Chapter 10

Missouri River Basin

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CHAPTER OUTLINE

INTRODUCTION

The Missouri River basin (MORB) is the second largest in the United States, surpassed in area only by the Mississippi River basin of which it is a part. It encompasses 4.2% (1,371,017 km^2) of the United States (including Alaska and Hawaii) and about 25,100 km^2 in Canada. The MORB trends in a northwest to southeast direction across the north-central United States (Fig. 10.2) and includes all or parts of 10 states, 2 Canadian provinces, and 29 Native American Tribal Reservations or Lands (74,500 km^2). Latitude of the basin ranges from 49.74°N in southwest Saskatchewan to 37.02°N in southeast Missouri.

About 20 Native American tribes belonging to four linguistic groups (Algonkian, Siouian, Caddoan, Shoshonean) lived in the MORB around 1500 CE. The Louisiana Purchase in 1803 put the entire MORB into Federal ownership and significant Euro-American expansion into the basin began in 1848 and the well-documented conflicts with Indigenous Americans ensued. Today, private, county, state, or Indigenous American tribes own about 86% of the basin.

FIG. 10.1 Morning aerial view of the lower Niobrara River in the Nebraska sandhills looking upstream from canoe access at State Highway 11, south of Butte, Nebraska. *(Photo by © Marek Uliasz | Dreamstime.com, ID 108128889.)*

Eight tributaries to the Missouri River are discussed in this chapter: Madison, Milk, Cheyenne, Niobrara, Big Sioux, Kansas, Grand (Missouri), and Osage rivers. These rivers extend over 88% of the Missouri River's total length and represent all three physiographic regions in the basin. All these Missouri River tributaries, except the Kansas and Grand, are fragmented by mainstem dams.

The MORB is one of the most important and contested interior basins of North America (Lokman, 2019). Over the past decade, a number of key events have underlined the need to reexamine the interrelationships among land and water, infrastructure, native species and their ecosystems, Indigenous sovereignty, and climate change. Most notable of these events include the Missouri River floods of 2011 and 2019, a record drought in 2012, the Bakken Formation fracking boom, protests surrounding the Keystone XL and Dakota Access Pipelines in 2016, and a 2018 U.S. Fish & Wildlife Service Biological Opinion on Missouri River endangered species and the ensuing Missouri River Recovery Management Plan.

Physiography and Climate

A wide range of climatic conditions, geologic complexity, and topographic relief exist within the three physiographic regions that contribute to the MORB. From west to east,

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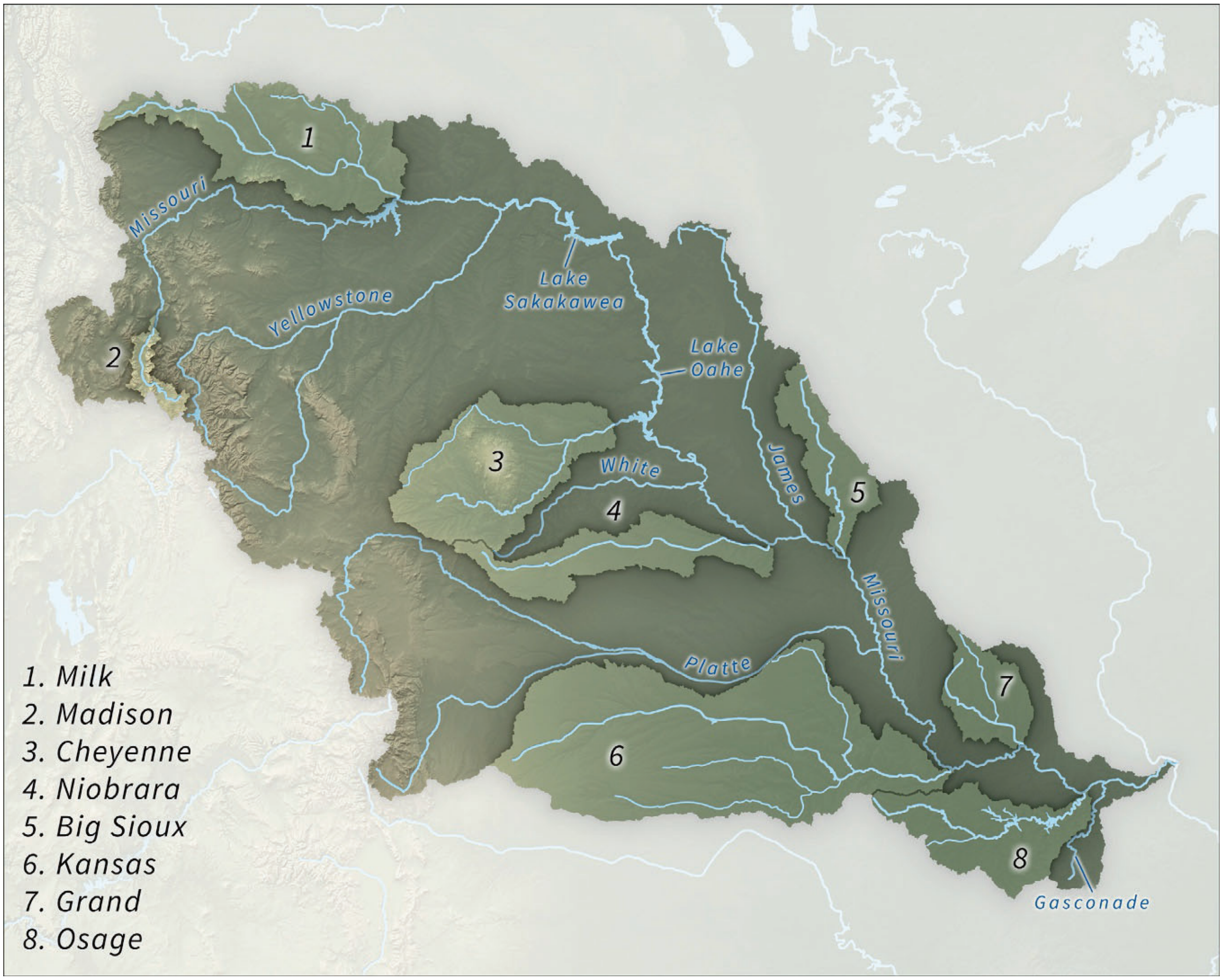

FIG. 10.2 Rivers of the Missouri River basin. Raised basin areas represent the focus rivers of the current edition. All other rivers are from the first edition of *Rivers of North America*.

these regions and the number of MORB physiographic provinces within each (parentheses) are: Rocky Mountain System (four), Interior Plains (two), and Interior Highlands (one). Basin elevation ranges from 4349 to 123 m asl. Its location near the geographical center of the North American continent results in wide climatic variations. Temperature, precipitation, and frost-free days vary greatly by latitude and altitude, and their ranges provided for the physiographic regions and provinces that follow are an integration of Wiken et al. (2011) and Kunkel et al. (2013). Runoff (1958–2019) to the Missouri River originates primarily at the upper and lower ends of the river in the Rocky Mountain System (11.2 cm/yr from the basin above Fort Benton, Montana) and the Central Lowland and Ozark Plateaus (28.2 cm/yr between Kansas City and Hermann, Missouri).

Rocky Mountain System. The Rocky Mountains form the MORB's western boundary and include about 10.7% (~142,400 km^2) of the Missouri River's U.S. drainage basin. Corresponding Level II terrestrial ecoregions include the Western Cordillera and Cold Deserts. The Rocky Mountains are characterized by great topographic relief, with mountain summits typically >1500 m above their bases. Missouri River headwaters originate along the eastern slope of the Rocky Mountain System that extends from Alberta, south to Colorado. This region is characterized by warm to cool summers and severe winters. Mean annual temperature and precipitation range from −9°C to 15°C and from 28 to >250 cm, respectively. Precipitation often arrives as snowfall and maximum annual snowfall of >400 cm/yr occurs. The frost-free period ranges from 25 to 140 days.

Interior Plains. Two MORB provinces occur within this vast physiographic region that spreads across much of central North America. Sloping eastward from the Rocky Mountains, the semiarid Great Plains province forms the heartland of the MORB and is its largest province, 70.3% (~932,400 km^2). It includes parts of Alberta, Saskatchewan, Montana, North Dakota, South Dakota, Colorado, Nebraska, and Kansas. Harsh winters, a short growing season, and prolonged droughts with frequent shorter periods of deficient moisture, interspersed with periods of abundant to excessive precipitation, are characteristic of the province (USACOE, 2018). Mean annual temperature and precipitation range from −1°C to 16°C and from <25 to 90 cm, respectively. The frost-free period ranges from 90 to 155 days.

The northern portion of the lower MORB is contained within the Central Lowland province and includes parts of North Dakota, South Dakota, Iowa, Nebraska, Kansas, and Missouri. Its western boundary with the Great Plains province approximates the 608 m asl contour and ~50 cm annual precipitation line (line from Jamestown, North Dakota to Salina, Kansas). It contributes about 17.1% (~227, 400 km^2) to the MORB's area and exhibits relatively flat relief with elevations ranging from 300 to 600 m asl. Most of the Central Lowland was glaciated during the Pleistocene, and glacial deposits of sands, gravels, and till dominate its contemporary surficial topography.

The northern portion of the Central Lowland province has a severe, mid-latitude, humid continental climate, marked by hot summers and cold winters with nearly continuous snow cover in the northernmost area. The southern portion exhibits a milder humid subtropical climate characterized by hot summers and mild to cold winters. Mean annual temperature ranges from about 1.5°C to 16°C, whereas mean annual precipitation ranges from 41 to 102 cm and occurs mainly during the growing season. The frost-free period ranges from 140 to 220 days.

Interior Highlands. The smallest physiographic region of the MORB, at about 2.0% (~28,300 km^2), is located in the southeast, lowermost basin and is represented by the unglaciated Ozark Plateaus province. The Ozark Plateaus are structurally and topographically a low, symmetrical dome of predominately dolomites and limestones with lesser quantities of shales, cherts, and sandstones. Highest elevations within this portion of the MORB range from 444 to 532 m asl. The Ozarks have karst topography; springs and losing streams (i.e., streams where discharge decreases due to groundwater losses) are common. This region is on the boundary between mild and severe mid-latitude climates and between humid continental and humid subtropical. It has hot summers and generally mild winters with no pronounced dry season. Mean annual temperature and precipitation range from about 11°C to 16°C and from 86 to 152 cm, respectively. Some snowfall occurs in winter, but generally lasts only a few days. The frost-free period ranges from 170 to 230 days.

Basin Climate Change. The MORB is projected to become warmer and wetter over the 21st century (Wise et al., 2018). This warming suggests that earlier, faster snowmelt could reduce stream flow in summer months, which would have major impacts on river-dependent resources and uses. The lower MORB has recently experienced increasing streamflow and flooding events; with a higher risk of extreme hydrologic impacts under predictions for an even wetter environment, there is a likelihood of more flooding (Qiao et al., 2014). Manifestations of decadal climate variability in the MORB have already been recognized as affecting river flows and reservoirs, riverine ecology, agricultural production, and urban water supplies (Metha, 2013).

Climatic effects on stream flows have not been uniform across the MORB. Norton et al. (2014) evaluated trends in stream flow for 227 stream gages in the MORB grouped into six regions for Water Years 1960–2011. Upward or downward significant trends in annual, monthly, and seasonal stream flow were pervasive within three regions. Downward trends occurred in upper Missouri River headwaters (25% of total stream flow), an important region for snowpack runoff into main-stem reservoirs. There were significant upward trends in the Great Plains and Central Lowland physiographic provinces and Niobrara River (10% of total stream flow), represented by a mix of semiarid prairies in the west and temperate prairies in the east that contribute streamflow to Lewis and Clark Lake. Significant downward stream flow trends occurred in the Kansas River basin (9% of total streamflow). This region is dominated by the South-Central Semiarid Prairies Level II terrestrial ecoregion transitioning to Temperate Prairies Level II terrestrial ecoregion in the easternmost portion. The Lower Missouri River (Osage, Grand, and Gasconade rivers) region is the largest water source to the Mississippi River (44% of total streamflow) as it flows from the Temperate Prairies Level II terrestrial ecoregion to the north into the Southeastern USA Plains and Ozark/Ouachita-Appalachian Forests Level II terrestrial ecoregions. This region showed significant upward trends in annual stream flow with subregional differences in upward trends among seasons.

Basin Landscape and Land Use

Seven Level II terrestrial ecoregions are represented in the MORB (Wiken et al., 2011; Omernik and Griffith, 2014), reflecting its diverse altitudinal, latitudinal, and climatic gradients. From west to east these ecoregions include the

Western Cordillera and its coniferous forests and alpine meadows of the Rocky Mountain System. Foothills here are partly wooded or shrub- and grass-covered; intermontane valleys are typically grasslands and shrublands. A small area of the Cold Deserts (i.e., Wyoming Basin) ecoregion, where arid grasslands and shrublands contrast with the surrounding forested mountains of the Western Cordillera, contributes to the headwaters of the Yellowstone and North Platte rivers.

The Great Plains (Interior Plains and Central Lowland provinces) portion of the basin includes the West-Central Semi-Arid Prairies, Temperate Prairies, and South Central Semi-Arid Prairies Level II terrestrial ecoregions. Vegetation here grades from short and mixed grasslands to tall grasslands and a grassland/deciduous forest mosaic. The Missouri River corridor from about central Missouri to the river's terminus is contained within the Southeastern USA Plains Level II terrestrial ecoregion. Bottomland deciduous forests and swamp forests were once extensive on poorly drained, nearly level, lowland sites, but most have been replaced by cropland. The Ozark, Ouachita-Appalachian Forests Level II terrestrial ecoregion (Interior Highlands region) constitutes the southeast corner of the basin. The vegetation mosaic here is characterized by oak-hickory and oak-hickory-short leaf pine forests; savannas and tallgrass prairies were historically more common.

Approximately 15.5 million people live in the MORB (2012 census information, USACOE, 2018). The basin contains some of the United States' most sparsely populated agrarian counties, as well as more than 2000 urban communities, including large metropolitan areas such as Omaha, Nebraska, Kansas City, Missouri, and Denver, Colorado, located adjacent to the Missouri River or its major tributaries (Mehta et al., 2012). Ninety-two percent of land within the basin was in agriculture during the mid-1970s (Missouri River Basin Commission, 1977), but by 2018, this was reduced to 62% (USACOE, 2018). Rangeland is the predominant contemporary use (37%), followed by cropland (27%), forest and woodlands (15%), shrubland (11%), developed (3.8%), wetlands (3.7%), and water (1.8%) (USACOE, 2018). The MORB is an essential food-producing region of the United States and the world (Mehta et al., 2012). Grain crops provide much of the MORB's agricultural income. The basin produces approximately 46% of U.S. wheat, 22% of its grain corn, and 34% of its cattle. About 47.4 million ha (474,000 km^2) are in cropland and of this, about 4.9 million ha are irrigated; thus, almost 90% of the basin's cropland is entirely dependent on precipitation. Estimated value of crops and livestock produced in the basin was over $100 billion in 2008 (Mehta et al., 2012).

Metallic minerals (gold, silver, copper, zinc, molybdenum) are important subsurface resources in the Rocky Mountains and non-metallics such as fluorspar, feldspar, phosphate, lime, mica, bentonite, and construction aggregate are also mined within the basin. Energy fuels are the basin's largest and most valuable resource commodity. The Bakken formation has emerged as one of the most important new sources of crude oil, and most U.S. Bakken oil production is within the Williston basin of Montana, North Dakota, and South Dakota. North Dakota ranked second in the nation for crude oil production in 2019 and experienced more than a 10-fold increase in annual production from 1981 (about 519 million barrels in 2019 vs. 45 million barrels in 1981; U.S. Energy Information Administration, 2020). Oil fracking demands for water from the Missouri River and its tributaries (e.g., Little Missouri River) are anticipated to be great and will exacerbate already contentious conflicts among MORB water users (St. Louis Beacon, 2012). The North Dakota Industrial Commission projects that 28,000 new oil wells could be drilled in the state during the next 15–25 years, requiring >75,700 m^3 of water per day (Congressional Research Service (CRS), 2012). This amount of water cannot be met from groundwater or non-Missouri River surface water sources, but requires direct access to water stored in Lake Sakakawea.

The MORB's mainstem is fragmented by six U.S. Army Corps of Engineers reservoirs (USACOE, 2018). These reservoirs contain about 89.3 km^3 of storage capacity, constituting >50% of the total storage in the MORB's >17,200 reservoirs. This system is the largest reservoir complex in the United States. It contains 84% of the basin's federal hydroelectric power capacity, provides most of the flow support for downstream navigation, and contributes greatly to flood protection for >809,400 ha of Missouri River floodplain. Collectively, these reservoirs provide about 398,200 ha of water surface area for recreation and fish and wildlife benefits.

The Rivers

The southern limit of continental glaciation largely defines the present course of the Missouri River. Tributaries to the mainstem within the Great Plains show unequal development (Fig. 10.2; Johnson et al., 1976). Tributaries on the west (only lightly glaciated) of the Missouri are larger and represent well-developed drainage systems dating to the early Tertiary (e.g., Knife, Cheyenne, and White rivers). Tributaries to the east (glaciated) side are small and have developed only since melting of the Wisconsin ice.

Three freshwater ecoregions (Upper Missouri, Middle Missouri, and Central Prairie; Abell et al., 2000) containing 47 rivers with drainage basins >1000 km^2 contribute to the Missouri River (Galat et al., 2005). Much of the Upper Missouri freshwater ecoregion was heavily glaciated 10–15,000 years ago and as a result has no known endemic fish, mussel, crayfish, or herpetofauna species (Abell et al., 2000). This ecoregion is largely fragmented by the mainstem Missouri River reservoirs and is subject to increasing water withdrawals from the aforementioned boom in oil production and potential contamination from oil pipeline transport. Nevertheless, above Lake Sakakawea (Fig. 10.2), the Missouri River and several tributaries (e.g., Yellowstone, Milk) support the largest wild population of the federally endangered pallid sturgeon; however, no natural recruitment occurs and the population is presently being maintained through stocking.

Similar to the Upper Missouri freshwater ecoregion, the northern portion of the Middle Missouri freshwater ecoregion was recently glaciated and that portion in the Great Plains province is semiarid with limited freshwater habitats outside of prairie potholes. These factors also result in no known endemic riverine freshwater species (Abell et al., 2000). Endangered pallid sturgeon use the mainstem Missouri River, and there are recent records from lower reaches of several Middle Missouri ecoregion tributaries (White, Niobrara (Fig. 10.1), James, Big Sioux, Platte, and Kansas rivers), but most, if not all, of these fish are of hatchery origin.

Many Missouri River tributaries in the Central Prairie freshwater ecoregion are meandering with low to moderate discharge. Flooding frequently occurs during extreme spring rain events due to high regional precipitation and the absence of mainstem dams. There is relatively low endemism of aquatic species, with most found in the Osage River and discussed in that section. Endangered pallid sturgeon use the mainstem Missouri River; wild individuals have been collected, and very limited natural recruitment has been recorded. Adults have also been recorded from the lower Grand River in this ecoregion.

Conservation status of imperiled MORB fishes by freshwater ecoregions was compiled by Jelks et al. (2008; see for definitions of terms) and updated from a previous 1989 report. Fifteen fish species are considered imperiled basinwide and of these two are endangered (pallid sturgeon, Topeka shiner), four are threatened (Alabama shad, pugnose shiner, Arctic grayling, and Ozark cavefish), and nine are vulnerable (i.e., in imminent danger of becoming threatened: lake sturgeon, paddlefish, alligator gar, western silvery minnow, plains minnow, sturgeon chub, sicklefin chub, blue sucker, southern cavefish). Since 1989, the status of five species remains the same, two species have improved (lake sturgeon, sicklefin chub), one has declined (Arctic grayling), and seven new species have been added. Eight of the 15 species listed are imperiled basinwide. One species (Topeka shiner) is imperiled in the Middle Missouri and Central Prairie freshwater ecoregions. One species is imperiled in the Upper Missouri ecoregion (Arctic grayling), one in the Middle Missouri ecoregion (pugnose shiner), and two in the Central Prairie ecoregion (Ozark cavefish and southern cavefish).

Thirty-seven tributaries with drainage areas $\geq$3000 km^2 enter the Missouri River. Those we discuss further (Fig. 10.2) are *italicized* below, and tributaries reported in the first edition are underlined. Ten tributaries have their origins within the Rocky Mountain System, including from upriver to downriver: Jefferson, *Madison*, Gallatin, Judith, Sun, Marias, *Milk*, Musselshell, Yellowstone, and Platte rivers. Rivers of similar minimum basin area that originate in the Great Plains province include the Dry, Redwater, Poplar, Big Muddy, Little Missouri, Knife, Heart, Cannonball, Grand, Moreau, *Cheyenne*, Bad, White, *Niobrara*, and *Kansas*. The James, Vermillion, *Big Sioux*, Little Sioux, Nishnabotna, Platte (Missouri), *Grand* (Missouri), Chariton, Lamine, and *Osage* rivers originate entirely or partially within the Central Lowland province. Four rivers—Lamine, Moreau (Missouri), *Osage*, and Gasconade rivers—have part or all of their headwaters in the Ozark Plateaus province.

MADISON RIVER

The Madison River originates in Yellowstone National Park, Wyoming, at the junction of the Firehole and Gibbon rivers. The Madison Valley, prior to westward expansion, was not home to large numbers of Native Americans. The Shoshone and Bannock tribes periodically journeyed through the valley and occasionally established seasonal hunting camps. Named by Meriwether Lewis in 1805 after the U.S. Secretary of State James Madison, it flows northerly for 240 Rkm to Three Forks, Montana, where it joins the Jefferson and Gallatin rivers to form the Missouri River (Figs. 10.3 and 10.11). Total area of the Madison River basin is 6747 km^2. The Madison River has two impoundments, Hebgen Reservoir (Hebgen Dam) and Ennis Reservoir (Madison Dam). Hebgen Reservoir is located about 2 km outside the boundary of Yellowstone National Park, and Ennis Reservoir is located approximately 100 Rkm downstream of Hebgen Reservoir.

The Madison River traverses a high-forested plateau in Yellowstone National Park to Hebgen Reservoir, after Hebgen Reservoir it enters a wide valley bookended by

FIG. 10.3 Lower Madison River near Three Forks, Montana, at the confluence of the Jefferson River *(lower right)*. *(Photo by Christopher Guy.)*

mountains—Madison Range to the east and the Gravelly Range and Tobacco Root Mountains to the west. Much of the basin is coniferous forests with valley bottoms dominated by montane sagebrush steppe where the land is used for cattle production. Groundwater sources from Yellowstone National Park influence the seasonal flow pattern of the Madison River by stabilizing discharge; thus, the Madison River discharge is more characteristic of a large spring-creek than a snow-melt mountain stream.

Physiography, Climate, and Land Use

The Madison River is formed near Madison Junction, Yellowstone National Park, in the Middle Rocky Mountains physiographic province. It then transitions to the Northern Rocky Mountains physiographic province where it exits the west side of Yellowstone National Park near West Yellowstone, Montana (Fig. 10.11). The Madison River is in the Middle Rockies Level III terrestrial ecoregion (Omernik and Griffith, 2014), characterized by conifer forests at higher elevations, with conifers transitioning to montane sagebrush steppe.

The climate of the Madison River basin is highly variable depending on elevation and is characteristic of high-elevation montane weather associated with forests and sagebrush steppe. Mean annual air temperature is −1.8°C at West Yellowstone and is 7.3°C at Three Forks, where the Madison River joins the Jefferson River (Fig. 10.12). The elevation of the Madison River at the confluence of the Fire Hole and Gibbon rivers is 2066 m asl, and the elevation where the Madison River meets the Jefferson River is 1232 m asl. Average rainfall varies from 34 cm/yr in Ennis, Montana, to 55 cm/yr in West Yellowstone, Montana, but is highest in May and June (>7 cm/mo). Precipitation in the form of snow is important to the hydrology of the Madison River, and similar to rainfall, it is highly variable across the basin. Ennis receives an average of 114 cm/yr of snow, and West Yellowstone receives 406 cm/yr.

Land use varies in the Madison River basin from 48% in public ownership used for timber harvest in conifer forests of high elevations (managed by the U.S. Forest Service) to 52%

in private ownership used for livestock and hay production in lower elevations. About 6400 ha of land is irrigated in the Madison River Valley from the Madison River and its tributaries (Tuck, 2001). Irrigation occurs primarily from ditch irrigation where irrigation diversions move water directly from the Madison River and its tributaries to supply canals.

River Geomorphology, Hydrology, and Chemistry

The Madison River is in a seismically active basin and runs roughly parallel to numerous faults, including the Madison Range Fault. On August 17, 1959, a 7.1 magnitude earthquake occurred near Hebgen Dam. A barrier created by the rock landslide, approximately 1 km downstream of Hebgen Dam, formed Quake Lake (Murphy and Brazee, 1964). The outlet to Quake Lake limits the maximum flow volume that can be released from Hebgen Dam (built in 1914) because of the risk of catastrophic bed-material movement at higher discharges. Hebgen Reservoir has a surface area of 5400 ha and a catchment area of 2340 km^2; it is used for water storage and occupies approximately 20% of the glacial valley. The river between Hebgen Dam and Ennis Reservoir (approximately 100 Rkm) is primarily single channel and dominated by wide, shallow riffles, boulders, and large cobble substrate. Substantial braiding occurs downstream of Ennis, Montana, until the Madison River enters Ennis Reservoir (~5 Rkm). Ennis Reservoir (1580 ha) is formed by Madison Dam, constructed in 1906 for power generation. Madison Dam was constructed at the northwestern edge of the Madison Range, at the head of a steeply incised canyon eroded from gneiss and schist from the Archean period (Kellogg and Williams, 2000). Below this structure, the river increases in grade and continues for 17 Rkm, emerging into a large Holocene era alluvial valley, traveling approximately 44 Rkm, before it combines with the Jefferson and Gallatin rivers to form the Missouri River.

May and June were the only months that had peak flow events (i.e., above the 50% annual exceedance probability). Flooding from ice gorging near Ennis and Three Forks, Montana, is commonplace with some ice dams migrating upstream 21 km during harsh winters (Stevens, 1940). Baseflow most years is reached by the end of July or the first week of August. Average annual discharge at McAllister was 49.0 m^3/s with 16% interannual variability from 1939 through 2020. Annual discharge varied from a low of 29.6 m^3/in 1941 to maximum of 68.6 m^3/s in 1971. June has the highest discharge average of 82.8 m^3/s and is a result of mountain snowmelt; conversely, the lowest average discharge occurs in January at 38.8 m^3/s (Fig. 10.12). The discharge in the Madison River is most variable in June (38%). The 1% exceedance probability or 100-year event using data collected between 1960 and 2016 was calculated as 289 m^3/s (Anderson, 2018).

Arsenic, fluoride, and mercury are greatly elevated upstream of Hebgen Dam. The median dissolved arsenic concentrations in the Madison River near West Yellowstone, Montana, was 270 μg/L, well above state and federal drinking water standards. Average water chemistry metrics at Varney Bridge from 1976 to 2006 were: pH = 8.2, turbidity = 6.52 NTU, alkalinity = 89.4 mg/L as $CaCO_3$, ammonia total = 0.03 mg/L, total phosphorus = 0.03 mg/L, and total arsenic = 0.09 mg/L.

Maximum annual water temperatures (subsurface release) exiting Hebgen Reservoir approach 19°C. Maximum water temperatures increase gradually in a downstream direction with annual maxima exceeding 28.9°C near the confluence with the Jefferson River.

River Biodiversity and Ecology

The Madison River is in the Upper Missouri freshwater ecoregion (Abell et al., 2008), which has no known endemic aquatic species.

Algae and Cyanobacteria

Headwater portions of the Madison River that flow through active geyser geology in Yellowstone National Park exhibit fivefold increases in algal growth rate. Increased rates of growth were attributed to warmer water temperatures and light-dependent incorporation of CO_2 (Wright and Mills, 1967; Boylen and Brock, 1973). Warmer water temperatures also select for thermophilic species of algae over cool-water species; *Phormidium tenue* is most prevalent with the thermophiles *Synechococcus lividus* occurring up to 32 km downstream of the Madison River hot springs in Yellowstone National Park (Jackson and Castenholz, 1975). The dominant species of algae throughout the Madison River is *Cladophera glomerata* (Dodds, 1991).

Plants

The Madison River and its tributaries in Yellowstone National Park host relatively dense and diverse populations of macrophytes, which has partially been attributed to higher levels of soluble CO_2 (Horpestad, 1969; Klarich, 1977). Backwaters and edge habitats throughout the Madison River mainstem support isolated areas of cattails and nonnative curlyleaf pondweed. The Madison River flows through a lower forest-valley ecotone of Idaho fescue, needlegrass, wheatgrass, and graminoids alternating with sagebrush communities. Riparian vegetation of tributaries and the Madison mainstem include stands of willows, cottonwoods, birches, alder, aspen, dogwood, and areas of wet grasslands.

Invertebrates

Percent composition of Ephemeroptera, Plecoptera, and Trichoptera (EPT) exceeds 50% of total species composition in most reaches of the Madison River from the headwaters to the confluence. Diptera, Coleoptera (Elmidae), and non-insects including the snails *Fossaria* and *Physa* are present, although at lower densities than the combined EPT taxa. Most of the Madison River supports cold-water or eurythermal macroinvertebrate taxa. Numerous high-density assemblages of EPT inhabit the cobble-boulder substrate upstream of Ennis Reservoir. However, geothermal areas of the Firehole River, Gibbon River, and upper Madison River in Yellowstone National Park exhibit distinct assemblages of aquatic invertebrates tolerant to low pH, high water temperature, and elevated concentrations of chemicals. For example, elmid beetles, blackflies, *Chironomus*, and the caddisfly *Brachycentrus* increase in dominance in geothermal areas (Clements et al., 2011).

Annual emergence of the salmonfly (giant stonefly; *Pteronarcys californica*) is of significant ecological importance to the Madison River. This iconic insect, often exceeding 6 cm in adult size, emerges synchronously over a short period, from the third week in June to the first week of July. The seasonal pulse of carbon from salmonfly emergence is important to numerous aquatic and terrestrial species (Walters et al., 2018). Recent evidence indicates that temperature-driven changes have occurred in salmonfly distribution and body size in the Madison River over the four decades preceding 2017 (Anderson, 2018).

The western pearlshell is the only cold-water mussel in Montana. It requires a host fish, historically the cutthroat trout, for distribution of glochidia. This pearlshell persists in the upper Madison River in Yellowstone National Park, but is extirpated in the lower Madison River below Beartrap Canyon.

Vertebrates

The fish assemblage in the Madison River includes 16 species from five families of which 12 are native to at least some reaches within the basin. Native westslope cutthroat trout, mountain whitefish, and Arctic grayling were the primary fishes prior to westward expansion and colonization in the late 18th century. Overharvest caused the subsequent federal and state stocking programs for nonnative rainbow trout and brown trout in the mainstem Madison River and its tributaries. Brook trout were also extensively stocked and are in many of the headwater streams of the Madison River basin. Remnant populations of genetically pure or hybridized populations of westslope cutthroat trout occupy some first and second-order streams, often upstream of natural (waterfalls) or manmade (e.g., culverts, irrigation dams) barriers. Arctic grayling are extirpated in the Madison River basin despite reintroduction efforts. The Rocky Mountain sculpin is abundant throughout the Madison River and its tributaries. The Madison River between Hebgen Dam and Ennis Reservoir is a legendary trout fishery; high densities of trophy-sized fish (400–500 mm) bring anglers, particularly for fly fishing, from all over the world. In some river reaches, average combined densities of brown trout and rainbow trout ($\geq$150 mm) are 2600 fish/km. Other species native to the Madison River are restricted to the last 30 Rkm upstream of the confluence with the Jefferson River; these are stonecat, longnose sucker, mountain sucker, white sucker, longnose dace, and northern redbelly dace. Utah chub were introduced by bait fishermen to Hebgen Reservoir at the turn of the 20th century.

Herpetofauna of the Madison River basin include frogs and toads (five species), snakes (eight species), one species of lizard (greater short-horned), and one salamander (western tiger salamander). The most common representatives of these groups in the Madison River basin are the Columbia spotted frog and western toad.

Records for 259 species of birds have been reported for the Madison River basin; of these, 215 have been confirmed to breed in the basin. This list includes passerines (110 species), waterfowl (22 species), grebes (4 species), and 14 species of falcons, hawks, and eagles. Species common to the Madison River corridor include sandhill crane, American white pelican, American dipper, great blue heron, spotted sandpiper, and mallard duck. Osprey are commonly seen nesting high in cottonwoods and tall human-constructed structures. In addition, moose, white-tailed deer, muskrat, and North American beaver are found along the river.

Ecosystem Processes

As previously mentioned, salmonfly nymphs may be a significant component of autochthonous and allochthonous detritus processing and provide important subsidies for a variety of terrestrial and aquatic consumers. Historically and currently, salmonids have been the numerically dominant tertiary consumer throughout the Madison River. Despite near replacement of native westslope cutthroat trout and Arctic grayling with nonnative trout in the mainstem Madison River and its tributaries, the Madison River supports world-renowned population densities of resident, fluvial, and adfluvial trout. Differences in aquatic and riparian linked food webs due to widespread species replacement are unknown, but may be noteworthy.

Human Impacts and Special Features

The Madison River near Three Forks, Montana, was identified in 1805 by Anglo-Americans during the Lewis and Clark expedition. From the early 1800s to 1850s, Anglo occupation was limited to fur trappers primarily in pursuit of beaver. Southwest Montana post-1860s was heavily prospected for gold. In 1863, a rich placer deposit of gold was discovered in Alder Gulch (Ruby River), approximately 32 km west of Ennis, Montana. Within a year, Virginia City grew to a population of 10,000. Cattle and horses became important commodities in support of the early gold rush.

Seasonal cattle grazing along riparian areas and bench lands of the Madison River was essentially uncontrolled until after 1870. By 1890, approximately 16,000 horses, 38,000 cattle, and 25,000 sheep seasonally occupied the Madison Valley. By 1930, sheep numbers exceeded 210,000 in Madison County (Wyckoff, 1991). Livestock numbers steadily increased until the severe drought of 1934 and subsequent federal regulation of public lands through the Taylor Grazing Act. Cattle ranching and hay production remain a dominant source of income for landowners in the Madison Valley.

Water use in Montana is governed by the prior appropriation doctrine (i.e., first in time, first in right). The Madison River basin is a closed basin with restrictions on new appropriations of water. The main water use in the basin is for hydropower, stock watering, and hay production. Ditch irrigation is common, but has been replaced in some areas with center-pivot sprinklers.

Angling, particularly fly fishing, has been practiced on the Madison River since at least the early 1930s. From the late 1950s to the late 1990s, yearly angler days varied between 50,000 and 75,000. Since 1999, recreational angling has increased 200% with a record 207,334 angler days in 2017. As such, the economic contribution from fishing and fishing-related activities is substantial. Eighty percent of the angling pressure between Hebgen Dam and Ennis Reservoir is from non-residents. At an average of $650 U.S. per day of expenses (Lewis and King, 2014), over $100 million U.S. is spent by out-of-state anglers in 100 Rkm of the upper Madison River over the fishable year.

Harvest of fish is virtually nonexistent in the Madison River. Catch-and-release angling has become the cultural norm on many rivers in southwest Montana. In 2017, 1262 individual interviews were conducted on the Madison River during a year-long creel survey and no fish were harvested between Quake Lake and Ennis Reservoir. Post-release mortality is becoming an increasing concern, particularly during high use in the months of June and July. Individual rainbow trout are caught on average five times per year in heavily fished reaches of the Madison (Horton et al., 2017).

Another concern for the Madison River is the introduction of aquatic nonnative species. The extraordinary amount of boat traffic throughout the large boatable rivers of Montana makes prevention and control difficult. Another potential source of aquatic nonnative species introduction is stocking of private ponds, which are becoming more common in the basin.

Areas of Need for Research and Management

Climate change is resulting in higher water temperatures, altered runoff timing, and often reduced baseflow. Cumulatively, these changes may limit survival of cold-water aquatic species, especially in the reach of the Madison River downstream from Madison Dam. Maximum water temperatures have increased nearly 2°C from the 1960s and 1970s (Travis Horton, Montana Fish, Wildlife and Parks, unpublished data, 2020) below Madison Dam despite ongoing artificial pulses released to attenuate peak water temperatures during summer months. In some years, these elevated summer river water temperatures (>28°C) have resulted in mortality of rainbow trout and brown trout. Under current climate-change scenarios, the control of summer water temperature maxima through increases in discharge may be inadequate for maintenance of this popular trout fishery. Research is needed to better understand water temperatures that will result in major changes to aquatic biota as well as viable solutions to the impending loss of this popular fishery.

Recreational use levels (angling and floating) continue to increase on the Madison River. Research is needed to determine population-level effects of repeated hooking events on wild trout and mountain whitefish. Aside from the level of angling pressure previously stated, the Bureau of Land Management estimates that over 600,000 floater launches occurred on the lower Madison River during summer 2018. Research is needed to understand and predict how recreational use in general influences the aquatic biota in the Madison River with an eye to conserving this important river for future generations.

MILK RIVER

The Milk River originates along the eastern foothills of the Rocky Mountains in western Montana and courses 1173 Rkm to its confluence with the Missouri River through a basin that includes portions of Montana, southeastern Alberta, and southwestern Saskatchewan (Fig. 10.4). Basin contributions from Alberta and Saskatchewan establish the Milk River as the northernmost river system draining to the Gulf of Mexico, and one of three Canadian basins draining to the Gulf. Behind the backdrop of a sparsely populated basin and broad expanses of grasslands and arable lands, the need for water in this semiarid landscape has pushed the Milk River to the center of international, and transboundary, water issues dating from the late 1800s and early 1900s (Halliday and Faveri, 2007).

An early account of the Milk River was provided by Captain Meriwether Lewis on May 8, 1805, at the Milk River confluence area: "……the bottoms of this stream are wide, level, fertile and possess a considerable proportion of timber, principally cottonwood…….the water of this river possesses a peculiar whiteness, being about the colour of a cup of tea with the admixture of a tablespoon full of milk. From the colour of it's [*sic*] water we called it Milk River" (Moulton, 1987).

Physiography, Climate, and Land Use

The Milk River flows through the mid-latitudes of the Great Plains physiographic province (Fig. 10.13) within an international and cross-provincial basin that includes portions of five Level III terrestrial ecoregions (Wiken et al., 2011;

FIG. 10.4 Milk River and Badlands in Writing-on-Stone Provincial Park, Alberta, Canada. *(Photo by © Photawa | Dreamstime.com, ID 12808218.)*

MRWCC, 2013). The Northwestern Glaciated Plains Level III terrestrial ecoregion composes the majority of the basin, extending from the foothills of the Rocky Mountains at the river's source, through southeastern Alberta, southwestern Saskatchewan, and continuing easterly through northern Montana to its confluence with the Missouri River. Other Level III terrestrial ecoregions include the Cypress Uplands on the northern margin of the basin with the Canadian Rockies along the far-western margin and fragmented portions of the Middle Rockies and Northwestern Great Plains ecoregions along its southern border (MRWCC, 2013).

The basin is mostly underlain by Cretaceous deposits of the Claggett/Pakowki formations, overlain by Belly River/Judith River formations, Bearpaw Shale, and surficial sediments (Petre et al., 2016). Much of the basin was affected by glacial activity, except higher-elevation igneous and erosional remnants of the Sweet Grass Hills, Cypress Uplands, and Little Rocky Mountains. These unique formations add ecosystem diversity to the more typical rolling plains/prairie attributes of the basin. Glacial deposits and badland erosion in the upper basin along with erosion of silt-clay sediments across the drainage network contribute to its "milky" nature.

Broad climatic variations exist across the nearly 200 km north to south and 500 km east to west basin, where elevation diminishes from 2663 m asl in the Rocky Mountains to 619 m asl at the river's terminus. As the dominant ecoregion, the Northwestern Glaciated Plains represents a mid-latitude, mostly dry steppe environment where winters are cold and summers are warm to hot (Wiken et al., 2011). Mean annual air temperature near the river's mouth is 6.3°C at Glasgow, Montana, with temperature extremes in January (mean = −10.1°C) and July (mean = 21.7°C; Fig. 10.14). Precipitation varies from 0.7 to 6.7 cm among months, averaging 29.5 cm/yr. Slightly cooler (mean annual temperature = 4.8°C) and moister conditions (mean annual precipitation = 38.2 cm/yr) characterize the Cypress Uplands ecoregion along the northern border of the basin in Alberta and Saskatchewan.

The majority of the 59,857 km^2 basin lies in Montana (65%), followed by Saskatchewan (24%), and Alberta (11%; MRWCC, 2013). The basin is sparsely populated (2012 population = 44,773 people; density = 0.75 people/km^2) with 79%, 15%, and 6% of the population base located in Montana, Saskatchewan, and Alberta, respectively. Indigenous peoples and lands include the Blackfeet, Gros Ventre, Assiniboine, Sioux, Nekaneet, and Chippewa-Creek tribes. Land coverage is about 51% grassland, 30% cropland (e.g., small grains, alfalfa), 12% shrubland, 4% water and wetlands, 2%

non-vegetated badlands, 2% forest, and 1% urban (MRWCC, 2013). Large waterbodies include water-storage facilities (Fresno Reservoir, Nelson Reservoir) and Lake Bowdoin in Montana. Although the basin retains high densities of semi-permanent and seasonal wetlands in some areas, an estimated 64%, 40%, and 25% of wetlands in Alberta, Saskatchewan, and Montana, respectively, have been lost due to draining and other anthropogenic alterations (MRWCC, 2013).

River Geomorphology, Hydrology, and Chemistry

The mainstem Milk River and its additive North Fork originate in western Montana along the east-slope foothills of the Rocky Mountains. It initially flows northeasterly from the Blackfeet Reservation in Montana, across southern Alberta, then back into and through central Montana. After receiving tributary inputs from Alberta, Saskatchewan, and Montana portions of the basin, the Milk River courses southeasterly to enter the Missouri River near Nashua, Montana. Formation of the Milk River and its basin was largely driven by glacial processes, and the basin maintains a state of geomorphic evolution in response to continued erosion and anthropogenic alteration. The pre-glacial Milk River flowed northward, but was diverted 40–60 km southward by glacial activity to its present-day location in Alberta (Beaty, 1990). Glacial meltwaters cut a deep, wide river valley with flows much greater than presently occur, establishing the Milk River as an underfit river (Beaty, 1990).

The morphology of the Milk River changes markedly as it courses west-to-east through southern Alberta and southeasterly through Montana. The upper river through Alberta and into northern Montana transitions from meandering to braiding (Simpson and Smith, 2001). The meandering segment extends about 245 Rkm downstream from its confluence with the North Fork, coursing through deep valleys and highly erodible badlands. The upstream portion of this meandering segment flows through mixed gravel-sand bed material, has a gradient of 1.3–1.9 m/km, and channel width varies from 45 to 85 m (AMEC, 2008). The downstream portion of the meandering segment transitions primarily to sand, slope decreases (0.5–0.6 m/km), and stream width increases to 70–120 m. After entering northern Montana, the river changes to a wide (110–160 m) braided channel where slope diminishes to 0.47 m/km and fine sediments increase near the headwaters of Fresno Reservoir (Simpson and Smith, 2001). Through the 700-Rkm long distance between Fresno Dam and the mouth, a series of dams and weirs confine flows primarily to a single channel, slope diminishes, and fine bed material predominates among patches of gravel (Stash, 2001).

Hydrology in the Milk River is driven by a combination of processes including natural catchment inputs, trans-basin diversion, and broad-scale water development projects. Natural flow in the Milk River has been augmented since 1911, when water draining to Hudson Bay was re-routed across the drainage through the 47 km St. Mary diversion into the North Fork. The adjacent St. Mary River system provides a larger and more reliable water supply than the lower-flow upper Milk River due to snow- and glacial-melt (USBR, 2012). Demands on St. Mary River waters and pre-emptive water infrastructure that routed water back to Canada (deemed the "Spite Ditch") led to an international dispute and ultimately the creation of the International Joint Commission in 1909 (Wolfe, 1992). Diversion of St. Mary's water to support irrigation typically occurs from April through October when discharge of the mainstem Milk River through Alberta and northern Montana is about three times greater ($\sim$18.0 m^3/s) than pre-diversion conditions (6.0 m^3/s; Bradley and Smith, 1984). St. Mary diversion flows have temporally shifted discharge regimes in the upper and middle portions of the basin. Peak flows prior to diversion typically occurred in late March-early April, but now occur during late May-early June (Simpson and Smith, 2001) (Fig. 10.14). Fall and winter base flows in the upper Milk River are low after augmentation from St. Mary's River is terminated.

In the central region of the basin near Havre, Montana, the Milk River enters Fresno Reservoir, impounded by Fresno Dam. Fresno Reservoir is the first in a series of dams and weirs, water storage projects, and diversions designed to meet irrigation and municipal needs for the next 700 Rkm. Downstream from Vandalia Diversion Dam, the lowermost dam on the system, the Milk River flows unencumbered for 190 km to its confluence at the Missouri River (Stash, 2001). Several tributaries (e.g., Lodge Creek, Battle Creek, Big Sandy Creek, Beaver Creek, Frenchman River) enter in the middle and lower portions of the basin.

The Milk River at its mouth near Nashua, Montana, has a mean annual discharge of 19.2 m^3/s (1939–2019). Mean annual discharge through the 80-year period of record has been highly variable (81.0%), ranging from 1.6 m^3/s (1984) to 97.0 m^3/s (2011). Average monthly discharge is $>$30 m^3/s during March through June, but is greatest in April (59.6 m^3/s) when runoff is elevated (Fig. 10.14). Discharge diminishes to $<$10 m^3/s during summer through fall irrigation extractions (USBR, 2012). Monthly discharge is highly variable across years, ranging from 57% in December to 256% in October.

The Milk River's elevated sediment load is one of its most recognized attributes. Suspended sediment concentrations can be high (e.g., 1100 mg/L) in Alberta as the river receives inputs from the highly erosive badlands (AMEC, 2008). Elevated sediment loads have contributed to a 28% loss of volume in Fresno Reservoir since 1939 (USBR, 2012). The Milk River discharges an average annual load of 289,000 Mt of suspended sediment (Lambing and

Cleasby, 2006). Several physical and chemical attributes of the Milk River are also elevated, including conductivity (400–1800 μS/cm), alkalinity (80–370 mg/L as $CaCO_3$), and hardness (130–440 mg/L as $CaCO_3$); pH typically ranges from 8.0 to 8.7. Total nitrogen varies from 0.7 to 4.6 mg/L, and total phosphorus from 0.06 to 1.8 mg/L (Lambing and Cleasby, 2006). Water temperature in the lower reaches can exceed 27.0°C.

River Biodiversity and Ecology

Traversing through the Western Cordillera and West Central Semi-Arid Prairies Level II terrestrial ecoregions and the Upper Missouri freshwater ecoregion, the Milk River basin contains ecologically unique areas for multiple species at the northern and western peripheries of their range. The basin supports a rich faunal assemblage owing to the diversity of habitats within and across its four Level III terrestrial ecoregions.

Algae and Cyanobacteria

Comprehensive studies of algal communities have not been conducted in the Milk River basin. Investigations of algae have focused primarily on water quality assessments and criteria.

Plants

Vegetation in the Milk River basin is characterized by a combination of relic natural conditions and modifications from agricultural practices and altered flows. Grasslands comprise about 50% of the basin and representative native taxa include spear grass, blue grama, wheat grass, sagebrush, and prickly pear cactus (Simpson, 1999). The broad expanse of rangeland supports extensive livestock grazing in the Canadian provinces and Montana.

The riparian community changes along the course of the Milk River. Upper reaches generally lack development of plants with deep root systems and are bordered by grasslands, croplands, and badlands (MTDNRC, 2012). Riparian woodland development increases downstream through Alberta and into northern Montana where stands of mixed-aged plains cottonwoods and willows occur along meander belts and terraces (Simpson, 1999). Toward Fresno Reservoir in Montana, the riparian area is poorly developed as cottonwood density and recruitment are diminished by ice processes (Smith and Pearce, 2000). Reductions in plains cottonwood recruitment occur downstream from Fresno Dam owing to flow regulation and associated channel alterations (e.g., channel incision; Bradley and Smith, 1986). Riparian vegetation increases toward the lower reaches with the addition of native taxa (e.g., green ash, red-osier dogwood, willows, western snowberry, common chokecherry). Nonnative Russian olive has become a dominant member of the riparian community in parts of the basin. Collectively, riparian areas for much of the Milk River and its tributaries are considered stressed to varying degrees due to flow alterations, water diversions, grazing, and nonnative species (MRWCC, 2013).

Invertebrates

Invertebrate surveys identified about 80 taxa in the Milk River of Alberta, where oligochaetes were abundant in the high-sediment and silty conditions (Cornish, 1988). About 160 invertebrate taxa have been recorded in Montana (David Stagliano, Montana Biological Survey, Unpublished data 2020) including Oligochaeta (5 taxa), Diptera (58 taxa), Ephemeroptera (30 taxa), Trichoptera (20 taxa), Coleoptera (11 taxa), Hemiptera (7 taxa), Odonata (6 taxa), and Plecoptera (1 taxon). Three mayflies (*Ametropus neavei, Analetris eximia, Lachlania saskatchewanensis*) occurring upstream from Fresno Reservoir are species of concern (Stagliano, 2016). Mollusks in the Milk River of Montana are represented by gastropods (seven taxa), clams (two taxa), and four mussels including two native species (giant floater, fatmucket) and two nonnative species (white heelsplitter, black sandshell; Stagliano, 2010).

Vertebrates

The Milk River basin has records of 58 fish species representing 17 families. The headwaters and reaches through Alberta account for 25 species (e.g., lake whitefish, mountain whitefish, Rocky Mountain sculpin, flathead chub, trout-perch; MRWCC, 2013). Species richness increases through Montana owing to natural longitudinal additions (Stash, 2001), and species additions emanating from stocking in tributaries and the mainstem. The lower 190 Rkm of free-flowing river downstream from Vandalia Diversion Dam is inhabited by species not found elsewhere in the basin (e.g., shortnose gar), and this section also provides habitat and migration accessibility for Missouri River fishes such as blue sucker, paddlefish, and sturgeons. Collectively, the 17 fish families in the Milk River basin are represented by Acipenseridae (2 species), Polyondontidae (1 species), Lepisosteidae (1 species), Hiodontidae (1 species), Cyprinidae (17 species), Gasterosteidae (1 species), Catostomidae (8 species), Ictaluridae (3 species), Esocidae (1 species), Salmonidae (7 species), Percopsidae (1 species), Gadidae (1 species), Cottidae (1 species), Moronidae (1 species), Centrarchidae (7 species), Percidae (4 species), and Sciaenidae (1 species). Seventeen nonnative fishes occur in the basin (e.g., black crappie, walleye). Additional species (e.g., trout-perch, lake whitefish) likely colonized the Milk River basin by downstream movement through the St. Mary Diversion (MRWCC, 2013).

Fish species status varies by governmental jurisdiction. Canada identifies three species as threatened (Rocky Mountain sculpin, stonecat, western silvery minnow), and two species are considered sensitive (northern redbelly dace, sauger). Pallid sturgeon, present only in lower reaches, are federally endangered in the United States.

Depending on season, 230–280 wildlife species may occur in the basin including 200 bird species (e.g., American bittern, great blue heron), 10 reptile species (e.g., painted turtle, prairie rattlesnake), eight amphibian species (e.g., northern leopard frog, Great Plains toad), and 50 mammalian species (e.g., white-tailed deer, beaver; MRWCC, 2013). Nearly one-quarter of the birds, most reptiles, nearly one-half of the amphibians, and about 20% of the mammals are recognized as sensitive, at-risk, species of concern, threatened, or endangered across the basin at national, provincial, or state levels. Eleven species occupying different niches in the basin (greater sage-grouse, sharp-tailed grouse, northern leopard frog, Great Plains toad, plains spadefoot, prairie rattlesnake, pronghorn, burrowing owl, ferruginous hawk, loggerhead shrike, Richardson's ground squirrel) are assessed for status and trends in the basin (MRWCC, 2013).

Ecosystem Processes

Comprehensive studies examining ecosystem processes have not been conducted in the Milk River basin. Several factors have likely affected nutrient regimes, production rates, and food web dynamics including flow regulation, dams and weirs, agricultural practices and runoff, and the large number of nonnative species.

Human Impacts and Special Features

The Milk River basin contains nearly 60 areas under federal, provincial, state, county, local, and private ownership that are maintained as parks, wildlife management areas, natural areas, and preserves (MRWCC, 2013). Totaling about 7% of the basin area, these tracts provide protection for maintenance of ecological functioning at varied scales depending on size of the areas. However, flow alterations and extractions throughout the basin, and the network of impassable dams and water-development infrastructure in the lower 700 Rkm, greatly affect aquatic and riparian communities of the Milk River. In addition to altered hydrology, influences include agricultural production, grazing practices, and potential expansion of groundwater extractions associated with irrigation and gas and oil development. Despite these multiple stressors, the Milk River contains two special river segments. One segment extends upstream from Fresno Reservoir and into Alberta. Although flows are influenced by the St. Mary diversion, this segment remains one of the few unfragmented river sections in the Great Plains (Stash, 2001). The second special segment extends from the lower-most dam on the Milk to the Missouri River. This segment is subjected to water extractions and low flows, but can function as spawning refugia for Missouri River fishes affected by regulated hypolimnetic water releases from Fort Peck Dam.

Areas of Need for Research and Management

The Milk River lacks comprehensive studies on ecosystem processes. The river segment bordering northern Montana and southeastern Alberta may be a target location for this work owing to its natural riverine character. Within the high-water demand Milk River basin, creative means are needed to provide more ecologically beneficial flow regimes for fishes and associated aquatic and riparian communities. This need may be paramount as climate change projections forecast the potential for increased water demands in the basin (USBR, 2012). Lastly, although much of the upper river lacks fish passage obstructions, the lower river is highly fragmented by dams and weirs. Innovative methods to provide bidirectional passage around these obstructions would benefit fishes in this Great Plains river system.

CHEYENNE RIVER

The lower Cheyenne River forms at the confluence of the comparable Belle Fourche and upper Cheyenne rivers (Fig. 10.15). The name Cheyenne refers to the Tsis tsis'tas and So'taeo'o peoples (Cheyenne Nation) prominent in the region in the 18th and 19th centuries. They called the river Māĭtōmŏnī' ohe ("Red Paint River") in reference to red clay on its banks (Grinnell, 1906).

Clovis and Goshen peoples occupied the basin as big-game (e.g., mammoth, bison) hunters by 10,600 years ago. The Black Hills likely provided refuge from drought and access to diverse biological resources. Communal hunting (e.g., bison, pronghorn) occurred by 1500 years ago. A succession of peoples occupied the basin during European contact and settlement, so it includes landmarks sacred to many Indigenous peoples including Lakota, Cheyenne, Suhtai, Arapaho, Kiowa, Kiowa-Apache, Arikara, and Mandan. The U.S. military expedition and gold rush of 1874, with termination of hostilities with Indigenous peoples by 1877, gave possession to the United States, although the region had been awarded to the Lakota, in the Treaty of Fort Laramie (1868). The Cheyenne River Sioux Tribe of the Cheyenne River Reservation, South Dakota, and Oglala Sioux Tribe reservations, remnants of this treaty, lie partly within the Cheyenne River basin. However, most of the basin was gradually removed, without consent, from Lakota ownership. Sovereignty over these lands (especially the Black Hills) is still disputed. European settlement began with late 19th century mining efforts and resorts developed around hot springs. The Black Hills were designated as a forest reserve in 1897, and irrigated agriculture was initiated along the Belle Fourche and Middle Cheyenne rivers in 1910. Development of the Black Hills into a summer vacationland began in 1920.

Physiography, Climate, and Land Use

The Cheyenne River basin exhibits a complex physiography, lying within the Upper Missouri freshwater ecoregion, the Great Plains physiographic province and Northwestern Great Plains Level III terrestrial ecoregion, but includes an inlier of the Middle Rockies Level III terrestrial ecoregion, the Black Hills uplift (Fig. 10.15). West of their confluence, the upper Cheyenne River and the Belle Fourche River encircle the Black Hills and extend across the Powder River Basin Level IV terrestrial ecoregion (hereafter, just Powder River Basin, not to be confused with the Powder River hydrological basin; Fig. 10.15). Because the headwaters reach beyond the Black Hills, the upper drainage is drier and lower in elevation than the middle drainage.

The Cheyenne River begins at the confluence of Antelope Creek and Dry Fork Cheyenne River within the Northwestern Great Plains Level III and Powder River Basin Level IV terrestrial ecoregions. These extensive headwater drainages comprise 6.2% of the basin (3921 km^2) and also drain stony, forested highlands of the Pine Scoria Hills Level IV terrestrial ecoregion. Downstream, the upper Cheyenne River flows intermittently 188 Rkm to Beaver Creek, which flows southeast within the Northwestern Great Plains Level III and Semiarid Pierre Shale Plains Level IV terrestrial ecoregion. Beaver Creek is the first Cheyenne River tributary to receive inflows from the relatively well-watered Middle Rockies Level III, and Black Hills Plateau and Black Hills Foothills Level IV terrestrial ecoregions.

Immediately north of the Cheyenne River headwaters, the Belle Fourche River forms from four intermittent streams (Belle Fourche, All Night, Fourmile, and Mud Spring creeks) flowing off the Pumpkin Buttes, also within the Powder River Basin. The upper Belle Fourche River is intermittent from Mud Spring Creek to Wild Horse Creek (31 Rkm). From there, it has sluggish discharge until reaching the Black Hills Foothills (200 Rkm). Soils in the Powder River Basin are entisols, aridisols, and mollisols. Mixed-grass prairie predominates, with Ponderosa pine and Rocky Mountain juniper savannas on uplands.

Upon leaving the Powder River Basin, the Belle Fourche River crosses a narrow strip of the Semiarid Pierre Shale Plains Level IV ecoregion and then flows 156 Rkm through a northwest extension of the Black Hills Foothills Level IV terrestrial ecoregion, receiving tributaries from an outlier of the Black Hills Plateau Level IV terrestrial ecoregion (i.e., Bear Lodge Mountains). At Stoneville, South Dakota, within the Semiarid Pierre Shale Plains Level IV terrestrial ecoregion, the Belle Fourche River turns southeast for 117 Rkm until reaching the Belle Fourche or “beautiful forks” (i.e., confluence with the Redwater River). Over the remaining 257 Rkm to its confluence with the Cheyenne River, the Belle Fourche River flows east across the Northwestern Great Plains, Semiarid Pierre Shale Plains, and River Breaks Level IV terrestrial ecoregions. Throughout most of this length, the Belle Fourche River receives tributaries from the Middle Rockies Level III, and Black Hills Core Highlands, Black Hills Plateau, and Black Hills Foothills Level IV terrestrial ecoregions along with the Northwestern Great Plains Level III and Dense Clay Prairies Level IV terrestrial ecoregions.

In contrast, the upper Cheyenne River skirts the Black Hills. From the Powder River Basin, it flows 25 Rkm southeast along the foothills-plains boundary. The Cheyenne River is incised across the southernmost tip of the Black Hills Foothills for 72 Rkm, creating a series of angosturas (Spanish for "narrow passages"). Below Angostura Dam, the Cheyenne River reenters the Semiarid Pierre Shale Plains and turns northeast, flowing 219 Rkm along the boundary of the Northwestern Great Plains Level III and White River Badlands Level IV terrestrial ecoregions (Fig. 10.5) to its confluence with the Belle Fourche River. This river segment receives tributaries from the Middle Rockies Level III, and Black Hills Core Highlands, Black Hills Plateau, and Black Hills Foothills Level IV terrestrial ecoregions. Soils in the Semiarid Pierre Shale Plains are alfisols, mollisols, vertisols, aridisols, and entisols. Montane Ponderosa pine forest and savanna in the three Black Hills ecoregions give way to mixed-grass prairie on the adjacent plains.

The Cheyenne-Belle Fourche confluence zone and lower Cheyenne River are within the Northwestern Great Plains Level III and River Breaks Level IV terrestrial ecoregions. Soils in the River Breaks ecoregion are mollisols, entisols, aridisols, vertisols, and inceptisols. A mosaic of blue grama, western wheatgrass, and buffalograss forms the dominant vegetation.

Average annual air temperature in Rapid City, South Dakota is 8.4°C (Fig. 10.16). Based on a 30-year record, it is lowest in December (−3.9°C) and highest in July (22.6°C). Average annual precipitation is 48 cm/yr (Fig. 10.16), lowest in January (0.7 cm/mo), and highest in May (8.1 cm/mo). Despite less drainage area, Belle Fourche River discharge equals or exceeds the upper Cheyenne River (virgin flows unmeasured). This is because cool, moist air from the northwest bestows more precipitation (>61 cm/yr) to Spearfish, False Bottom, Whitewood, and Bear Butte creeks within the Belle Fourche River drainage.

FIG. 10.5 Cheyenne River flowing across a Great Plains landscape in Buffalo Gap National Grassland, near Red Shirt, South Dakota, with Badlands National Park in the background. *(Photo by © Tom Bean 1997 with permission, ID AGPix-0087.)*

Thus, the Belle Fourche River is expanding its basin and has captured tributaries from the upper Cheyenne River in recent geological time (Clausen, 2018).

Pre-contact land use centered on hunting and gathering in the biodiverse Black Hills where freshwater mussels were a staple food (Sundstrom, 1995-1996). Modern land use across the basin is 8% agriculture, 69% grassland/pasture, 18% forest/shrub, 5% sparse vegetation/badlands, and 1% urban. The most diffuse, widespread land uses are ranching (cattle, sheep) and dryland farming. Logging, outdoor recreation, and tourism prevail in the Black Hills. Industrial use began with the 1874 Black Hills Gold Rush, and gold mining persisted until 2007. Mining in the Powder River Basin ecoregion extracts coal, coalbed methane, oil and gas, and uranium.

River Geomorphology, Hydrology, and Chemistry

The Cheyenne River headwaters within the Powder River Basin extend to the Pine Ridge (Wyoming), an outlier of the Pine Scoria Hills, 1920 m asl. Nearby, North Middle Butte of the Pumpkin Buttes (1835 m asl) is the highest point in the Belle Fourche River headwaters. Both rivers describe tortuous meanders across the Powder River Basin, which along with inliers of the Pine Scoria Hills houses 29.9% of the drainage basin by area. Tributaries are ephemeral or intermittent. The upper Cheyenne River at Spencer, Wyoming, has 1.3 ± 0.2 SE m^3/s mean annual discharge, with bankfull width of 11.7–18.9 m. Similarly, the Belle Fourche River at Moorcroft, Wyoming, has 0.6 ± 0.1 SE m^3/s mean annual discharge, with bankfull width of 11.9–17.6 m.

The sub-basin where the Cheyenne and Belle Fourche rivers encircle the three Black Hills terrestrial ecoregions comprises 55.7% of the drainage basin. Elevations exceed 2000 m asl with Black Elk Peak (formerly Harney Peak), the highest point in the basin at 2208 m asl (Fig. 10.15). Evermann and Cox (1896) reported on October 17, 1892 that the upper Cheyenne River at Cheyenne Falls (present Angostura Dam) had a sandy, shifting channel much wider than the wetted area and a discharge of 19.8 m^3/s (including recent rains). They described the Belle Fourche River at the beautiful forks as "of some size except during dry weather" with "fairly pure" water (i.e., low alkalinity and turbidity).

Before regulation, combined discharge of the Belle Fourche and Redwater rivers was 16.6 m^3/s over 27 nonconsecutive months, 1903–1906, with nearly equal contributions from each river and peak flow in May and June (Darton, 1909). Bankfull width of each fork at the confluence exceeds 40 m. Mean annual discharge from the middle Cheyenne (11.1 ± 1.1 SE m^3/s) and Belle Fourche (10.8 ± 1.1 SE m^3/s) supplies most of the 23.4 ± 1.8 SE m^3/s discharge in the lower Cheyenne River.

The lower Cheyenne River, below the Belle Fourche River confluence, comprises 14.4% of the drainage basin and receives one major tributary, Cherry Creek (7.7% of the drainage basin). This largely unaltered tributary has mean annual discharge of 1.5 ± 0.2 SE m^3/s. The remainder of the lower valley, with minor tributaries, comprises the final 6.7% of the basin and is largely free flowing, but hydrology reflects upstream alterations. The lower river has an active sand-gravel channel and bankfull width exceeds 90 m. Average annual discharge near the Cheyenne River mouth is 23.4 ± 1.8 SE m^3/s over a 61-year period of record (1935–1994) ranging from 2.7 to 49.5 m^3/s, with variability of interannual discharge at 59%. Historical monthly discharge is highest in June (69.2 ± 9.5 SE m^3/s) and lowest in January (2.8 ± 0.3 SE m^3/s) (Fig. 10.16). June discharge variation was 105%, and January discharge variation was 83% among years. On average, ice out, snowmelt, and rains from March into July elevate discharge above 30 m^3/s. Lower precipitation coupled with heat (summer) or cold (winter) from late July through February limits discharge below 20 m^3/s.

The Belle Fourche diversion dam and (off-channel) reservoir (Fig. 10.15) initially regulated river flows in 1910, and discharge became increasingly regulated thereafter (e.g., Angostura Dam 1949, Keyhole Reservoir 1952, Pactola Reservoir 1963). Diversions from the Middle Cheyenne and Belle Fourche rivers irrigate >28,000 ha. Tributary dams are now numerous and stock ponds on headwater channels and small tributaries are innumerable.

Relatively high loads of dissolved ions and suspended sediments occur naturally throughout the basin. Native species generally tolerate high ion and sediment loads and can be negatively affected where turbidity is eliminated (e.g., dam tailwaters). Turbidity can be extreme along the middle-lower Cheyenne River from Sand Creek (Oral, South Dakota) to the mouth because tributaries that issue from the White River Badlands (e.g., Fig. 10.5) carry fine clays that tend to remain suspended. Suspended sediment reported from the middle Cheyenne River near Wasta, South Dakota, averages 5981 ± 11,797 SD mg/L and from the lower Cheyenne River near Eagle Butte, South Dakota, averages 11,889 ± 13,761 SD mg/L. Suspended sediment is less in the upper Cheyenne River near Spencer, Wyoming (1757 ± 3632 SD mg/L), lower Belle Fourche River near Elm Springs, South Dakota (1183 ± 3498 SD mg/L), and upper Belle Fourche River below Moorcroft, Wyoming (684 ± 1647 SD mg/L), but can be elevated during floods.

River water throughout the basin is hard to very hard. Specific conductance in the headwaters averages 2518 ± 926 SD μS/cm (Belle Fourche River below Moorcroft, Wyoming) and 3617 ± 1669 SD μS/cm (Cheyenne River near Spencer, Wyoming). In the middle sub-basin specific conductance averages 2159 ± 815 SD μS/cm in the lower Belle Fourche River near Elm Creek, South Dakota, and 1742 ± 517 SD μS/cm in the middle Cheyenne River near Wasta, South Dakota. Specific conductance in the lower Cheyenne River near Eagle Butte, averages 1870 ± 633 SD μS/cm. Lower Cheyenne River near Eagle Butte pH averages 7.8 ± 0.5 SD; nitrate plus nitrite averages 1.1 ± 0.9 SD mg/L; total phosphorus averages 1.1 ± 2.6 SD mg/L; and orthophosphate averages 0.04 ± 0.05 SD mg/L.

River Biodiversity and Ecology

Algae and Cyanobacteria

Low standing crops of cyanobacteria, green algae, and diatoms occupy both forks in the Powder River Basin. This likely also pertains to the lower valleys.

Plants

High sediment loads and channel instability restrict common three-square, softstem bulrush, and sago pondweed to channel margins. Plains cottonwood, green ash, boxelder, American elm, common hackberry, peachleaf willow, and bur oak characterize riparian-tree assemblages.

Invertebrates

Chironomidae (Diptera) is the most prevalent insect taxon (Kopp and Troelstrup Jr., 2008). *Stictochironomus*, *Micropsectra*, and *Pseudochironomus* dominate in the Powder River basin. Riverine Plecoptera are *Isoperla*, *Acroneuria*, and *Perlesta*. Ephemeropterans *Baetis* and *Caenis* are widespread in the Powder River basin. *Paracloedes* and *Tricorythodes* dominate the Black Hills reach of the Belle Fourche River, where *Certatopsyche* and *Cheumatopsyche* are abundant trichopterans. *Simulium* (black flies) are widespread. *Dubiraphia* are an abundant coleopteran in the Belle Fourche River, along with the crustacean *Hyalella*. Oligochaeta are abundant in the Powder River basin. Mollusks within the basin include white heelsplitter, pink heelsplitter, and giant floater.

Vertebrates

Of 57 fishes in the basin, 34 are native. Native common shiner, hornyhead chub, and burbot are extirpated. Riverine assemblages fluctuate dramatically among years. Nonnatives have low dominance outside of impoundments, except smallmouth bass are abundant in the tailwater below Angostura Dam. Extant sensitive riverine fishes include western silvery minnow, plains minnow, sturgeon chub, and flathead chub. Native big-river species (i.e., goldeye, emerald shiner, northern river carpsucker, shorthead redhorse, channel catfish, sauger, walleye, freshwater drum) range between the river and Lake Oahe, using the river more in high-water years. Channel catfish is an abundant, native game species.

Riparian amphibians include northern leopard frog and tiger salamander. American bullfrog is considered native in the upper Cheyenne River. Aquatic turtles include common snapping turtle, spiny softshell, and smooth softshell. Riparian snakes include plains and common gartersnakes. Riparian and aquatic birds include interior least tern, spotted sandpiper, cliff swallow, barn swallow, and eastern kingbird. The recently federally delisted endangered interior least tern nests in the lower Cheyenne River and adjacent Lake Oahe. North American beaver is widespread, with North American river otter sometimes present.

Ecosystem Processes

In the Powder River basin, latitude (i.e., northing), riparian disturbance, specific conductance, water temperature, and alkalinity correlate to algal community composition, with specific conductance and alkalinity important for macroinvertebrates (Peterson et al., 2009). Dams, impervious surfaces, oil and gas development, and drought negatively influence fishes. Studies of ecosystem productivity, nutrient cycling, food-webs, and species life histories are needed.

Human Impacts and Special Features

Stock ponds built profusely from 1920 to 1960 within the Powder River basin depleted runoff by ~32% in the Cheyenne River above Angostura Dam (Culler, 1961) and are widespread elsewhere. Coal mines are prominent across the Belle Fourche headwaters (the river is re-routed around one mine) and in Antelope Creek (upper Cheyenne). There is minimal riparian buffer, and frequent low-water (bridgeless) fords impact channel morphology.

Mainstem dams affect hydrology and geomorphology. Owing to withdrawals and evaporation, annual discharge in the Cheyenne River below Angostura Dam averages only 37 ± 6 SE % of inflow to Angostura Reservoir. Channel migration has ceased since construction of this dam. Bankfull width declines from 22 m above the reservoir to 17 m below, although it would naturally increase because drainage area grows 22%. Riverine fishes (western silvery minnow, plains minnow, flathead chub) have disappeared and nonnative smallmouth bass are abundant. Beginning at Sand Creek, 31 Rkm downstream, a series of uncontrolled tributaries from the White River Badlands (Fig. 10.5) attenuate dam control over 143 Rkm.

Similarly, annual discharge in the Belle Fourche River below Belle Fourche Diversion Dam is only 30 ± 3 SE % of that upstream and is a mere 16% of that reported by Darton (1909) under pre-development conditions. Coarse substrate armors the river channel and small-stream fishes (red shiner, plains sand shiner) have replaced riverine fishes. Attenuation of dam control is abrupt at Whitewood Creek, 30 Rkm downstream, where goldmine tailings from the Black Hills (discharged from 1876 to 1977) inundate the Belle Fourche river channel all the way to the Cheyenne River confluence (225 Rkm). High mercury and selenium in fishes (Walter et al., 1973) and high mercury in piscivorous birds (Hesse et al., 1975) of the lower river are linked to these goldmine tailings upstream. People of the Cheyenne River Sioux Tribe exhibit elevated autoimmune responses, possibly due to exposure to mine-tailing contaminants through fish consumption (Ong et al., 2014).

Oahe Dam on the Missouri River perennially inundates the mouth and lowest reach of the Cheyenne River. This has resulted in formation of a 37-km long delta upstream from the point of perennial inundation (Volke et al., 2015).

Devils Tower (U.S. National Monument, Wyoming) and Bear Butte (South Dakota State Park) overlook the Belle Fourche valley. World-renowned Jewel and Wind caves and the White River Badlands (Badlands National Park, Buffalo Gap National Grasslands) flank the upper Cheyenne valley.

Areas of Need for Research and Management

Long inter-dam reaches (395 Rkm from Angostura Dam to Lake Oahe; 431 Rkm from Belle Fourche Diversion Dam to Lake Oahe) support imperiled riverine minnows and nesting sites for the interior least tern. Further, plains minnow and flathead chub persist in the 235 Rkm between Keyhole Dam and Belle Fourche Diversion Dam and in the undammed Cheyenne River above Angostura Reservoir. Better understanding of population dynamics and life histories of these minnows is needed (Worthington et al., 2018), as is more information on how flow regime, geomorphology, and reservoir level affect least tern nest geography and success (Schwalbach et al., 2018). Future studies should explicitly recognize the presence of the distinct inter-dam zones described above (sensu Skalak et al., 2013).

NIOBRARA RIVER

The archeological, biological, and recreational significance of the Niobrara River and its valley is unmatched by any river in the Great Plains physiographic province (NPS, 2006). The river extends 914 Rkm across diverse and largely unglaciated landscapes of the Great Plains Level I terrestrial

FIG. 10.6 Sunrise on the Niobrara River, Niobrara National Scenic River, Nebraska. *(Photo by National Park Service.)*

ecoregion (Fig. 10.17). The Niobrara Valley is a biological refugium from Pleistocene glacial times and also a migration corridor across the Great Plains for species normally associated with boreal and cool-temperate forests (Joeckel et al., 2017). The Niobrara, its name from the Omaha and Ponca meaning "spreading waters," drains 32,600 km^2 of northern Nebraska and adjacent parts of eastern Wyoming and south-central South Dakota (Fig. 10.6). From the early 1700s, numerous Indigenous peoples occupied the Niobrara valley including the Lakota, Pawnee, and the Plains Comanche. The Ponca built their earthen lodges on river terraces near the mouth of the Niobrara. The Ponca Restoration Act of 1990 re-recognized the Ponca Tribe of Nebraska, but without the ability to establish a reservation.

Cattlemen were the first Euro-Americans to exploit the central Niobrara River basin, profiting from the sandhills and the Niobrara River valley open-range grasslands. Fort Niobrara was built in 1879 to monitor Brule Sioux activity at the nearby Rosebud Agency. Farmers moved into the central Niobrara valley in the 1890s, lured by dubious claims of high land productivity and ample rainfall; dry-land farming by homesteaders often failed.

Physiography, Climate, and Land Use

The Niobrara is a young river, having formed after the retreat of the last ice sheet about 12,000 years ago (Hrabik et al., 2015). The modern Niobrara originates at an elevation of about 1500 m asl in the High Plains Level III terrestrial ecoregion (25% of basin area) of east-central Wyoming. It then travels east passing through the Nebraska Sand Hills Level III terrestrial ecoregion (35% of basin area) and along the southeastern border of the Northwestern Great Plains Level III terrestrial ecoregion (35% of basin area) and northern border of the Nebraska Sand Hills ecoregion. It continues through the southernmost corner of the Northwestern Glaciated Plains Level III terrestrial ecoregion (2% of basin area) to its terminus at the Missouri River near Niobrara, Nebraska, at an elevation of about 425 m asl. It is the only major Missouri River tributary in the inter-reservoir reach between Fort Randall and Gavins Point dams.

The interior continental location of the Niobrara Valley produces a highly seasonal climate with cold winters and hot summers. Average annual air temperature is 9.8°C at Valentine, Nebraska (Fig. 10.18). Air temperature is lowest in February (−10°C) and highest in July (32°C). Average annual precipitation is low at about 51 cm/yr and varies from about 45 cm/yr in the upper basin to about 60 cm/yr at its mouth. Precipitation is greatest from May through July (8–9 cm/mo) and lowest in December and January (<1 cm/mo; Fig. 10.18). Snowfall is of minor importance averaging 14 cm/yr with most occurring during February and March (6–7 cm/mo). Direct surface runoff from precipitation is very low in much of the basin due to the high infiltration capacity of the Nebraska Sand Hills ecoregion. Water is fed to Niobrara streams largely through groundwater seepage (Alexander et al., 2010).

Land use in 2005 for the seven Nebraska counties containing the Niobrara River was 82% range/pasture/grass, 4% riparian forest, 4% wetlands, 3.9% non-irrigated agriculture, 2.5% irrigated agriculture, about 1% open water, summer fallow or barren, and < 0.2% urban (Dappen et al., 2007). Most non-irrigated cropland acreage is devoted to alfalfa (29%), corn (25%), and small grains (23%), whereas alfalfa (39%), corn (35%), and soybeans (12%) are the major irrigated crops.

River Geomorphology, Hydrology, and Chemistry

The main channel of the Niobrara has been divided into three fluvial geomorphic provinces (Alexander et al., 2009). The uppermost "meandering bottoms" reach is characterized by open valleys and a sinuous, equal-width channel (mean channel slope = 1.67 m/km; sinuosity = 1.16). Next, is a "central canyons and restricted bottoms" reach defined by mixed valley and channel settings, including several entrenched canyon sub-reaches (mean channel slope = 1.50 m/km; sinuosity = 1.22). The valley is wide, yet restricted, in the lower "braided bottoms" reach with a persistently braided, sand-bed channel (mean channel slope = 1.33 m/km; sinuosity = 1.34; Fig. 10.1). A wide delta has formed at the confluence of the Niobrara River and the western end of Lewis and Clark Lake on the Missouri River, raising the Niobrara's bed elevation between 1950 and 1966 by as much as 2.3 m (Alexander et al., 2010). This delta has elevated the groundwater table and reduced the flood-carrying capacity of the Niobrara River (Johnsgard, 2007). Primary bed material in the Niobrara's active channel ranges from coarse silt (0.03–0.06 mm) to coarse sand (0.5–1.0 mm) with the majority being fine to medium sand (0.2–0.5 mm). The Niobrara River discharges about 2.6 million metric tons of sediment per year; about 70% is sand and the remainder silt and clay.

Two salient hydrological attributes characterize the Niobrara River (Joeckel et al., 2017). It has few, but large tributaries for a basin area of its size; these are the Snake River, Minnechaduza Creek, Keya Paha River, and Long Pine Creek. Also, the Niobrara exhibits a comparatively stable discharge within a region of erratic precipitation; it rarely floods, except during winter ice jams. This is a consequence of 80–90% of its baseflow around Valentine (~Rkm 251) being derived from groundwater, whereas only about 15% of base flow near the mouth originates from groundwater (Wanner et al., 2011).

Low variability in flow is demonstrated by discharge at Verdel, Nebraska (Rkm 24). Average annual discharge is 50.9 m^3/s over most of the period of record (1959–2018), ranging from 34.6 to 77.8 m^3/s, with interannual discharge variability of 21%. Mean monthly discharge is greatest in March (72.9 m^3/s) and lowest in July (35.2 m^3/s) (Fig. 10.18). Variability within months is generally <25% from September through February and highest in July at 53% during irrigation season.

The Niobrara River and its tributaries have four dams and associated water diversions (Fig. 10.17). Two of these, Box Butte Dam (Mirage Flats Irrigation Project) on the upper Niobrara and Merritt Dam (Ainsworth Irrigation Project) on the Snake River tributary, have altered its hydrology by diverting water during the summer irrigation season. Average daily flows are reduced by 90%, but the river regains significant flow downstream, mainly from groundwater seepage (Alexander et al., 2010). The mainstem Niobrara River also had two hydroelectric dams: Cornell Dam (~Rkm 222), near Valentine (presently inactive and proposed for removal), and Spencer Dam built in 1927 (Rkm 62).

In mid-March 2019, a combination of a heavy snowpack, a bomb-cyclone rain event, and rapid snow melt on top of frozen ground resulted in ice breakup, ice jams, and historic flooding (ASDSO, 2020). An ice-water surge breached Spencer Dam (Fig. 10.17), unleashing a 3–4-m high wall of water destroying downstream bridges and stream gauges. Peak instantaneous river discharge following dam failure on March 14, 2019 at the Verdel U.S. Geological Survey gauge about 39 km downstream from Spencer Dam was estimated at 3508 m^3/s; previous maximum instantaneous discharge was 1104 m^3/s in 1988.

As a groundwater dominated river, the Niobrara is generally clear, except following precipitation runoff and ice breakup. Turbidity within the Niobrara National Scenic River averages 8 NTU (range: 3–15 NTU). Nutrient concentrations in the lower Niobrara River at Verdel, Nebraska, are moderately high with total nitrogen averaging 1.8 mg/L and total phosphorus averaging 0.27 mg/L. Conductivity is also moderately high (266 μS/cm), and pH is basic averaging 8.0. Alkalinity (115 mg/L as $CaCO_3$) and hardness (115 mg/L as $CaCO_3$) are moderately high as is dissolved silica (47 mg/L), both reflective of the Ogallala aquifer water source. Average annual water temperature at Verdel is 15.2° C, with a range of 0–32°C.

River Biodiversity and Ecology

The Niobrara River valley is a biogeographic crossroads (Johnsgard, 2007). Of the 404 plant and animal taxa with clear geographic affinities: 33% are eastern, 32% western, 15% Great Plains, 14% northern, and 6% southern.

Algae and Cyanobacteria

A rich algal community of 86 genera has been recorded in the lower Niobrara River at Verdel, Nebraska (1974–2016; U.S. Geological Survey Water Resources gauge 06465500). Diatoms (seven genera) and green algae (six genera) are numerically (number/mL) co-dominant within 20 or more of the 54 samples collected over the 42-year period. Diatom taxa from these collections in decreasing order of frequency of occurrence are: *Nitzschia*, *Cyclotella*, *Navicula*, *Fragilaria*, *Gomphonema*, *Diatoma*, and *Cocconeis,* and for green algae: *Scenedesmus*, *Ankistrodesmus*, *Chlamydomonas*, *Oocystis*, *Tetrastrum*, and *Pediastrum*.

Plants

The Niobrara River valley provides an unbroken east/west riparian corridor connecting the dryer western landscape with the more humid midwestern prairie and eastern deciduous forest (NPS, 2006). About 160 plants are at the edge of their natural range with ponderosa pine, eastern deciduous, and northern boreal forest types converging. Ponderosa pine forest is at its eastern limit in the river valley. Eastern deciduous forest includes bur oak, American elm, black walnut, green ash, basswood, and hackberry. Broadleaf shrubs and vines are dominated by sumac, western snowberry, gooseberry, wild plum, and wild grape. Eastern and western red cedars (Rocky Mountain juniper) converge in the valley and have become dominant with infrequent fires. Northern boreal forest is found on cool, moist, north facing slopes and includes paper birch, a hybrid species of quaking and bigtooth aspens, ferns, and several species of club mosses. These plants are Pleistocene glacial relics from when they were more widely distributed on the Great Plains.

Wetland plant communities are widespread in the Niobrara Valley; common plants are prairie cordgrass, northern reed grass, sedges, rushes, spikerushes, false indigo, red osier dogwood, and nonnative yellow iris, purple loosestrife, and reed canarygrass (Johnsgard, 2007). Perennial sandbars are common especially in the lower "braided bottoms" reach (Johnsgard, 2007). These are characterized by sandbar and peachleaf willow, false indigo, and eastern cottonwood saplings. River terraces adjacent to shorelines are populated by mature plains cottonwood, box elder, green ash, chokecherry, wild plum, willows, and buffaloberry; nonnative salt cedar has recently invaded.

Invertebrates

The Niobrara River valley has a particularly specious dragonfly and damselfly fauna with 44 dragonfly species and 34 damselfly species recorded (Johnsgard, 2007). Little quantitative information exists on aquatic invertebrates from the middle or lower Niobrara River. A dip-net survey was conducted in summer 2003 in the Niobrara National Scenic River (Rkm 129–251) where substrate composition averaged 38% bedrock and 60% sand (Rust, 2006). An average of 1773 invertebrates was collected per sample representing 18 species. Dominant invertebrates included Ephemeroptera (*Tricorythodes, Traverella*) and non-insects (*Girardia* and *Physa*). Collector-gatherers contributed the most to feeding guild abundance (52%), whereas swimmers (41%) and clingers (31%) were the most abundant habit-use guilds.

A systematic, long-term analysis of Niobrara River aquatic invertebrates exists for the upper reach at Agate Fossil Beds National Monument, Nebraska (about 23-km east of the Wyoming border (Tronstad and Hotaling, 2017). Here the Niobrara is only about 2.5-m wide and flows through short- and mix-grass prairies at about $0.4\,m^3/s$. Eighty-four taxa from five phyla (Annelida, Mollusca, Nematoda, Nemertea, and Arthropoda) were collected during summer 2010–2014 using Hess samplers. Crustacea, Diptera, and Mollusca were most numerous with *Hyallella* and *Gammarus* the most abundant crustaceans, and Ancylidae, Sphaeriidae, and Planorbidae as the most abundant mollusk families. The number of aquatic insect taxa and the three numeric dominants in each were Coleoptera (20): *Dubiraphia*, *Liodessus*, and *Colymbetes*; Diptera (20): non-Tanypodinae Chironomidae, *Simulium*, and Tanypodinae; Ephemeroptera (seven): *Hexagenia*, *Heptagenia*, and *Baetis*; Hemptera (seven): *Palmacorixa*, *Belostoma*, and *Hesperocorixa*; Trichoptera (seven): *Cheumatopsyche*, *Polycentropus*, and *Oxyethira*; and Odonata (six): *Coenagrion/Enallagma, Calopteryx*, and *Hetaerina*.

Mussels are represented in the Niobrara basin by five species, including the cylindrical papershell, white heelsplitter, creeper, and nonnative fingernail clams (Schainost, 2016a). Four crayfish species have been collected from the Niobrara and its tributaries including virile crayfish, calico crayfish, ringed crayfish, and devil crayfish (Schainost, 2016b).

Vertebrates

Sixty-seven fish species are recorded from the Niobrara River basin within the Upper and Middle Missouri freshwater ecoregions. Cyprinids dominate with 27 species, followed by nine species of centrarchids, five species each of catostomids and perchids, and four species of ictalurids. Niobrara River fishes have been clustered into five assemblage guilds based on species occurrences and habitat characteristics (Pegg et al., 2014). Lobate Margin Guild fishes inhabit low-velocity, shallow-depth channel margins and include bigmouth shiner, red shiner, plains topminnow, fathead minnow, brook stickleback, and age-0 channel catfish. Runs are main channel areas with greater velocities and depths; representative species are sand and emerald shiners. Riffles are clear water, low velocity main channels with coarse substrate and aquatic vegetation whose guild members include the brassy minnow, central stoneroller, longnose dace, and river shiner. The Slackwater Guild includes off-channel pools or backwaters near stream edges, with lower velocity and greater depths whose fishes include largemouth bass, bluegill, green sunfish, and yellow perch. Habitat Generalists Guild members inhabit a wide range of areas within river channels and backwaters, some with low dissolved oxygen and fluctuating water temperature and include white sucker, creek chub, shorthead redhorse, and age-0 river carpsucker.

Several cool-water minnows representing glacial relict populations remain in small, spring-fed headwater tributaries. These include lake chub, northern pearl dace, finescale dace, northern redbelly dace, and blacknose shiner; all are Nebraska state listed as sensitive species. Recently, the federally endangered pallid sturgeon has been collected from the lowermost Niobrara River. Several cool-water, nonnative sport fishes have been introduced into spring fed-tributaries, including rainbow trout, brown trout, brook trout, smallmouth bass, rock bass, muskellunge, pumpkinseed, and rudd.

Amphibian, reptile, breeding bird, and mammal associations in riparian forests, riparian edges, wet meadows, and swamps in the Central Niobrara Valley (Valentine to about 97 km east) are summarized by Johnsgard (2007). Fourteen species of amphibians and reptiles occur in these habitats, including the tiger salamander, Great Plains toad, northern leopard frog, western chorus frog, and northern cricket frog. Plains and red-sided gartersnakes, northern watersnake, milksnake, bullsnake, and blue racer also reside in these habitats as do the snapping turtle, eastern painted turtle, and spiny softshell.

Over 230 birds use the Niobrara basin during a portion of their life cycle (Johnsgard, 2007). Twenty-eight species breed in the central Niobrara Valley with riparian forests (21 species) and riparian edges (eight species) being favored habitats. Black-crowned night heron, mallard, blue-winged teal, wood duck, spotted sandpiper, and belted kingfisher frequent the riparian edge habitat and the federally threatened piping plover and recently federally delisted least tern nest on exposed sandbars. Sandhill crane, white pelican, osprey, and the federally endangered whooping crane use the Niobrara River during migrations and over 100 bald eagles winter along the lower Niobrara with about 10 pairs nesting. Twenty mammal species use these habitats with most species observed in riparian forests (18) and riparian edges (eight) (Johnsgard, 2007). Raccoon, American mink, North American beaver, muskrat, and northern river otter are small mammals that frequent riparian edge habitat. Large mammals using riparian forests include elk and eastern white-tailed deer.

Ecosystem Processes

A few static measurements of process-related variables exist for the Niobrara River, but there has been no systematic examination of river processes (U.S. Geological Survey Water Resources gauge 06465500). Total organic carbon in Niobrara water at the Verdel U.S. Geological Survey gauge averages 7.9 mg/L (range 0–27 mg/L). Periphyton biomass ash-free weight is low averaging 1.5 g/m^2 (range 0.1–8.0 g/m^2) and periphyton chlorophyll *a* averages 8.5 mg/m^2 (range = 0.1–23 mg/m^2).

Human Impacts and Special Features

The Niobrara River valley is renowned for its outstanding ecological diversity and recreational opportunities. It is universally recognized for its mixing of six distinct continental ecosystems resulting in an east-west, north-south species crossroads (NPS, 2006). Backpacker magazine (January 1988) identified the Niobrara as one of America's "10 best paddling rivers" and National Geographic Adventure magazine labeled the Niobrara as one of America's "100 best outdoor adventures" (April 2000). Although the majority of the Niobrara basin is in private ownership, numerous public use areas exist to conserve and share its archeological, ecological, and recreational uniqueness. Agate Fossil Beds National Monument is the best known of the >160 mapped paleontological sites within the basin and is recognized for its well-preserved Miocene mammals (Johnsgard, 2007). About 15 Rkm of the upper Niobrara River lies within the Fort Niobrara National Wildlife Refuge, formerly the site of Fort Niobrara. The western one-third of the 120-Rkm long Niobrara National Scenic River (established in 1991) boasts over 200 waterfalls, with the 19-m high Smith Falls plunging over a sandstone cliff in Smith Falls State Park. The Nature Conservancy's 56,000 ha Niobrara Valley Preserve is located about midway within the Niobrara National Scenic River and protects 40 km of the Nebraska Sand Hills ecoregion along the south bank of the Niobrara River and 14 km of the Northwestern Great Plains ecoregion along its north bank. Here, hills and bluffs rise 122 m above the riverbank. The final 32 Rkm of the Niobrara River is included in the Missouri National Recreational River with Niobrara State Park at the river's Missouri River confluence.

About 243,000 ha of private land in the Niobrara basin is irrigated. Groundwater irrigation accounts for approximately 202,000 ha, and more than 18,600 ha is irrigated when surface water is available (USBR, 2015). Water withdrawals and diversions are depleting groundwater supply and reducing in-stream flows (Alexander et al., 2010, USBR, 2015). Integrated model simulations under a variety of climate change scenarios suggest average annual surface water demands will outpace supply by 27–43 million m^3 (USBR, 2015). Total economic value associated with recreational floating in the Niobrara National Scenic River was $10.9 million in 2008 (Shultz, 2009). Low river flows are the primary concern of floaters and economic losses associated with lower river flows were estimated to range from $4.7 to $6.6 million (2008 dollars, Shultz, 2009).

Additional human impacts and issues that affect the Niobrara River and its valley include increased recreational use of the river and associated damage to natural and cultural resources, nonnative species, sedimentation of the Niobrara delta, and a shift in private land-use from ranching-farming to residential and recreational properties.

Areas of Need for Research and Management

Like many midwestern rivers, competing water uses are a primary issue for the Niobrara. Projected increases in river-based recreation, residential development along the river corridor, agricultural irrigation withdrawals, all within the context of climate change induced reductions in instream flows and aquatic resources pose a formidable challenge to maintaining the Niobrara's scenic qualities and its value as a crossroads of biodiversity.

BIG SIOUX RIVER

The Big Sioux River courses north to south along the eastern border of South Dakota. The name refers to Očhéthi Šakówiŋ (Sioux) people prominent in the region in the 19th century. Lewis and Clark encountered Yankton Sioux in 1804, reporting 700 individuals living in the area (Cutright, 1969). Thirty years later, Joseph Nicollet (Bray and Bray, 1976) reported this tribe and the related Yanktonai Sioux in the Big Sioux basin, with Sisseton Sioux on the eastern boundary. Sisseton-Wahpeton and Santee Sioux still hold reservation lands within the basin. Representatives from these and many other nations often journeyed to the Pipestone quarry (Pipestone National Monument), a source for soft red rock valued for pipe-making, located on Pipestone Creek (tributary to the Big Sioux River via Split Rock Creek).

Earliest peoples in the Big Sioux basin were mobile, single-family groups present 11,200–10,500 BCE, likely as warm-season residents (Gibbon, 2012). From 10,500 to 3000 BCE, the region transitioned from forest to grassland and pedestrian bison hunting became the main lifeway. Populations remained sparse and family-oriented. Resource use diversified from 3000 BCE to 1000 CE, with increased use of aquatic and semi-aquatic biota (e.g., wild rice, fish, shellfish, waterfowl), and base camps became more fixed and supported multi-family groups. Farming emerged between 950 and 1050 CE within the Great Oasis Culture who established villages across the Prairie Couteau and along the lower Big Sioux River (Missouri River Valley, Tiffany and Alex, 2001). Adaptation to plains and prairies produced the Middle Missouri tradition, with villages at the Sioux Falls (Fig. 10.7) and along the lower Big Sioux River (Mitchell, 2012). Lower villages—with those in the adjacent Little Sioux basin—comprised the Mill Creek Culture, which conducted trade with Mississippian cultures farther east. Between 1200 and 1300 CE, the aggressive Oneota Culture spread west from the Mississippi River valley, across the Big Sioux basin.

Impacts of European immigration began with the fur trade and spread of diseases. Gradual westward expansion of European influence initiated a westward shift of Indigenous Nations. Anglo-American settlement began at Sioux City, Iowa (Missouri River valley) by 1854; Sioux Falls, South Dakota in 1856; and at Flandreau and Medary, South Dakota (Prairie Couteau) in 1857. The 1878–1887 land rush populated the region, and life for land-rush settlers is chronicled in the famed children's books of Laura Ingalls Wilder. Thereafter, agriculture was the dominant land use, with urbanization localized to Sioux Falls, South Dakota (population >190,000 in 2020) and Sioux City, Iowa (population >80,000 in 2020). Presently, ~75% of land is in row-crop agriculture or pasture/hay. The 21st century trend is conversion of grass/pasture and smaller wetlands to fields of corn and soybeans (Alemu et al., 2020). Hence, remnant prairies are highly fragmented (Wimberly et al., 2018).

Physiography, Climate, and Land Use

The Big Sioux River basin lies within the Central Lowland physiographic province (Fig. 10.19) and the Middle Missouri freshwater ecoregion, beginning in the Aspen Parkland/Northern Glaciated Plains Level III terrestrial ecoregion where glacial ice built an elevated plateau called the "Prairie Coteau" behind an outcrop of Precambrian Sioux Quartzite. The Coteau diverted the Des Moines and James glacial lobes to the east and west, respectively. The Big Sioux River traverses the length of the Coteau, crosses the quartzite, and then issues onto the Western Corn Belt Plains Level III terrestrial ecoregion where surface rocks are glacial till, outwash, and loess.

The Big Sioux River valley was ice-free during the last glaciation. Ice blocks breaking off glacial fronts pushed onto the valley boundaries, leaving a fringe of basins that

FIG. 10.7 Big Sioux River falls in Sioux Falls, South Dakota, including ruins, park paths, and train track bridge in the background. *(Photo by © Jeremy Christensen | Dreamstime.com, ID 113901535.)*

straddles the eastern drainage divide. For instance, an abandoned valley indicates Lake Shaokatan once discharged to Deer-Medary Creek (Big Sioux basin) prior to or concurrent with its present discharge to the Yellow Medicine River (Minnesota basin). Nicollet (Bray and Bray, 1976) reported that high water historically connected the Big Sioux basin with the Des Moines River basin between Beaver Creek and North Branch Chanarambie Creek (respectively) and the Minnesota River basin via dual (eastern and western) outlets of Lake Benton. Likely, more inter-drainage locations existed before industrial wetland drainage and stream channelization. During flooding, Lake Hendricks still discharges both to the Minnesota (Lac qui Parle River) and Big Sioux (Deer-Medary Creek) basins.

Average annual air temperature in Sioux Falls, South Dakota, is 6.9°C (Fig. 10.20). Air temperature, based on a 30-year record, is lowest in January (−8.6°C) and highest in July (22.8°C). Average annual precipitation is 67 cm/yr, with precipitation lowest (1.5 cm/mo) in January and February and highest (9.9 cm/mo) in June (Fig. 10.20). Soils are mollisols and tallgrass prairie predominates, featuring big and little bluestem, Indiangrass, switchgrass, green needlegrass, and western wheatgrass. Rolling pasture is common in the north with flatter areas tilled for small grains, corn, and soybeans. Steep areas harbor bur oak, green ash, and elm. The southern basin is more extensively tilled for small grains, corn, sunflowers, soybeans, and grain sorghum. Urbanization is concentrated around the Sioux Falls and Sioux City metropolitan areas.

Subsistence farming dates to the Great Oasis (950–1050 CE) and Middle Missouri (1000–1300 CE) cultures, both leaving archeological remains. The basin is now highly developed. Remnant wetlands and glacial lakes comprise 6% of the basin. Forest comprises 1%, 20% of which is ungrazed. Grassland-herbaceous land comprises 12%, including undisturbed grasslands—concentrated in non-contributing basins and along the Bemis Moraine. These are mostly unprotected (Wimberly et al., 2018). Remaining land is row-crop agriculture (66%) pasture/hay (9%), and urban/developed (6%).

River Geomorphology, Hydrology, and Chemistry

The Big Sioux basin formed in the Late Pleistocene. The river begins as grassy swales that coalesce into a channel with sequential pools along irregular meander bends on the high side of the Prairie Coteau escarpment (~626 m asl) near Summit, South Dakota. The river is creek-like for 52 Rkm with silt-gravel substrate, mean annual discharge of 0.4 ± 0.05 SE m^3/s, and bankfull width < 7.5 m.

It then joins Indian River, the first major tributary, followed by Soo, Mahoney, Mud, Willow, Stray Horse, and Hidewood creeks. In this segment, mean annual discharge triples to 1.2 ± 0.18 SE m^3/s. Gravel is the dominant substrate and bankfull width is 11.0–23.5 m. The Bemis Moraine (Des Moines lobe, last glacial maximum) forms the northeastern watershed divide where aforementioned streams originate at >610 m asl. These are the main contributors to streamflow along the upper 181 Rkm. Punished Woman Mound (634 m asl, Bemis Moraine, Mud Creek basin) is the highest point in the contributing basin. At the triple confluence of Mud Creek, the Big Sioux River, and Lake Kampeska, the upper river and creek fill the lake during high water, whereas the lake discharges back to the river during low flow. Non-contributing subbasins (rarely discharging surface flow) lie north and west, totaling 33.6% of the entire basin. These have high densities of wetlands (i.e., prairie potholes). The 1974 km^2 Waubay Lakes complex includes the highest elevation of the greater Big Sioux basin (unnamed point 646 m asl, Bemis Moraine).

From Hidewood Creek, the Big Sioux River describes irregular meanders for 191 Rkm to first contact with Sioux Quartzite at Dell Rapids, South Dakota. Substrate transitions to silt-sand. Bankfull width ranges from 25.5 to 44.5 m. The channel is locally anastomosing. Migrating meanders, meander scrolls, and oxbows indicate a dynamic channel. Mean annual discharge swells to 13.7 ± 1.56 SE m^3/s. Water conductivity is <1000 μS/cm, highest during low flow. Main constituents are calcium, magnesium, bicarbonate, and sulfate. Wetlands store snowmelt and recharge shallow aquifers, feeding headwater streams that typically flow until September. However, widespread tile drains can reduce water residence times, depending on their installation (Werner et al., 2016).

The river is superimposed across Sioux Quartzite for 102 Rkm and entrenched therein at Dell Rapids, and from the Split Rock Creek confluence, South Dakota, to the Gitchie Manitou State Preserve, Iowa. Here, it has irregular meanders and silt-sand substrate, with localized gravel. Bankfull width is 28–76 m. Advance of the James glacial lobe 11.7 kya created an s-bend by blocking the southward courses of the Big Sioux River and Skunk Creek. Water backing up behind the glacier first spilled northeast, into Slip-up Creek (which reversed its flow) and then overflowed east from there into Split Rock Creek. This established the Sioux Falls (30 m drop over 0.8 km) where erosion by the re-routed, northeast-flowing river (Fig. 10.7) exposed an outcrop of Sioux Quartzite. Silver, Skunk, Slip-up, and Split Rock creeks join the Big Sioux River within the 60-Rkm long s-bend, expanding drainage area by 42.5%. Downstream, mean annual discharge is 22.5 ± 3.40 SE m^3/s. Conductivity sometimes exceeds 1000 μS/cm, but remains <2000 μS/cm. Major constituents are calcium, bicarbonate, and sulfate.

The lower river traverses glacial till for 46 Rkm, via irregular meanders, to Little Beaver Creek. From there, Loess Hills flank the valley for 114 Rkm (e.g., Newton Hills State Park, South Dakota), and the river receives its largest tributary, Rock River (21.7% of the total basin), swelling mean annual discharge to 40.8 ± 3.80 SE m^3/s. The channel transitions to tortuous meanders—actively migrating in places—with bankfull width of 69–80 m. Conductivity seasonally exceeds 2000 μS/cm at low flow. The river enters the Missouri River valley at Brule Creek, following the northeastern valley margin for 56 Rkm to the Missouri River.

Average annual discharge near the river mouth (Akron, Iowa) was 42.8 ± 3.8 SE m^3/s over a 90-year period of record between 1929 and 2018. Annual discharge ranged from 3.4 to 177.6 m^3/s, with interannual variability of discharge at 89%. Historical monthly discharge is highest in April (99.2 ± 12.6 SE m^3/s) and lowest in January (9.2 ± 1.3 SE m^3/s) (Fig. 10.20). This also varies, with April discharge variation of 120% and January discharge variation of 130% among years. On average, discharge becomes elevated (>60 m^3/s) with ice out, snowmelt, and rains from March into July and then limited (<30 m^3/s) by lower precipitation coupled with heat (summer) or cold (winter) from late July through February. In part due to low relief and an abundance of natural lakes and wetlands, river regulation is limited to small diversion dams, dams on lake outlets, and widespread stock ponds. Upstream from Sioux Falls, groundwater supplies 18–24% of river flow in high- and low-flow periods, respectively (Neupane and Kumar, 2020).

Because of abundant croplands, suspended sediment from soil erosion is a general concern. Whereas conservation efforts help to reduce sediments reaching the river (McLaury and Basile, 2015), ongoing conversion of grassland to cropland increases them (Taghizadeh-Mehrjardi et al., 2019). Garrett (2012) provided a summary of water chemistry near the river mouth (Akron, Iowa) for water years 2004–2008. In this period, mean suspended sediment was 245 mg/L and mean turbidity was 73.0 NTU. Also, mean pH was 8.1, mean alkalinity was 238 mg/L, mean specific conductance was 881 μS/cm, mean total nitrogen was 7.22 mg/L, mean total phosphorus was 0.46 mg/L, and mean orthophosphate was 0.16 mg/L. The Big Sioux River stands out from other Iowa rivers with relatively high concentrations of silica (mean = 13.0 mg/L) and nitrate (mean = 5.66 mg/L). Most nitrate in the river at Sioux

Falls originates from municipal wastewater, livestock manure, and mineralized fertilizer (Hoogestraat, 2012). Contamination from wastewater effluent is most severe in the upper Big Sioux River where discharge from Watertown, South Dakota, can account for much of total river flow (Sando et al., 2005).

River Biodiversity and Ecology

Algae and Cyanobacteria

Algae of the Big Sioux River are largely unstudied, but presumably resemble adjacent wetlands where major phyla include Cyanophyta, Bacillariophyta, and Chlorophyta. In the Big Sioux River at Akron, chlorophyll *a* ranges from 0.9 to 384.0 μg/L (mean = 78.8 μg/L), and pheophytin *a* ranges from 0.9 to 128.0 μg/L (mean = 30.9 μg/L).

Plants

Macrophytes are restricted to bulrushes and cattails on river margins. Floodplain wetlands have distinct vegetation zones and dynamic successional regimes. Riparian trees include green ash, peachleaf willow, boxelder, common buckthorn, plains cottonwood, American elm, and northern hawthorn, with silver maple in the south.

Invertebrates

Chironomidae (Diptera) is the most abundant and diverse family (Kafle et al., 2013). Stoneflies include *Taeniopteryx*, *Acroneuria*, *Agnetina*, *Isogenoides*, and *Pteronarcys*. Aquatic snails include *Campeloma*, *Probythinella*, *Cincinnatia*, *Fossaria*, *Stagnicola*, and *Physella*. Freshwater mussels include threeridge, white heelsplitter, fragile papershell, fatmucket clam, giant floater, round pigtoe, paper pondshell, and ellipse.

Vertebrates

Of 82 documented fishes, 71 are native. Paddlefish, longnose gar, mooneye, American eel, western silvery minnow, hornyhead chub, golden shiner, blackchin shiner, carmine shiner, flathead chub, highfin carpsucker, northern hogsucker, and black buffalo may be extirpated. Persistent species include the federally threatened shovelnose sturgeon (listed under the "Similarity of Appearances" provisions of the Endangered Species Act) and endangered Topeka shiner. Assemblages are segregated above and below the Sioux Falls. Wetland-stream species dominate upstream, whereas riverine species are more prevalent downstream. The lower river is frequented by migrant blue sucker from the Missouri River during spring, possibly for spawning (Neely et al., 2010). Federally endangered pallid sturgeon has also recently been collected from the lower Big Sioux River (Kirk Steffensen, Nebraska Game and Parks Commission, pers. comm., October 2020). Native channel catfish support a robust recreational fishery.

Riparian amphibians include northern leopard frog, plains leopard frog, and tiger salamander. American bullfrog is considered native along the lower river. Aquatic turtles include western painted turtle, common snapping turtle, spiny softshell, smooth softshell, false map turtle, and Blanding's turtle. Riparian snakes include plains and common gartersnakes. At least 63 bird species nest along the Big Sioux River (Gentry et al., 2006). The broader Madison Wetland Management District houses 96 wetland species and 329 bird species. North American beaver is widespread, most abundant in ungrazed areas. From 1998 to 2000, the Flandreau Santee Sioux Tribe of South Dakota successfully reintroduced North American river otter from Louisiana.

Ecosystem Processes

Riverine ecosystem processes are little studied. Low shading elevates primary production, whereas water turbidity can be limiting. Regionally, the Big Sioux River has relatively low suspended sediment yield (Garrett, 2012). Riverine food webs still need detailed study.

Human Impacts and Special Features

Discharge in rivers of the Midwest and Great Plains is increasing largely due to variability in climate and land-use practices (Hoogestraat and Stamm, 2015). The source of high spring discharge has changed in the Big Sioux River basin from predominantly snow melt to rainfall (Hoogestraat and Stamm, 2015).

Levees confine the s-bend of the Big Sioux River through the Sioux Falls metropolitan area and a dam diverts some flow into a 4.5-km long artificial bypass channel. For water years 2005–2018, this dam reduced mean annual discharge along the bypassed 26 Rkm by 77%. Fragmentation by dams extends 27 Rkm upstream to a low-head dam at Baltic, South Dakota, and another 55 Rkm farther upstream at Flandreau.

Although fish assemblages impacted by industrial pollution of the early 20th century recovered somewhat after the Clean Water Act (Milewski et al., 2001), the lower Big Sioux River received the 14th highest single toxic discharge into a U.S. river in 2010 (John Morrell & Co., Smithfield Foods Inc.), making it the 13th most toxic river in the country (Kerth and Vinyard, 2012). Elevated total nitrogen and phosphorus from nonpoint agricultural and residential sources also impact the lower river (Garrett, 2012).

Municipal wastewater discharge is a concern in the upper valley where effluent from Watertown may contribute >50% of discharge at base flow. Efforts to reduce nonpoint pollution in the upper basin have had some success

(McLaury and Basile, 2015), but nuisance blooms of cyanobacteria occur during summer, notably in Lake Kampeska. In addition, grasslands and wetlands are still being converted to croplands (Wright and Wimberly, 2013).

Areas of Need for Research and Management

The Big Sioux River is contiguous with the Missouri River, where restoration of federally listed species is ongoing. Significance of the Big Sioux River to this effort deserves further study, especially given recent collections of pallid sturgeon in the lower Big Sioux. Removal of all lowhead dams from the lower Big Sioux River, culminating with the 2013 removal of Klondike Dam, has eliminated fish-dispersal barriers. Now, there are 267, 261, and 205 undammed Rkm from the Missouri River to the Sioux Falls, up Split Rock Creek to the first dam at Garretson, South Dakota, or up Rock River to the first dams at Rock Rapids, Iowa, respectively. Further, a 209-Rkm long undammed reach from Watertown to Flandreau also deserves study. This reach includes annual wetland-river interactions with unknown significance to the riverine ecosystem. Tributaries provide high-quality habitat for Topeka shiner, and the river itself upstream from Lake Kampeska is of moderate to high water quality for this species (Wall et al., 2004).

KANSAS RIVER

The Kansas River basin encompasses 159,171 km^2 in Kansas, Nebraska, and Colorado. The river and its tributaries generally flow from eastern Colorado to where it enters the Missouri River at Kansas City, Missouri. The Kansas River proper is relatively short at 274 Rkm and begins where the Republican River joins the Smoky Hill River at Junction City, Kansas. Therefore, the Republican and Smoky Hill rivers are the predominant tributaries, but other tributaries include the Saline and Solomon rivers (which enter the Smoky Hill) in central Kansas and the Big Blue River, which flows south from Nebraska to the Kansas River near Manhattan, Kansas.

Multiple Indigenous Americans occupied the Kansas River basin from the Comanche in the west to Kiowa and Pawnee in central Kansas to the Kanza (from where the Kansas gets its name) in eastern Kansas. The Kanza were a primary tribe along the Kansas River from the mid-17th century until the 1840s, when they were displaced south to Oklahoma and today constitute the Kaw Nation, Oklahoma.

Physiography, Climate, and Land Use

The Kansas River basin is contained within the Great Plains and Central Lowland physiographic provinces (Fig. 10.21). About the eastern one-fourth of the basin lies within the Central Irregular Plains and Western Corn Belt Plains Level III terrestrial ecoregions, whereas the remaining basin resides in the High Plains, Central Great Plains, and Flint Hills Level III terrestrial ecoregions. The High Plains ecoregion in the westernmost part of the basin is composed of silt and eolian deposits with relatively low stream channel erosion of 70 metric tons/km^2/yr. In contrast, the Central Great Plains Level III ecoregion (Smoky Hill) in the central Kansas River basin has predominantly sandstone and sediment yields of 70–211 metric tons/km^2/yr (Sanders et al., 1993). The Flint Hills ecoregion in the eastern part of the basin has shallow rocky limestone soils that are primarily ranchlands and contains the largest tallgrass prairie in North America.

Average annual air temperature varies slightly from west to east. Colby, Kansas, on the western part of the basin, averages an annual air temperature of 11.1°C, whereas Kansas City, Kansas, in the east averages 13.7°C (Fig. 10.22). Air temperature is lowest in January (−0.6°C in Kansas City and −1.7°C in Colby) and highest in July (27.2°C in Kansas City and 24.4°C in Colby). Precipitation patterns are markedly different along an east-west gradient where Kansas City receives 1.5–3.6 times greater precipitation than Colby, depending on month. Average annual precipitation is 99 cm/yr in Kansas City, but only 46 cm/yr in Colby. Precipitation is greatest during summer and early fall months (>10 cm/mo in Kansas City; >6 cm/mo in Colby), and lowest in winter with December, January, and February having <5 cm/mo in Kansas City and less than 1.3 cm/mo in Colby (Fig. 10.22).

Land use is over 90% agriculture in the basin with only 2% forest and 3% urban. The largest urban areas are along the lower Kansas River with Kansas City (Rkm 0–16, population 147,700; Fischer et al., 2015) and Topeka (Rkm 130–145, population 122,000) being the largest cities. Over 50% of the agricultural land is in cultivated crops (corn, soybeans, wheat), with the remainder in ranchland (Sanders et al., 1993). The Flint Hills in eastern Kansas has some of the largest remaining tallgrass prairie in the United States.

River Geomorphology, Hydrology, and Chemistry

The mainstem Kansas River is a sand-bed river where gradients are typically low, ranging from 0.5 to 1.2 m/km (Sanders et al., 1993). The river has shifting substrate throughout its mainstem, but only 12% of the mainstem has shifted laterally to areas greater than the channel width from 1936 to 1975 (Sanders et al., 1993). The mean depth of the river ranges from 0.79 to 1.33 m with no discernable longitudinal pattern, except where diversions and low-head dams create deep water areas near Lawrence, Topeka, and

FIG. 10.8 Kansas River near Manhattan, Kansas, during summer. Sandbars are a common geomorphic feature. *(Photo by Craig Paukert.)*

Kansas City, Kansas. Channel width also varies with the narrowest reach at the start of the Kansas River (96 m) and the widest section (220 m) in the lower reaches (Rkm 24 to 60; Eitzmann and Paukert, 2010a). Sandbars are the dominant feature in the Kansas River (Fig. 10.8), ranging from 1 to 30/km with their origin related to increased cropland and urban area in the basin (Fischer et al., 2015).

There are few off-channel oxbows and floodplain areas due to levee construction after major floods in the 1950s. There are secondary channels throughout the mainstem Kansas River, however, that do receive water at least annually (Jacobson et al., 2019). Channel sidebars and point bars are common throughout most of the Kansas River (Fig. 10.8) with about 20% of bank-full width in sand bars, whereas in urban reaches it is <6% (Eitzmann and Paukert, 2010a). Sandbar formation and destruction occur annually and within-channel migration varies up to 200 m (O'Neill and Thorp, 2011). There are few vegetated islands, but those that do occur are more prominent in the upriver reaches where approximately 20% of the bank-full width is grass island (Eitzmann and Paukert, 2010a). From a geomorphic perspective, the Kansas River clusters with the Yellowstone, Upper Mississippi, Platte, Illinois, and Wabash Rivers, with all having narrow floodplains and levee development (Jacobson et al., 2019).

The mainstem Kansas River has no major impoundments, although 18 large reservoirs (659–6483 ha; built between 1948 and 1977) occur on its tributaries. However, only 11 were in operation between 1950 and 1965 following substantial basin-wide flooding in 1951. In addition, there are over 13,000 small impoundments that control over 80% of the drainage basin (Sanders et al., 1993) with density <1.0/km^2 in the west to 3/km^2 in the east (Perkin et al., 2016).

Mean annual discharge in the upstream mainstem reaches (Wamego, Kansas) was 145 m^3/s for the period of record (1919–2019), whereas downstream near the mouth (DeSoto, Kansas) it was 209 m^3/s for 1918–2019, with much of the additional discharge coming from large tributaries. Mean annual discharge ranges from 54 to 636 m^3/s, with an interannual variability of 71%. Peak monthly discharge is in June at 429 m^3/s in DeSoto with January having the lowest discharge at 87 m^3/s. Runoff is only 0.15 cm/mo in

January, but exceeds 0.50 cm/mo from May to July (Fig. 10.22). Mean annual discharge increased 24%–26% from pre-dam (1920–1945) conditions (113 m^3/s at Wamego; 165 m^3/s at DeSoto) to current (1994–2019) conditions (140 m^3/s at Wamego and 207 m^3/s at DeSoto). Median annual discharge increased 47%–60% over the same time period.

Water temperature in the lower river near the Kansas City metropolitan area (Desoto, Kansas) peaks in July at 27.2°C (1999 to 2014) and is lowest in January (1.8°C). This lower river site is typically <0.5°C warmer than the upriver site at Wamego, Kansas. Average dissolved oxygen at DeSoto is 10.9 mg/L and is greatest in winter with December-February above 13 mg/L, but never below 8 m/L in any month. Specific conductance averages 755 μS/cm and ranges from 500 μS/cm to 948 μS/cm. Average turbidity is 83.6 FNU and is substantially higher in June (210 FNU) and lowest in January (15 FNU). NO_2-N from 2018 to 2019 averaged 0.012 mg/L, whereas NO_3-N averaged 0.86 mg/L for the same period. PO_4-P averaged 0.204 mg/L.

River Biodiversity and Ecology

The Kansas River is located in the Middle Missouri freshwater ecoregion (Abell et al., 2008). The ecoregion has no known endemic mussels, crayfishes, fishes, or aquatic herpetofauna.

Algae and Cyanobacteria

Little information exists about the algae and cyanobacteria on the Kansas River, particularly before 1960. However, benthic algae may be the primary source of planktonic chlorophyll (Marzolf, 1979). Chlorophyll *a* concentration from DeSoto to Wamego, Kansas from 1999 to 2014 averaged 29.0 μg/L and peaked in October (51.4 μg/L) and April (49.2 μg/L). Chlorophyll *a* concentration was typically >10 μg/L and would classify the Kansas River as a mesotrophic to eutrophic system (Graham et al., 2018). Cyanobacteria levels range from about 500 cells/mL to over 10,000 cells/mL and increase downriver, with highest values generally during summer (Graham et al., 2018). *Microcystis* cyanotoxins were collected in 20–23% of sites and concentrations ranged from <0.01 μg/L to 2.41 μg/L (Graham et al., 2018).

Phytoplankton abundance and diversity are similar across habitats, but vary seasonally. Taxa richness ranged from 18 to 45 per site and peaked in mid-August. Composition, based on number of cells, varies by year and primarily comprises cyanobacteria, green algae, and diatoms. Phytoplankton densities also vary with flow, and low flows are associated with increased phytoplankton abundance (Sanders et al., 1993).

Plants

The central and western part of the Kansas River basin has been substantially converted to agriculture (corn, wheat, soybeans). The Tallgrass Prairie (Flint Hills ecoregion) is in the eastern portion of the basin and contains little and big bluestem, Indiangrass, switchgrass, and various forbs. Common riparian plants include eastern red cedar, eastern cottonwood, American elm, sycamore, and box elder. Willow species are also common in the riparian zone and on the few islands and established sandbars within the Kansas River mainstem (O'Neill and Thorp, 2011).

Aquatic plants are very limited in the mainstem Kansas River and do not contribute to ecosystem function, as photosynthetic production is tied to planktonic and benthic algae (Sanders et al., 1993). In addition, reservoir releases in the tributaries do not contribute substantially to chlorophyll concentrations in the mainstem.

Invertebrates

Zooplankton diversity in the Kansas River is similar to other prairie rivers with rotifers comprising over 99% of zooplankton taxa (Thorp and Mantovani, 2005). Rotifer density (as individuals per L) was 34.4/L, with *Monostyla* (6.75/L), *Notholca* (6.19/L), *Brachionus* (6.06/L), *Trichocera* (4.69/L), and *Proales* (3.13/L) being most abundant. *Diaphansoma* is the most abundant cladoceran crustacean at 0.42/L and copepod crustaceans (primarily nauplii) are 0.70/L. Zooplankton density in the Kansas River may be related to environmental factors, since as turbidity increases rotifer abundance decreases and crustacean zooplankton increases (Thorp and Mantovani, 2005). Also, rotifer density peaks in August and September, but this observation could not be linked to flows.

Benthic invertebrates consist primarily of Diptera (Chironomidae and Ceratopogonidae) and oligochaetes that are typically sand-bed habitat or depositional habitat specialists (O'Neill and Thorp, 2011). Drifting aquatic invertebrate density is highly variable, ranging from <100 to 1000/1000 m^3, whereas benthic samples had densities of <5 to 40/m^2 and, depending on year, are primarily mayflies, caddisflies, biting midges, Oligochaete worms, and Chironomids (Gerken, 2015).

Little is known about freshwater mussels in the Kansas River, but they have presumably declined over the last 100 years (Sanders et al., 1993). Of the 13 species of native mussels historically found in the mainstem Kansas River in the 1880s, only four remained by 1980 (pink papershell, fatmucket, fragile papershell, giant floater; Sanders et al., 1993) and were still common in 2007 (Pilger and Gido, 2012). However, recent sampling has suggested that an average of eight mussel species occur in larger (fifth to seventh order) tributaries of the Lower Kansas River basin (Pilger and Gido, 2012), and of the 13 mussel species found in Sanders et al. (1993), only two (hickorynut and mucket) were not in the 22 species reported by Pilger and Gido (2012). The nonnative zebra mussel is found throughout the Lower Kansas River and its reservoirs.

Vertebrates

Recent fish surveys coupled with historical surveys of the Kansas River mainstem and basin indicated that there are 106 species in the basin with 78 of them native. Sanders et al. (1993) listed 99 species in the Kansas River basin and 24 of them have been introduced. An additional seven species (four nonnative: bighead carp, saugeye, silver carp, and hybrid striped bass) and three native (redfin shiner, shoal chub, slenderhead darter) were collected by Moore and Thorp (2008), Eitzmann and Paukert (2010b), Fischer et al. (2012), and Gerken (2015) in the Kansas River mainstem. A total of 80 of these 106 species occurred in the mainstem Kansas River or its lower tributaries with 81% (65) considered native and 15 (19%) nonnative. Many of the 15 introductions were intentional and occurred to create sport fisheries in reservoirs (e.g., yellow perch, striped bass, hybrid striped bass, walleye, black crappie), whereas some have been long established (e.g., common carp, grass carp) and others were unintentional and more recent (last 25 years, such as silver and bighead carps). Common species include channel catfish, flathead catfish, shovelnose sturgeon, blue sucker, common carp, freshwater drum, river carpsucker, red shiner, bullhead minnow, and sand shiner.

There are two federally endangered fishes in the Kansas River Basin: the Topeka shiner and pallid sturgeon. The Topeka shiner is found in smaller streams in the Flint Hills of eastern Kansas. The pallid sturgeon has historical records in the Kansas River as far upstream as Lawrence, Kansas, below Bowersock Dam after flooding events, but they are not established in the Kansas River. Occasional specimens are found in the extreme lower reaches and are likely from stocking and recovery efforts along the Missouri River. Recent fish surveys of the mainstem Kansas River have found two state threatened species (plains minnow, shoal chub) and two species in need of conservation (blue sucker, Johnny darter).

Numerous reptiles and amphibians live along the Kansas River corridor, including common snapping turtle, Ouachita map turtle, false map turtle, painted turtle, and smooth and spiny softshells. Migratory waterfowl are common as well as muskrat and North American beaver. Least tern and the federally threatened piping plover nested on sandbars in the Kansas River in 1996 and 1997 (Busby et al., 1997).

Ecosystem Processes

Photosynthetic production in the Kansas River is very high (30 g C/m^2/yr) and is tied to planktonic and benthic algae, but not aquatic vascular plants (Sanders et al., 1993). In an experimental study in the upper Kansas River, net ecosystem production was negative and NH_4^+ uptake length was 2.1 Rkm. The rates of microbial metabolism were actually similar to small streams, when scaled to unit area of the river/stream (Dodds et al., 2008).

The Kansas River food web differs by river reach and riparian land use. Trophic positions of piscivorous, insectivorous, and omnivorous fishes were higher where braided channels and urbanization were lowest (Eitzmann and Paukert, 2010a). Areas of high urban development in the riparian zone led to reduced channels and more homogenization of habitats and thus more limited carbon sources for fishes.

Human Impacts and Special Features

The primary human impacts to the Kansas River basin are land conversion to agriculture, creation of dams throughout the basin, and levee construction that limits access to floodplains. The impacts of land use conversion to agriculture and the construction of reservoirs are well established and include altered water temperature and flows and increased erosion and nutrients. Gerken (2015) found that lateral connectivity on Kansas River intermittent secondary channels provided diverse macroinvertebrate and fish composition suggesting these habitats, when available, do provide unique habitats used by native biota.

The mainstem Kansas River also has substantial threats including barriers that may limit fish movement and migration (and sediment transport), instream sand dredging, and nonnative species. Although the Kansas River does not have any large mainstem impoundments, there are several barriers that alter river structure and function. Bowersock Dam, a 7-m high low-head dam constructed in 1874, created a 5–6-km long reservoir near Lawrence, and a rock weir at Rkm 27 near Kansas City may limit native fish migrations such as blue sucker or alter habitat near these structures (Eitzmann et al., 2007; Eitzmann and Paukert, 2010b). Although fish passage has been considered at Bowersock Dam, nonnative Asian carp are in the lower Kansas River, so there is concern that allowing passage may allow passage of nonnative species.

The sand obtained by dredging in the Kansas River is known as some of the best (and least expensive) in the United States for construction and concrete, and dredging has occurred in the river since the 1900s, primarily in the lower mainstem reaches. This has led to 2.4–4.6 m of bed degradation (Cross et al., 1982), and 1.7 million tons of sediment are still removed per year as of 2011 (Fischer et al., 2012). Dredging creates deep water habitats and lowers riverbed velocities, but fish communities were similar between dredged and undredged sites, likely because the Kansas River was already degraded and species were lost prior to dredging (Paukert et al., 2008; Fischer et al., 2012). Although sites replenish with sand soon after dredging ceases, that sand is typically coming from bank erosion and head cutting and thus is impacting the habitats upstream of the former dredging operations.

Areas of Need for Research and Management

As with most large rivers, the Kansas River has numerous anthropogenic stressors. Although nonnative species are not prominent throughout the Kansas River, bighead and silver carps are present below Bowersock Dam in Lawrence. Therefore, understanding how native fishes may respond to nonnative fishes, and mechanisms that limit their spread upriver may be warranted. In addition, aquatic biota in these prairie rivers are adapted to harsh conditions (e.g., floods, drought, high salinity, and water temperature). However, understanding how the native aquatic biota (which are generally tolerant taxa) may respond to altered flow regimes may be needed given projected increases in drought and irrigation from the river. Development of ecological flows to meet the life-history needs of native aquatic biota may be necessary for their persistence. Restoring lateral connectivity would increase nutrient exchange with the mainstem and may be possible given the large amount of agricultural land along the floodplain, where levee setbacks may be feasible (as opposed to floodplains in large cities). Instream sand dredging creates bed degradation (Fischer et al., 2012), and diversions and dams alter the fish community and habitat (Eitzmann et al., 2007) so developing restoration initiatives that modify or eliminate these alterations (as well as maintaining or restoring instream flows) may help return the Kansas River's natural structure and function.

GRAND RIVER

The Grand River originates in southwestern Iowa in the Western Corn Belt Plains Level III terrestrial ecoregion and flows through the Central Irregular Plains Level III terrestrial ecoregion in northwestern Missouri to its confluence with the Missouri River at Rkm 450 near Brunswick, Missouri, again in the Western Corn Belt Plains ecoregion. The basin is entirely within the Central Lowland physiographic province and consists of 20,461 km^2 with over three-fourths in Missouri (Fig. 10.23).

As early as 1723, the French referred to this river as "La Grande Riviére," and the French explorer Étienne de Veniard, Sieur de Bourgmont established Fort D'Orleans just west of its mouth. The basin was occupied by various Indigenous groups into the early 19th century including the Sauk, Fox, and Pottawatomi. Anglo-Americans entered the basin as hunters and trappers in the early 19th century. Permanent settlement began in the 1820s in the southern edges along the Missouri River and progressed northward in valleys of perennial streams during the 1830s and 1840s (Nigh and Schroeder, 2002; Fig. 10.9). The Missouri Legislature declared the Grand River navigable to the Iowa state line in 1835, but steamboat navigation was never possible much above Chillicothe (USACOE, 1963).

Physiography, Climate, and Land Use

Most of the Grand River basin's landscape was formed on pre-Illinoisan glacial till, varying in thickness from <1 m to over 90 m. This till is overlain by a <3-m thick veneer of post-glaciation late Pleistocene and Holocene loess. The landscape, which is contained in the Western Corn Belt Plains and Central Irregular Plains Level III terrestrial ecoregions, is typically a gently rolling plain with a relief of 24 to 46 m, with valleys cut shallowly into the till and loess (Fig. 10.9). Slopes are gentle to moderately steep. Valley bottoms are quite broad for the small size of the streams and are poorly drained. Stream dissection has hardly affected the till-loess surface in places and uplands with less than 30 m of relief remain (Nigh and Schroeder, 2002).

Geology, soils, and topography in the Grand River basin reflect the historical glacial-derived geomorphology of the region and subsequent reworking by fluvial dynamics (Heitmeyer et al., 2011). Geology consists of alternating deposits of shale, limestone, coal, and small amounts of sandstone that dip gently northwest exposing outcrops of successively younger formations from its mouth to the headwaters. Bedrock is ≥9 m below the surface and alluvial fill contains Pleistocene gravels, sands, and silts. Dominant soils are mostly alluvium derived from a mixture of loess and glacial till eroded from upland terraces adjacent to floodplains (Heitmeyer et al., 2011). Riparian soils typically have coarser texture and are moderately to well-drained, whereas soils in floodplain depressions and swamps contain mostly clay surfaces and are poorly drained.

Average annual air temperature at Trenton, Missouri, is 11.3°C (Fig. 10.24). Air temperature is lowest in January (1.7°C) and highest in July (31°C). Average annual precipitation is 101 cm. Precipitation is greatest in May and June (14 cm/mo) and lowest in January (2.6 cm/mo). Snowfall is of minor importance and occurs from November through March, averaging 46 cm/yr.

Historically, the landscape of the Lower Grand basin was a diverse mix of prairie, savanna, and forest communities with numerous small oxbows, bottomland lakes, and sloughs. Present land use in the basin is approximately 50% grassland, 25% cropland, 15% forest, 5% developed, 4% wetland, and 1% water (MODNR, 2016). There is little manufacturing and limited recreation and tourism within the basin and commercial activity is largely restricted to the few small towns. Land use is overwhelmingly agricultural with most farmland in pasture. Soybeans, corn, and grass-legumes are the dominant crops. Timber and woodlands occupy moderate to steep slopes and some narrow, eroded ridgetops. Most bottomlands are in row crops. Some tracts remain scarified from historical coal mining. The number of farms and the percent of land devoted to cropland and pasture along with the basin's population have declined over the past few decades.

FIG. 10.9 Grand River just north of "Adam-ondi-Ahman" (Jameson), Missouri, believed by Mormons as the site where Adam and Eve lived after being evicted from the Garden of Eden. *(Photo by LatinGal.)*

River Geomorphology, Hydrology, and Chemistry

The mainstem Grand River is formed near Albany, Missouri, by the confluence of the West Fork (also known as the Grand River) with the Middle and East forks. The basin is approximately 240-km long and 145-km wide. Only one-fifth of the Grand River's tributaries are south of the mainstem, whereas four-fifths are north, flowing south. This asymmetric drainage pattern results in the mainstem Grand serving largely as a distribution channel for its many parallel tributary basins (>1000 third-order and larger streams; USACOE, 1963). Tributaries and the mainstem transport high suspended loads, especially upon nearing the Missouri River. A few tributary reaches are on bedrock with shoals at locations where they have cut through the glacial tills to underlying sedimentary rock. Tributary channels are typically silty and generally have low gradients (≥fifth-order streams averaging 0.6 m/km) and extremely meandering courses with reasonably stable banks. However, many long reaches have been channelized, shifting them into a degrading mode. Banks are no longer stable and channel depth has increased. Frequency of flooding has increased at the ends of these channelized reaches with thick layers of silt deposits resulting in valley aggradation and chronic wetness. As a consequence of channelization, adjustment to a new geomorphic equilibrium is occurring in some segments (Nigh and Schroeder, 2002).

Streams within the Grand River basin are quite flashy, largely a consequence of its clayey, glacial till soils and compaction from long-term agriculture. These conditions result in the basin's hydrograph resembling an "urban" runoff pattern, where runoff moves rapidly through the system to the downstream portion of the basin (USACOE, 2019). Highest runoff occurs during June when soils are fully saturated after high spring precipitation. Many of these tributaries revert to low flows once rains cease. For example, average discharge in August for the Grand River near Sumner, Missouri, is only one-fifth of its average discharge in June (Nigh and Schroeder, 2002) and tributaries with drainage areas <130 km^2 stop flowing for 7 consecutive days or more at some time every 2 years (Pitchford and Kerns, 1998).

Average annual discharge near Sumner is 121.9 m^3/s over a 94-year period of record. Annual discharge ranges from 13.5 to 441.8 m^3/s, with variability of interannual discharge at 66%. Maximum instantaneous peak discharge (5097 m^3/s) occurred in June 1947 and peak discharge during the record 1993 Missouri River flood was 4248 m^3/s (Pitchford and Kerns, 1998). Daily mean discharge ranges from 1.1 to 2489 m^3/s. Highest discharge usually occurs in June (mean = 226.8 m^3/s, CV = 124%) and is lowest in January (mean = 55.8 m^3/s, CV = 147%) (Fig. 10.24). Reflective of its flashy tributaries, interannual variability of Grand River discharge is high within months, ranging from 93 to 215% and averaging over 100% for 11 months annually for the period of record. Although the Grand River basin comprises only about 1.5% of the Missouri River basin, it contributes 7% of the Missouri's average annual discharge (Pitchford and Kerns, 1998).

The Grand River is characterized as a turbid, hardwater prairie river. Turbidity averages 150 NTU, but ranges widely from <1 to 2600 NTU. Suspended solids can range from 6 to >2600 mg/L (mean = 355 mg/L). Specific conductance is moderately high (mean = 385 μS/cm; range 115–743 μS/cm) as is pH (mean = 7.7; range 5.5–8.6). High variability in pH is likely a consequence of acidic runoff from abandoned coal mines. Alkalinity averages 154 mg/L as $CaCO_3$ and ranges from 53 to 250 mg/L as $CaCO_3$ and hardness is also high (181 mg/L as $CaCO_3$, range 53–320 mg/L as $CaCO_3$). A history of coal mining in the basin is reflected in high iron and magnesium concentrations (Fe mean = 102 μg/L; Mg mean = 264 μg/L). Iron can also be quite high in suspended sediment averaging 7.1 mg/L. Nutrient concentrations are high, with total nitrogen averaging 2.5 mg/L and levels as high as 27 mg/L. Total phosphorus averages 0.36 mg/L (range = 0.02–3.5 mg/L). Average annual water temperature is 13.7°C and ranges from 0°C to a critically warm 34°C.

River Biodiversity and Ecology

Algae and Cyanobacteria

A diverse phytoplankton and periphyton community of 90 genera was recorded in the Grand River near Sumner, between 1974 and 1981 (U.S. Geological Survey Water Resources gauge 06902000). Green algae and diatoms dominated. The 10 most abundant taxa from ≥25 samples in decreasing order of frequency of occurrence were: *Nitzschia, Cyclotella, Ankistrodesmus, Scenedesmus, Navicula, Melosira, Osscillatoria, Trachelomonas, Dictyosshpaerium,* and *Actinastrum.* Periphyton biomass has also been measured from the Grand River on a few occasions and averaged 11.4 g/m^2 ash-free dry mass.

Plants

Most of the upland Grand River basin was historically tallgrass prairie. Prairies graded into oak savannas and woodlands on steeper lands, especially on the eastern fire-shadow sides of larger stream valleys. Bottomlands were a mixture of wet prairies, marshes, and bottomland forests (Nigh and Schroeder, 2002). Row crops now occupy the bottomlands and hills are largely in pasture.

Remnant forest in the lower Grand River appears to be shifting toward wetter communities compared with pre-settlement conditions. This is likely a result of upstream and local flood control and drainage projects, conversion of forest and prairie to cropland, and climate change

(Heitmeyer et al., 2011). Floodplain forest woodland communities now contain up to 60% water tolerant species such as green ash, silver maple, sycamore, cottonwoods, river birch, and black willow and $<30\%$ pin oak, bur oak, and pecan (Heitmeyer et al., 2011).

River oats and Virginia wild rye are common grasses in the understory of floodplain forests, and wood nettle is an abundant forb that hampers human foot travel. Dominant plants in wet floodplain and wet-mesic prairies include buttonbush, sedges and rushes, smartweeds, beggar ticks, rice cutgrass, and a variety of flowering forbs (e.g., brown-eyed susan, late goldenrod, asters).

Invertebrates

Eighteen orders and 71 families of aquatic invertebrates have been collected from the Grand River basin since 1977. Aquatic insects frequently collected within the basin include caddisflies (*Cheumatopsyche, Hydropsyche*), mayflies (*Baetis, Caenis, Hexagenia, Stenonema*), dragonflies and damselflies (*Gomphus, Ischnura, Argia, Macromia*), beetles (*Stenelmis, Dubiraphia*), and true flies (*Chironomus, Simulium*) (Pitchford and Kerns, 1998).

A 1913 survey indicated that the Grand River had numerous mussel shells of commercial value, but by 1915, modifications to the Grand River mainstem had already begun and the river held few species (Pitchford and Kerns, 1998). Today, mussels are drastically reduced due to pollution from agricultural chemicals and sedimentation. Twenty species have been reported from the Grand River basin (McMurray et al., 2012). Species with the most encounters include pink papershell, fragile papershell, white heelsplitter, and yellow sandshell. No mussels are common in the basin; none are federally listed, but hickorynut and flat floater are species of conservation concern in Missouri. Crayfish species collected within the Grand River basin in decreasing order of abundance are calico crayfish, virile crayfish, prairie crayfish, devil crayfish, and White River crayfish (MODC, 2020a, 2020b). Devil crayfish is a floodplain burrowing species, and White River crayfish has been introduced.

Vertebrates

Dunn (2020) reported 80 fish species collected from the Grand River within the Middle Missouri and Central Prairie freshwater ecoregions. Common species within the basin include shortnose gar, bigmouth shiner, red shiner, creek chub, sand shiner, central stoneroller, fathead minnow, bluntnose minnow, common carp, river carpsucker, black bullhead, yellow bullhead, channel catfish, flathead catfish, bluegill, green sunfish, and Johnny darter (USACOE, 2019). Channel and flathead catfish are popular sport fishes within the mainstem Grand River and nonnative bighead and silver carps are now two of the most abundant fishes observed. Two federally listed fishes occur within the Grand River basin: Topeka shiner and pallid sturgeon. Dunn (2020) divided fishes from Missouri's mid-sized rivers, including the Grand, into three stream-size preference guilds: large-river (big-river) specialist dispersers from the Missouri River (i.e., great-river sourced species); headwater specialists dispersing from small ($\leq$third order) basin tributaries to the mainstem Grand River; and core species (common throughout the mainstem and another stream-size category). Core species dominate the mainstem Grand (32 species), followed by large-river species (23 species) with headwater species richness being lowest (13 species). Tributaries to the Missouri River, including the Grand River, support more large-river specialist fishes than previously documented and may help sustain large-river fish populations by mitigating habitat losses within the highly modified Missouri River.

There is a rich herpetofauna within the Grand River floodplain. Common to abundant amphibians include the small-mouthed salamander, American toad, northern cricket frog, gray treefrogs (eastern and Cope's), boreal chorus frog, plains leopard frog, southern leopard frog, and American bullfrog. Midland smooth softshell, western spiny softshell, and common snapping turtles frequent the Grand River along with red-eared slider and western painted turtle in slower-moving waters. Fourteen species of snakes are expected to occur along the Grand River, including northern and plain-bellied watersnakes and eastern and red-sided gartersnakes. Small populations of the federally threatened western massasauga rattlesnake occur in remnant wet-floodplain and wet-mesic prairies within Pershing State Park (Locust Creek) and Swan Lake National Wildlife Refuge.

The Grand River basin is in the heart of what is known as the "Golden Triangle" because of its importance to migratory waterfowl, shorebirds, and other wetland dependent migratory bird species. Thirteen species of waterfowl, including snow and Canada geese, mallard, wood duck, and blue- and green-winged teals commonly use riverine wetlands within the basin (e.g., Swan Lake National Wildlife Refuge). Waterfowl hunting is a popular activity on public land (e.g., Fountain Grove Conservation Area) and the ~1200 ha of private hunting clubs and recreational properties within the basin. Remnant wet-floodplain prairies and managed wetlands host about 20 species of shorebirds during migrations, including numerous sandpipers (eight species), dowitchers and yellowlegs. Birds reported frequently nesting in floodplain forests, wetlands and wet prairies include bald eagle, red-shouldered hawk, great blue heron, least bittern, pied-billed grebe, wood duck, red-headed woodpecker, Acadian flycatcher, willow flycatcher, prothonotary and northern parula warblers, and wood thrush. Muskrat, beaver, mink, otter, coyote, bobcat, raccoon, and white-tailed deer are mid-sized to large mammals that frequent the Grand River corridor. Nine bat species occur within the basin including three federally listed species: gray bat, Indiana bat, and northern long-eared bat.

Ecosystem Processes

A few static measurements of process-related variables exist for the Grand River, but there has been no systematic examination of river processes (U.S. Geological Survey Water Resources gauge 06902000). Total organic carbon in the Grand near Sumner averages 20 mg/L (range 3.4–180 mg/L). Periphyton biomass ash-free dry mass averages 11.5 g/m^2 (range 0–58 g/m^2), and periphyton chlorophyll *a* averages 1.1 mg/m^2 (range = 0.04–3.5 mg/m^2).

Human Impacts and Special Features

Conversion of upland prairies to row crop agriculture and large hog and cattle operations, clearing of floodplain woodlands and forests, and construction of uncoordinated drainage and levee projects throughout the Grand River basin have increased total water, sediment, and nutrient discharges to the lower Grand River. Consequently, surface water within the Grand River basin is often of poor quality, especially during low-flow periods. High turbidity is common during periods of runoff. Runoff from historical coal mines is a further risk to local water quality. Groundwater is naturally saline or brackish and has prompted construction of numerous lakes for domestic water supplies.

Principal water quality issues for the Grand River as a result of these activities include high turbidity from suspended sediment, high total nitrogen and total phosphorus concentrations and loads, elevated water temperatures, high acidity, pesticides, low dissolved oxygen concentrations, and loss of riverine pool habitat. State water quality standards are commonly exceeded for bacteria, manganese, and iron.

The lower reaches of Locust Creek, a major tributary of the Grand River, are within Pershing State Park and Fountain Grove Conservation Area. This ~30 Rkm segment is listed on the National Rivers Inventory for its outstandingly remarkable fish, historic, recreational, scenic, and wildlife values. Unfortunately, the 130 Rkm of Locust Creek above Pershing State Park has been channelized, leveed, and there are several flow diversions. These actions have produced log jams, excessive sedimentation, and aggradation that have degraded Locust Creek's wet prairies, emergent marshes, floodplain forest, and riverine aquatic habitats. To address this degradation, lower Locust Creek is a focus area basin in the Natural Resources Conservation Service (NRCS) Mississippi River Basin Healthy Watersheds Initiative (MODNR, 2016). The NRCS and U.S. Army Corps of Engineers along with state- and private-land partners have embarked on a Healthy Watershed Plan to improve awareness of the basin and of practices that contribute to: stewardship of water quality and water supply; improvements in soil health; reductions in streambank erosion, sediment and nutrient transport, and bacteria levels; and improvements in water quality and wildlife habitat of streams within the lower Grand River basin.

Areas of Need for Research and Management

A Lower Grand River Watershed Healthy Watershed Plan was created to help guide efforts in maintaining and improving water in the basin (MODNR, 2016). Stakeholders identified soil erosion, log jams, flooding, stream impairment, and bacterial contamination as the most important problems to be improved. Over the past decade, several project grants have been provided to local groups to improve water quality through stream channel stabilization, water quality monitoring, education/outreach efforts, and incentivized water conservation practices. Additionally, the NRCS has funded and implemented cost-share programs to conserve soil and improve water quality by reducing sedimentation to Grand River tributaries and streams. Recent studies evaluating Grand River basin nutrient concentrations as part of the Lower Grand River Mississippi River Basin Healthy Watersheds Initiative have reported mixed results (Wilkison and Armstrong, 2016; Krempa and Flickinger, 2017) suggesting further refinement and evaluation of conservation practices may be beneficial.

An evaluation of ecosystem restoration and management options for floodplains in the Grand River basin (Heitmeyer et al., 2011) identified reducing soil and drainage-channel bank erosion, and restoring natural stream corridors, surface water drainage pathways, floodwater distribution and duration, and drier more seasonal inundation regimes as critical to mediating problems with excessive sedimentation. Implementing these management options may aid in restoring and sustaining aspects of communities and ecological functions in the Grand River ecosystem. Heitmeyer et al. (2011) conclude success will depend on how well changes in water, sediment, and land type management can emulate historical ecological processes and community type, abundance, and productivity.

OSAGE RIVER

The Osage River, named for the Indigenous peoples inhabiting the region when Anglo settlers arrived, is the largest tributary of the Missouri River in Missouri (Fig. 10.10). The named Osage River is formed in southwestern Missouri by the confluence of the Marais des Cygnes and Little Osage rivers both originating in Kansas. Its total length is over 800 Rkm and named length to where it joins the Missouri River is 444 Rkm (Fig. 10.25).

FIG. 10.10 Osage River at dusk from a bluff on Monegaw Springs, Missouri. *(Photo by © Tommy Brison | Dreamstime.com, ID 83277814.)*

As early as 1673, the Osage Nation was trading furs for French iron tools and guns and trading became a major economic activity during French occupation. The Osage people were displaced from Missouri to Kansas and Oklahoma following acquisition of the Louisiana Territory and signing of the Osage Treaty of 1808. The basin was part of the largest timber producing region in the nation at the end of the 1800s. In 1837, the first steamboat ascended the Osage River. However, its meandering, fluctuating water levels, shallow pools, and numerous sand bars hindered navigation.

A low-head lock and dam were constructed on the lower Osage River (Rkm 19.5) in 1906 to facilitate river travel, but with little improvement. By the late 1920s, logging, land clearing, burning, and overgrazing had eroded soils and gravels from hillsides, degrading riverine habitats. Bagnell Dam was privately constructed on the central Osage River (Rkm 131) in 1931, primarily for hydropower generation, impounding Lake of the Ozarks, which subsequently became a major recreation destination. The U.S. Army Corps of Engineers completed the Harry S. Truman dam and reservoir (i.e., Truman Lake) in 1979 for flood control, power generation, recreation, and wildlife management.

Physiography, Climate, and Land Use

The upper two-thirds of the Osage River system, including the Marais des Cygnes, Little Osage, Marmaton, and South Grand rivers, drains the Central Irregular Plains Level III terrestrial ecoregion within the Central Lowland physiographic province (Fig. 10.25). The Osage River continues flowing eastward across the Springfield and Central (Salem) Plateau Level IV terrestrial ecoregions within the Ozark Highlands Level III terrestrial ecoregion of the Ozark Plateaus physiographic province. It then flows through the Interior River Valleys and Hills Level III, and River Hills Level IV terrestrial ecoregions of the Missouri River alluvial plain to its confluence with the Missouri River at Rkm 209.5. The Central Irregular Plains ecoregion is an unglaciated prairie characterized by a flat to gently rolling landscape underlain by soft shales, interbedded with sandstones and limestones of late Mississippian to Pennsylvanian age (USFS, 1999). Soils are primarily derived from these shales and sandstones with a silty, loess surface mantle. Extensive wetlands are also associated with streams of the upper Osage River in this ecoregion (USFS, 1999).

The Ozark Highlands ecoregion is a low structural dome of horizontally bedded strata that has undergone erosion and weathering for a quarter billion years into a thoroughly dissected plateau (Nigh and Schroeder, 2002). The Springfield Plateau within the Ozark Highlands is underlain by limestones and cherty limestones of Mississippian age, whereas the Central Plateau is underlain by dolomites, cherty dolomites, sandstones, and limestones of Cambrian and Ordovician age. Topography within the Ozark Highlands ecoregion ranges from gently rolling hills in the Springfield Plateau to rugged landscapes with relief up to 150 m in the Central Plateau (USFS, 1999). Karst limestone features are common with dissolution along fractures and faults having produced numerous cave systems, sinkholes, and natural tunnels. Soils are largely derived from limestone, dolomite, and chert, and are typically erosive, droughty, and stony.

Average annual air temperature is 13.3°C at Lake Ozark (Fig. 10.26) and is lowest in January (−3.7°C) and highest in July (25.1°C). Average annual precipitation is 110 cm/yr. Precipitation is greatest between April and June (>11 cm/mo) and lowest in January and February (~5 cm/mo). Snowfall is of minor importance, averaging 23 cm/yr, and occurs from November through March.

The Osage basin is 98% in private ownership, and its economy is based primarily on agriculture, forest products, mining, and lake-oriented recreation and tourism. Presettlement prairie in the Central Irregular Plains ecoregion of western Missouri was about 66% of total land area, whereas today it is about 1% (Fantz et al., 1997). Contemporary land use varies across the basin. Agriculture is the dominant activity in the Osage's western subbasin (i.e., area above Truman Dam). About 78% of the western subbasin's land is in row crops, pasture, and hayfield, 20% is forested, and 0.7% is mined, mostly coal (Schubert, 2001). Principal row crops are soybeans, wheat, corn, and sorghum. Pastureland for beef cattle grazing occupies river bottoms and slopes of the uplands throughout the basin (Adamski et al., 1995). Agriculture in the eastern subbasin (i.e., area below Truman Dam to the Missouri River) has shifted from a crop-based system in the early days of settlement to a livestock-based system today. Cropland comprises 4% of land cover, whereas grassland is 41%, deciduous forest is 44%, coniferous forest 3%, and urban is about 1% (NRCS, 2008).

Open water of the two mainstem reservoirs constitutes about 2% of the Osage basin. About 60% of the eastern subbasin is classified as highly erodible (NRCS, 2008) and commercial gravel mining occurs on several Osage tributaries in the Ozark Plateaus ecoregion. Recreation and tourism associated with Lake of the Ozarks are the primary industry in the eastern subbasin. It is a major recreation and retirement destination with over 70,000 homes and condominiums; tourism-related expenditures exceeded $225 million in 2017.

River Geomorphology, Hydrology, and Chemistry

About 64% of the Osage River's total length is impounded (Jacobson et al., 2019). Once in Missouri, the Osage flows east into a long-meandering arm of Truman Lake (~158-km long, 225 km^2 surface area). The Sac River enters the Osage from the southwest near the headwaters of Truman Lake after exiting Stockton Reservoir [Lake] (~100 km^2 surface area). Truman Reservoir also receives the South Grand River, the only major south-flowing tributary of the Osage River and draining the Central Irregular Plains ecoregion, and the Pomme de Terre River entering from the south downstream from Pomme de Terre Reservoir (32 km^2 surface area). Downriver from Truman Lake, the Osage becomes the serpentine Lake of the Ozarks (~219 km^2 surface area), stretching eastward 150 km to Bagnell Dam and with 2092 km of shoreline (Schubert, 2001). The Niangua River is the primary unregulated Osage River tributary flowing into Lake of the Ozarks. Below Bagnell Dam, the Osage flows northeasterly in broad meanders through forested bluffs before entering the Interior River Valleys and Hills terrestrial ecoregion where it joins the Missouri River.

Drainage patterns of Osage River tributaries throughout much of the Ozark Plateaus are often radial following geologic faults and joints. Entrenched stream meanders are common with narrow stream valleys subject to flash flooding. The river's pre-development channel in the Ozark Plateaus was meandering and comprised a series of pools, shallow shoals, bars, and islands. Below Bagnell Dam, the Osage River channel exhibits an increase in cross-sectional area due to bed degradation, channel widening, and base-level lowering (Schubert, 2001). Over 100 springs and >22 losing streams occur in the karst geology of the Ozark Highlands ecoregion (Schubert, 2001). These Ozark Highlands streams are generally clear with limestone fragments and chert being common substrates (Duchrow, 1984).

The Osage is ranked as the seventh highest mean annual discharge river of the top 10 "large" rivers of the Upper Midwest (Jacobson et al., 2019), and it contributes about 9% to the Missouri River's total annual discharge. Average annual discharge at St. Thomas, Missouri (downriver from all mainstem impoundments), is about 364 m^3/s (1997–2019) and among years ranges widely from 60.4 to 719 m^3/s with variability of interannual discharge at 48%. Highest mean monthly discharge occurs in May (629 m^3/s) and June (606 m^3/s) along with the lowest variability among months, 67% and 61%, respectively. Average discharge is uniformly low between September and December (Fig. 10.26), ranging from 196 to 217 m^3/s, but with the highest variability among months, ranging from 103% to 143%. Flooding on the Osage was frequent and severe prior to mainstem and tributary dam construction. Impoundment of the Osage River by Bagnell and Truman dams dramatically affects lower Osage River hydrology. Collectively, these dams have reduced catastrophic flooding, but have increased frequency of moderately high flows and very low flows. (Schubert, 2001). Hydropeaking of Bagnell Dam also increases variability of daily and hourly flows routinely resulting in discharge rising from 26 m^3/s to >1000 m^3/s within an hour.

Turbidity of the Osage River near St Thomas (61 Rkm downstream of Bagnell Dam) is low, averaging 10 NTU, as is suspended sediment concentration (69 mg/L). Upstream reservoirs sequester sediment despite highly erodible lands in the Central Irregular Plains ecoregion above Truman Lake where turbidity and suspended sediment average 139 NTU and 320 mg/L, respectively. Conductivity in the lower Osage River is moderate (279 μS/cm), and pH averages 7.8. Alkalinity (110 mg/L as $CaCO_3$) and hardness (134 mg/L as $CaCO_3$) are moderately high due to the dominance of limestones in the Ozark Plateaus ecoregion. Nutrient concentrations are also quite high, with total nitrogen averaging 2.5 mg/L, and total phosphorus averaging 0.36 mg/L. Average annual water temperature is 16.1°C, with a range of 0.5–31°C.

River Biodiversity and Ecology

Algae and Cyanobacteria

A diverse algal community of 74 genera exists in the Osage River below St. Thomas (1974–2020; U.S. Geological Survey Water Resources gauge 06926510). Diatoms dominate samples and the most abundant taxa from 20 or more samples in decreasing order of frequency of occurrence are: *Cyclotella, Melosira, Nitzschia, Navicula, Oscillatoria, Chlamydomonas, Scenedesmus, Ankistrodesmus,* and *Synedra*.

Plants

Historically, the Central Irregular Plains ecoregion was nearly pure tallgrass prairie. Today it is a transitional mosaic of woodland, cropland, and grassland. An elm-ash-cottonwood association occurs along the river riparian corridor. Oak-hickory forests are typical of the Ozark Highlands ecoregion. Post oak, blackjack oak, black oak, white oak, hickories, little bluestem, Indiangrass, big bluestem, and eastern red cedar glades are the dominant upland terrestrial plants (Wiken et al., 2011). Most woodlands of the Ozarks Plateaus are now second or third growth due to past logging, although their composition is similar to the old growth (Adamski et al., 1995). Riparian forest of the Ozark Plateaus includes American sycamore, plains cottonwood, silver maple, black walnut, pin oak, bur oak, hackberry, sassafras, river birch, and pawpaw.

Aquatic macrophytes in the Osage and its tributaries include watercress near tributary springs. Water willow occurs in riffle areas and along rocky shores and gravel bars. Macrophytes observed in backwaters include coontail, watermilfoil, spatterdock, and pond weeds. Three federally listed plants reside in the Osage River sub-basin: Missouri bladder pod (endangered), Meads milkweed, and tinytim (threatened).

Invertebrates

Over 250 taxa of aquatic invertebrates have been reported from the Osage River basin and 132 from the Osage River just prior to closure of Truman Dam in 1979 (Duchrow, 1984). The most specious orders of aquatic insects collected from major Osage basin rivers and streams were: mayflies (41 species), caddisflies (40 species), beetles (34 species), true flies (25), odonates (21), stoneflies (19), and hemipterans (12 species). Insect community richness was noticeably less for the mainstem Osage River below Bagnell dam with dipterans dominating (12 taxa), followed by mayflies (10 species), caddisflies (9 species), and 7 species each of stoneflies, beetles, and odonates. Perlidae was the dominant family of stoneflies. *Caenis*, *Tricorythodes*, *Stenonema* and *Emphemerella* were the most frequently collected mayflies, with *Hexagenia* becoming more frequent near the Missouri River confluence. *Cheumatopsyche* was the most commonly collected caddisfly. Density of aquatic invertebrates in the lower Osage was lowest below Bagnell dam (Osage Rkm 126), highest at Rkm 53, and decreased again near the Missouri River at Rkm 6.4 (Duchrow, 1984).

Freshwater mussel richness is high with 48 native species recorded (Angelo et al., 2009; McMurray et al., 2012); washboard (32%) three-ridge (11%), pimpleback (10%), purple pimpleback (9.2%), and plain pocketbook (5.3%) are the most abundant species from MODC (2020b) collections (≥5% of total numbers) in the Osage River below Bagnell dam and its major Missouri tributaries. Snuffbox, pink mucket, spectaclecase, scaleshell, and winged mapleleaf are federally endangered; 15 mussels from this basin are listed as of concern in Missouri, and 10 are listed in Kansas. Asian clams and zebra mussels are nonnative species. Density of mussels among the seven Ozark basin 8-digit hydrologic units in the Ozark Plateaus ranges from 0.5 to 4.1/100 km^2 (mean 1.9/100 km^2; USFS, 1999).

Nine species of crayfish are present in the Osage River basin (MODC, 2020a, 2020b). Virile crayfish, golden crayfish, prairie crayfish (a burrowing species), and calico crayfish have been most frequently collected. The bristly cave and Salem cave crayfishes are restricted to subterranean habitats within the Osage basin, and the White River crayfish has been introduced to the basin. Density of crayfishes among the seven Osage River basin 8-digit hydrologic units in the Ozark Plateaus ranges from 0.04 to $0.12/100\,km^2$ (mean = $0.08/100\,km^2$; USFS, 1999).

Vertebrates

Bridging the Central Prairie and Ozark Highlands freshwater ecoregions, the Osage River basin has a rich fish fauna of 133 species representing 22 families (Schubert, 2001; Fantz et al., 1997; Horton and Hutson, 2002; Schultz, 2001; Pherigo, 2019). Families represented by four or more species include: Cyprinidae (40), Percidae (20), Catostomidae (15), Centrarchidae (12), Ictaluridae (10), Clupeidae (4), Cyprinodontidae (4), and Percichthyidae (4). Nonnative sport fishes include brown and rainbow trout (Niangua River), northern pike, muskellunge, striped bass, and striped x white bass hybrids (multiple reservoirs). Rudd (Kansas only), and grass, bighead, silver and black carps are contemporary nonnative species in the Osage River and its larger tributaries. The federally endangered Topeka shiner occurs only in Central Irregular Plains ecoregion tributaries. Federally threatened Niangua darter and Ozark cavefish reside within the Ozark Highlands ecoregion. A popular paddlefish snagging fishery exists in Truman Lake, Lake of the Ozarks, and in the Osage River below Bagnell dam.

Two salamanders, the common mudpuppy and Ozark hellbender, occur in Osage basin streams. The Ozark hellbender is federally endangered, and a captive breeding and stocking program is underway to aid recovery. *Rana* are the most numerous frogs with five species using the Osage River or its tributaries. Turtles are common in the basin (12 aquatic species); map turtles are the most diverse group (four species/subspecies) followed by softshells (two species/subspecies). Seven species of aquatic and semiaquatic snakes are reported from the basin; four of these are watersnakes and one, the cottonmouth, is venomous.

Construction of large reservoirs on the Osage and Pomme de Terre rivers created wintering and nesting habitat for large numbers of bald eagles. Northern river otter were largely extirpated from the Ozarks by the early 1900s, but are now common following reintroduction in 1990. Gray and Indiana bats are federally endangered mammals within the basin.

Ecosystem Processes

A few static measurements of process related variables exist for the Osage River, but there has been no systematic examination of river processes (U.S. Geological Survey Water Resources gauge 06926510). Total organic carbon in Osage water at St. Thomas averages 6.5 mg/L (range 2.2–23 mg/L). Periphyton biomass ash-free dry weight averages $23.1\,g/m^2$ (range $1.2–77.6\,g/m^2$), and periphyton chlorophyll *a* averages $5.1\,mg/m^2$ (range = $0.1–21\,mg/m^2$).

Human Impacts and Special Features

Major reservoirs (Lake of the Ozarks, Truman Lake, Stockton Lake, Pomme de Terre) inundated 969 km of flowing waters in the Osage basin, or about 21% of $\geq$ fourth-order stream habitat (Duchrow, 1984). Conversion of native grasslands, savannas, forests, and river floodplains to row crop agriculture, pasture, and large impoundments has substantially altered native plant communities. Remnant upland and riparian forest areas are typically small, isolated, and cut over or grown up in dense timber in the absence of fire. Development and urbanization associated with the large reservoirs and towns will continue to grow and affect aquatic resources and ecosystems. Water quality problems associated with increased urban and commercial development are an ongoing concern, particularly in the area surrounding Lake of the Ozarks. Numerous concentrated animal feeding operations, gravel mining operations, wastewater treatment plants, and urban construction projects currently exist within the basin and also degrade water quality.

Despite these impacts, the Osage River basin has generally good surface and groundwater quality. The Ozark Plateaus prominence within the basin is its distinctive biogeographic feature, exhibiting high physiographic diversity due to its exceptional length of geologic erosion and central location in North America. These features have created a region of unique ecosystems with over 200 endemic species (Nigh and Schroeder, 2002) including a rich and diverse fish and mussel fauna.

Areas of Need for Research and Management

Sustained monitoring and evaluation of Bagnell Dam operations relative to a 2007 Federal Energy Regulatory Commission relicensing agreement may benefit aquatic resources of the lower Osage River. Resource protection mitigation measures include improving instream flows, increasing dissolved oxygen during project operation, reducing bank and channel erosion, and reducing fish mortality from dam operation. Implementation of the Lower Osage River Protection and Enhancement Plan to restore populations of endangered pink mucket and scaleshell mussels below Bagnell Dam is an important component of this agreement (USFWS, 2020). It will be critical to assess if these mitigation measures adequately benefit aquatic habitats and resources in lieu of changing Osage Project operation to a more natural run-of-river (nonpeaking) operation.

With the majority of stream frontage in private ownership, it is important to implement management strategies that identify and reduce surface and groundwater pollution sources. Significant contributions include sewage treatment facilities, animal waste facilities, agricultural runoff, and septic systems. Much can be done to reduce pollution through educating landowners on the value of good stream stewardship and providing technical assistance for sound stream and riparian habitat conservation and improvement. This may be facilitated through promoting and implementing existing and expanding state and federal basin-based cost-share incentives for streambank stabilization, alternative watering provisions, and establishment and maintenance of quality riparian corridors. The impact of the largely reservoir-based sport fishery on the Osage basin's economy is enormous. A challenge is to maintain quality sportfish populations in the basin's reservoirs to satisfy the angling public while conserving its native riverine biota.

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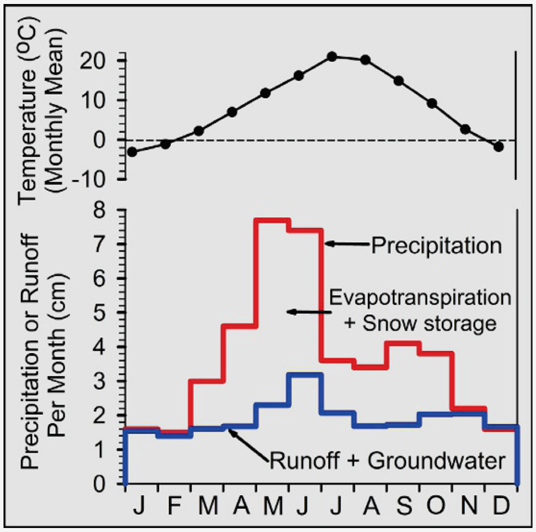

FIG. 10.12 Mean monthly air temperature, precipitation, and runoff for the Madison River basin.

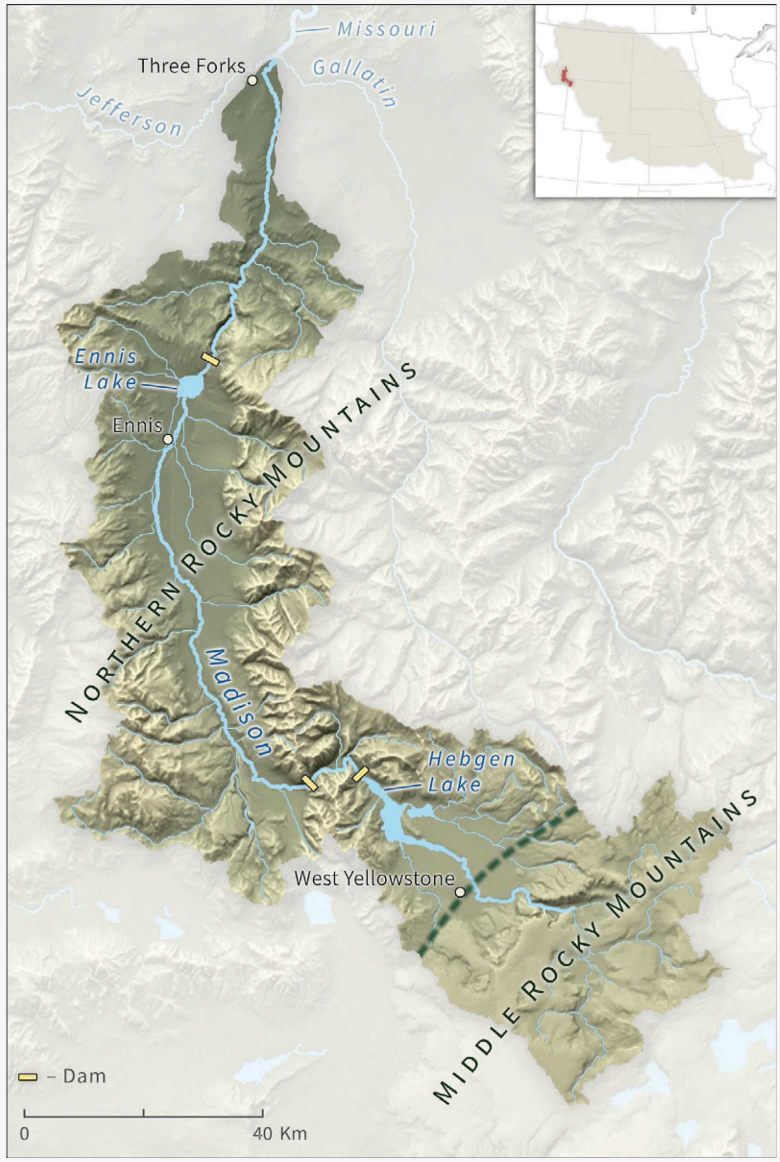

FIG. 10.11 Map of the Madison River basin. Physiographic provinces are separated by a *green-dashed line*.

MADISON RIVER

Relief: 2217 m
Basin area: 6747 km^2
Mean discharge: 49.0 m^3/s
River order: 6
Mean annual precipitation: 34 cm
Mean air temperature: 2.6°C
Water temperature: 12.6°C (April-October only)
Physiographic provinces: Middle Rocky Mountains, Northern Rocky Mountains
Freshwater ecoregion: Upper Missouri
Terrestrial ecoregions: Northwestern Forested Mountains (Level I); Western Cordillera (Level II); Middle Rockies (Level III)
Number of fish species: 16
Number of endangered species: none
Major fishes: rainbow trout, brown trout, mountain whitefish, brook trout, rocky mountain sculpin, stonecat, longnose sucker, mountain sucker, white sucker, longnose dace, northern redbelly dace
Major other aquatic vertebrates: Columbia spotted frog, boreal chorus frog, plains spadefoot, northern leopard frog, western toad, common gartersnake
Major benthic invertebrates: stoneflies (*Pteronarcys*, *Hesperoperla*), mayflies (*Baetis*, *Ephemerella*, *Serratella*, *Rhithrogena*), caddisflies (*Hydropsyche*, *Brachycentrus*, *Rhyacophila*), snails (*Fossaria*, *Physa*), mussel (western pearlshell)
Nonnative fish species: rainbow trout, brown trout, brook trout
Major riparian plants: sandbar willow, Bebb's willow, alderleaf buckthorn, green alder, black cottonwood, red-osier dogwood, spring birch, awned sedge, Bebb's sedge, blue-joint reedgrass
Special features: birthplace of wild-trout management; world-renowned trout fishery
Fragmentation: 2 dams (Hebgen Dam and Madison Dam) and several irrigation diversions
Water quality pH = 8.2; turbidity = 6.5 NTU, alkalinity = 89.4 mg/L as $CaCO_3$, ammonia = 0.03 mg/L, total P = 0.03 mg/L, total arsenic = 0.09 mg/L
Land use: 48% public, 52% in private ownership and of that 88% is in agricultural production, which is primarily livestock production
Population density: ~0.38 people/km^2 in Madison Valley
Major information sources: https://www.arcgis.com/apps/Cascade/index.html?appid=ebbfd33d94ad4c7da0557bd97f6cd2d7, PBS&J. (2011)

FIG. 10.13 Map of the Milk River basin.

MILK RIVER

Relief: 2044 m
Basin area: 59,857 km^2
Mean discharge: 19.2 m^3/s
River order: 7
Mean annual precipitation: 29.5 cm
Mean air temperature: 6.3°C
Mean water temperature: 19.4°C
Physiographic province: Great Plains
Freshwater ecoregion: Upper Missouri
Terrestrial ecoregions: Northwestern Forested Mountains, Great Plains (Level I); Western Cordillera, West Central Semi-Arid Prairies (Level II); Canadian Rockies, Cypress Uplands, Middle Rockies, Northwestern Glaciated Plains, Northwestern MiGreat Plains (Level III)
Number of fish species: 58
Number of endangered species: 3 fishes, Canada; 1 fish, United States
Major fishes: shovelnose sturgeon, paddlefish, flathead chub, western silvery minnow, longnose sucker, shorthead redhorse, river carpsucker, bigmouth buffalo, stonecat, channel catfish, sauger, Iowa darter

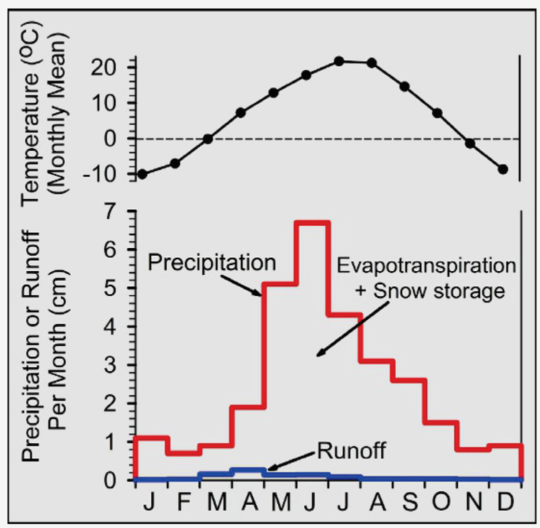

FIG. 10.14 Mean monthly air temperature, precipitation, and runoff for the Milk River basin.

Major other aquatic vertebrates: painted turtle, beaver
Major benthic invertebrates: oligochaetes (Naididae, Tubificidae), mayflies (*Fallceon, Caenis, Hexagenia*), stoneflies (Perlodidae, Capniidae), dragonflies (Gomphidae, Coenagrionidae), caddisflies (*Hydropsyche, Hydroptilla, Potamyia, Oecetis)*, beetles *(Dubiraphia, Liodessus)*, mussels (giant floater, fatmucket)
Nonnative species: black crappie, bluegill, green sunfish, largemouth bass, pumpkinseed, smallmouth bass, white crappie, common carp, black bullhead, walleye, brook trout, northern pike, brown trout
Major riparian plants: plains cottonwood, willows, red-osier dogwood, Russian olive
Special features: meandering, braided channel, incised; segment in northern Montana and southeastern Alberta one of few remaining unfragmented Great Plains rivers
Fragmentation: Fresno Dam, multiple diversion dams and weirs on the lower 700 Rkm
Water quality: pH = 8.4, alkalinity = 246 mg/L as $CaCO_3$, total N = 1.5 mg/L, total P = 0.4 mg/L
Land uses: 51% grassland, 30% cropland, 12% shrubland, 4% water and wetlands, 2% non-vegetated badlands, 2% forest, 1% urban
Population density: 0.75 people/km^2
Major information sources: MRWCC (Milk River Watershed Council Canada (2013)), Stash (2001), Simpson (1999)

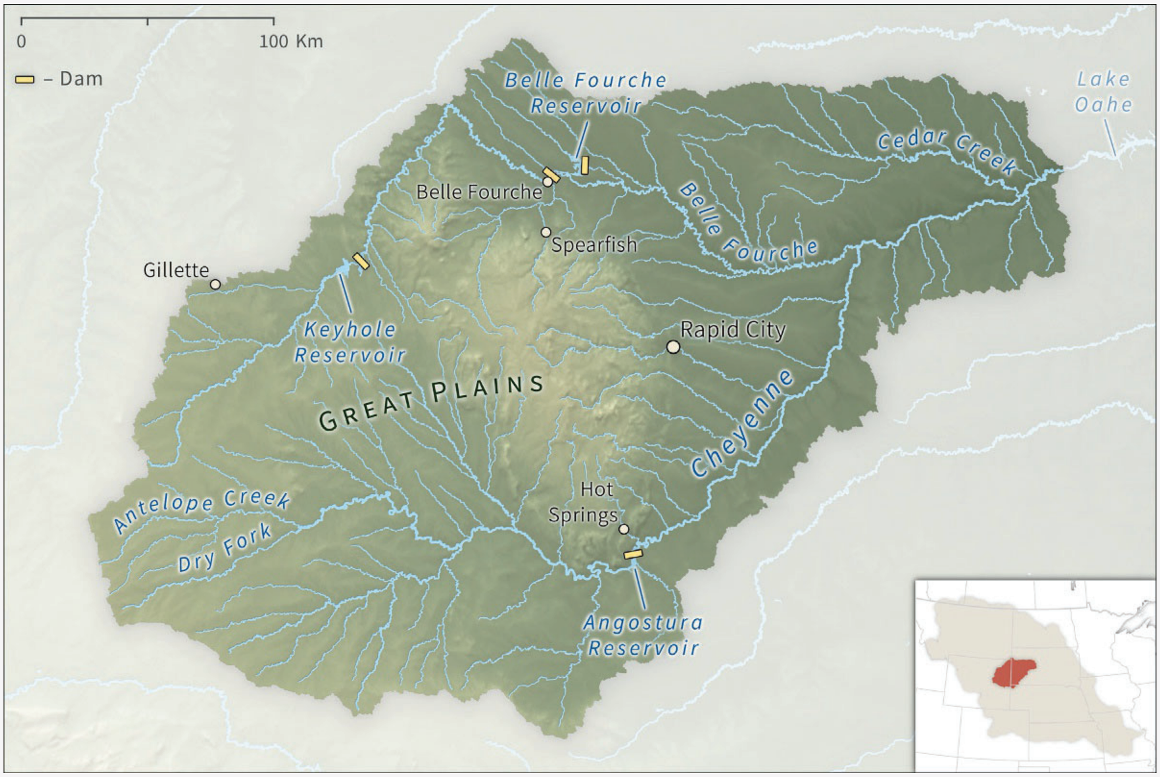

FIG. 10.15 Map of the Cheyenne River basin showing the Black Hills uplift between the Belle Fourche and upper Cheyenne rivers.

CHEYENNE RIVER

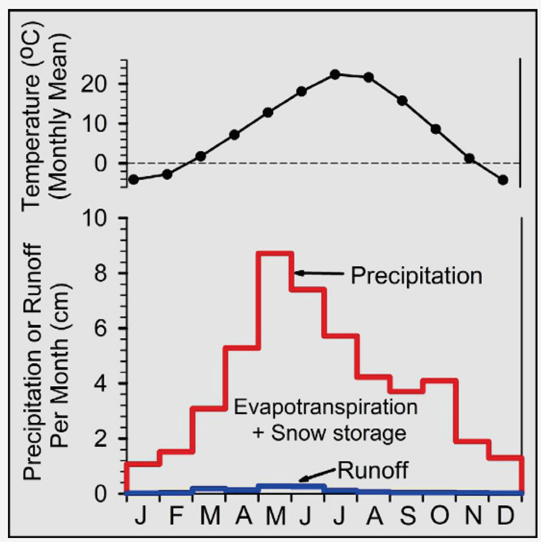

FIG. 10.16 Mean monthly air temperature, precipitation, and runoff for the Cheyenne River basin.

Relief: 1706 m
Basin area: 62,937 km^2
Mean discharge: 23 m^3/s
River order: 7
Mean annual precipitation: 48.0 cm
Mean air temperature: 8.4°C
Mean water temperature: 18.3°C
Physiographic province: Great Plains
Freshwater ecoregion: Upper Missouri
Terrestrial ecoregions: Northwestern Forested Mountains, Great Plains (Level I); Western Cordillera, West Central Semi-Arid Prairies (Level II); Middle Rockies, Northwestern Great Plains (Level III)
Number of fish species: 57 (34 native)
Number of endangered species: 1 bird
Major fishes: goldeye, red shiner, western silvery minnow, plains minnow, sturgeon chub, plains sand shiner, fathead minnow, longnose dace, northern river carpsucker, shorthead redhorse, channel catfish, stonecat
Major other aquatic vertebrates: northern leopard frog, tiger salamander, common snapping turtle, spiny softshell, interior least tern, beaver
Major benthic invertebrates: bivalves (white heelsplitter, giant floater), stoneflies (*Isoperla*, *Acroneuria*), mayflies (*Baetis*, *Caenis*), caddisflies (*Ceratopsyche*, *Cheumatopsyche*), true flies (*Simulium*, *Stictochironomus*, *Micropsectra*), beetles (*Dubiraphia*), amphipods (*Hyalella*)
Nonnative species: tamarisk, Russian olive, common carp, smallmouth bass
Major riparian plants: common three-square, softstem bulrush, sago pondweed, plains cottonwood, green ash, boxelder, American elm, common hackberry, peachleaf willow, bur oak
Special features: Jewel and Wind caves are each within the top 10 longest mapped caves on Earth
Fragmentation: 3 mainstem dams, impounded river mouth, numerous tributary dams
Water quality: dissolved Ca = 140 mg/L, ammonia = 0.02 mg/L, total N = 0.6 mg/L, pH = 8.2, total P = 0.8 mg/L, specific conductance = 1867 µS/cm, total dissolved solids = 1436 mg/L, total suspended solids = 1126 mg/L
Land use: 8% agriculture, 69% grassland/pasture, 18% forest/shrub, 5% sparse vegetation/badlands, 1% urban
Population density: 4.0 people/km^2
Major information sources: Driscoll et al. (2002), Duehr (2004), Hoagstrom et al. (2007), Peterson et al. (2009)

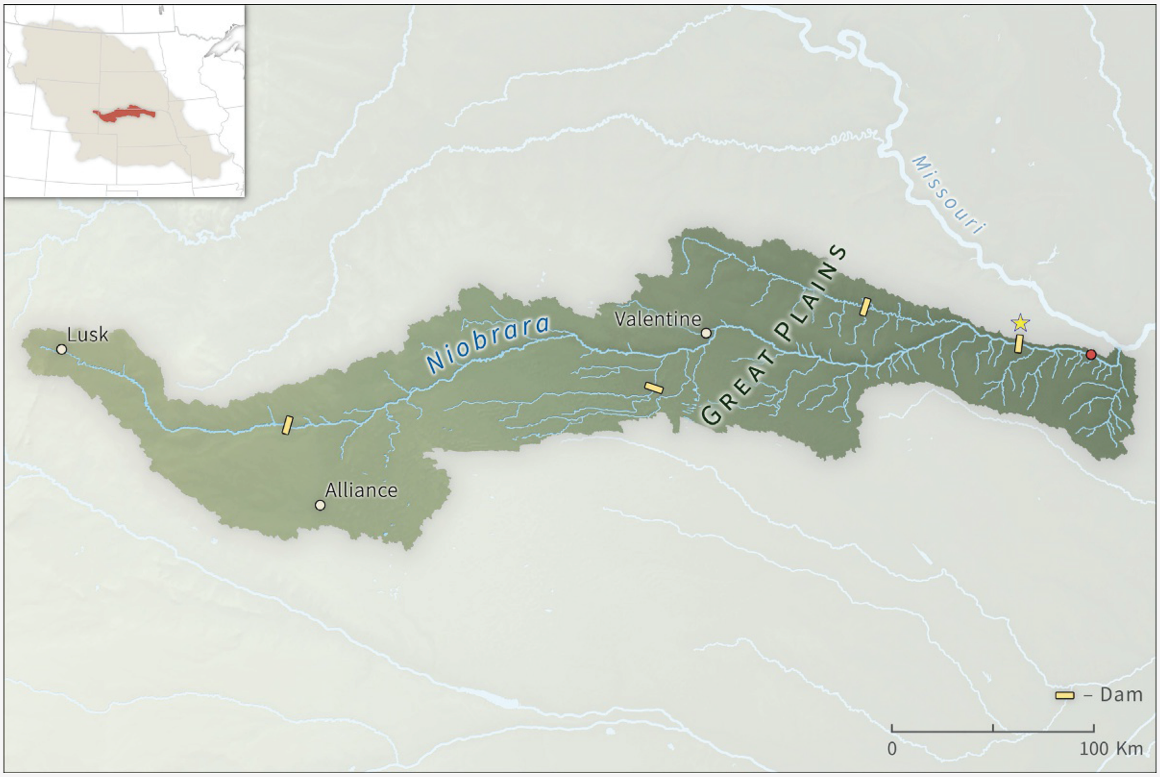

FIG. 10.17 Map of the Niobrara River basin. Red dot is location of U.S. Geological Survey gauge near Verdel, Nebraska. Star denotes the former location of Spencer Dam.

NIOBRARA RIVER

Relief: 1182 m
Basin area: 32,600 km^2
Mean discharge: 50.9 m^3/s
River order: 4
Mean annual precipitation: 50.9 cm
Mean air temperature: 9.8°C
Mean water temperature: 15.2°C
Physiographic province: Great Plains
Freshwater ecoregions: Middle Missouri, Upper Missouri
Terrestrial ecoregions: Great Plains (Level I); Temperate Prairies, West Central Semi-Arid Prairies, South Central Semi-Arid Prairies (Level II); Northwestern Glaciated Plains, Northwestern Great Plains, Nebraska Sand Hills, High Plains (Level III)
Number of fish species: 67
Number of endangered species: 1 fish, 2 birds, 1 insect, 1 mammal
Major fishes: sand shiner, red shiner, white sucker, creek chub, river carpsucker, shorthead redhorse, channel catfish, largemouth bass
Major other aquatic vertebrates: northern leopard frog, spiny softshell, northern watersnake, blue-winged teal, wood duck, spotted sandpiper, belted kingfisher, bald eagle, mink, beaver, muskrat, river otter

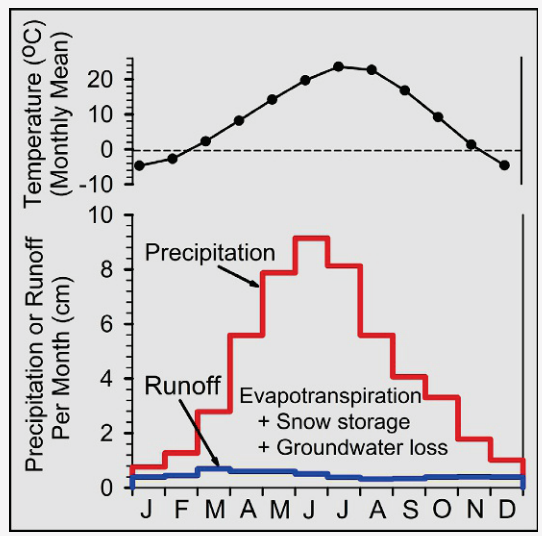

FIG. 10.18 Mean monthly air temperature, precipitation, and runoff for the Niobrara River basin.

Major benthic invertebrates: crustaceans (*Hyallella, Gammarus*, *Faxonius*), mollusks (*Physa*, giant floater), true flies (*Simulium*, Tanypodinae), mayflies (*Tricorythodes, Traverella*), true bugs (*Palmacorixa, Belostoma*), caddisflies (*Cheumatopsyche, Polycentropus*), beetles (*Dubiraphia*, *Liodessus*), dragonflies/damselflies (*Coenagrion, Enallagma*)
Nonnative species: yellow iris, purple loosestrife, reed canarygrass, Canada thistle, saltcedar, rainbow trout, brown trout, brook trout, muskellunge, rock bass, rudd, fingernail clams
Major riparian plants: plains cottonwood, green ash, willows, buffaloberry, prairie cordgrass, northern reed grass
Special features: groundwater dominated river, >200 waterfalls, National Wild and Scenic River sections, U.S. Fish & Wildlife Fort Niobrara Refuge; Missouri National Recreational River, nationally significant paddling river
Fragmentation: 2 mainstem dams, 2 tributary dams, multiple water diversions
Water Quality: moderately high, but high fecal coliforms in summer; turbidity = 8 NTU, pH = 8.0, alkalinity = 115 mg as $CaCO_3$/L, conductivity = 266 μS/cm, total N = 1.8 mg/L, total P = 0.27 mg/L, dissolved silica = 47 mg/L
Land Use: 82% range, 6% agriculture, 4% riparian forest, 4% wetlands, <1% open water, urban
Major information sources: Johnsgard (2007), Alexander et al. (2010), NPS (2006)

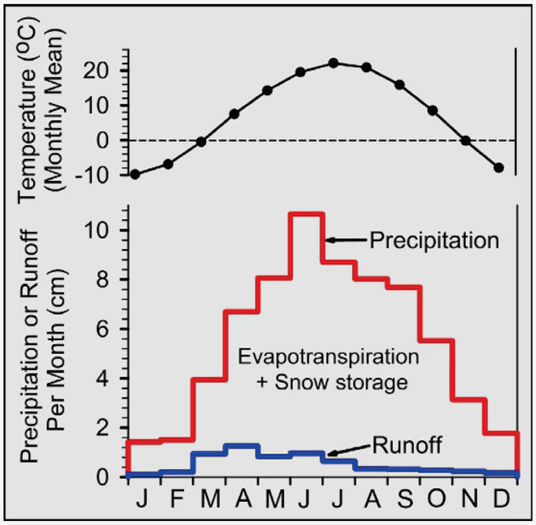

FIG. 10.20 Mean monthly air temperature, precipitation, and runoff for the Big Sioux River basin.

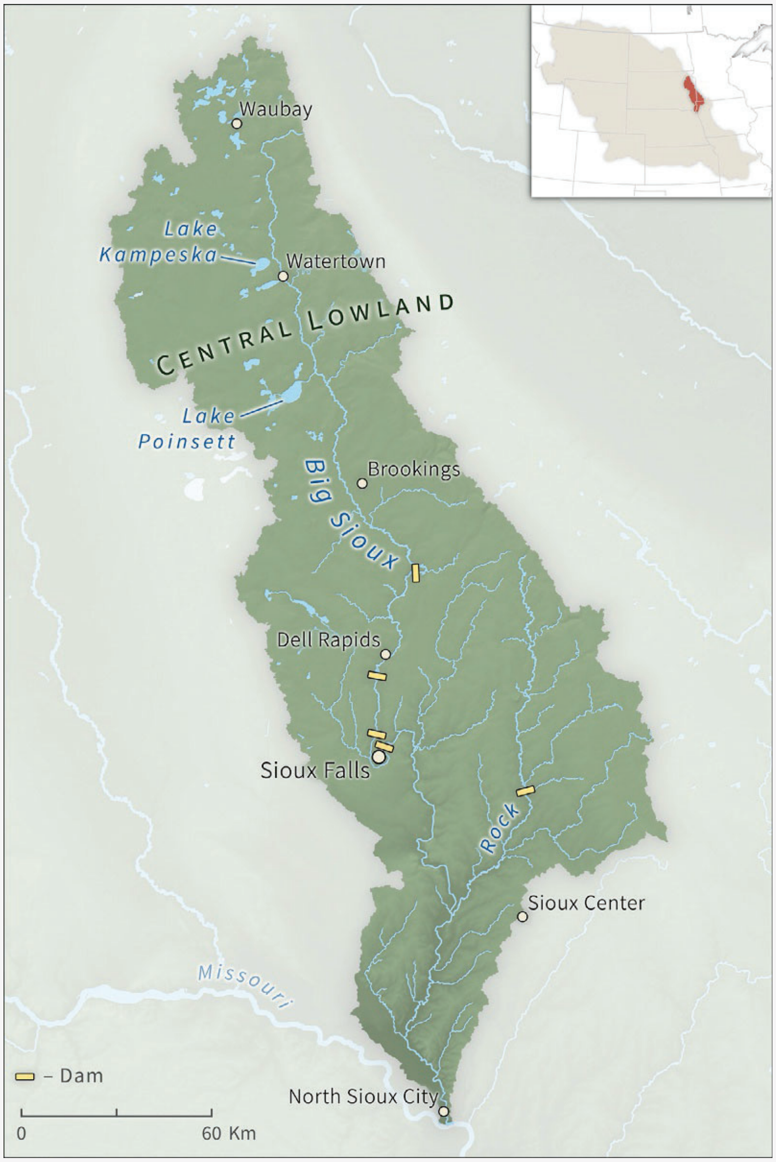

FIG. 10.19 Map of the Big Sioux River basin.

BIG SIOUX RIVER

Relief: 320 m
Basin area: 20,798 km^2
Mean discharge: 42.8 m^3/s
River order: 7
Mean annual precipitation: 67 cm
Mean air temperature: 6.9°C
Mean water temperature: 14.4°C
Physiographic province: Central Lowland
Freshwater ecoregion: Middle Missouri
Terrestrial ecoregions: Great Plains (Level I); Temperate Prairies, West Central Semi-Arid Prairies (Level II); Aspen Parkland/Northern Glaciated Plains, Western Corn Belt Plains (Level III)
Number of fish species: 82 (71 native)
Number of endangered species: 2 fishes
Major fishes: goldeye, red shiner, common shiner, fathead minnow, creek chub, northern river carpsucker, white sucker, shorthead redhorse, channel catfish, sauger, freshwater drum
Major other aquatic vertebrates: northern leopard frog, tiger salamander, common snapping turtle, spiny softshell turtle, smooth softshell turtle, beaver, river otter
Major benthic invertebrates: chironomids, stoneflies (*Taeniopteryx*, *Acroneuria*, *Agnetina*), snails (*Campeloma*, *Fossaria*, *Probynthinella*), mussels (threeridge, white heelsplitter, fragile papershell)
Nonnative species: common carp, bighead carp, silver carp, smallmouth bass
Major riparian plants: green ash, peachleaf willow, plains cottonwood, silver maple
Special features: prairie potholes, Sioux quartzite outcrop, Pipestone National Monument
Fragmentation: natural falls in Sioux Falls; lowhead dams in Sioux Falls (2), Baltic, and Flandreau, SD; lowhead dams on Split Rock Creek (Garretson, SD) and Rock River (Rock Rapids, IA)
Water quality: pH = 8.1, alkalinity = 238 mg/L as $CaCO_3$, specific conductance = 881 μS/cm, dissolved organic carbon = 5.5 mg/L, total N = 7.22 mg/L, NO_3-N + NO_2-N = 5.66 mg/L, NH_3-N = 0.11 mg/L, total P = 0.46 mg/L, orthophosphate = 0.16 mg/L, turbidity = 73 NTU
Land use: 66% agriculture, 12% grassland/herbaceous, 9% pasture/hay, 6% urban/developed, 4% open water, 2% wetlands
Population density: 23.9 people/km^2
Major information sources: Milewski (2001), Jungwirth et al. (2005), Neebling (2009), Garrett (2012)

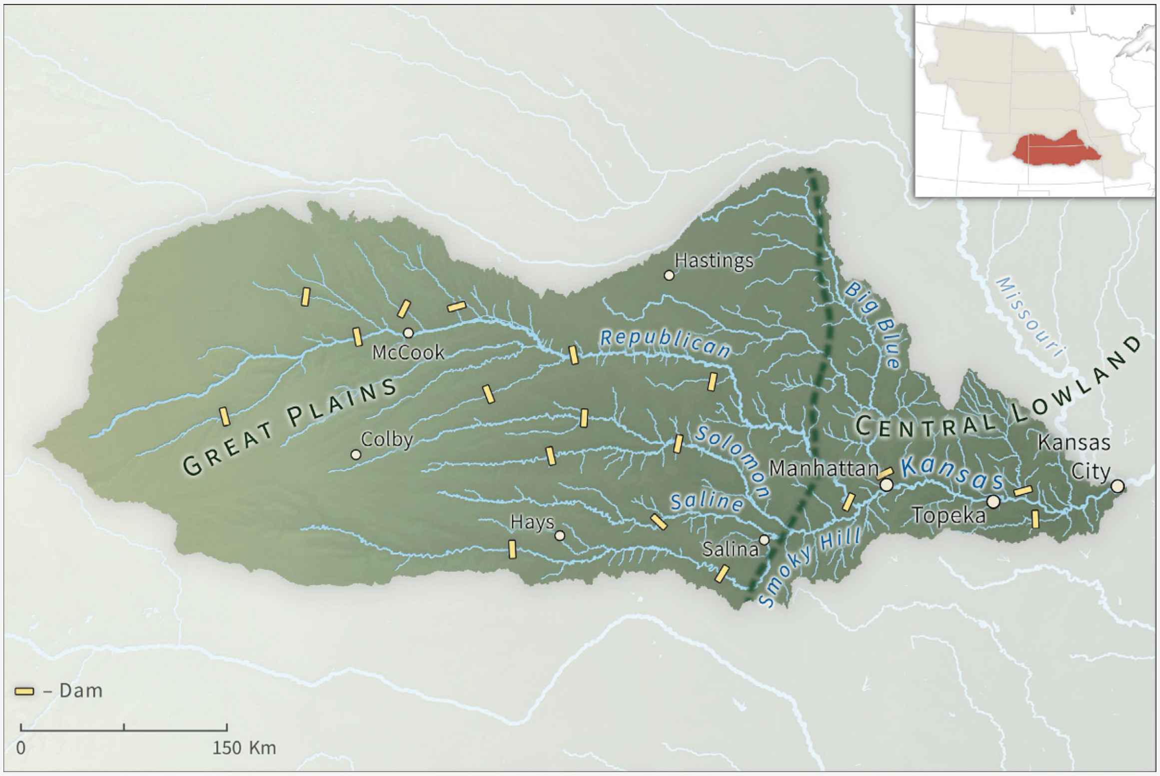

FIG. 10.21 Map of the Kansas River basin. Physiographic provinces are separated by a *green-dashed line*.

KANSAS RIVER

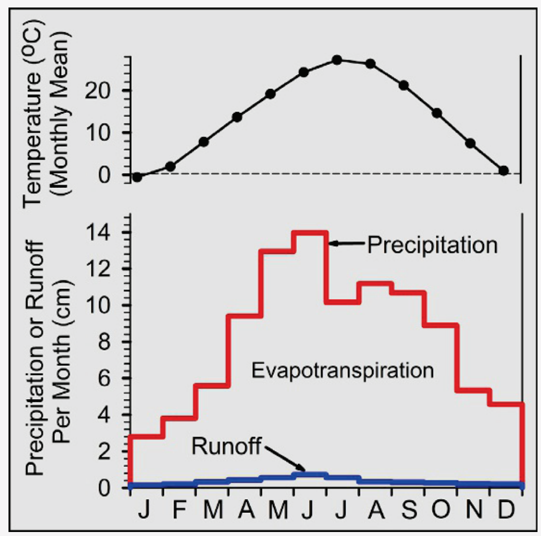

FIG. 10.22 Mean monthly air temperature, precipitation, and runoff for the Kansas River basin.

Relief: 975 m
Basin area: 159,171 km^2
Mean discharge: 209 m^3/s
River order: 7
Mean annual precipitation: 99 cm at Kansas City, KS
Mean air temperature: 13.7°C at Kansas City, KS
Mean water temperature: 16.7°C
Physiographic provinces: Great Plains, Central Lowland
Freshwater ecoregion: Middle Missouri
Terrestrial ecoregions: Great Plains (Level I); Temperate Prairies, South-Central Semi-arid Prairies (Level II); Western Corn Belt Plains, Central Irregular Plains, High Plains, Central Great Plains, Flint Hills (Level III)
Number of fish species: 106 (78 native)
Number of endangered species: 2 fishes
Major fishes: channel catfish, flathead catfish, shovelnose sturgeon, blue sucker, common carp, freshwater drum, river carpsucker, red shiner, bullhead minnow, sand shiner
Major other aquatic vertebrates: smooth softshell turtle, migratory waterfowl, beaver, river otter
Major benthic invertebrates: mussels (fragile papershell, giant floater, pink papershell), chironomids
Nonnative species: common carp, bighead carp, silver carp, bullhead minnow
Major riparian plants: eastern red cedar, eastern cottonwood, American elm, sycamore, box elder, willows
Special features: Tallgrass Prairie Preserve and Konza Prairie
Fragmentation: 18 large reservoirs (659 ha to 6483 ha), 13,000 small impoundments; no major impoundments on mainstem; a 5 to 7 m lowhead dam (Bowercok Dam) at Lawrence, KS
Water quality: pH = 8.2, NO_3-N = 0.86 mg/L, specific conductance = 755 μS/cm, chlorophyll a = 29 μg/L
Land use: >90% agriculture, 3% urban, 2% forest
Population density: 12.7 people/km^2
Major information sources: Sanders et al. (1993), Eitzmann and Paukert (2010b)

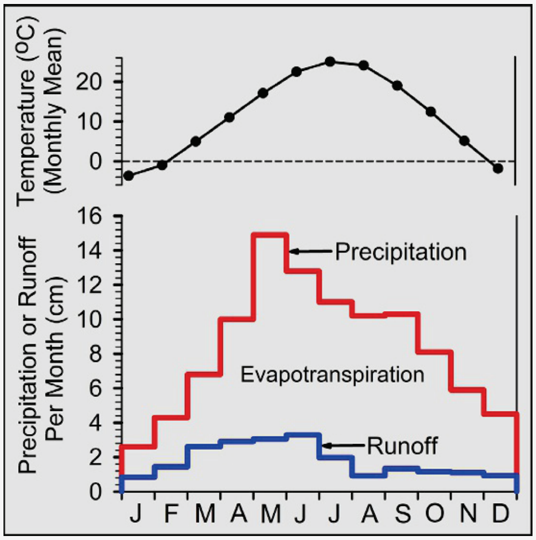

FIG. 10.24 Mean monthly air temperature, precipitation, and runoff for the Grand River basin.

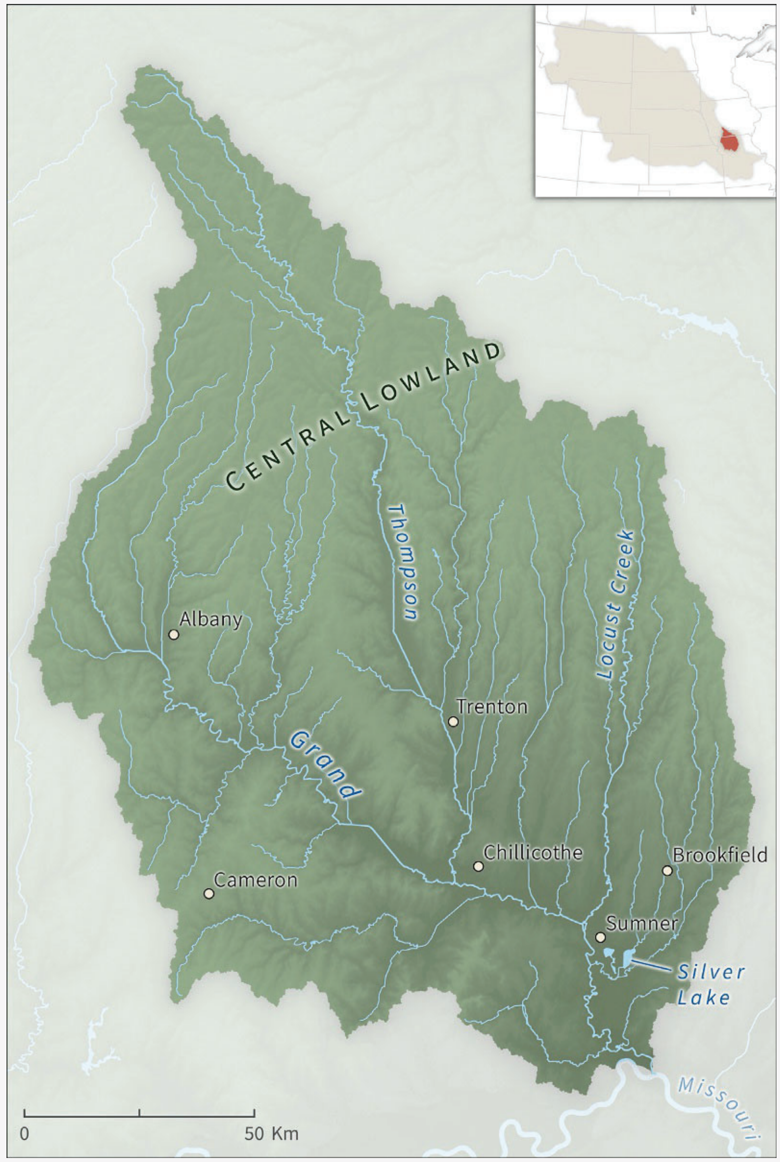

FIG. 10.23 Map of the Grand River basin.

GRAND RIVER

Relief: 238 m
Basin area: 20,461 km^2
Mean discharge: 122 m^3/s (~90% of basin)
River order: 7
Mean annual precipitation: 101.4 cm
Mean air temperature: 11.3°C
Mean water temperature: 13.7°C
Physiographic province: Central Lowland
Freshwater ecoregions: Middle Missouri, Central Prairie
Terrestrial ecoregions: Great Plains (Level I); Temperate Prairie (Level II); Western Corn Belt Plains, Central Irregular Plains (Level III)
Number of fish species: 80
Number of endangered species: 2 fishes, 1 herptile, 3 mammals
Major fishes: shortnose gar, bigmouth shiner, creek chub, central stoneroller, fathead minnow, bluntnose minnow, river carpsucker, black bullhead, channel catfish, green sunfish, Johnny darter
Major other aquatic vertebrates: northern spring peeper, northern cricket frog, plains and southern leopard frogs, American bullfrog, midland smooth softshell, common snapping turtle, red-eared slider, northern watersnake, muskrat, beaver, mink, river otter
Major benthic invertebrates: caddisflies (*Cheumatopsyche, Hydropsyche*), mayflies (*Baetis, Caenis, Hexagenia*), dragonflies and damselflies (*Gomphus, Ischnura*), beetles (*Steneimis, Dubiraphia*), true flies (*Chironomus, Simulium*), mussels (pink papershell, fragile papershell, white heelsplitter), crayfishes (calico, virile, prairie)
Nonnative species: reed canarygrass, Johnson grass, purple loosestrife, grass carp, bighead carp, silver carp
Major riparian plants: green ash, silver maple, cottonwoods, black willow, Virginia wild rye
Special features: pre-glacial channel of ancestral Missouri River; largest prairie river in Missouri unaffected by dams; included in Mississippi River Basin Healthy Rivers Initiative
Fragmentation: no mainstem dams; about 30 impoundments >20 ha on tributaries; numerous 2 to 4 ha flood-control structures on tributaries; extensive channelization and leveeing of mainstem and tributaries
Water quality: pH = 7.7, alkalinity = 154 mg/L as $CaCO_3$, total N = 2.5 mg/L, total P = 0.36 mg/L, PO_4-P = 0.04 mg/L; high suspended sediment, elevated water temperatures, low DO, high *E coli*, pesticides
Land use: 50% grassland, 25% cropland, 15% forest, 5% developed, 4% wetland, 1% water
Population Density: 6.5 people/km^2
Major information sources: Pitchford and Kerns (1998), Heitmeyer et al. (2011), USACOE (2019)

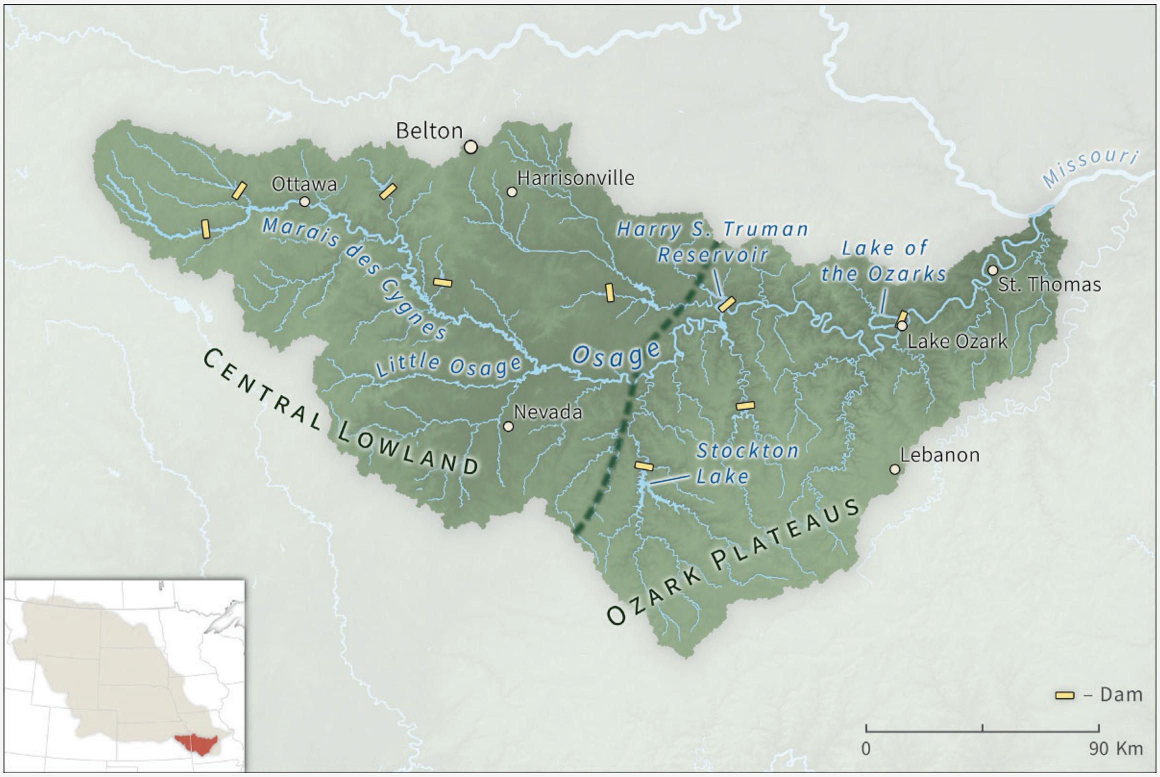

FIG. 10.25 Map of the Osage River basin. Physiographic provinces are separated by a *green-dashed line*.

OSAGE RIVER

Relief: 270 m
Basin area: 39,627 km^2
Mean discharge: 364.2 m^3/s
River order: 8
Mean annual precipitation: 110 cm
Mean air temperature: 13.3°C.
Mean water temperature: 16.1°C
Physiographic provinces: Central Lowland, Ozark Plateaus
Freshwater ecoregions: Central Prairie, Ozark Highlands
Terrestrial ecoregions: Eastern Temperate Forests, Great Plains (Level I); Southeastern USA Plains, Ozark, Ouachita-Appalachian Forests, Temperate Prairies, South Central Semi-Arid Prairies (Level II); Interior River Valleys and Hills, Ozark Highlands, Central Irregular Plains, Flint Hills (Level III)
Number of fish species: 133
Number of endangered species: 3 plants, 5 mussels, 1 amphibian, 3 fishes, 2 mammals
Major fishes: largescale stoneroller, bleeding shiner, Ozark minnow, creek chub, southern redbelly dace, northern hogsucker, yellow bullhead, black redhorse, slender madtom, blackspotted topminnow, rainbow darter, green sunfish, bluegill, smallmouth bass, largemouth bass
Major other aquatic vertebrates: American bullfrog, green frog, plains leopard frog, snapping turtle, western painted turtle, map turtles, red-eared slider, midland smooth softshell, watersnakes, northern cottonmouth, bald eagle, belted kingfisher, green heron, great blue heron, spotted sandpiper, muskrat, beaver, mink, river otter
Major benthic invertebrates: mussels (*Megalonaias*, *Amblema*, *Cyclonaias*), crayfishes (*Cambarus*, *Orconectes*, *Procambaris)*, mayflies (*Caenis*, *Tricorythodes*), caddisflies (*Cheumatopsyche*), stoneflies (*Allocapnia*, *Neoperla*)
Nonnative species: Asian clam, bighead carp, silver carp, black carp, rainbow trout, brown trout, striped bass
Major riparian plants: American sycamore, plains cottonwood, silver maple, green ash, black walnut, river birch
Special features: Lake of the Ozarks is one of the largest privately constructed and managed reservoirs in USA and known as recreation and tourist center; major paddlefish recreational fishery in river below Lake of the Ozarks
Fragmentation: 64% of length impounded by 2 mainstem reservoirs; 969 km of $\geq$ fourth-order streams inundated by impoundments; >14,000 small impoundments
Water Quality: moderate; pH = 7.8, alkalinity = 110 mg/L as $CaCO_3$, total N = 2.5 mg/L, total P = 0.36 mg/L
Land Use: western sub-basin: 78% agriculture, 20% forest; eastern sub-basin: 45% agriculture, 47% forest
Major information sources: Duchrow (1984), Fantz et al. (1997), Schubert (2001)

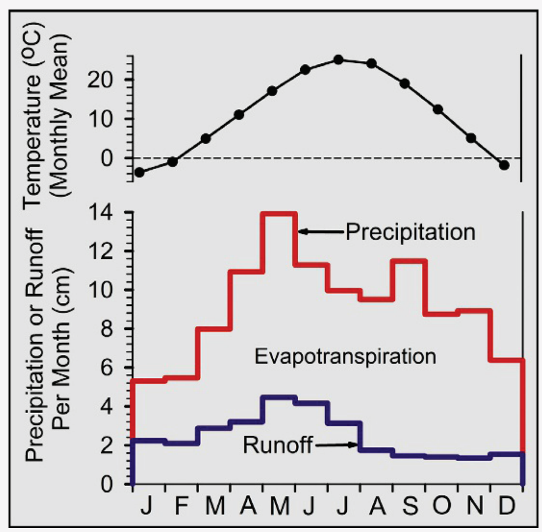

FIG. 10.26 Mean monthly air temperature, precipitation, and runoff for the Osage River basin.