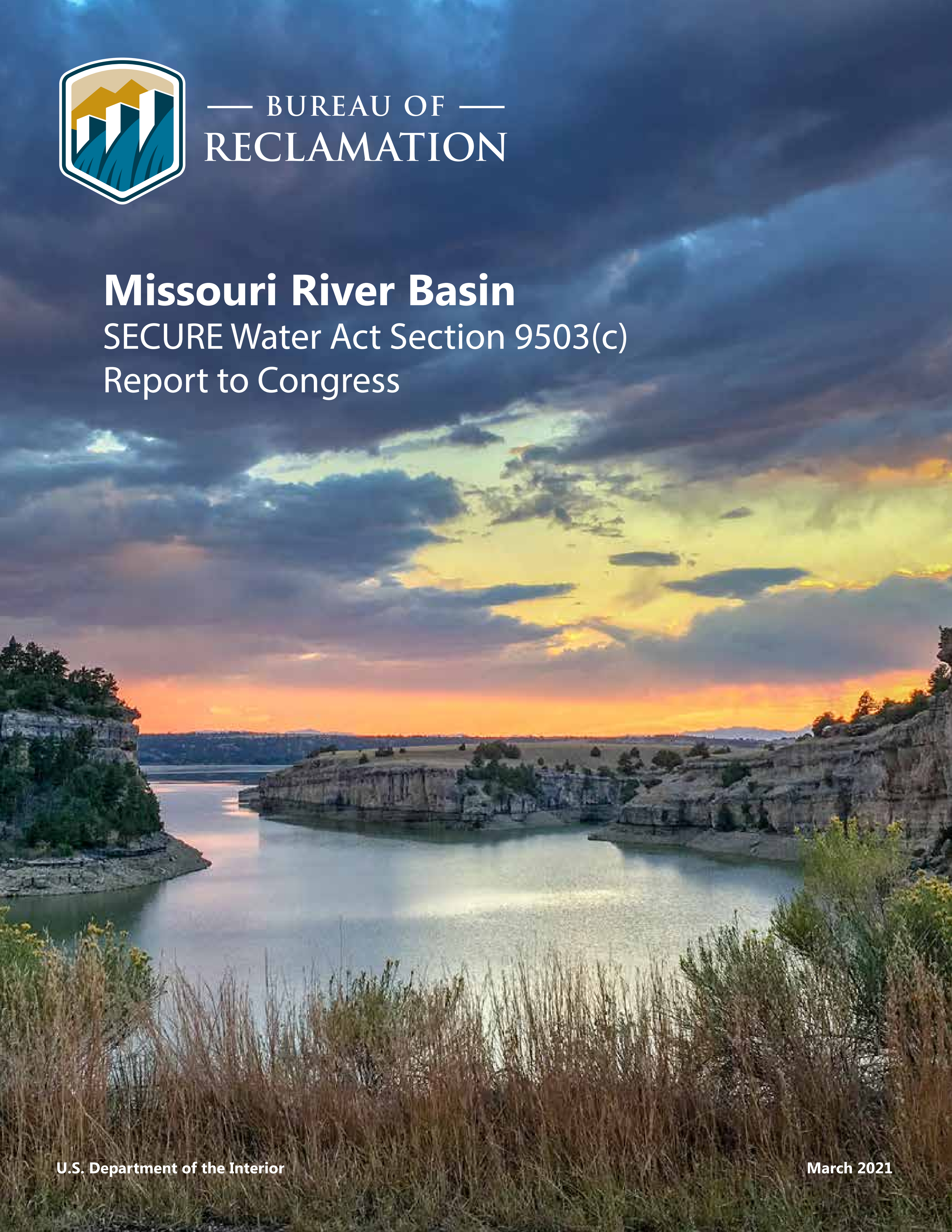
BUREAU OF RECLAMATION

Missouri River Basin

SECURE Water Act Section 9503(c) Report to Congress



U.S. Department of the Interior

March 2021

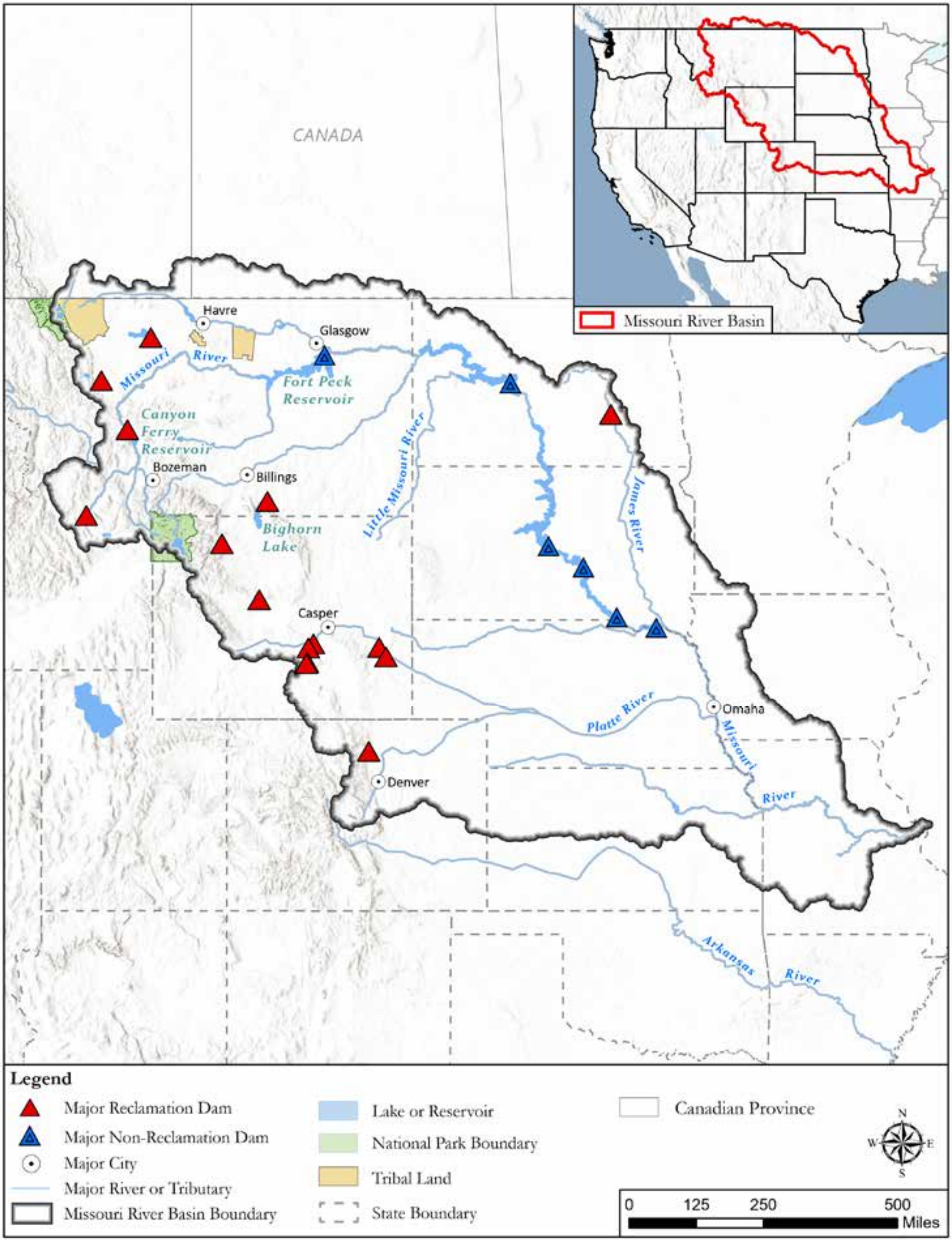
Mission Statements

The Department of the Interior conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acronyms and Abbreviations

°F	Fahrenheit
cfs	cubic feet per second
ET	Evapotranspiration
First Increment	First Increment of the Platte River Recovery Implementation Program scheduled to run from January 1, 2007, through December 31, 2019
Impacts Assessment	Upper Missouri River Basin Impacts Assessment
MCA	2017 Montana Climate Assessment
NCA	4th National Climate Assessment
Program	Platte River Recovery Implementation Program
Reclamation	Bureau of Reclamation
SECURE Water Act	Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act
signatories	Platte River Recovery Implementation Program signatories – Governors of Colorado, Nebraska, and Wyoming, and the Secretary of the Interior
SWE	snow water equivalent
USACE	U.S. Army Corps of Engineers
USGCRP	U.S. Global Climate Change Research Program


CANADA
Missouri River Basin
Havre
Glasgow
Missouri River
Fort Peck Reservoir
Canyon Ferry Reservoir
Bozeman
Billings
Little Missouri River
James River
Bighorn Lake
Casper
Platte River
Omaha
Missouri River
Denver
Arkansas River
Legend
Major Reclamation Dam
Major Non-Reclamation Dam
Major City
Major River or Tributary
Missouri River Basin Boundary
Lake or Reservoir
National Park Boundary
Tribal Land
State Boundary
Canadian Province
N
W
E
S
0 125 250 500 Miles

Missouri River Basin Setting

U.S. States and Canada Provinces

Montana · North Dakota · South Dakota · Wyoming · Colorado

Nebraska · Iowa · Kansas · Missouri · Minnesota

Alberta · Saskatchewan

Major U.S. Cities:

- Great Falls
- Billings
- Casper
- Cheyenne
- Denver
- Rapid City
- Lincoln
- Omaha
- Bismarck
- Pierre
- Sioux Falls
- Kansas City
- St. Louis
- Topeka

Major Water Uses:

Agriculture
(108.8 million acres of land)

Municipal
(12 million people)

Fish and Wildife Habitat
(including anadromous salmon and steelhead)

Hydropower
(38 hydroelectric dams federally operated by Reclamation and the U.S. Army Corps of Engineers)

Recreation

Navigation

River Basin Area: 525,000 square miles

River Length: 2,500 miles

Major Rivers/ Tributaries:

- Milk
- Yellowstone
- Little Missouri
- Niobrara
- Platte
- James
- Republican Rivers

Notable Reclamation Facilities:

40
dams

Contents

ABOUT

This basin report is part of the 2021 Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act Report to Congress, prepared by the Bureau of Reclamation in accordance with Section 9503(c) of the SECURE Water Act of 2009, Public Law 111-11. The 2021 SECURE Water Act Report follows and builds upon the first two SECURE Water Act Reports, submitted to Congress in 2011 and 2016. The report characterizes the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

The 17 Western States form one of the fastest growing regions in the Nation, with much of the growth occurring in the driest areas. The report provides information to help water managers address risks associated with changes to water supply, quality, and operations; hydropower; groundwater resources; flood control; recreation; and fish, wildlife, and other ecological resources in the West.

To see all documents included in the 2021 SECURE Water Act Report to Congress, go to: https://www.usbr.gov/climate/secure/

Crow Irrigation Project irrigation structure, part of the Crow Irrigation Project, near Yellowtail Dam, Montana.

SECTION 1

Water Management Challenges

At 2,636 miles in length, the Missouri River is the longest river in the United States and the fifteenth longest river in the world. Its watershed spans more than 525,000 square miles (one-sixth of the entire lower 48 United States) through portions of ten States and two Canadian provinces, making it the largest watershed within the United States. The Missouri River Basin presents unique water management challenges due to the size and complexity of the basin. It encompasses different geographical areas, climates, and uses. In addition, the basin is prone to flooding which requires careful coordination between the Bureau of Reclamation (Reclamation) and the U.S. Army Corps of Engineers (USACE) to keep homes and businesses along its banks safe.

Further, the basin provides water for international obligations and differing interstate needs across a large geographic area, albeit with a relatively small annual flow volume (40 million acre-feet) compared with other major United States river basins including the Columbia River (199 million acre-feet) and Ohio River (181 million acre-feet). Reclamation works with both American and Canadian members of the Saint Mary and Milk Rivers (tributaries to the Missouri River) International Joint Commission, which is responsible for measurement and apportionment of waters between the two countries.

Basin Overview

The headwater tributaries of the Missouri River form along the Continental Divide in southwestern Montana. The origin of the river is at Brower's Spring near the Montana and Idaho border. This water, combined with flows from adjacent basins and tributaries, eventually develops into the Jefferson River. Snowmelt runoff from adjacent mountain basins form the Gallatin and the Madison Rivers, which converge with the Jefferson River near Three Forks, Montana, to create the Missouri River mainstem. From these headwaters, the Missouri River flows through Montana, North Dakota, South Dakota, Nebraska, Iowa, Kansas, and Missouri to its confluence with the Mississippi River near St. Louis, Missouri. Basin topography varies from glaciated mountain ranges to flat and rolling prairies and grasslands to wide floodplain valleys, all of which play a part in the water availability of the Missouri River.

Figure 1. Confluence of Marias and Missouri River.

Glaciated Mountain Ranges

The major contributors of the Missouri River mainstem originate predominantly in the Rocky Mountains of Montana, Wyoming, and Colorado along the Continental Divide where high elevation catchments capture and store large volumes of water as winter snowpack that are later released as spring and early summer snowmelt. In addition to the flows from the Gallatin, Madison, and Jefferson Rivers, the upper Missouri River also receives major flows from the Marias **(Figure 1)**, Judith, Sun, Teton, and Musselshell Rivers. Through a series of Reclamation dams, flows are eventually impounded at Fort Peck Lake in northeastern Montana. Fort Peck Lake is formed by Fort Peck Dam maintained by USACE and is the 5th largest reservoir in the United States storing over 18 million acre-feet at its maximum elevation (USACE, 2012). From its headwaters to Fort Peck Lake, there are 16 major dams used to control flooding in the spring and early summer, as well as to provide irrigation to farms in the late spring, summer, and early fall.

Downstream of Fort Peck Lake, major contributors to the flow in the Missouri River whose basins also originate from the Rocky Mountains snowmelt in Montana, include the Milk, St. Mary and the Yellowstone Rivers. From the Rocky Mountains in Wyoming, snowmelt flows east and discharges into the Bighorn River (contributor to the Yellowstone River subbasin) and the North Platte River (a contributor to the Platte River). In Colorado, the South Platte River flows east and also contributes to the Platte River that empties into the Missouri River near Omaha, Nebraska. These rivers ultimately discharge at various locations along the Missouri River's path, well east of the Rocky Mountains.

This mountain water is an important component of the total annual flow of the Missouri River. It accounts for 30 percent of the annual discharge delivered to the Mississippi River on average, with a range of 14 percent to more than 50 percent from year to year, most of which is delivered during the critical warm season months (May to September) (Martin et al., 2020).

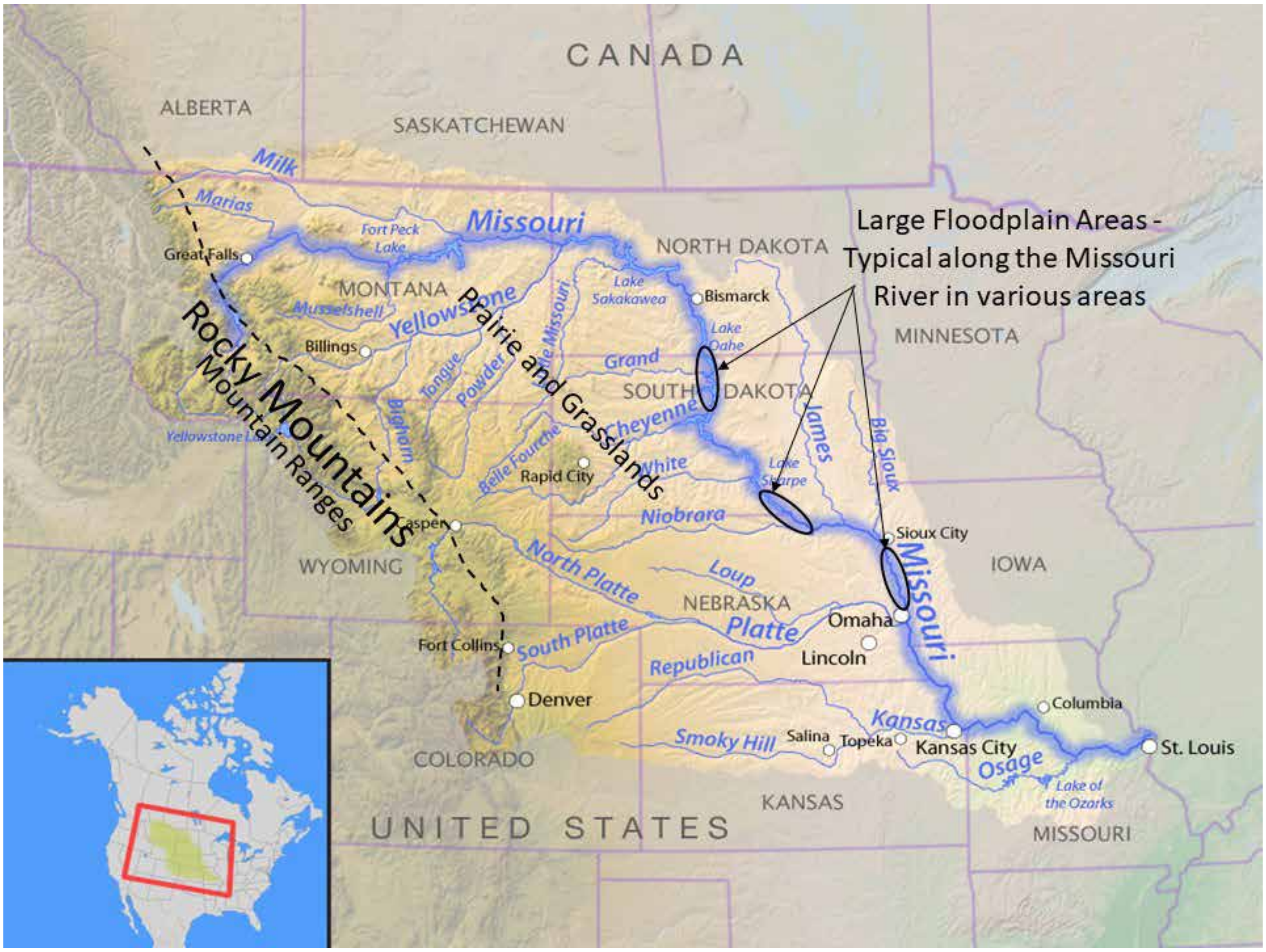


Figure 2. The Missouri River Basin and its major tributaries from its source in western Montana to its discharge into the Mississippi River near St. Louis, Missouri. The map highlights the variety of terrain the Missouri River flows through ranging from large floodplain areas, prairie and grasslands, and mountains.

Across much of the upper Missouri River Basin, cool season precipitation (October to May) stored as winter snowpack has historically been the primary driver of streamflow, with observed April 1 snow water equivalent (SWE) usually accounting for at least half of the variability in observed streamflow from the primary headwaters regions (Wise et al., 2018).

Flat and Rolling Prairies and Grasslands

From its headwaters in Montana, the Missouri River flows east into North Dakota from the higher mountainous elevations to the lower, flatter plains and then into Lake Sakakawea **(Figure 2)**. The river exits the southeastern portion of Lake Sakakawea and continues to flow southeast into central South Dakota (through Lakes Oahe, Sharpe, and Francis Case), eastern Nebraska (through Lewis and Clark Lake) and northeastern Kansas and eventually through Kansas City.

The large, flatter plains area between the Rocky Mountain range and the Missouri River, as well as its smaller drainage basins further east, may be characterized as prairie. This prairie has complex and varied hydrology. Major river basins that contribute to the prairie flows into the Missouri River are the Little Missouri River (North Dakota), the Cheyenne River (South Dakota), the Niobrara and Platte Rivers (Nebraska), and the Republican River (Nebraska and Kansas).

Additionally, the James River (North and South Dakota) on the east side of the Missouri River is located in this prairie region as well. Only one third of annual precipitation occurs over the winter and the surface SWE distribution is highly heterogeneous due to wind redistribution of snow during blowing snowstorms. Blowing snow can transport and redirect as much as 75 percent of annual snowfall from open prairie fields. The prairie region is characterized by glacially formed depressions that fill with water to form pothole sloughs and wetlands that are important to prairie hydrology due to their surface storage capacity. As a result of this complex geomorphology of depressional storage and poorly and internally drained basins in the prairie region, surface runoff does not contribute significantly to the Missouri River system (Fang and Pomeroy, 2007).

In the prairie region, seasonal rainfall occurs in the period from May to early July and provides water for the growth of crops. Most of the rainfall is consumed by seasonal evaporation, which leads to little surface runoff during the summer period. A primary mechanism for most rainfall events during early summer on the prairies is the frontal weather system, while the most intense short duration rainfalls are associated with local convective storms (Gray, 1970).

Wide Floodplain Valleys

As the Missouri River travels southeast through the Midwestern States, it widens significantly. Due to the flat terrain and flooding that occurred during the late 1800s, large floodplain valleys were formed. While surface runoff along these floodplain valleys contribute little-to-no flows to the Missouri River, the constant threat of flooding makes living and farming in these valleys challenging.

Center Pivot Irrigation increases efficiency and reduces runoff.

Historical Foundation of Water Management in the Basin

Water management decisions made in the Missouri River Basin are informed by the Flood Control Act of 1944. The act includes both USACE and Reclamation management plans for the Missouri River that came to be known as the Pick-Sloan Missouri Basin Program, named after the authors of USACE and Reclamation's plans, respectively. Section 9 of the Flood Control Act of 1944, as amended, authorized the Pick-Sloan Missouri Basin Program for flood control, navigation, irrigation, power, water supply, recreation, fish and wildlife, and water quality purposes. Notably, the Pick-Sloan Missouri Basin Program added flood control as an integral part of dam building efforts along the Missouri River. The program led to the formation of a collaborative partnership between Reclamation and USACE to manage flooding on the Missouri River. The Flood Control Act of 1944 also included the O'Mahoney-Millikin Amendment, which made navigation subordinate to beneficial consumptive uses of water west of the 98th meridian.

Summary of Studies in the Missouri River Basin

- Missouri Headwaters Basin Study (Reclamation and Montana DNRC, 2019)
- Niobrara River Basin Study (Reclamation and Nebraska DNR, 2016)
- 2017 Montana Climate Assessment (Whitlock et al., 2017)
- Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief (USGCRP, 2018)
- Upper Missouri River Basin Impacts Assessment: Summary Report (Reclamation, 2019 [Summary Report])
- Upper Missouri River Basin Impacts Assessment: Water Supply (Reclamation, 2019 [Water Supply])

Cows enjoying the water near drop at St. Mary Canal in Babb, Montana.

SECTION 2

Analysis of Impacts to Water Resources

Since the 2016 SECURE Report, two significant subbasin studies associated with the Missouri River Basin have been completed—the Missouri Headwaters Basin Study (Reclamation and Montana DNRC, 2019) and the Niobrara River Basin Study (Reclamation and Nebraska DNR, 2016). These two reports, along with the Upper Missouri River Basin Impacts Assessment: Summary Report (Reclamation, 2019 [Summary Report]) and the Upper Missouri River Basin Impacts Assessment: Water Supply (Reclamation, 2019 [Water Supply]) (Impacts Assessment), the 2017 Montana Climate Assessment (MCA) (Whitlock et al., 2017), and the 4th National Climate Assessment (NCA) (USGCRP, 2018), released in 2017, are the primary resources for examining the impacts in this section. For a detailed explanation of climate projections relied on by Reclamation, please refer to Reclamation's 2021 West-Wide Climate and Hydrology Assessment, Section 2.1, and for a discussion of associated uncertainties, please refer to Section 9.1.

Temperature

In 2017, as part of the NCA, the U.S. Global Climate Change Research Program (USGCRP) noted the observed changes in annual average temperature throughout the United States. Comparing the present day (1986 to 2016) annual average temperature to the first half of the last century (1901 to 1960) resulted in a 1.69°F (degrees Fahrenheit) increase in the annual average temperature for the Great Plains – North Region[1], the greatest change in annual average temperatures for any region in the assessment. The Great Plains – North Region experienced a 4.40°F increase in the coldest day of the year and a 1.08°F decrease in the warmest day of the year. The NCA projected that the Great Plains – North Region may see a 4.05°F to 5.10°F increase in annual average temperatures by mid-century (2036 to 2065) and a 5.44°F to 9.37°F increase by late-century (2071 to 2100). The estimates are based on a high scenario and a low scenario.

The MCA projects that Montana will continue to warm in all geographic locations and seasons throughout the 21st Century and will see larger than average changes projected globally and nationally. In the Niobrara River subbasin, the temperatures in the 2000s have been warmer than the long-term average and comparable to the previous record warmest period of the early 1930s Dust Bowl era.

[1] The NCA divided the United States into seven regions and the Great Plains – North Region best represents the Missouri River Basin. The Great Plains – North Region includes the States of Montana, Nebraska, North Dakota, South Dakota, and Wyoming.

Precipitation

Mesoscale convective systems, which contribute substantially to warm season precipitation in the tropics and subtropics, account for about half of rainfall in the central United States (Feng et al., 2016). Further, Feng et al. found upward trends in mesoscale convective systems frequency of occurrence, lifetime, and precipitation amount, which they attribute to an enhanced west-to-east pressure gradient (enhanced Great Plains low-level jet) and enhanced specific humidity throughout the eastern Great Plains (2016). The NCA projected that the Great Plains – North Region could have an 8 to 10 percent increase in the 20-year extreme precipitation (when the air is nearly completely saturated) by mid-century and a 10 to 16 percent increase by the late-century. Across much of the upper Missouri River Basin, precipitation is projected to increase in winter, spring, and fall and decrease in the summer.

In the southern part of the basin, the largest increases are expected to occur during the spring. In the central and southern parts of the basin, the largest decreases are expected to occur during the summer.

Historically, the Niobrara River subbasin has a substantial moisture gradient from west to east. The western semiarid portion receives 16 inches of mean annual precipitation and the eastern more humid portion receives 22 inches of mean annual precipitation. This is represented in **Figure 3.** The State of Nebraska and the Niobrara River subbasin area are particularly vulnerable to both high and low extreme precipitation. In particular, the frequency of heavy rain events has increased in recent years with Nebraska experiencing an above-average number of 2-inch rain events between 2000 and 2014. In addition, the area experiences periodic episodes of severe drought, which can sometimes last for several years. In 2012, Statewide precipitation averaged only 3.74 inches during the summer months, well below the historical average of 9.42 inches (Frankson et al., 2017).

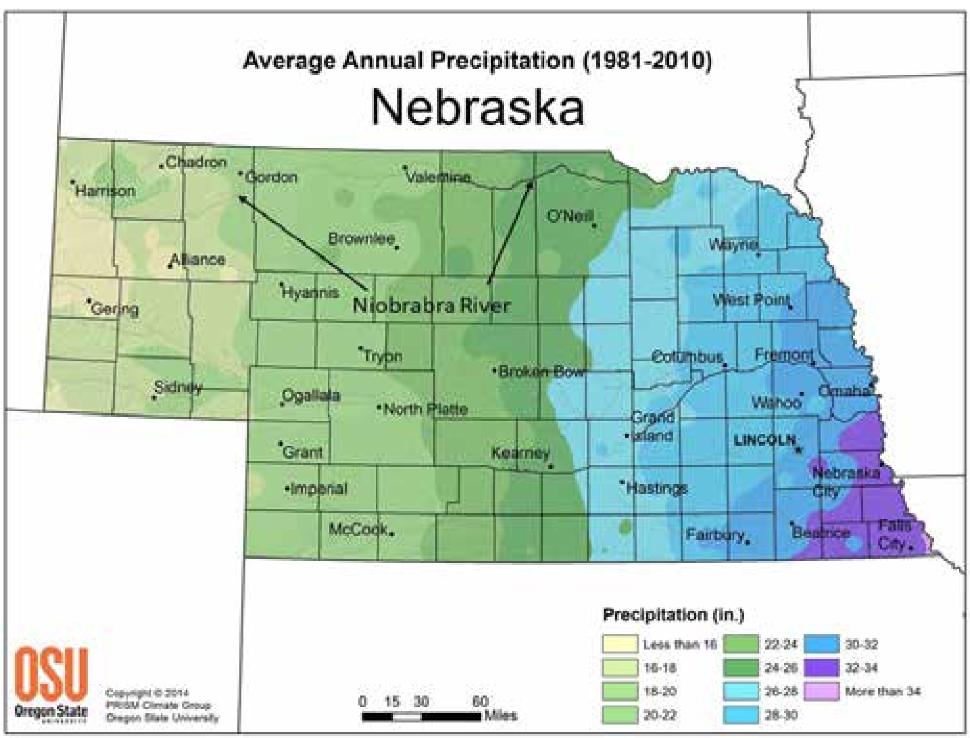


Figure 3. The average annual precipitation in the State of Nebraska over a 30-year period showing the increasing moisture gradient from west to east (Oregon State, 2020).

Snowpack

Mountain snowpack is the primary factor used to predict May, June, and July runoff volumes in the Fort Peck mainstem reservoir reaches. As the date of peak snowpack accumulation (usually around April 15) approaches, the correlation between the level of mountain snowpack and May, June, and July runoff increases. Therefore, mountain snowpack becomes a good predictor of runoff into Fort Peck Reservoir.

As seen in **Figure 4**, for the winter of 2019 to 2020, snowpack accumulation through April 15, 2020, was approximately 17.8 SWE compared to the average SWE in the last 20-year period (1981 to 2010) of approximately 16.2 SWE. Additionally, the graphs in Figure 4 add a comparison to the two highest SWEs (1997 and 2011) and the lowest (2001). Figure 4 considers snowpack in lower elevations along the Missouri River prairie and grasslands area of eastern Montana and North Dakota, and between Fort Peck Reservoir and Lake Sakakawea (Garrison Dam). The snowpack SWEs correlate closely with the totals above Fort Peck Reservoir (USACE, 2020).

In the upper Missouri River Basin, findings from the Impacts Assessment, including evaluation of projected future conditions, as well as conditions from the distant past as quantified from tree rings, are organized into four regions within the study area. These regions have similar characteristics, including hydrology, water use, and management objectives.

As illustrated in **Figure 5**, the regions are:

- Rocky Mountain Front (subbasins including and north of Dearborn River)
- Upper Missouri Headwaters (subbasins upstream of Canyon Ferry Reservoir)
- Musselshell and Judith River Basins
- Lower Missouri Mainstem

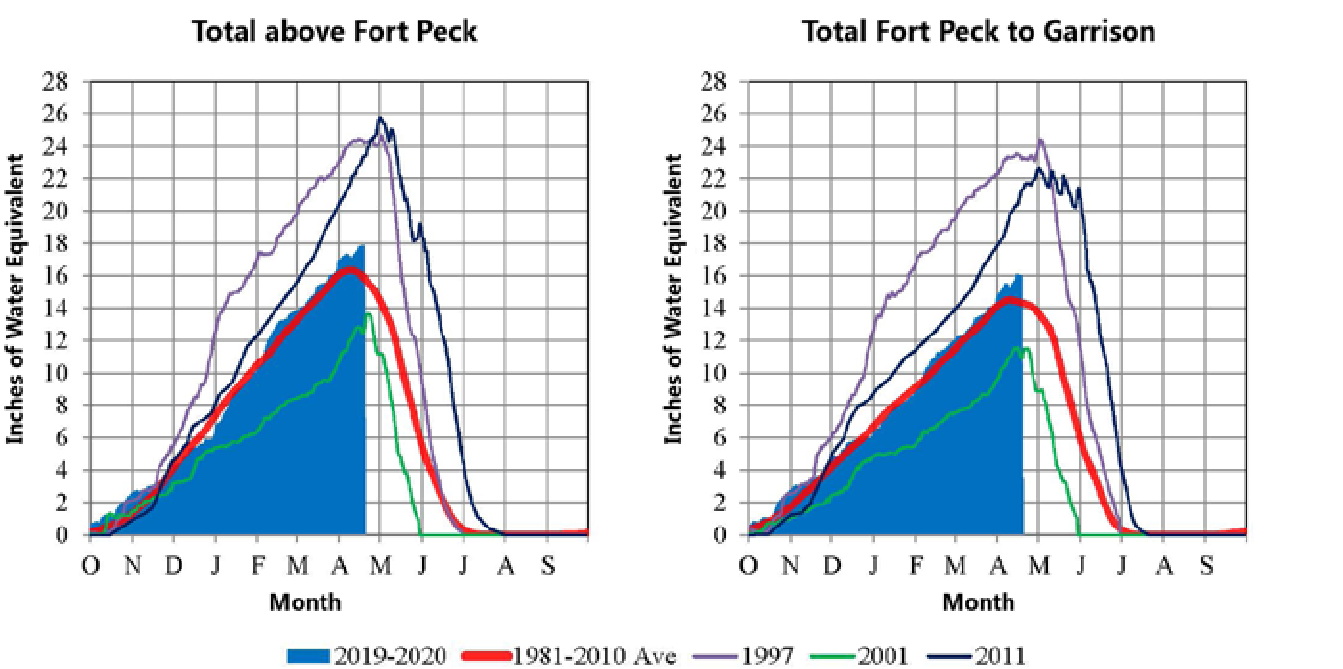


Figure 4. The upper Missouri River Basin mountain snowpack water content 2019 to 2020 with comparison plots from 1997 and 2001 (the highest recorded snow water equivalent) and 2011 (the lowest recorded snow water equivalent).

The impacts of different future scenarios on snowpack and runoff in each of the defined regions are illustrated in **Figure 6**. The figure shows the range of projected changes based on future scenarios without paleohydrology, assuming that any one of these scenarios is a plausible future condition. Most of the scenarios indicate progressively larger decreases in peak snowpack in the future for the four regions, primarily due to increasing temperatures. Interestingly, more future scenarios in the Upper Missouri River Headwaters region than the other regions suggest a possible increase in peak snowpack (Reclamation and Montana DNRC, 2019).

In the Niobrara River subbasin, there is very little snowfall that drives overall water supply. This subbasin is unique in that it has had a constant water supply from rainfall higher in the watershed in eastern Wyoming, southern South Dakota, and western Nebraska that produces a constant water supply.

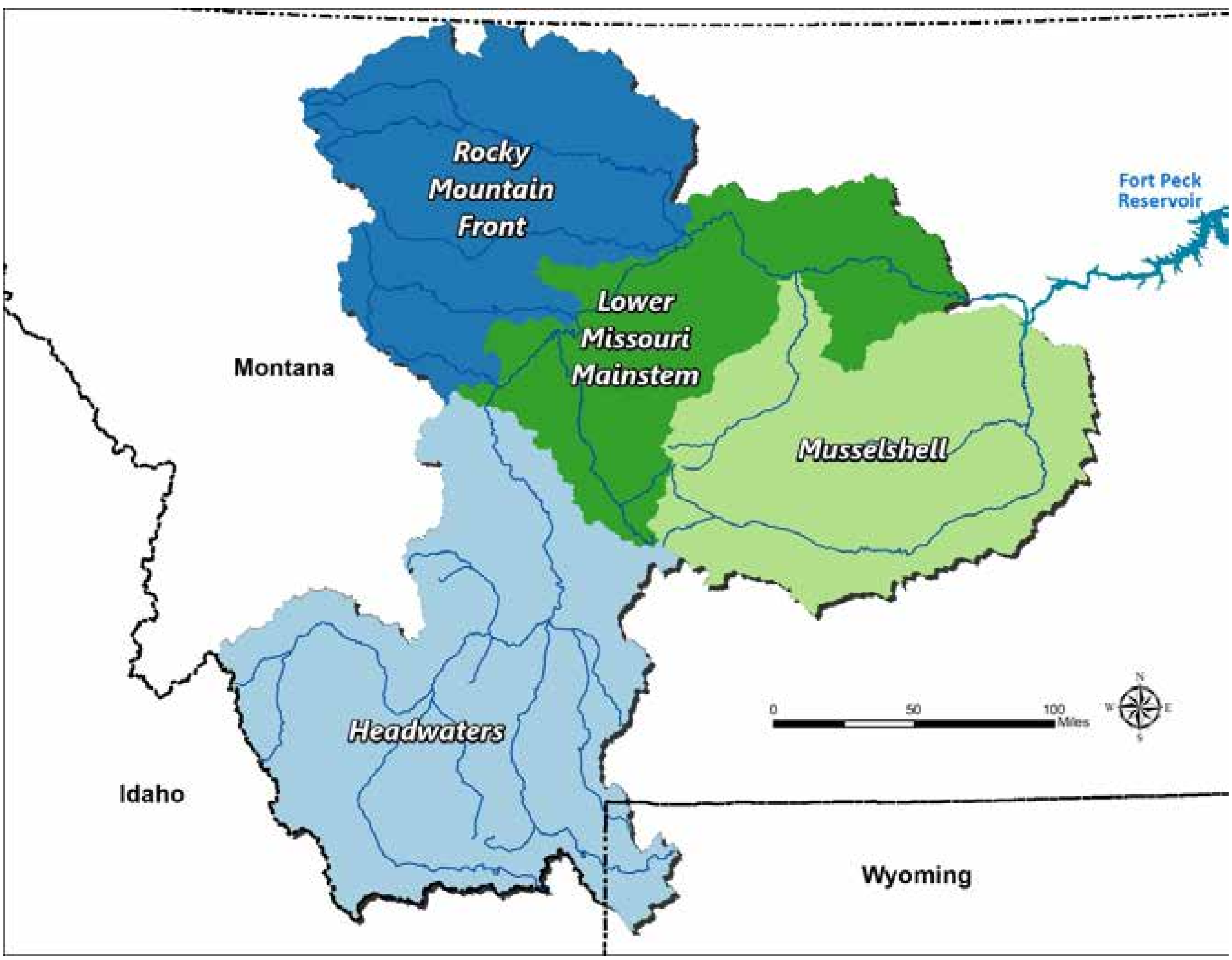


Figure 5. The four subbasins of the upper Missouri River Basin where tree rings were used to reconstruct streamflow.

Runoff

Runoff tends to be directly correlated to snowpack. One of the largest snowpack quantities above the basin reaches of Fort Peck occurred in 2011. Consequently, in 2011 there was the largest runoff on record at 61 million acre-feet. In 2019, runoff was 60.9 million acre-feet, the second highest runoff in the 121 years of record-keeping (1898 to 2018). In the Niobrara River subbasin, analysis of historical mean annual runoff for the period 1960 to 2010 indicated the eastern part of the subbasin experiences a mean annual runoff of almost 2 inches compared to about 1 inch in the western portion of the subbasin. Projected changes in mean annual runoff for the future time period (mid-century) indicates an increase in runoff ranging from approximately 11 percent in the eastern portion of the subbasin to 15 percent in the western portion.

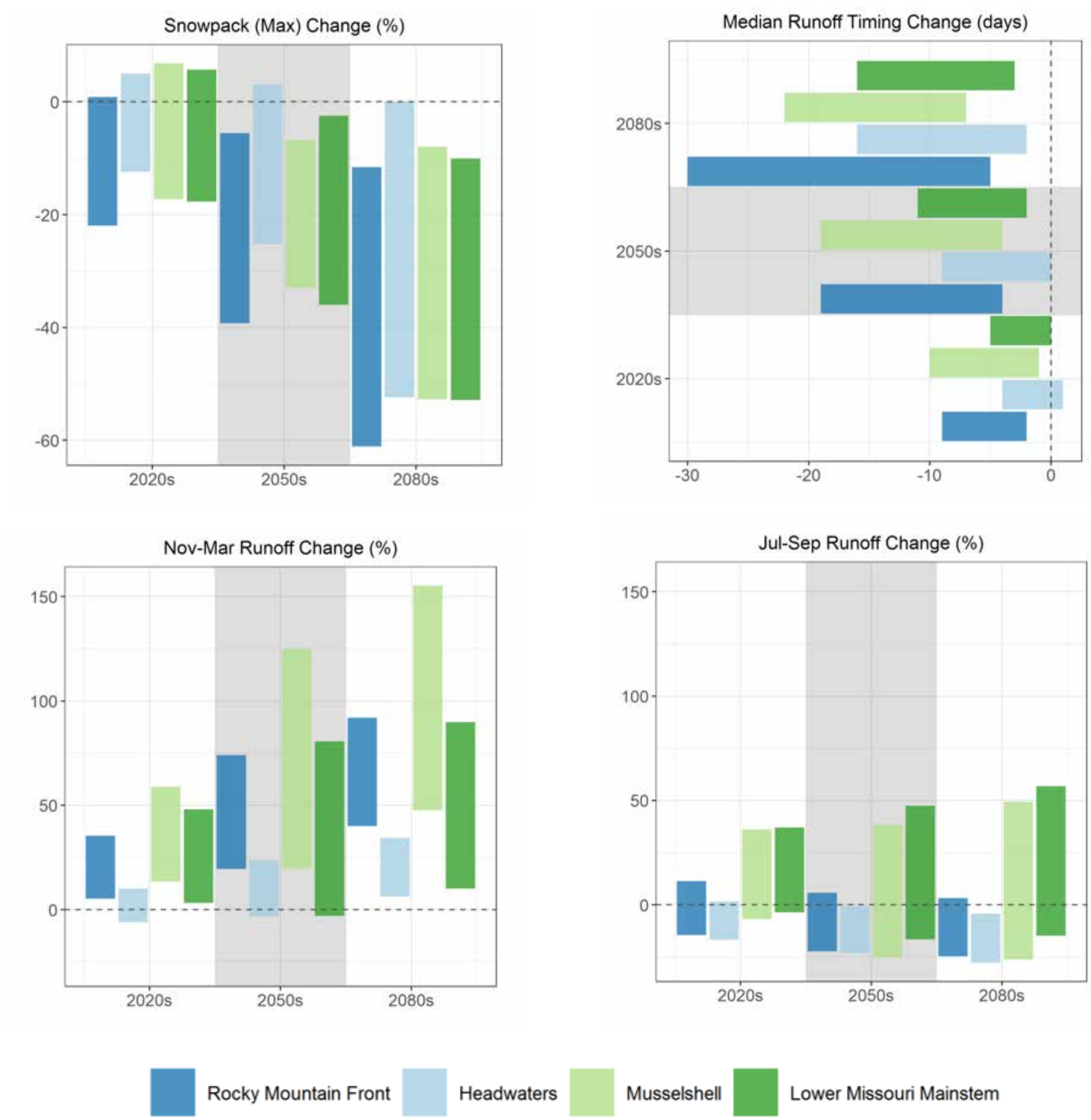


Figure 6. Comparison of percent change in snowfall and seasonal runoff for the four studied subbasins of the upper Missouri River Basin.

Figure 7. Niobrara River in Nebraska Sand Hills.

Water Management Impacts

Water Delivery

End-of-water-year storage is projected to decrease in the future for most of the reservoirs located in the upper Missouri River Basin that were modeled in the Impacts Assessment. Future scenarios combined with paleohydrology (discussed in detail in Section 4 of this document, *Innovations*) suggest that even higher decreases in end-of-water-year storage are possible. Due to increases in temperature, this basin is expected to experience increases in agricultural demands. The projected increases in precipitation will not be sufficient to offset the increased demand.

In the Niobrara River subbasin (**Figure 7**), groundwater resources are used primarily for agriculture. Of the approximately 600,000 acres of irrigated area within the Niobrara River subbasin, groundwater irrigation accounts for approximately 83 percent. The remaining 17 percent (or approximately 102,000 acres) rely on surface water availability. Reclamation irrigation districts (Mirage Flats Project and Ainsworth Unit) irrigate more than 46,000 acres, but that is still well short of the water needs of the subbasins.

Water imbalances are becoming even more dramatic in recent years. During the first few years of operation in the 1950s, the Mirage Flats Irrigation District delivered over 15,000 acre-feet of water to farms. Historical records also show that just prior to widespread groundwater irrigation development, Mirage Flats Irrigation District consistently delivered between 8,000 and 11,000 acre-feet of irrigation water to its service area. Periods of past robust surface water supply can be contrasted with the more recent period between 2006 and 2015, when surface water deliveries declined to a level between 1,200 and 4,800 acre-feet. The Mirage Flats Irrigation District is not alone in experiencing water supply challenges.

Hydropower

The Pick-Sloan Program resulted in a complex series of interactions between Reclamation, USACE, and the Western Area Power Administration, with hydropower being one of the primary uses concerning this interagency relationship. Within the entire Missouri River Basin, there are 23 hydroelectric powerplants operated by Reclamation, 15 of which are administered by the Western Area Power Administration. Reclamation's only hydroelectric powerplant located directly on the Missouri River is the Canyon Ferry Powerplant in central Montana **(Figure 8)**. Reclamation's remaining powerplants are located along tributaries to the Missouri River in Montana, Wyoming, and eastern Colorado primarily along the Front Range (eastern side of the Rocky Mountains base). In addition to providing hydroelectric power, the dams associated with these powerplants work with USACE to provide flood control to the Missouri River and its tributaries. USACE has six dams directly on the Missouri River that have a primary purpose of flood control with an additional hydroelectric powerplant component associated as well. There are also many privately-owned powerplants within the Missouri River Basin that are owned and operated by power producing companies.

Annual hydropower production is one important measure of impacts to water resources due to projected hydrologic changes. An example of this is the hydropower facility at Tiber Dam on the Marias River in the upper Missouri River Basin where production is expected to continue to decrease in the coming decade. These decreases are projected for most months of the year, except for February through April, when wetter periods are anticipated. However, the production increases in these months are projected to be modest. In the Niobrara River subbasin, the only hydropower facility is Spencer Hydropower Dam, which is operated by the Nebraska Public Power District. It is a senior water rights holder and a shortage of seasonal water supplies in recent years has led the facility to enforce its water rights in the basin. This has resulted in halting irrigation deliveries to upstream junior surface water appropriators on days when streamflow is insufficient to satisfy the senior water rights. However, in spring 2019, the Spencer Hydropower Dam was destroyed by a massive spring storm and, at the time of the writing of this report, reconstruction has not started.

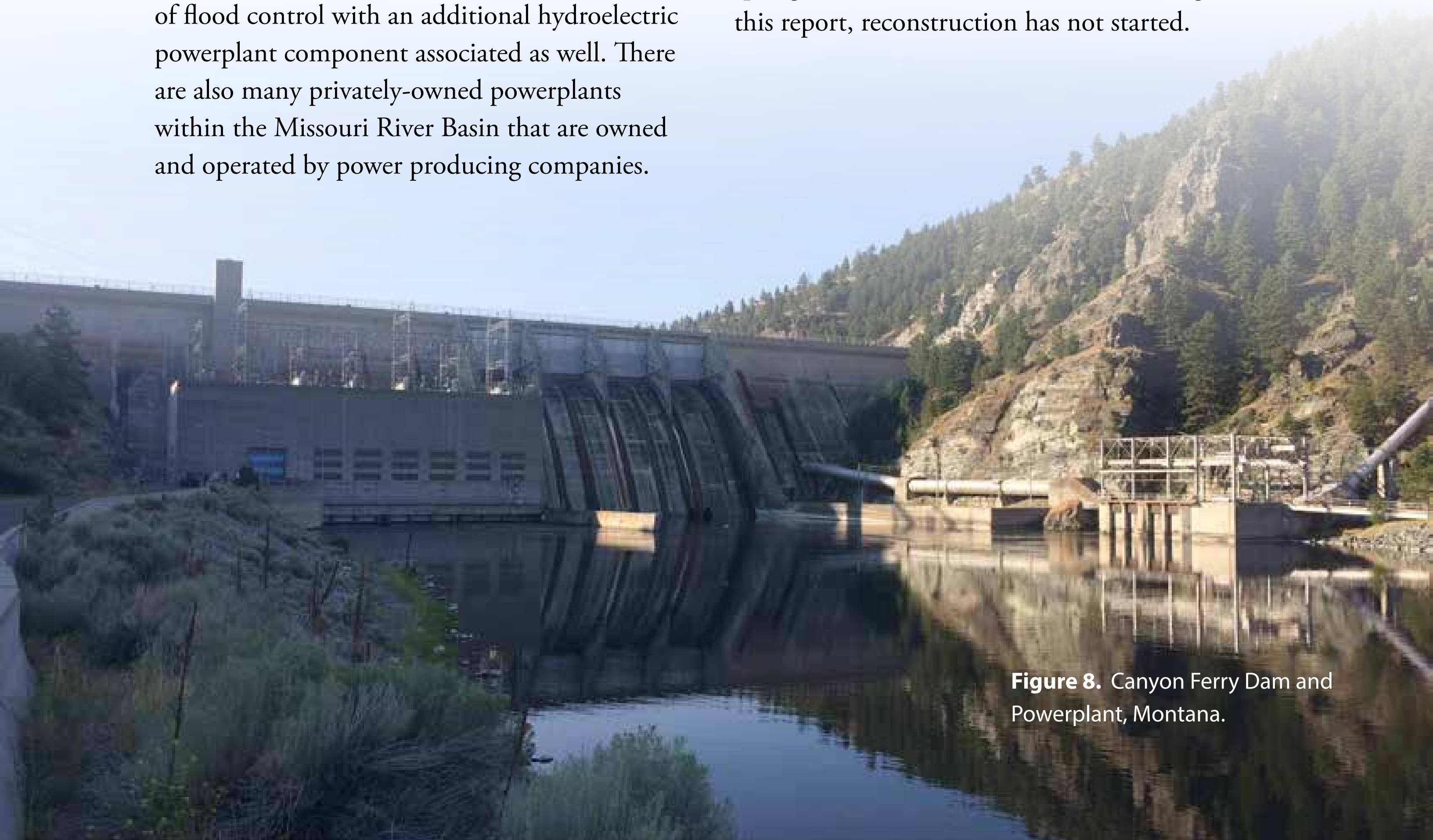


Figure 8. Canyon Ferry Dam and Powerplant, Montana.

Figure 9. Pueblo Dam in Pueblo, Colorado.

Figure 10. Bighorn sheep at the Sun River just upstream of the Sun River Diversion Dam, Montana.

Flood Management

Flood control within the Missouri River Basin is primarily controlled by Reclamation working in concert with USACE **(Figure 9)**. USACE retains jurisdiction over mainstem dams and the tributary projects designed primarily for flood control and navigation. Reclamation retains jurisdiction over most of the tributary projects, as well as over irrigation development. Projected water availability ranges from a modest decrease in mean annual water availability to a substantial increase in mean annual water availability. The projection indicates an overall increase in water availability (10 percent above normal). With a slight projected increase, flood management will become more critical to prevent future flooding. In many Missouri River reservoirs, the average number of spring days per month above flood pool elevation are expected to increase, while the average number of summer days per month above flood pool elevation is projected to decrease.

Fish and Wildlife

Developments of the Pick-Sloan Program, as well as other projects in the Missouri River Basin, have transformed the Missouri River and some related tributaries from alluvial streams and rivers to a chain of long and relatively deep reservoirs. Such a quantity of surface water did not exist naturally in the region. It is also a relatively dry climate. As a result, there has been a great impact on the environment. The purchase and subsequent management of the lands associated with the individual Pick-Sloan Program projects has changed use patterns of the lands adjacent to the projects **(Figure 10)**. Regulation of the reservoirs has also affected the river where it is still in a relatively natural state.

Looking ahead, in the Rocky Mountain Front (northwestern Montana), flows during winter and spring months are likely to increase while summer flows are likely to decrease. Any decreases in summer streamflow would likely have negative effects on ecological resources. While all ecosystems in Nebraska will be affected by climate change, aquatic ecosystems (wetlands, lakes, streams, and rivers) may be the most highly impacted (Bathke et al., 2014). In the Missouri River Basin, climate changes will alter both water quality and quantity.

Increases in the frequency and intensity of high precipitation events, particularly in a landscape dominated by agriculture, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies. Increased frequency of drought and heat waves, combined with increased human demand for water, will result in lower streamflows and an increase in the frequency of stream segments being de-watered and wetlands drying up.

Recreation

Recreation as an authorized Pick-Sloan Program purpose has grown far beyond original expectations as recreation facilities have become more developed and the opportunities have increased.

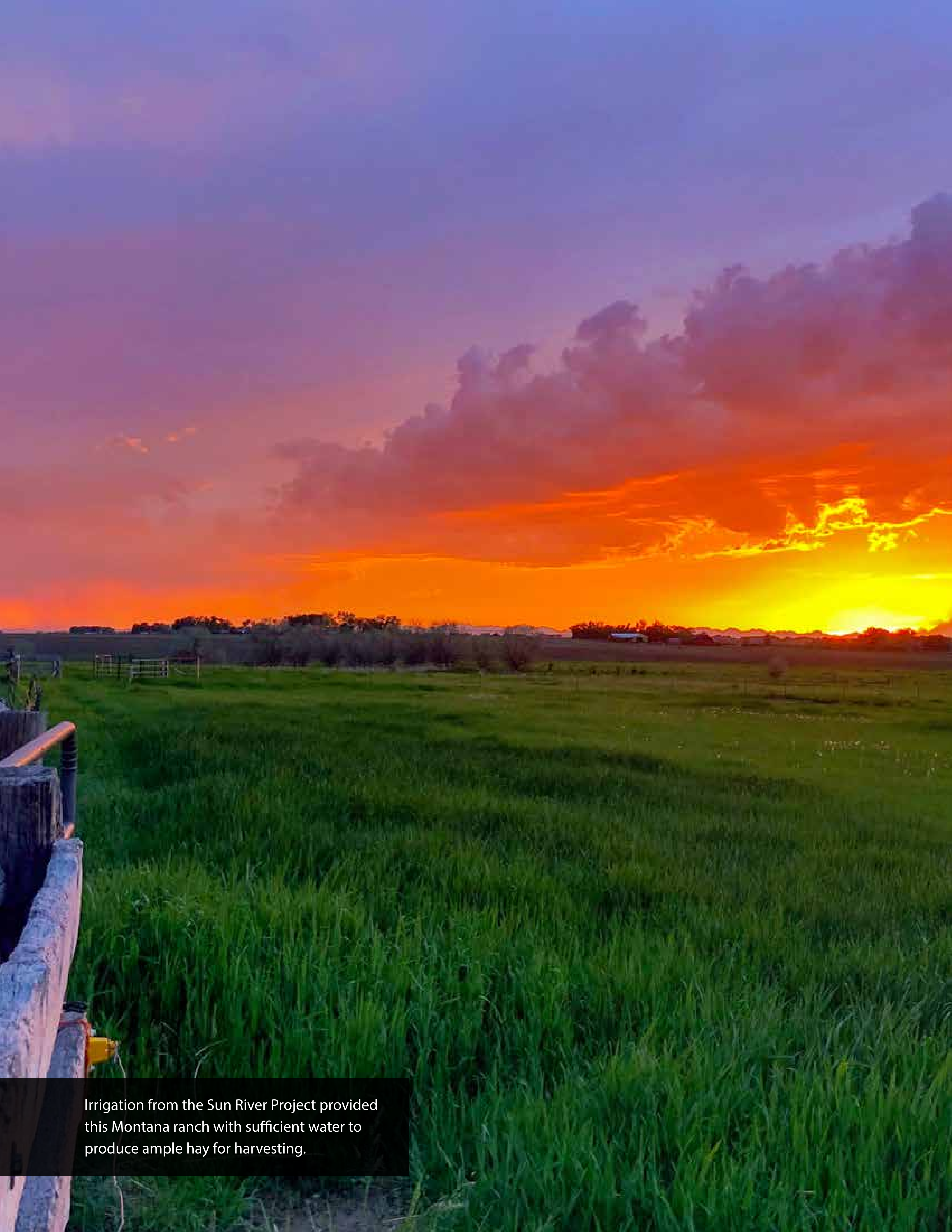
Recreation is also a source of income for businesses catering to boating, hunting, fishing, camping, and other forms of recreation **(Figure 11)**. In the future, lower pool elevations in the reservoirs and lower streamflows in the summer months will lead to decreased access to boat ramps for recreation and, on average, more unusable days. This could result in reductions of overall recreational opportunities.

Water Quality

Water quality characteristics that are of greatest concerns in the basin are chemicals, temperature, biological organisms, taste, odor, and floating material. The Missouri River and its tributaries have historically contained high sediment loading and naturally occurring high concentrations of metals, such as arsenic and selenium. These water quality characteristics have also changed over the past several decades. The changes are a result of past and current changes in land use practices, increased urbanization, atmospheric deposition of pollutants, and dam construction and regulation within the Missouri River Basin.

Figure 11. Kyle Converse, Technical Service Center Mechanical Engineer, enjoys the blue ribbon fishery on the Big Horn River by Yellowtail Dam, Montana.

With the exception of some tributary streams and isolated reaches of the Missouri River below cities and industries, water quality problems in the basin have been relatively minor. Storage space has been provided in some tributary reservoirs for water quality. Wastewater treatment facilities rather than dilution have been emphasized for water quality. However, increases in runoff due to climate change would be expected to increase contaminant loads to surface waters. Increased contaminant loads could lead to additional impaired water designations within the Niobrara River subbasin, as well as continued impairment of waters currently classified as impaired. Seventeen of the 251 Niobrara River subbasin stream segments monitored by the State of Nebraska are classified as impaired due to known and unknown contaminants (NDEQ, 2005).



Irrigation from the Sun River Project provided this Montana ranch with sufficient water to produce ample hay for harvesting.

Potential Adaptation Strategies to Address Vulnerabilities

Adaptation strategies have been developed to address future water needs in the basin and to adjust future water infrastructure operations to changing hydrologic conditions. The strategies also addressed major issues identified by the project partners and various stakeholders. Where possible, strategies have been developed to be proactive rather than reactive. That is, they were developed to make the system more resilient to water supply changes rather than to react to discrete circumstances when they occur. Since most of the future water supply scenarios project increases in average annual runoff, strategies also were formulated to evaluate changes in operational strategies that might be possible with increases in seasonal streamflow.

Upper Missouri River Basin

Providing Water for Future Domestic, Municipal, and Industrial Uses in the Gallatin Valley

The objectives of this strategy are to explore options that provide potential sources of water for future domestic, municipal, and industrial demands in the City of Bozeman, Montana and the greater Gallatin Valley with a focus on those potentially linked to Reclamation's Canyon Ferry project.

Two options were evaluated for this strategy:

1. High capacity groundwater wells in conjunction with aquifer recharge.
2. A conceptual pipeline from Canyon Ferry Reservoir to the Gallatin Valley.

As discussed in the Missouri Headwaters Basin Study and through ongoing discussions, the options are being examined in the context of the greater Gallatin Valley and include the future water needs for surrounding communities and unincorporated areas that have more limited water supply options.

Figure 12. View looking southeast from the Fish Hawk Day Use Area located on the west shore of Canyon Ferry Reservoir, Montana.

Ecological Flow Releases from Canyon Ferry Reservoir and Lake Elwell

The objectives of this strategy are to evaluate the potential of ecological pulse flow releases from Canyon Ferry Reservoir **(Figure 12)** and Tiber Dam to improve aquatic habitat in the Missouri and Marias Rivers, and to potentially trigger pallid sturgeon (*Scaphirhynchus albus*) spawning in the lower Missouri River. Modeled reservoir releases would begin with a lesser peak release in May to simulate prairie snowmelt and to initiate upstream movement in the lower Missouri River by native fish, including pallid sturgeon. This would be followed by a greater reservoir release in June to mimic the mountain snowmelt hydrograph peak and to coincide with pallid sturgeon spawning. The flow would then be quickly ramped down to maximize pallid sturgeon larvae drift time following spawning. It is important to note that in modeling this strategy, only streamflow in the Missouri River system above Fort Peck Reservoir was considered.

During times of flooding, both locally and along the Missouri River in downstream States, flood control operations are coordinated by USACE, and releases such as those described under this strategy would not be made if they contributed to flood risks.

Water Management Strategy for Increased Drought Resilience

The objectives of this strategy are to continue ongoing efforts to build drought resilience capacity in the upper Missouri River Basin to manage drought when it occurs, as well as to incorporate and adapt to changing drought characteristics in the future. The strategy will continue the efforts begun through the National Drought Resilience Partnership and Reclamation's drought contingency planning processes by preparing for drought rather than responding to crises as they occur. The partners will continue to work collaboratively to engage and train community-based drought coordinators to lead planning, mitigation, and project implementation in eight watersheds in the Missouri River headwaters. These ongoing efforts will prepare stakeholders to mitigate for drought while preserving cultural and ecological values in the face of a changing future.

Beaverhead River Subbasin Strategies

Decreasing Drawdown for Flood Storage and Clark Canyon Reservoir

Currently, 79,075 acre-feet of Clark Canyon Reservoir storage is allocated for exclusive flood control **(Figure 13)**. This upper zone of the reservoir only can be used to store water to reduce flooding downstream, and any water stored for flood control must be released promptly once the risk of flooding has passed. Under this strategy, 20,000 acre-feet of this exclusive flood control zone would be reallocated to joint use purposes where water could be stored for later release after the spring runoff peak has passed. The stored water would be released later to decrease irrigation water shortages and to improve summer flows in the 16 miles of the Beaverhead River between Clark Canyon Dam and the Barrett's Diversion Dam for the East Bench Canal.

Capping the Winter Release from Clark Canyon Reservoir at 100 Cubic Feet per Second

This strategy's objective is to provide a more consistent winter instream flow rate by reducing the maximum rate to 100 cubic feet per second (cfs) during years when water supply conditions are wetter going into the winter. This might result in more carry-over storage for the instream flow during the following year and also reduce irrigation water shortages for the East Bench Irrigation District and Clark Canyon Water Supply Company users.

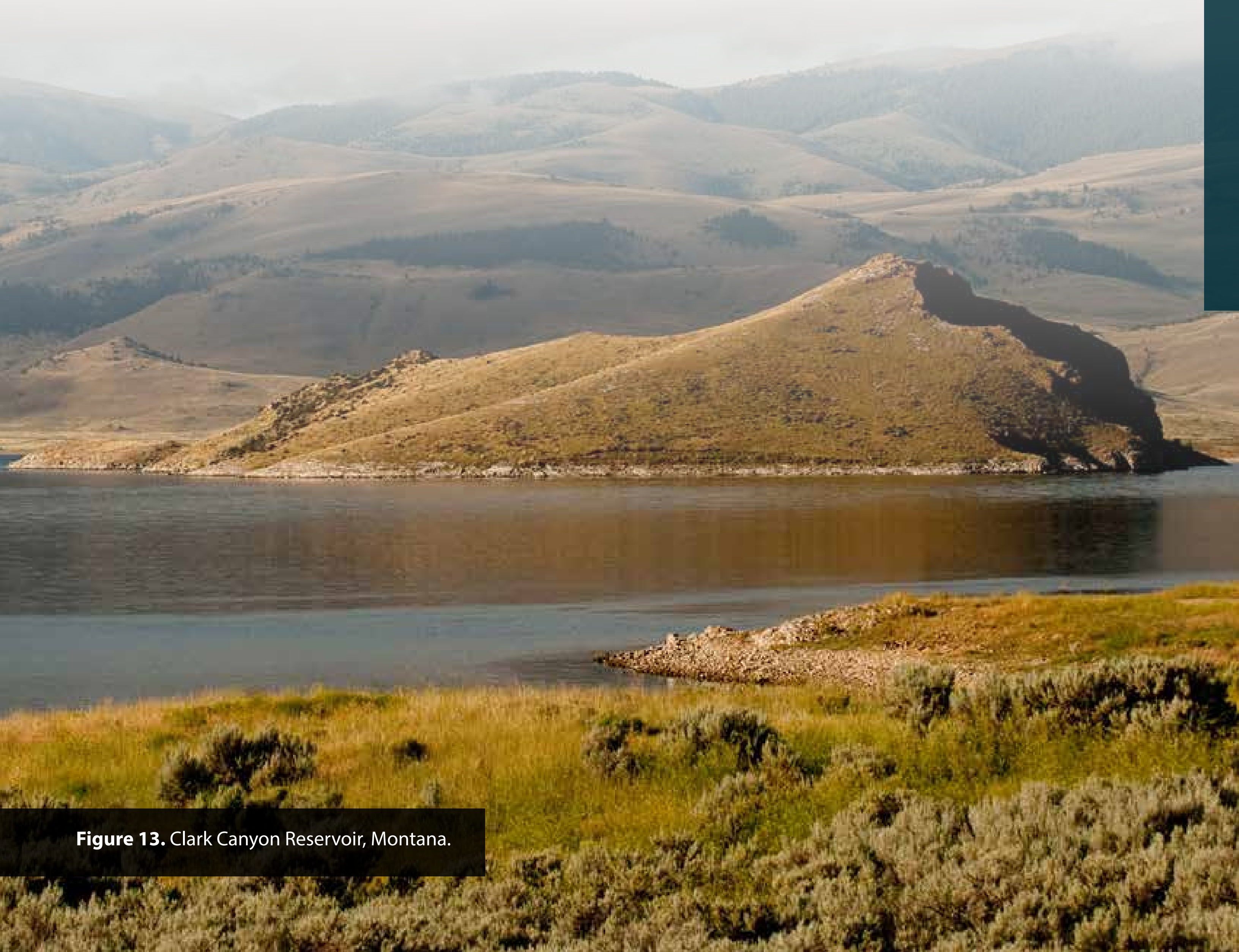


Figure 13. Clark Canyon Reservoir, Montana.

Sun River Subbasin Strategies

Increasing Willow Creek Feeder Canal Capacity

Increasing the capacity of the Willow Creek Feeder Canal would generally result in more water stored in the reservoir and a fuller reservoir at the end of the irrigation season. **Figure 14** illustrates the impact of increasing the capacity of the canal to 175 cfs under one of the Hot-Dry[1] paleohydrology scenarios for the 2080s future time horizon, which results in the lowest Willow Creek end-of-water-year storage over a 50-year period. This sequence may be considered the worst-case scenario for Willow Creek storage. Although the increased feeder canal capacity would result in a typically fuller reservoir, note that during extreme drought years the reservoir would still be drawn down to minimum pool (2,233 acre-feet) with or without this strategy. For wetter scenarios, flows are projected to increase overall. If wetter conditions bear out in the future, this strategy might be a way to capture additional water for later release.

Increasing Pishkun Supply Canal Capacity

At times, diversions of water to storage in Pishkun Reservoir are constrained by the capacity of the Pishkun Supply Canal. With a higher canal capacity, it might be possible to convey more early-season Sun River water to off-stream storage. This could be advantageous in the future because most future climate scenarios are projecting increased early season flow. Under this strategy, the capacity of the Pishkun Supply Canal would be increased from 1,400 cfs to 1,512 cfs (the reservoir outflow capacity) to potentially allow for the diversion of more water to the reservoir during peak flow times.

Musselshell River Subbasin Strategy

New Off-Stream Storage in the Lower Musselshell River Subbasin

The objectives of this strategy are to evaluate the potential benefits of new off-stream storage in the lower Musselshell River subbasin using the Horse Creek Coulee Reservoir project as an example.

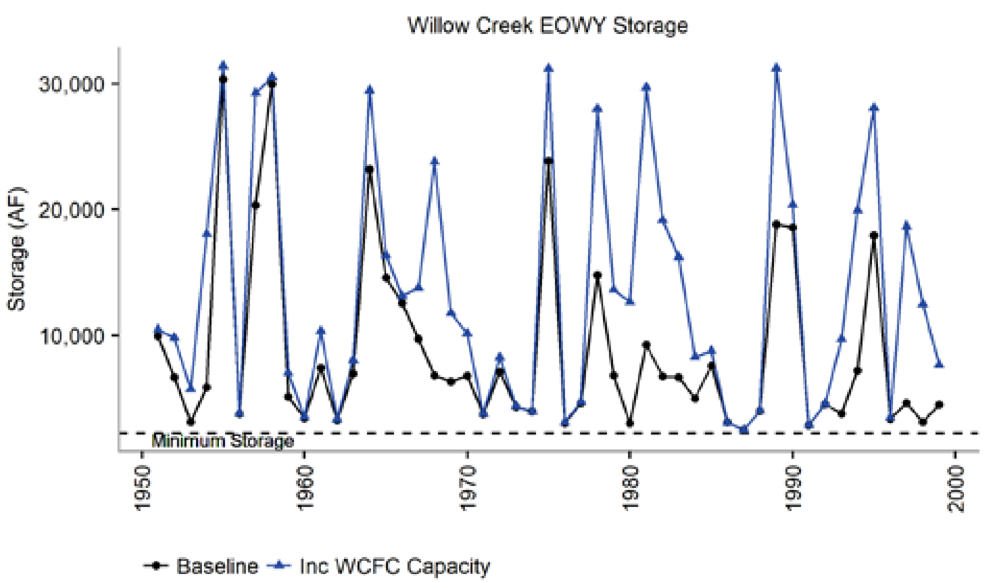


Figure 14. Modeled Willow Creek end-of-water-year storage for the increased Willow Creek Feeder Canal capacity strategy. Figure shows worst-case paleohydrology scenario compared to baseline conditions.

[1] The Hot-Dry scenario is one of several future scenarios that were developed as a way of using the best available science for long-term planning under uncertain future conditions. The Hot-Dry scenario assumes a higher-than-projected temperature change and a lower-than-projected precipitation change.

Figure 15. Bridge over the Niobrara River in the Nebraska Sand Hills.

The reservoir was modeled using the Upper Missouri RiverWare planning model. Water storage was modeled to occur during the fall and early spring and releases for downstream irrigation were modeled at the rate needed to offset a shortage at any time during the irrigation season. During August and September, if stored water was still available, water could be released to supplement the instream flow in the lower river to bring the rate of flow closer to the Montana Department of Fish Wildlife and Park's water reservation instream flow right of 70 cfs. Stored water was managed in the model to supplement the supply for 2,500 irrigated acres, and a canal efficiency of 67 percent was assumed for deliveries to the reservoir. The canal that supplies the reservoir was assumed to be off from November 15 until March 1.

Niobrara River Subbasin

The overarching objectives of the Niobrara River Basin Study were to identify the effects of climate change on future water supplies and pinpoint potential management options in the basin. The basin study relied on a series of models to assess hydrological effects of potential alternatives aimed at improving basin resiliency.

The basin study confirmed that the Niobrara River **(Figure 15)** faces a range of potential future imbalances between water supply and demand. Addressing such imbalances may require additional analysis and may not be resolved through any single approach or alternative.

The Mirage Flats Irrigation District Pumping Station

This strategy would bypass a relatively inefficient portion of the Mirage Flats Irrigation District's canal that allows infiltration of the groundwater system and, in turn, move the district's diversion point 9 miles downstream and install a high-aquifer well field (Mirage Flats Pumping Station). While this action would improve surface water transportation efficiency in the Mirage Flats Irrigation District area, it would also lower the groundwater table and result in a reduction in water available for groundwater pumping. However, under all climatic change scenarios, this strategy would increase the volume of surface water delivered to irrigators and reduce the need for supplemental groundwater pumping. Additional analyses would be required to determine the tradeoffs between increased surface water deliveries and reduced recharge from canal seepage.

The Mirage Flats Irrigation District Canal Recharge

The objective of this strategy proposes an operational change by using the Mirage Flats Irrigation District main canal and lateral system to recharge local groundwater. This action would cease surface water irrigation deliveries and convert the district to groundwater. The district would continue to divert water during the growing season and allow water to seep from its canals as recharge to mitigate the effect of the increased pumping. The increase in recharge from the canal seepage would exceed any decrease in recharge resulting from changing the on-farm irrigation practice. This water management strategy ensures sufficient water volume to irrigators. It also improves the timing of irrigation water by eliminating the dependency on surface water supplies and canal management practices. This strategy would be worth considering in any future scenario.

The Platte River Recovery Implementation Program

The Platte River Recovery Implementation Program (Program) began on January 1, 2007, following the approval of the Governors of Colorado, Nebraska, and Wyoming, and the Secretary of the Interior (signatories) and was scheduled to run for 13 years through December 31, 2019 (First Increment). The Program provides continued Endangered Species Act compliance for water-related activities in the Platte River basin of the three States (including Federal water projects) while providing defined benefits for the Program's four target threatened and endangered species (whooping crane *(Grus Americana)*, interior least tern *(Sterna antillarum)*, piping plover *(Charadrius melodus)*, and pallid sturgeon).

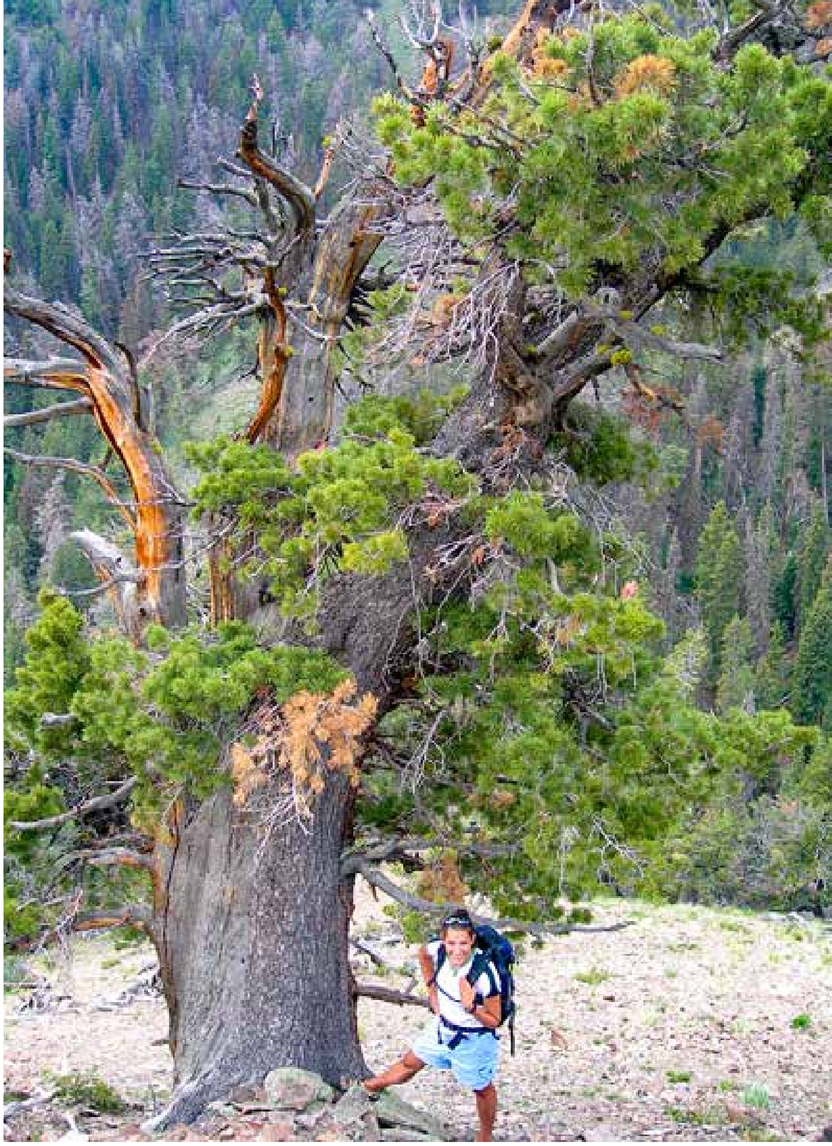
Continuing climate change and the availability of water in streams, reservoirs, wetlands and riparian habitats will have an impact on these species **(Figure 16)**. Like most reservoir and other water-related environments, the abundance of food available is largely dictated by changing reservoir, wetland, and riparian elevations. Additionally, high water temperatures and low flows during the summer months would continue to be a limiting factor to the fish community and those species that rely on fish as a food source.

The Program signatories committed to achieving the following objectives by the end of the First Increment of the Program:

- Providing water capable of improving the occurrence of Platte River flows in the central Platte River associated habitats relative to the present occurrence of species and annual pulse target flows by an average of 130,000 to 150,000 acre-feet per year at Grand Island, through re-regulation and water conservation and supply projects (referred to as the Water Action Plan Milestone).
- Protecting, restoring where appropriate, and maintaining at least 10,000 acres of habitat in the central Platte River area between Lexington and Chapman, Nebraska (referred to as the Land Plan Milestone).
- Implementing a systematic analysis and evaluation of how the river processes are working and applying the information learned to water management decisions (referred to as the Adaptive Management Plan).

In 2019, the Program's Governance Committee unanimously approved an extension of the First Increment of the Program through December 31, 2032, and the Governors of Colorado, Nebraska, and Wyoming and the Secretary of the Department of the Interior agreed to additional State and Federal contributions to the Program to implement the extension. The extension is necessary for the Program to complete the Water Action Plan Milestone and for the State of Nebraska to complete the Nebraska New Depletions Plan Milestone as these milestones were not achievable by the original scheduled end of the First Increment on December 31, 2019. During the extension, the Program is committed to achieving the remaining two milestones while continuing habitat restoration and maintenance activities, as well as the continued implementation of the Program's Adaptive Management Plan and Integrated Monitoring and Research Plan.

Figure 16. Fishing on the North Platte River.



Images show scientists in the upper Missouri, Smith River, and Wind River basins collecting core samples for paleohydrology analyses using tree rings. The trees sampled here are between 500 and 1,400 years of age.

SECTION 4

Innovations

In addition to the strategies described in Section 3 of this document, *Potential Adaptation Strategies to Address Vulnerabilities*, a variety of innovative research has occurred in the Missouri River Basin to address challenges and improve water management since the 2016 SECURE Report. Specifically, the use of paleohydrology in the Missouri River and integrated modeling in the Niobrara River subbasin.

Missouri River Headwaters Paleohydrology

Two primary goals of the Upper Missouri River Basin Study were to assess how well the existing water and power operations infrastructure in the basin performs under current, as well as future, water supply conditions, and to develop strategies to improve that level of performance. Accurately estimating natural variability and change in water supply is thus a key step in that process. While reliable records of current water supply are readily available across much of the basin, future supplies are more difficult to assess, particularly when it comes to estimating potential extreme wet and dry periods. A fundamental limitation in using historical observations to estimate future conditions is the uncertainty in whether historical measurements reflect the full range of hydrologic variability that the river system may experience. This is because extreme hydrologic conditions are rare and, as a result, may not have occurred over the relatively short period of time streamflow across the basin has been reliably measured.

To address this limitation, and in order to better understand the full range of hydrologic variability in the basin, tree-ring based paleohydrologic records were developed to provide estimates of streamflow at key gaging locations that date back 1200 years or more (Martin et al., 2019 [Data] and Martin et al., 2019 [Journal Article]). Because of their length, these innovative records have provided greater insight into both common and, more importantly, rare and extreme hydrologic conditions that are particularly challenging to river management. Such paleohydrologic information can be used to characterize and understand climate and hydrologic variability over substantially longer time periods than is possible using instrumental records. This information is developed from physical or biological climate "proxy" records. Here, tree-rings are used as the climate proxy since the upper Missouri River Basin contains an extensive network of records that span multiple centuries to millennia and contain climate information that is strongly related to streamflow.

The thickness of annual tree rings, for example, is strongly correlated with the annual climate and hydrologic conditions that control streamflow. This statistical relationship allows scientists to derive information on past climate variability based on year-to-year changes in annual tree rings over thousands of years. By providing information over a longer period, paleohydrologic information provides a broader context for understanding past and potential future streamflow variability. This broader context helps water managers and decision makers to better understand the range of possible future water supplies for meeting current and future demands. Paleohydrologic information can also be used to develop an improved understanding of the climatic controls that affect hydrologic variability over decadal and longer time scales.

In addition to the Upper Missouri River Basin Study, Reclamation supported the U.S. Geological Survey in the development of the first reconstruction of annual streamflow in the upper Missouri River using tree rings.

This work was published in a peer reviewed journal article (Martin et al., 2019 [Data] and Martin et al., 2019 [Journal Article]). Paleohydrology scenarios were developed and used as input into a RiverWare planning model which helped test operations under a large range of conditions. The upper Missouri River Basin Study used this paleohydrology information, in part, to gain a better understanding of streamflow variability since there is little carryover storage capacity in the Upper Missouri River Region's reservoirs.

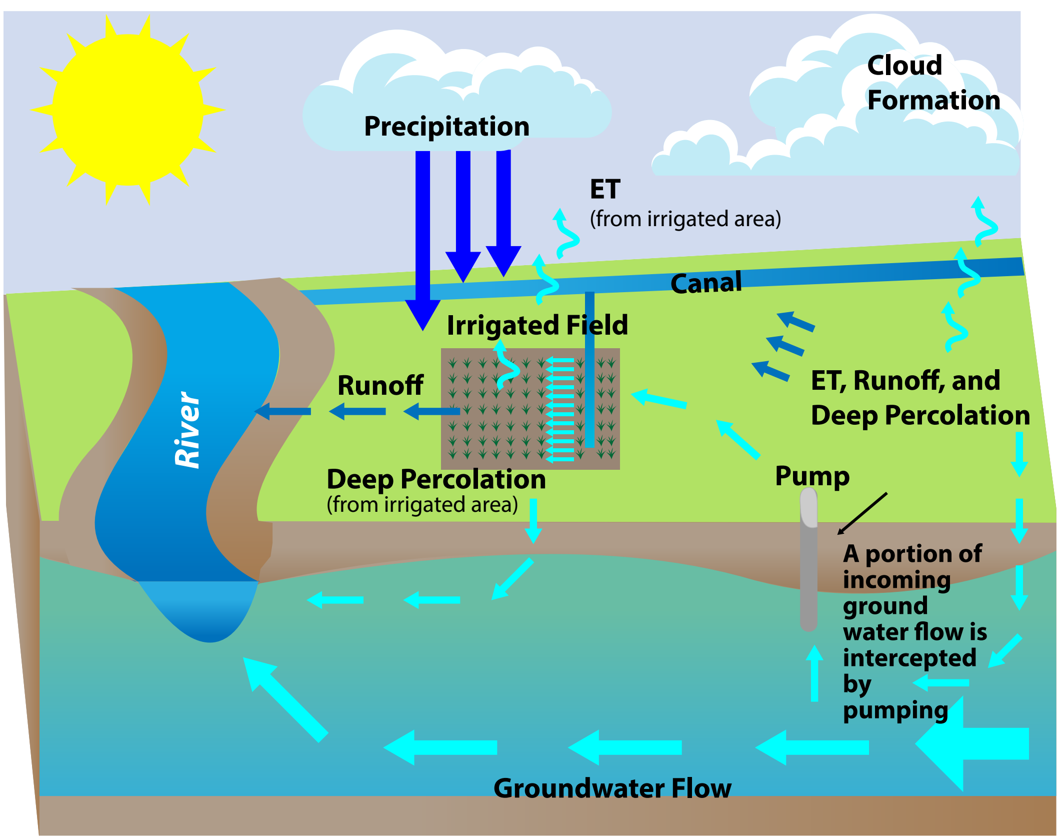


Figure 17. Illustration of hydrologic cycle in which irrigation is important.

ET = evapotranspiration

Using the Missouri River Basin as a case study, this work found that regionwide drought intensities were likely unprecedented in the last millennium during the Turn-of-the-Century Drought (ca. 2000 to 2010). Warming temperatures have increasingly influenced streamflow through decreasing runoff efficiency since at least the mid- to late-20th century (Martin et al., 2020).

Integrated Modeling in the Niobrara River Subbasin

Three different models were selected for the Niobrara River Basin Study—the watershed model, groundwater model, and surface water operations model—and all were linked to form an innovative integrated model designed to present a dynamic representation of the total water budget for the Niobrara River. The three modeling tools were selected to simulate the three primary parts of the hydrologic cycle—land, river, and aquifer **(Figure 17)**. The integrated model provides decision makers with reliable quantitative information about the hydrologic consequences of alternative water management strategies as it provides a better understanding of surface and groundwater interaction.

Watershed Model – This model was used to represent the land and soil part of the hydrologic cycle. The objective of a land and soil water model is to calculate water demands for irrigation, and the fate of rainfall and applied water on the land. This requires use of a method to simulate the soil water balance as a function of climate, soil, and land use.

Groundwater Model – This model was used to represent the aquifer part of the hydrologic cycle. The objective of a groundwater model is to quantify changes in aquifer water levels (thus water in storage) resulting from recharge to and pumping of the aquifer. A groundwater model also aims to simulate the effects of pumping on baseflow contributions to streamflow, and to predict subsurface flows in and out of the study area. The primary model requirements are knowledge of aquifer properties and stream connections.

Surface Water Operations Model – This model was used to represent the river part of the hydrologic cycle. The objective of a surface water operations model is to route flows down the river and to simulate the storage, release, diversion, and use of water along the Niobrara River and the canals that draw from the river. This requires a method that can replicate operation of the system (reservoirs and canals) and routing of water to meet surface water demands.

Each individual model is operated independently from the other models and then the integration occurs through a series of data processing and transfer of results between models. This approach is considered to be a "passive" linkage. The primary purpose of integration is to use outputs from the watershed and groundwater models as inputs into the surface water operations model. Inputs into the water operations model form a dynamic representation of the total water budget of the Niobrara River. Thus, streamflow estimates are the integrated results of all three models. Moving forward, it is anticipated that this integrated model approach can and will be used anywhere in the State of Nebraska.

Reclamation's Missouri Basin Region drill crew taking core samples at Fresno Dam, Montana.

SECTION 5

Next Steps

Reclamation is currently working with partners in the Missouri River Basin to update the St. Mary River and Milk River Basins Study. The updated study was funded in 2018 by Reclamation and the Montana Department of Natural Resources and Conservation. The study will update the 2012 St. Mary River and Milk River Basins Study (the first completed basin study under Reclamation's Basin Study Program); improve water resources planning capability for the region; and support the identified goals in the updated Montana State Water Plan that was submitted to the 2015 Montana Legislature. The State Water Plan lays out a path for managing Montana's water resources over the next 20 years, including recommendations for Montana Department of Natural Resources and Conservation to work with local water users and other government agencies to address water management challenges.

The updated study takes a different approach to modeling hydrology in the northern Great Plains region by incorporating the concept of contributing watershed area that varies in time. This region consists of networks of shallow depression storage, often called potholes or wetlands, that are seasonally linked via surface and groundwater, which is particularly challenging for quantifying water supply. This approach, combined with current approaches for quantifying agricultural irrigation water demand and riparian water demand, will allow for improved quantification of water supply and demand. The improvements, combined with an updated river systems model in RiverWare, will allow study partners to explore water management strategies with greater confidence.

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Cover photo: View of Guernsey Reservoir in Wyoming looking west toward Laramie Peak in the background.