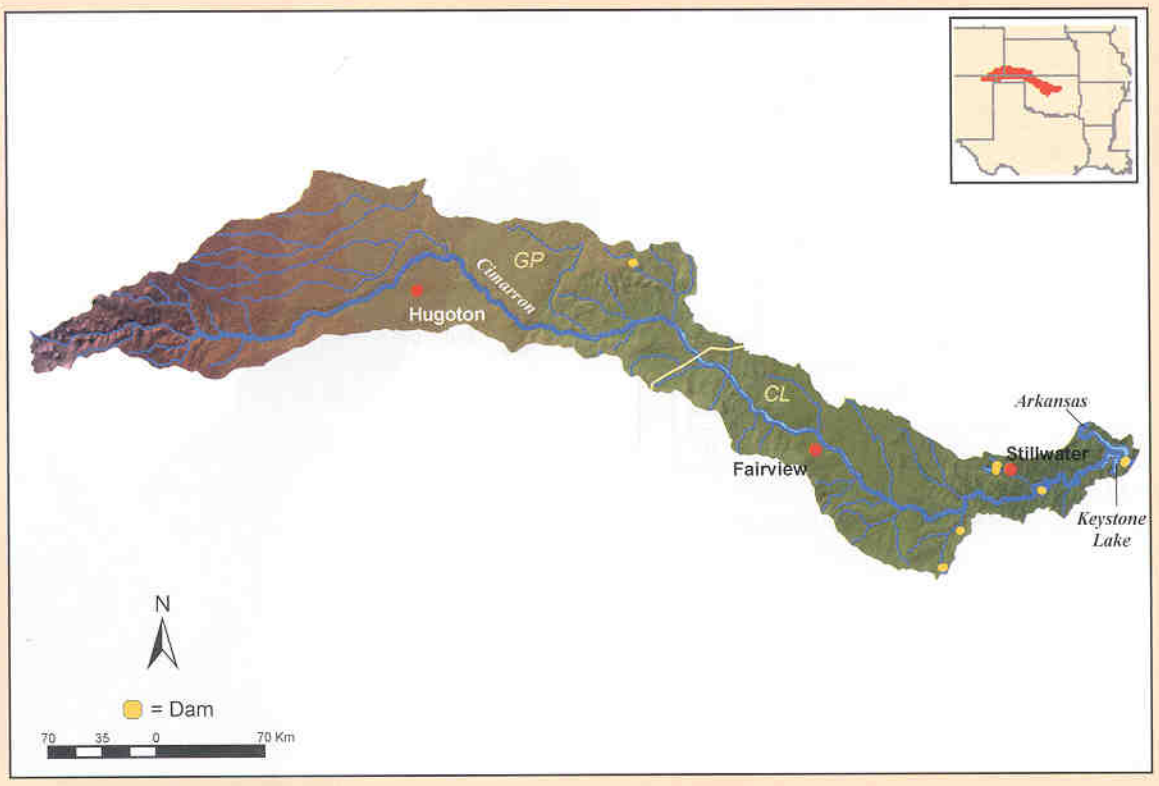

FIGURE 7.15 Map of the Cimarron River basin. Physiographic provinces are separated by a yellow line.

CIMARRON RIVER

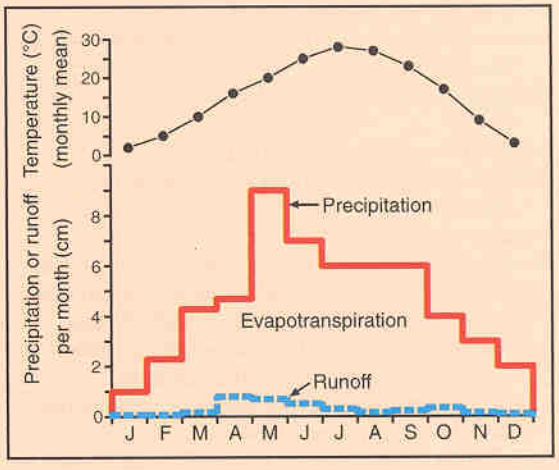

FIGURE 7.16 Mean monthly air temperature, precipitation, and runoff for the Cimarron River basin.

Relief: 2036 m
Basin area: 50,540 km^2
Mean discharge: 42 m^3/s
River order: 4
Mean annual precipitation: 55.3 cm
Mean air temperature: 15°C
Mean water temperature: 18.4°C
Physiographic provinces: Great Plains (GP), Central Lowland (CL)
Biomes: Temperate Grasslands, Temperate Deciduous Forest
Freshwater ecoregion: Southern Plains
Terrestrial ecoregions: Western Short Grasslands, Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone
Number of fish species: 48
Number of endangered species: 1 fish, 1 bird
Major fishes: red shiner, plains minnow, plains killifish, gizzard shad, white bass, channel catfish, western mosquitofish; Arkansas River shiner now much reduced in abundance
Major other aquatic vertebrates: snapping turtle, beaver
Major benthic invertebrates: mollusks (fingernail clam), crayfish (*Orconectes nais*), oligochaete worms (*Chaetogaster*, *Limnodrilus*), mayflies (*Caenis*, *Baetis*), caddisflies (*Cheumatopsyche*, *Hydropsyche*), beetles (*Stenelmis*)
Nonnative species: Asian clam, Red River shiner, striped bass, saltcedar
Major riparian plants: silver maple, box elder, ash, hackberry, cottonwood, sandbar willow, black willow, saltcedar, American elm
Special features: drains some of most arid lands of southern Great Plains; long reaches of western main stem intermittent; harsh conditions, but relatively diverse fish fauna
Fragmentation: two large reservoirs on main stem; other fragmentation by natural or human-enhanced desiccation of main-stem reaches
Water quality: pH = 8.1, alkalinity = 169 mg/L as $CaCO_3$, NO_3-N = 1.32 mg/L, total phosphorus = 0.84 mg/L
Land use: 50% rangeland or pasture, 35% cropland, up to 30% forest in east; no large cities
Population density: 6.7 people/km^2
Major information sources: Hoagland 2000, ONHI 2001, Solley et al. 1998

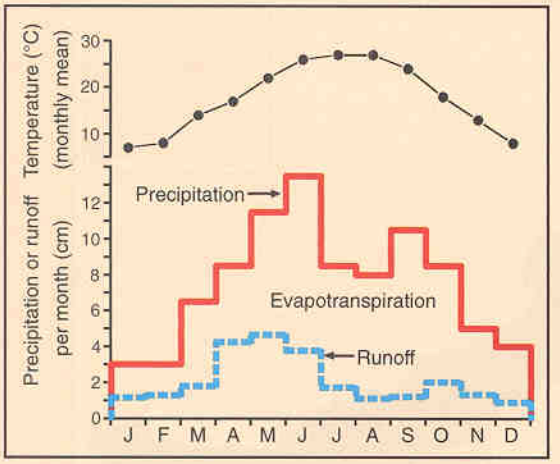

FIGURE 7.18 Mean monthly air temperature, precipitation, and runoff for the Neosho River basin.

FIGURE 7.17 Map of the Neosho River basin. Physiographic provinces are separated by a yellow line.

NEOSHO (GRAND) RIVER

Relief: 325 m
Basin area: 54,550 km^2
Mean discharge: 254 m^3/s
River order: 6
Mean annual precipitation: 91 cm
Mean air temperature: 12°C
Mean water temperature: 15.4°C
Physiographic provinces: Central Lowland (CL), Ozark Plateaus (OZ)
Biomes: Temperate Grasslands, Temperate Deciduous Forest
Freshwater ecoregion: Central Prairie
Terrestrial ecoregion: Central Forest Grassland Transition Zone
Number of fish species: 94 native
Number of endangered species: 1 fish, 1 bird, 1 mussel
Major fishes: upstream: Topeka shiner, orangethroat darter, cardinal shiner, southern redbelly dace, endemic Neosho madtom; downstream: paddlefish, gizzard shad, numerous native minnows, smallmouth buffalo, river carpsucker, white bass, largemouth bass, sunfishes
Major other aquatic vertebrates: hellbender (threatened in Kansas), mudpuppy, snapping turtle, spiny softshell turtle, smooth softshell turtle, common slider, false map turtle, Ouachita map turtle, painted turtle, diamondback water snake
Major benthic invertebrates: 33 species of mussels (threeridge, monkeyface, Neosho mucket), caddisflies (*Hydropsyche*, *Potamyia*), crayfishes (*Orconectes virilis*, *O. neglectus*), chironomid midges (*Glyptotendipes*)
Nonnative species: Asian clam, common carp, rainbow trout
Major riparian plants: silver maple, box elder, red maple, river birch, hackberry, pecan, eastern swamp privet, ash, blackgum, sycamore, cottonwood, pin oak, American elm
Special features: drains unique uplifted region of Kansas known as "Flint Hills"; streams comprising clear water "outposts" disjunct from and containing species common to Ozark Plateaus
Fragmentation: four impoundments on main stem
Water quality: pH = 7.4, alkalinity = 52 mg/L as $CaCO_3$, NO_3-N = 0.25 mg/L, PO_4-P = 0.02 mg/L
Land use: upper basin: 60% rangeland and pasture, 20% crops; lower basin: 75% forest, 20% pasture, 5% crops; no large cities
Population density: 13.5 people/km^2
Major information sources: Covich et al. 1978, Hoagland 2000, Obermeyer et al. 1997, Nulty 1980, Reimer 1969, Solley et al. 1998, Vaughn 1998

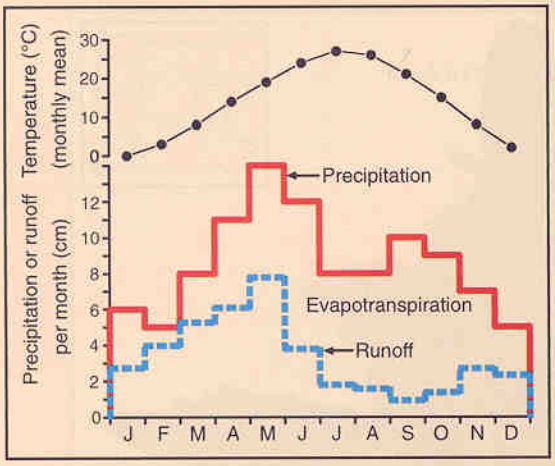

FIGURE 7.20 Mean monthly air temperature, precipitation, and runoff for the Illinois River basin.

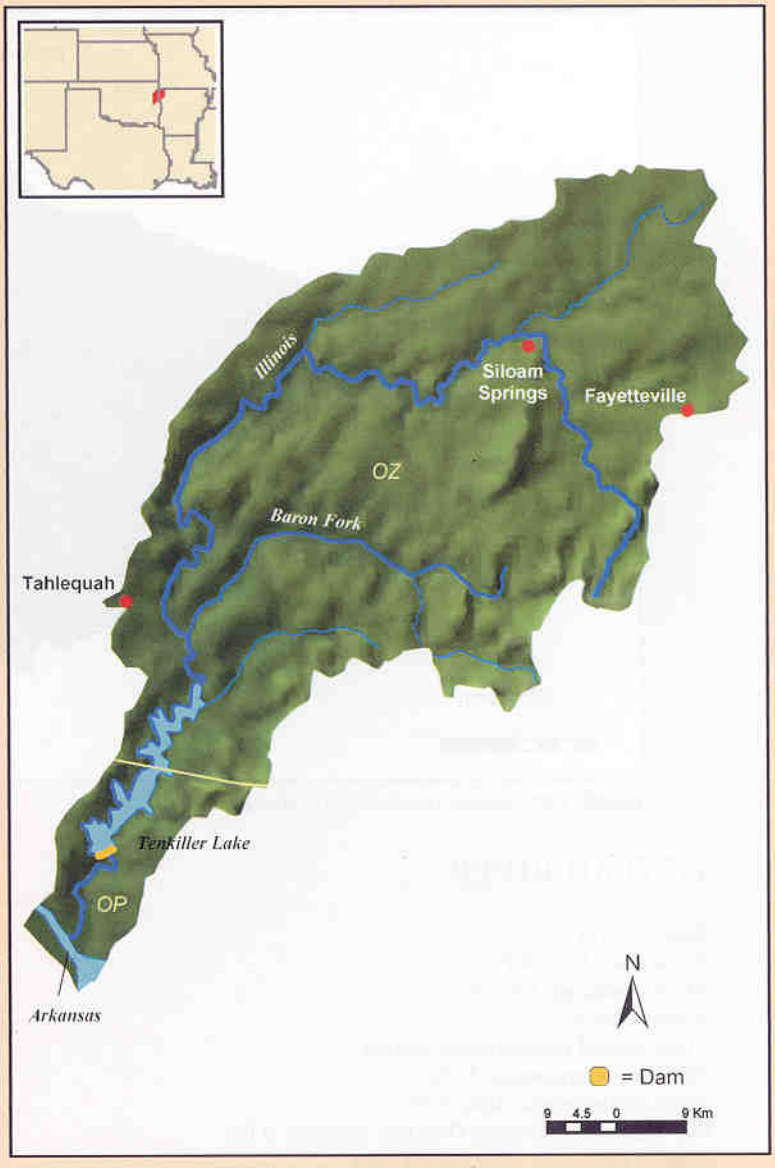

FIGURE 7.19 Map of the Illinois River basin. Physiographic provinces are separated by a yellow line.

ILLINOIS RIVER

Relief: 390 m
Basin area: 4260 km^2
Mean discharge: 54 m^3/s
River order: 5
Mean annual precipitation: 103 cm
Mean air temperature: 14°C
Mean water temperature: 16.5°C
Physiographic province: Ozark Plateaus (OZ), Ouachita Province (OP)
Biome: Temperate Deciduous Forest
Freshwater ecoregions: Ozark Highlands, Central Prairie
Terrestrial ecoregion: Ozark Mountain Forests
Number of fish species: 101
Number of endangered species: 1 bird and 1 mussel federally threatened
Major fishes: southern brook lamprey, longnose gar, central stoneroller, bigeye shiner, Ozark minnow, rosyface shiner, cardinal shiner, redspot chub, golden redhorse, slender madtom, blackspotted topminnow, brook silverside, smallmouth bass, spotted bass, longear sunfish, green sunfish, white bass, stippled darter, orangethroat darter, greenside darter, banded darter, banded sculpin
Major other aquatic vertebrates: American bullfrog, common slider, spiny softshell turtle, false map turtle, water snakes, cottonmouth
Major benthic invertebrates: 22 species of mussels (elktoe, threeridge, pigtoe), fingernail clams (*Sphaerium*, *Pisidium*), snails (*Elimia*, *Physa*), crayfish (*Orconectes meeki*), mayflies (*Baetis*, *Pseudocleon*), caddisflies (*Helicopsyche*, *Cheumatopsyche*)
Nonnative species: Asian clam, striped bass, rainbow trout
Major riparian plants: silver maple, box elder, red maple, river birch, pecan, eastern swamp privet, possum haw, sycamore, black gum, cottonwood, pin oak, American elm
Special features: state Scenic River (Oklahoma); generally a clear upland river, but water quality deterioration (municipal wastes) in headwaters (Arkansas); heavily used for recreation
Fragmentation: one major impoundment (Tenkiller); old spillway (former Lake Frances) at Arkansas–Oklahoma border impedes upstream movement of fishes
Water quality: pH = 7.4, alkalinity = 52 mg/L as $CaCO_3$, NO_3-N = 0.25 mg/L, PO_4-P = 0.02 mg/L
Land use: 70% forest, 20% pasture, 10% cropland; no large cities
Population density: 18.3 people/km^2
Major information sources: Gordon et al. 1979, Hoagland 2000, ONHI 2001, Moore and Paden 1950, Reimer 1969

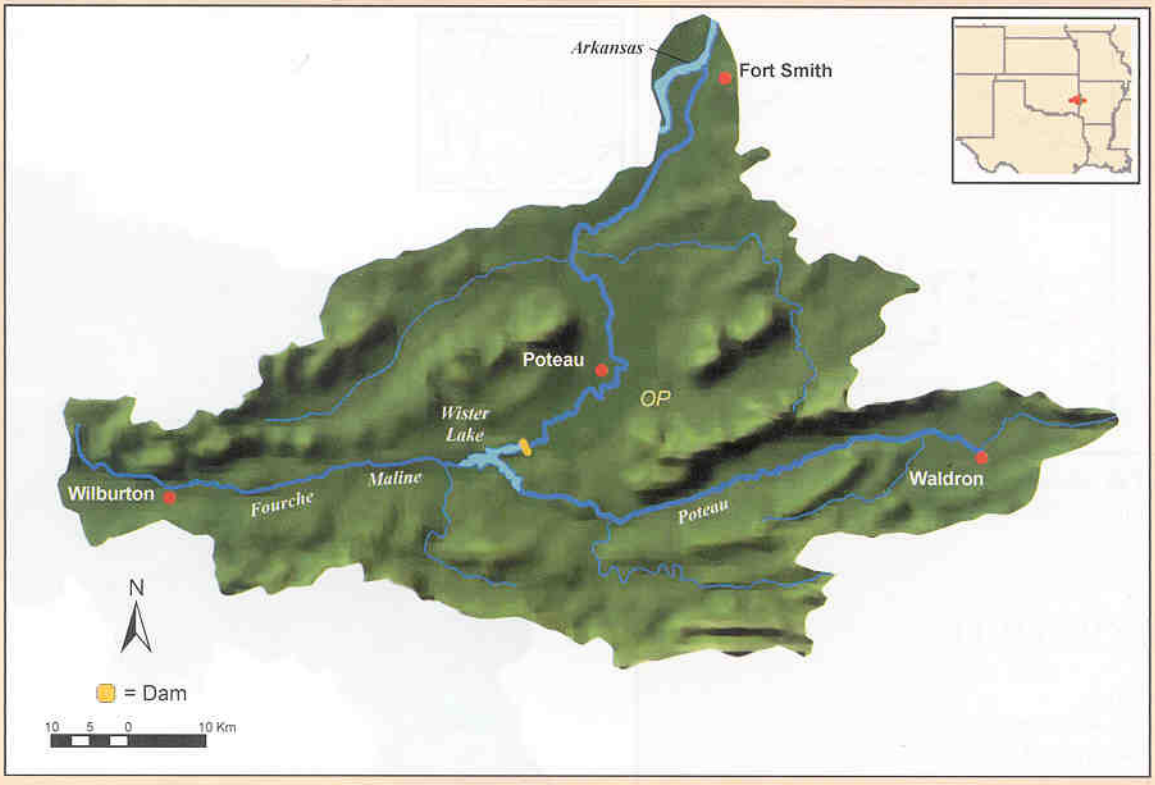

FIGURE 7.21 Map of the Poteau River basin.

POTEAU RIVER

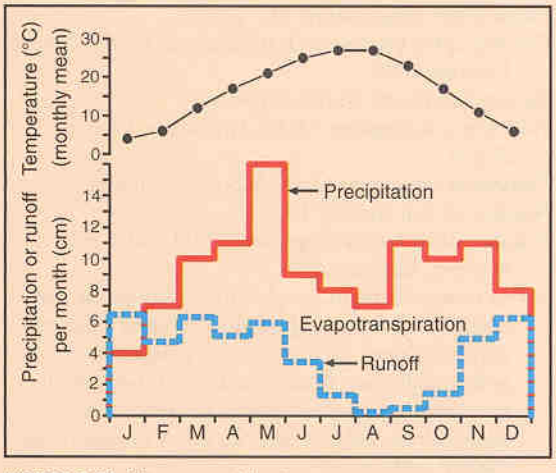

FIGURE 7.22 Mean monthly air temperature, precipitation, and runoff for the Poteau River basin.

Relief: 680 m
Basin area: 4840 km^2
Mean discharge: 68 m^3/s
River order: 4
Mean annual precipitation: 112 cm
Mean air temperature: 16°C
Mean water temperature: 17°C
Physiographic province: Ouachita Province (OP)
Biome: Temperate Deciduous Forest
Freshwater ecoregions: Ouachita Highlands, Central Prairie
Terrestrial ecoregion: Ozark Mountain Forests
Number of fish species: 95
Number of endangered species: none
Major fishes: spotted gar, grass pickerel, pugnose minnow, steelcolor shiner, redfin shiner, bluntnosed minnow, central stoneroller, smallmouth buffalo, river carpsucker, creek chubsucker, channel catfish, blackstriped topminnow, western mosquitofish, largemouth bass, spotted bass, longear sunfish, white crappie, logperch, redfin darter, orangethroat darter
Major other aquatic vertebrates: mudpuppy, common slider, snapping turtle, beaver, river otter
Major benthic invertebrates: 32 species of mussels (threeridge, washboard, fluted shell), freshwater shrimp (*Palaemonetes kadiakensis*), mayflies (*Pseudocleon*, *Choroterpes*), caddisflies (*Cheumatopsyche*, *Hydroptila*), beetles (*Microcylloepus*, *Stenelmis*, *Dubiraphia*)
Nonnative species: Asian clam, common carp, striped bass, inland silversides
Major riparian plants: silver maple, box elder, red maple, smooth alder, blue beech, ash, black gum, cottonwood, willow oak, American elm, slippery elm
Special features: arises in steep upland slopes of Ouachita Mountain "Ridge and Valley" structural features but makes abrupt transition to low-gradient, turbid conditions before flowing into Arkansas River; commercially harvested for mussels
Fragmentation: one large impoundment (Lake Wister)
Water quality: pH = 7.1, alkalinity = 19 mg/L as $CaCO_3$, NO_3-N = 1.11 mg/L, total phosphorus = 0.15 mg/L
Land use: 65% forest, 20% pasture, 5% to 10% cropland; no large cities
Population density: 9.4 people/km^2
Major information sources: Cross and Moore 1952, Hoagland 2000, Lindsay et al. 1983, Solley et al. 1998

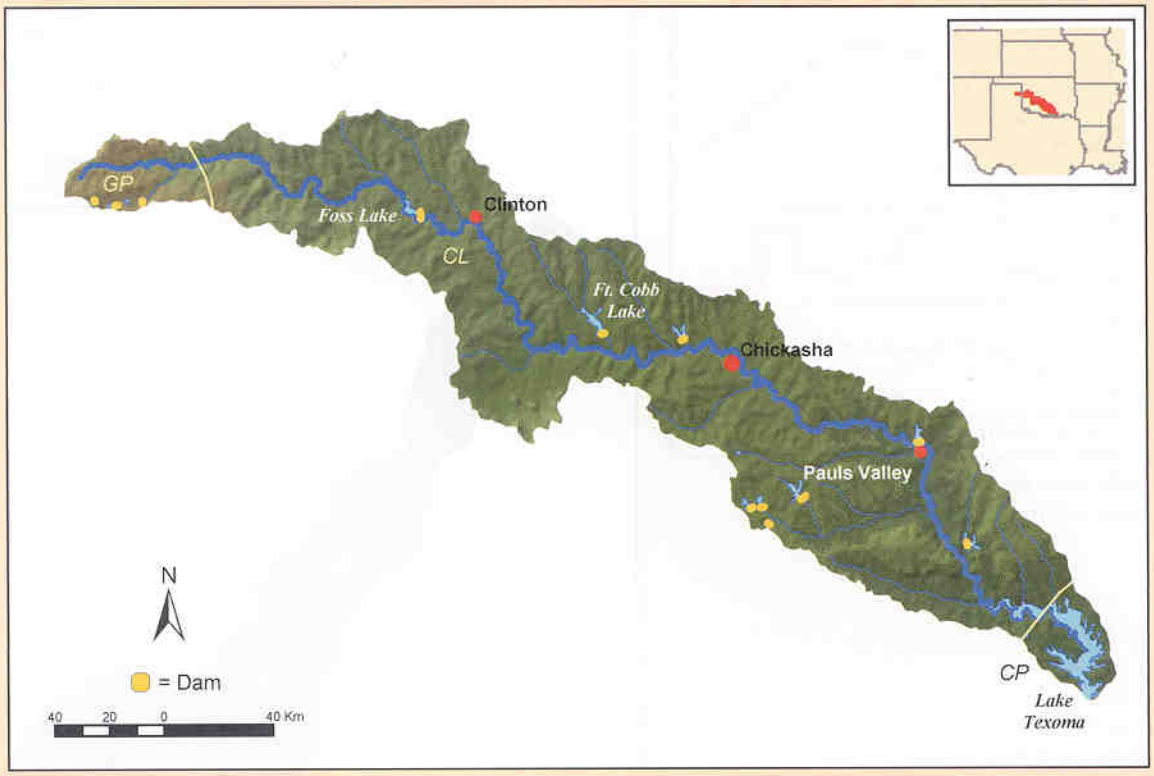

FIGURE 7.23 Map of the Washita River basin. Physiographic provinces are separated by yellow lines.

WASHITA RIVER

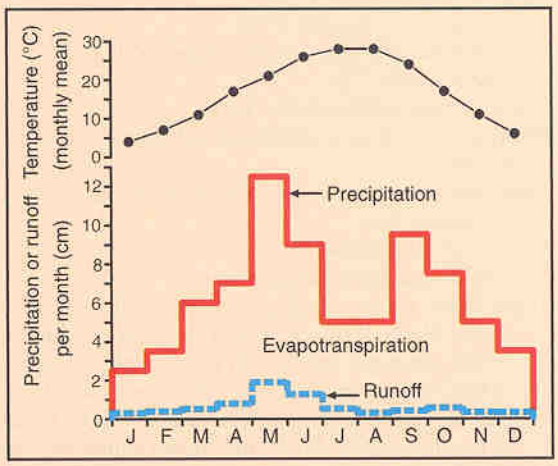

FIGURE 7.24 Mean monthly air temperature, precipitation, and runoff for the Washita River basin.

Relief: 714 m
Basin area: 20,230 km^2
Mean discharge: 44 m^3/s
River order: 4
Mean annual precipitation: 76 cm
Mean air temperature: 16°C
Mean water temperature: 18.4°C
Physiographic provinces: Great Plains (GP), Central Lowland (CL), Coastal Plain (CP)
Biomes: Temperate Grasslands, Temperate Deciduous Forest
Freshwater ecoregion: Southern Plains
Terrestrial ecoregions: Central and Southern Mixed Grasslands, Central Forest Grassland Transition Zone
Number of fish species: 51
Number of endangered species: none
Major fishes: gizzard shad, speckled chub, channel catfish, longear sunfish, green sunfish, bluegill, red shiner; carpsuckers common in lower river
Major other aquatic vertebrates: common slider, false map turtle, plain-bellied water snake, beaver
Major benthic invertebrates: At least 10 mussels (bleufer, white heelsplitter, yellow sandshell), chironomid midges (31 genera), mayflies (*Baetis*, *Choroterpes*), caddisflies (*Hydropsyche*, *Hydroptila*), beetles (*Dubiraphia*, *Heterelmis*)
Nonnative species: Asian clam, striped bass, threadfin shad, inland silversides, common carp, saltcedar
Major riparian plants: silver maple, box elder, ash, hackberry, cottonwood, bur oak, sandbar willow, black willow, saltcedar, American elm
Special features: lower main stem one of most turbid rivers in North America, extremely heavy load of silt or clay; very muddy bottoms; large snag piles common, likely to be major habitat
Fragmentation: two impoundments on main stem
Water quality: pH = 8.0, alkalinity = 170 mg/L as $CaCO_3$, NO_3-N = 2.53 mg/L, PO_4-P = 0.051 mg/L
Land use: 55% rangeland or pasture, 30% crops, 5% to 10% forest; no large cities
Population density: 8.7 people/km^2
Major information sources: Branson 1982, 1983, 1984, Hoagland 2000, Johnson and Vaughn 1995, Magdych 1984, Morris and Madden 1978, ONHI 2001, Solley et al. 1998

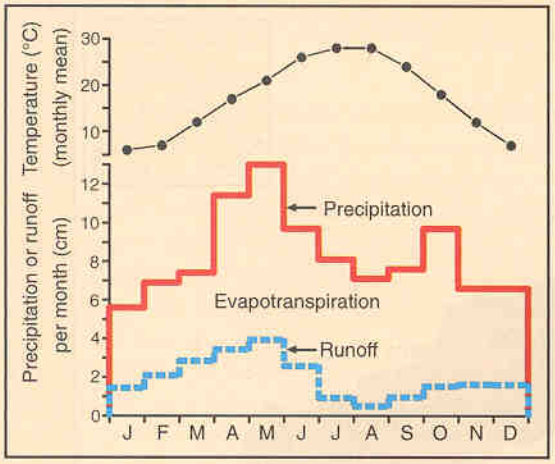

FIGURE 7.26 Mean monthly air temperature, precipitation, and runoff for the Blue River basin.

FIGURE 7.25 Map of the Blue River basin. Physiographic provinces are separated by a yellow line.

BLUE RIVER

Relief: 330 m
Basin area: 1650 km^2
Mean discharge: 9 m^3/s
River order: 4
Mean annual precipitation: 100 cm
Mean air temperature: 17°C
Mean water temperature: 17°C
Physiographic provinces: Central Lowland (CL), Coastal Plain (CP)
Biome: Temperate Deciduous Forest
Freshwater ecoregions: Ouachita Highlands, Southern Plains
Terrestrial ecoregion: Central Forest Grassland Transition Zone
Number of fish species: 85
Number of endangered species: none
Major fishes: redspot chub, central stoneroller, bigeye shiner, blacktail shiner, rocky shiner, spotted sucker, golden redhorse, largemouth bass, longear sunfish, channel darter, orangethroat darter, smallmouth buffalo, river carpsucker, blue sucker; unique forms of the orangebelly darter and striped shiner are distinct from those found elsewhere in their range
Major other aquatic vertebrates: westernmost tributary of Red River with razor-backed musk turtle, cottonmouth
Major benthic invertebrates: 24 species of mussels (threeridge, pigtoe, pistolgrip), amphipod crustaceans (*Hyalella azteca*), crayfish (*Orconectes virilis*), mayflies (*Stenonema*, *Tricorythodes*), beetles (*Dubiraphia*, *Helichus*), caddisflies (*Cheumatopysche*, *Hydropsyche*)
Nonnative species: Asian clam, common carp, rainbow trout, possibly rudd
Major riparian plants: silver maple, box elder, hackberry, pecan, ash, American elm, sycamore, desert false indigo
Special features: upper portion strongly marl-depositing; marl dikes a prominent feature forming pools and small waterfalls; disjunct populations of seaside alder and redspot chub
Fragmentation: no large impoundments
Water quality: pH = 8.2, alkalinity = 186 mg/L as $CaCO_3$, NO_3-N = 1.65 mg/L, total phosphorus = 0.43 mg/L
Land use: 50% pasture, 20% cropland, 30% forest; no large cities
Population density: 18.9 people/km^2
Major information sources: Hoagland 2000, ONHI 2001, Reimer 1969, Vaughn 1997

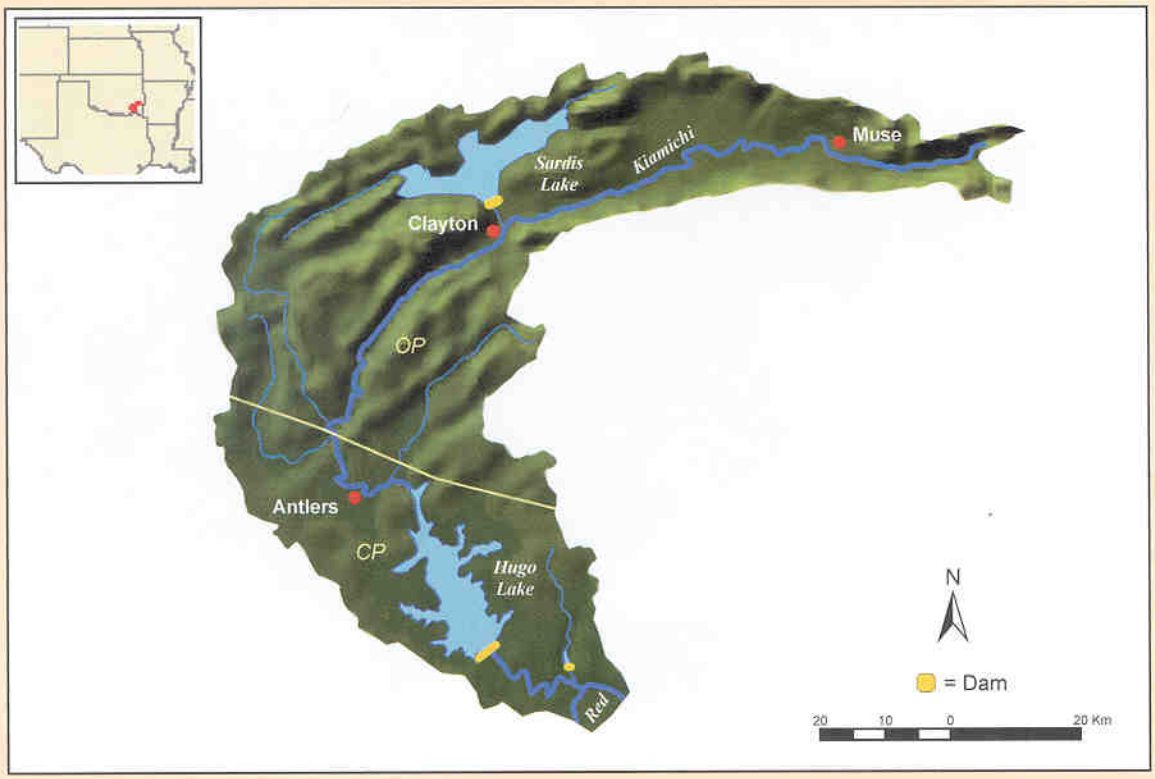

FIGURE 7.27 Map of the Kiamichi River basin. Physiographic provinces are separated by a yellow line.

KIAMICHI RIVER

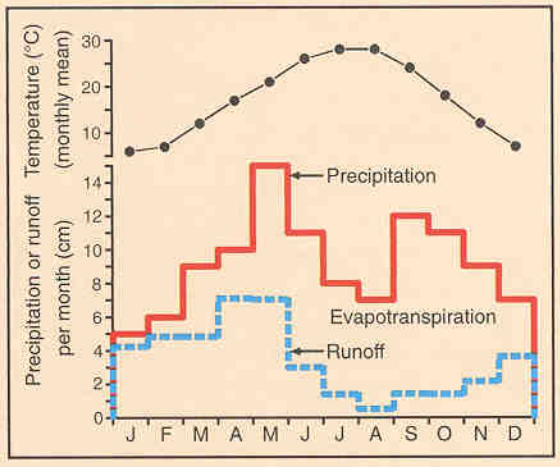

FIGURE 7.28 Mean monthly air temperature, precipitation, and runoff for the Kiamichi River basin.

Relief: 701 m
Basin area: 4650 km^2
Mean discharge: 48 m^3/s
River order: 5
Mean annual precipitation: 110 cm
Mean air temperature: 17°C
Mean water temperature: 16.7°C
Physiographic provinces: Ouachita Province (OP), Coastal Plain (CP)
Biome: Temperate Deciduous Forest
Freshwater ecoregion: Ouachita Highlands
Terrestrial ecoregions: Ozark Forests (although not in Ozark Mountains proper), Central Forest Grassland Transition Zone
Number of fish species: 86
Number of endangered species: 2 mussels
Major fishes: orangebelly darter, Johnny darter, dusky darter, central stoneroller, bigeye shiner, redfin shiner, rocky shiner, steelcolor shiner, spotted sucker, flathead catfish, smallmouth bass, spotted bass, largemouth bass, blackstriped topminnow, red shiner, gizzard shad, gars, blue sucker, river carpsucker
Major other aquatic vertebrates: snapping turtle, false map turtle, stinkpot turtle, spiny softshell turtle, plain-bellied water snake, cottonmouth, beaver
Major benthic invertebrates: 29 mussel species (threeridge, mucket, pigtoe, pimpleback) freshwater shrimp (*Palaemonetes kadiakensis*), crayfish (*Octonectes menae*), mayflies (*Stenonema*, *Caenis*), caddisflies (*Oecetis*, *Nectopsyche*), beetles (*Stenelmis*, *Microcylloepus*)
Nonnative species: Asian clam, common carp, striped bass in lower main stem, threadfin shad
Major riparian plants: silver maple, box elder, red maple, smooth elder, river birch, blue beech, ash, sweetgum, swamp tupelo, black gum, sycamore, cottonwood, willow oak, American elm, slippery elm
Special features: identified by The Nature Conservancy as one of most critical watersheds in United States for protecting freshwater biodiversity; population of endangered Ouachita rock pocketbook mussel; reintroduction of river otters
Fragmentation: one major impoundment on main stem; one major impoundment on tributary
Water quality: pH = 7.3, alkalinity = 120 mg/L as $CaCO_3$, NO_3-N = 0.31 mg/L, total phosphorus = 0.71 mg/L
Land use: 75% forest, 15% pasture, 10% crops; no large cities
Population density: 5.6 people/km^2
Major Information sources: Echelle and Schnell 1976, Hoagland 2000, Master et al. 1998, Moulton and Stewart 1996, Pigg and Hill 1974, Vaughn and Pyron 1995, Vaughn et al. 1996