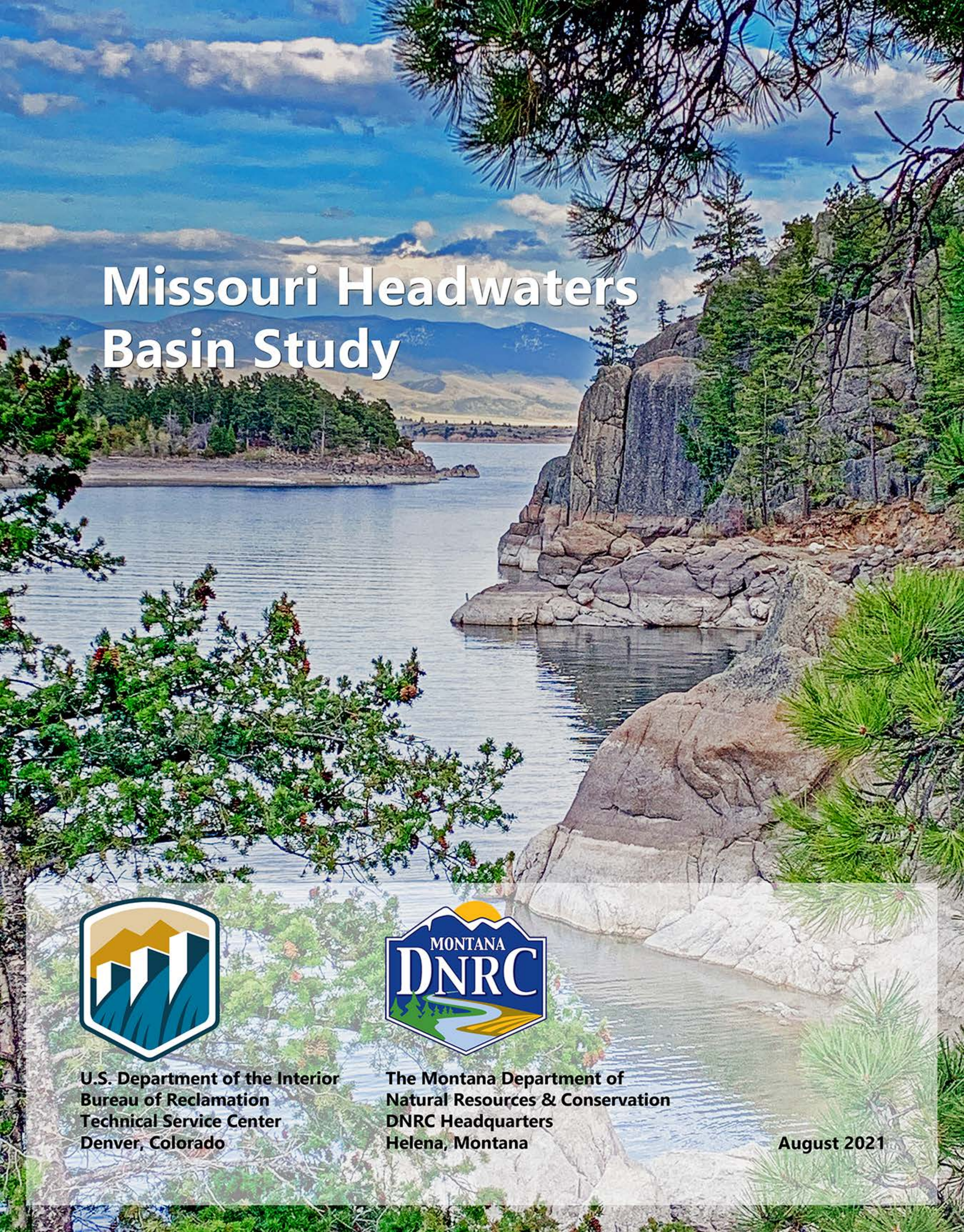

Missouri Headwaters Basin Study

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

The Montana Department of
Natural Resources & Conservation
DNRC Headquarters
Helena, Montana

August 2021

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

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.

Montana Department of Natural Resources and Conservation's mission is to help ensure that Montana's land and water resources provide benefits for present and future generations.

Technical Memorandum Number. ENV-2020-081

Acronyms

°F	degree Fahrenheit
AEES	Advanced Engineering and Environmental Services
ARM	Administrative Rules of Montana
Basin Study	Missouri Headwaters Basin Study
BHWC	Big Hole Watershed Committee
BLM	Bureau of Land Management
CCAA	Candidate Conservation Agreements with Assurances
CE	Common Era
cfs	cubic feet per second
CT	Central tendency climate scenario
EOWY	end of water year
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FSID	Fort Shaw Irrigation District
gcpd	gallons per capita per day
GID	Greenfields Irrigation District
GPMU	Great Plains Management Unit
HD	Hot-dry climate scenario
HUC8 sub-basins	Hydrologic Unit Code eight-digit level drainage areas
HW	Hot-wet climate scenario
Impacts Assessment	Upper Missouri Basin Impacts Assessment
IWRP	Integrated Water Resources Plan
LD	longest drought
LP	longest pluvial (wet period)
MBMG	Montana Bureau of Mines and Geology
MCA	Montana Code Annotated
MID	most intense drought
MIP	most intense pluvial
M&I	municipal and industrial
Montana DFWP	Montana Department of Fish, Wildlife and Parks
Montana DNRC	Montana Department of Natural Resources and Conservation
msl	mean sea level

MW	megawatt
NDRP	National Drought Resilience Partnership
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NGO	non-governmental organization
PSMBP	Pick-Sloan Missouri Basin Program
RCM	Revised Codes of Montana
Reclamation	Bureau of Reclamation
SECURE Water Act	Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act (Public Law 111-11, Subtitle F of Title IX, §9501 – §9510)
SNAPP	Science for Nature and People Partnership
State Water Plan	2015 Montana State Water Plan
UMH	Upper Missouri Headwaters
UMOWA	Upper Missouri Watershed Alliance
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VIC	Variable Infiltration Capacity hydrologic model
WaterSMART	Water Sustain and Manage America's Resources for Tomorrow
WCFC	Willow Creek Feeder Canal
WD	Warm-dry climate scenario
WW	Warm-wet climate scenario

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1. Introduction

Through the WaterSMART[1] program, the Bureau of Reclamation (Reclamation) is working with external partners to understand and address current and future risks to water resources in the Western United States. Reclamation, in partnership with the Montana Department of Natural Resources and Conservation (Montana DNRC) and with support from the U.S. Geological Survey (USGS), conducted the Upper Missouri Basin Impacts Assessment (Impacts Assessment) and Missouri Headwaters Basin Study (Basin Study) to evaluate risks in the Upper Missouri River basin upstream of Fort Peck Reservoir. This region includes the Upper Missouri and the Musselshell Rivers. In addition to serving as the headwaters to much of the nation, these watersheds support habitats for numerous fish and wildlife species and supply water for agriculture, hydropower, recreation, and tribal, municipal, industrial, and domestic uses. The Upper Missouri River and Musselshell River basins together encompass a drainage area of about 50,000 square miles. They are the primary water source for 320,000 people and approximately 1.1 million acres of irrigated land. Topography ranges from high Rocky Mountain peaks in Glacier National Park to rolling plains in central and eastern Montana, with corresponding elevations ranging from approximately 2,200 feet to 11,000 feet above mean sea level (msl).

The Impacts Assessment (Reclamation 2019a) provides foundational information on historical and projected future water supply and demand and potential risks to future water supplies. This Basin Study uses this information on future water supply, demand, and risks, along with modeling tools developed as part of the Impacts Assessment, to identify and evaluate strategies for alleviating potential future risks to water resources in the study area. This report presents results from the Basin Study, with a focus on the identification and analysis of strategies for alleviating potential risks to water supplies through improved management and reducing demands.

1.1. Basin Study Purposes and Objectives

The purpose of the Basin Study is to develop and evaluate strategies for addressing water resource challenges under a range of potential future conditions, including population growth, changes in future water supply and demand related to climate change, and supply conditions based on a broad range of historical conditions drawn from paleohydrology analysis. Strategies were developed in coordination with watershed groups and other stakeholders to address challenges identified in the Impacts Assessment. These strategies include alternative management and operating policies, as well as construction of new water resources infrastructure and modification of existing infrastructure. Strategies are

[1] Water Sustain and Manage America's Resources for Tomorrow.

evaluated by considering their effects on five resource categories—water deliveries, hydroelectric power resources, flood control operations, ecological resources (including water quality, fish and wildlife habitat, and Endangered Species Act [ESA] listed species), and recreation.

The Basin Study was conducted for a variety of reasons. First, the 2015 Montana State Water Plan directed Montana DNRC to plan for future management of water in the Missouri Headwaters given population and economic growth and changing water supplies and demands. Also, previous studies, including the Reclamation SECURE Water Act[1] Report to Congress (Reclamation 2021) and the Impacts Assessment (Reclamation 2019a), identified potential changes in future conditions that highlight the need for a long-term planning study. Specifically, a future warming trend and changes in spring runoff volume and timing are projected. Evapotranspiration and associated crop demand as well as reservoir evaporation are also projected to increase with warming temperatures. Projected changes in runoff timing in the snowmelt dominated watersheds of the Missouri Headwaters are likely to have a significant effect on the timing of streamflow for irrigation and municipal demands. Projected changes in runoff timing and volume are also likely to impact the amount and timing of water available for fish, wildlife, and recreation, which have become an important component of the region's economy. Reclamation's storage reservoirs in the study area may play an even larger role meeting the region's water management objectives in the future with warmer temperatures increasing demand for stored water and higher annual runoff volume along with earlier spring runoff possibly increasing the need for flood control storage.

Finally, because much of the Missouri Headwaters area is closed to most new surface water appropriation, groundwater may be increasingly used to meet water demands in the future. However, new groundwater uses are complicated by the interaction between surface and groundwater. Aquifer recharge, return flow patterns, and discharge from aquifers to streams are likely to change with increasing demands and more efficient irrigation.

The Basin Study seeks to address the needs identified above by achieving the following objectives.

- Assess current and projected future water supply; this study focuses on use of information characterizing the distant past (paleo), the recent past (historical), and projected future conditions.

- Assess current and projected future water demand; this study includes, but is not limited to, existing information related to groundwater sources in high-demand areas, such as the Gallatin and Beaverhead valleys.

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[1] Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act (Public Law 111-11, Subtitle F of Title IX, §9501 – §9510)

- Evaluate water supply risks by analyzing simulated performance of water and power infrastructure and operations under paleo, historical, and future hydrology scenarios.
- Identify and evaluate potential strategies that may reduce any imbalances; development and evaluation of strategies includes outreach and involvement by stakeholders.

As previously mentioned, this Basin Study builds on the Impacts Assessment (Reclamation 2019a) that Reclamation also conducted in partnership with Montana DNRC. Additionally, USGS provided guidance and technical support for the Impacts Assessment by developing paleo reconstructed streamflow records, which Reclamation used to develop paleohydrology streamflow scenarios for the study. Figure 1 depicts how the Impacts Assessment and Basin Study are interrelated, with the Impacts Assessment (blue) focused on assessing water supply and demand and evaluating future risks to water supplies, and the Basin Study (brown) focused on identifying and evaluating potential strategies in collaboration with basin stakeholders.

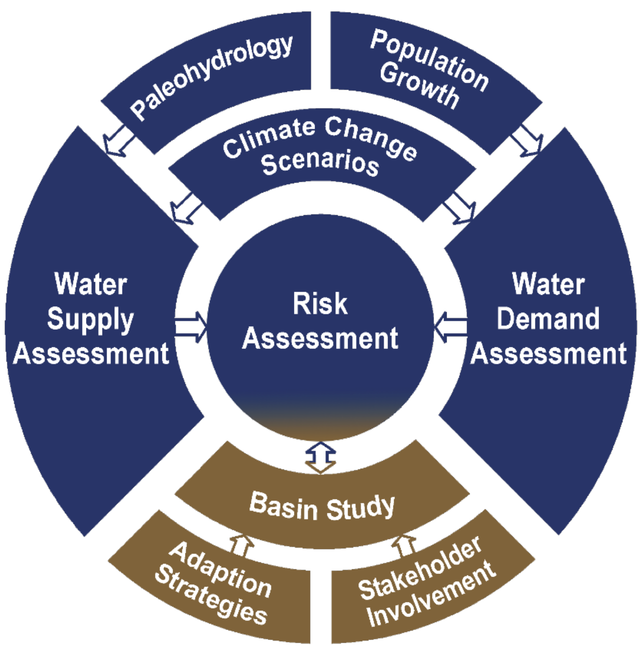

Figure 1.—Upper Missouri Basin Impacts Assessment and Missouri Headwaters Basin Study process diagram.

The datasets, models, and information generated for the Impacts Assessment and Basin Study provide a foundation for future investigations and implementation of strategies. The partnerships developed between Reclamation, Montana DNRC, and local stakeholders will also facilitate future planning efforts.

1.2. Location and Description of the Missouri Headwaters Study Area

This Missouri Headwaters Basin Study area encompasses the Upper Missouri River and Musselshell River basins upstream of Fort Peck Reservoir (Figure 2). The study area covers about 50,000 square miles, and the watershed outflow averages about 6.7 million acre-feet annually.

The Missouri River begins in the Rocky Mountains of southwestern Montana where the drainages for the Jefferson, Madison, and Gallatin Rivers join to form the Missouri River near the town of Three Forks. These drainages include a series of mountain ranges with peaks that approach 12,000 feet, and intermountain valleys with elevations of 4,000 to 6,000 feet. Along the Continental Divide to the north, the Sun River joins the Missouri River in the city of Great Falls, while the Teton, and Marias Rivers join the Missouri River near Fort Benton. The study area also encompasses central Montana watersheds, including the Smith and Judith Rivers (generally ranging from 3,000 feet to 6,000 feet), and the extensive tributary drainage of the Musselshell River (ranging from about 2,000 to 5,000 feet).

The downstream-most gaging stations in the study area are USGS Musselshell River at Mosby gaging station (#06127500) for the Musselshell River basin portion of the study area and USGS Missouri River at Landusky gaging station (#06115200) for the remainder of the study area. At the downstream end of the study area, the Missouri River and Musselshell River flow into Fort Peck Reservoir (at about elevation 2,250 feet msl). Fort Peck Reservoir is the first of a series of major Missouri River main-stem reservoirs managed primarily by the U.S. Army Corps of Engineers (USACE) for flood control. This study focuses on the watersheds upstream of Fort Peck Reservoir and including water supply reservoirs managed by Montana DNRC and Reclamation, not the collectively managed Missouri River main-stem reservoirs.

Figure 2.—Missouri Headwaters Basin Study location map.

1.3. Water Use and Development

This section describes water uses and water resources development in the study area. Water uses in the study area include consumptive uses such as irrigation and municipal use as well as non-consumptive uses such as hydropower and instream flow for fisheries. This section also describes the major infrastructure that is used to regulate, manage, and deliver surface water to users throughout the study area.

1.3.1. Irrigation

Irrigation in the Helena Valley.

Irrigation is by far the largest consumptive use in the study area. The study area encompasses about 1.1 million irrigated acres, mostly for livestock forage and small grains. Primary irrigated crops include alfalfa, pasture grass, other hay crops, and grains such as wheat, barley, and corn. Surface water supplies over 97 percent of irrigation water (Montana DNRC 2014). As described in the Impact Assessment, the Montana DNRC inventoried irrigated lands for the 2015 State Water Plan (Montana DNRC 2014) and refined those estimates for the Impacts Assessment and Basin Study. Irrigated acreage within the study area is summarized by Hydrologic Unit Code eight-digit level drainage areas (HUC8 sub-basins) in Table 1 and depicted in Figure 3.

1.3.1.1. Federal Irrigation Projects and Reservoirs

The study area encompasses several Federal irrigation projects, including five units of the Pick-Sloan Missouri Basin Program (PSMBP) as well as the Sun River Project. The PSMBP supplies irrigation water to about 20 percent of the irrigated lands within the study area. The Sun River Project, which was authorized prior to PSMBP, encompasses additional irrigation units which comprise about 10 percent of the study area's irrigated lands. These projects and features are summarized in Table 2. Canyon Ferry Reservoir, part of the Canyon Ferry Unit of PSMBP, also stores and releases water to mitigate impacts of irrigation withdrawals and crop water consumption on downstream hydropower water rights. This mitigation of impacts on downstream water rights makes reliable irrigation possible for a substantial amount of agricultural land in the headwaters.

Table 1.—Summary of Irrigated Areas by HUC8 Sub-Basin

HUC-8	HUC-8 Name	Area (acres)	HUC-8	HUC-8 Name	Area (acres)
10020001	Red Rock	65,491	**10030105**	Belt	37,299
10020002	Beaverhead	77,566	**10030201**	Two Medicine	8,244
10020003	Ruby	37,590	**10030202**	Cut Bank	22,945
10020004	Big Hole	150,396	**10030203**	Marias	90,315
10020005	Jefferson	51,402	**10030204**	Willow	2,333
10020006	Boulder	10,530	**10030205**	Teton	47,190
10020007	Madison	33,392	**10040103**	Judith	17,031
10020008	Gallatin	102,208	**10040201**	Upper Musselshell	60,503
10030101	Upper Missouri	67,789	**10040202**	Middle Musselshell	16,956
10030102	Upper Missouri-Dearborn	17,386	**10040203**	Flatwillow	14,819
10030103	Smith	34,632	**10040204**	Box Elder	7,756
10030104	Sun	135,531	**10040205**	Lower Musselshell	5,230

Total irrigated acreage within study area: 1,114,534 acres.

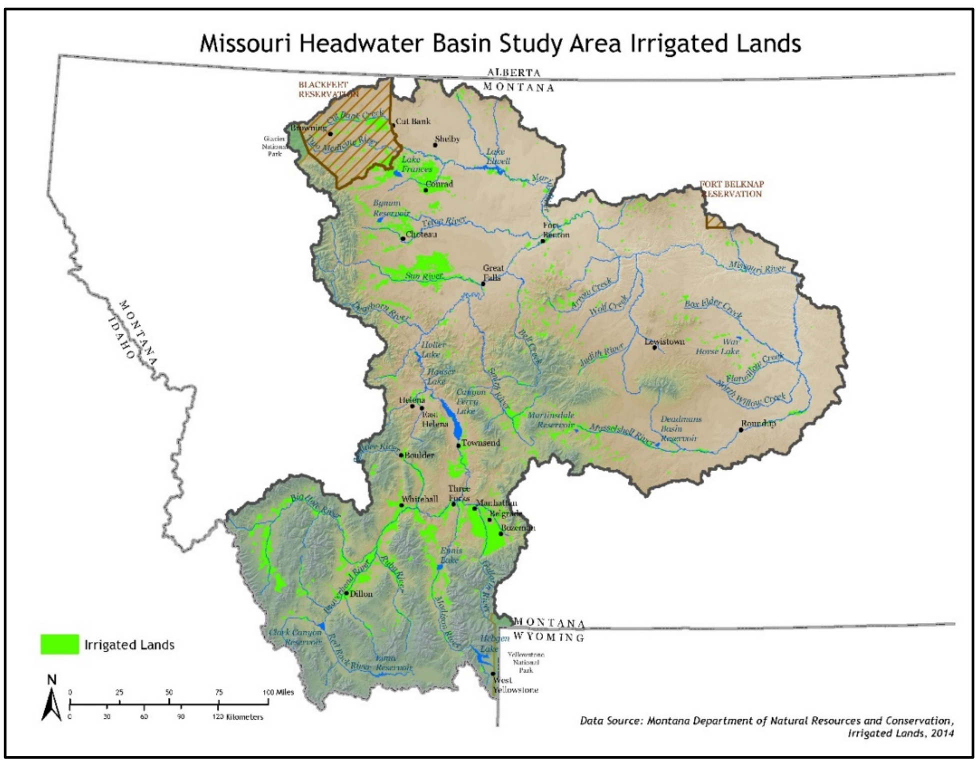

Figure 3.—Irrigated lands in the Missouri Headwaters Basin study area.

Table 2.—Summary of Reclamation Projects in the Missouri Headwaters Basin Study Area

Project/Program	Unit	Purpose and Associated Water Source
Pick-Sloan Missouri Basin Program (PSMBP)	East Bench Unit	Irrigation deliveries for 56,000 acres from Clark Canyon Reservoir on the Beaverhead River
	Crow Creek Pump Unit	Irrigation deliveries for 23,400 acres from the Mainstem Missouri River near Toston
	Canyon Ferry Unit	Multi-purpose deliveries from the Mainstem Missouri River near Canyon Ferry Reservoir; hydropower generation
	Helena Valley Unit	Irrigation deliveries for 17,000 acres and municipal and industrial deliveries for City of Helena from the Mainstem Missouri River and Lake Helena
	Lower Marias Unit	Irrigation deliveries for up to 127,000 acres (ultimately not developed) from Lake Elwell; currently this unit meets flood control, recreation, fish and wildlife, and municipal and industrial water supply needs
Sun River Project	Gibson Reservoir, Pishkun and Willow Creek Dikes	Irrigation deliveries for 93,000 acres from Sun River from Gibson, Pishkun, and Willow Creek Reservoirs

1.3.1.2. State-Owned Storage Reservoirs

Nine state-owned dams and reservoirs provide full service and supplemental irrigation water supplies and underpin flow management in some watersheds. State-owned dams that store irrigation water are listed in Table 3.

Ruby Reservoir.

Montana DNRC also owns and operates the Toston Dam on the Missouri River just upstream of Canyon Ferry Reservoir. Although Toston Dam is a run-of-river facility,[1] it provides about 29,200 acre-feet of water for irrigation annually through the Broadwater-Missouri Canal. The reservoirs also provide recreational benefits.

Figure 4 shows the locations of the major water storage reservoirs in the study area, including the Federal, State, and privately-owned reservoirs. Privately-owned reservoirs primarily supply water for irrigation. Privately-owned reservoirs are not discussed in detail in this report but include: Swift Reservoir, Lake Frances, Bynum Reservoir, Eureka Reservoir, Whitetail Reservoir, Lima Reservoir, Petrolia Reservoir, and Newlan Creek Reservoir.

[1] A run-of-river facility operates on the flow of the river and has very little storage capacity in the reservoir behind the dam.

Table 3.—Summary of State-Owned Reservoirs in the Missouri Headwaters Basin Study Area

Reservoir	Source(s)	Active Storage (acre-feet)	Approximate Acres Irrigated*
Ruby Reservoir	Ruby River	37,611	33,000
Middle Creek Reservoir (Hyalite Lake)	West and East Hyalite Creeks	10,184	16,000**
Willow Creek Reservoir	Willow Creek Dry Hollow Creek Norwegian Creek	18,000	12,950
Lake Sutherlin	North Fork Smith River	11,528	12,095
Nilan Reservoir	Smith Creek Ford Creek	10,092	10,000
Ackley Lake	Judith River	5,721	5,000
Bair Reservoir	North Fork Musselshell River	7,300	35,000***
Martinsdale Reservoir	South Fork Musselshell River	23,348	-
Deadman's Basin Reservoir	Musselshell River	72,218	30,000

*Includes full-service and supplemental acres

**Hyalite Lake also supplies up to 5,900 acre-feet of water for City of Bozeman.

***Bair and Martinsdale Reservoirs work in conjunction with each other to irrigate a combined total of 35,000 acres.

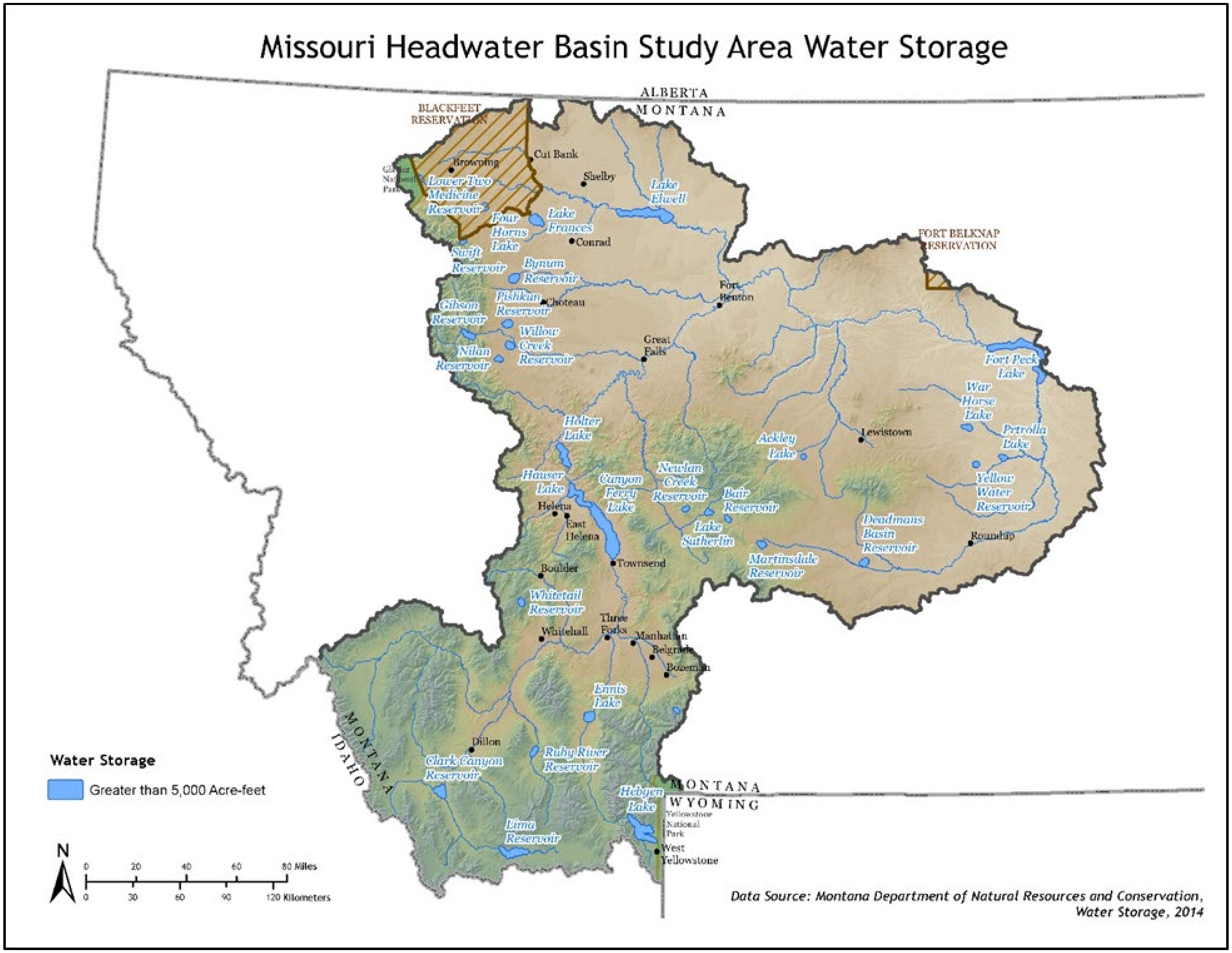

Figure 4.—Major water storage reservoirs in the study area.

1.3.2. Hydropower Facilities

Black Eagle Dam at Great Falls, Montana.

Table 4 summarizes the major hydropower facilities in the Missouri Headwaters, listed from upstream to downstream. Hydropower facilities in the study area have a combined capacity of 400.5 megawatts (MW).

The upstream-most hydropower facility on the Missouri River mainstem is at Montana DNRC's Toston Dam, which contains the Broadwater Power Facility, a 10-MW, run-of-the-river facility. Toston Dam is just upstream of Canyon Ferry Reservoir. Hydropower facilities at Reclamation's Canyon Ferry Dam have a generation capacity of 50 MW. Facilities at Canyon Ferry Dam also include a single mechanical turbine that pumps water to the Helena Valley Reservoir but does not produce electricity. Tiber Dam has a privately-owned hydropower facility built in 2004, but Tiber Dam operational procedures are not altered for power generation objectives.

The remaining hydropower facilities within the study area are owned and operated by NorthWestern Energy. NorthWestern Energy's Missouri-Madison Project is upstream of Canyon Ferry Reservoir. This project includes the Madison Plant on the Madison River near Ennis, Montana. The Madison Plant is operated in conjunction with Hebgen Lake, which is near the Madison River headwaters and stores and releases water for the project. The remaining seven NorthWestern Energy projects are on the Missouri River downstream of Canyon Ferry Reservoir (Figure 5).

Table 4.—Major Hydropower Facilities in the Missouri Headwaters

Dam	Stream	Hydraulic Capacity* (cfs)	Generating Capacity (MW)	Owner or Operator
Madison	Madison River	1,650	8	NorthWestern Energy
Toston	Missouri River	7,200	10	Montana DNRC
Canyon Ferry	Missouri River	6,390	50	Reclamation
Hauser	Missouri River	4,740	19	NorthWestern Energy
Holter	Missouri River	7,100	48	NorthWestern Energy
Black Eagle	Missouri River	5,040	21	NorthWestern Energy
Rainbow	Missouri River	8,000	60	NorthWestern Energy
Cochrane	Missouri River	10,000	69	NorthWestern Energy
Ryan	Missouri River	5,900	60	NorthWestern Energy
Morony	Missouri River	8,280	48	NorthWestern Energy
Tiber	Marias River		7.5	Tiber-Montana LLC
Total			**400.5**	

*Based on water rights filings
cfs = cubic feet per second

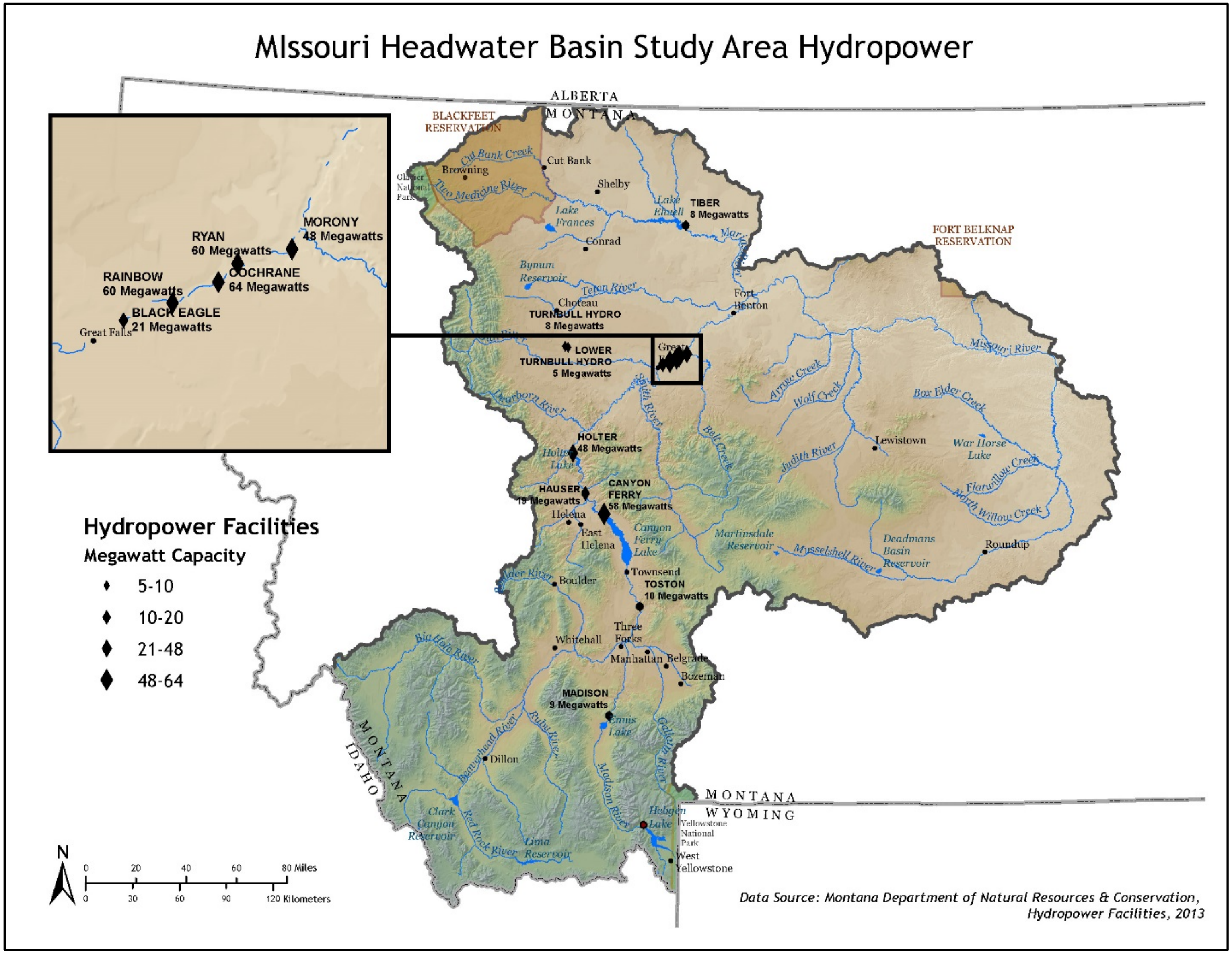

Figure 5.—Hydropower facilities in the study area.

Canyon Ferry hydropower operations are primarily governed by the Missouri River Coordination Agreement (Reclamation and Montana Power Company 1972). NorthWestern Energy projects are also operated in accordance with the Missouri River Coordination Agreement, and in accordance with provisions and requirements specified in the Federal Energy Regulatory Commission (FERC) license for the Missouri-Madison Project (Hydropower Reform Coalition and River Management Society 2014). Objectives of the Missouri River Coordination Agreement include:

- Maximize power generation benefits for both Canyon Ferry and the downstream Northwestern Energy hydropower facilities
- Provide irrigation and municipal and industrial (M&I) water supply
- Provide flows for fish, wildlife, and recreational use
- Manage flows for flood control
- Prevent ice-jam flooding above Canyon Ferry

During median and drier years, the larger dams have the capacity and water rights to generate electricity with the entire flow of the river during all months in most years except May and June. The water rights for some of the larger-capacity facilities have relatively early priority dates and can effectively limit the flow available for junior water rights holders. A Montana DNRC water availability analysis (Montana DNRC 1981) found that water might only be available for storage, diversion, and use during spring runoff in 60 percent of years. The study further found that due to the senior water rights for some larger-capacity hydropower facilities, water is seldom available for storage, diversion, and use after August 9 until early spring of the next year.

Figure 6 is a comparison of observed streamflow for the Missouri River below Holter gaging station (USGS station number 06066500) and the turbine capacity for the Holter Dam hydropower facility. The Holter Dam hydropower facility has a right to use all flow up to the turbine capacity. When streamflow falls below the turbine capacity, then flow to junior water users upstream is curtailed. Note that during most years (the middle year line and below), the flow is only above the turbine capacity for a short time during spring runoff.

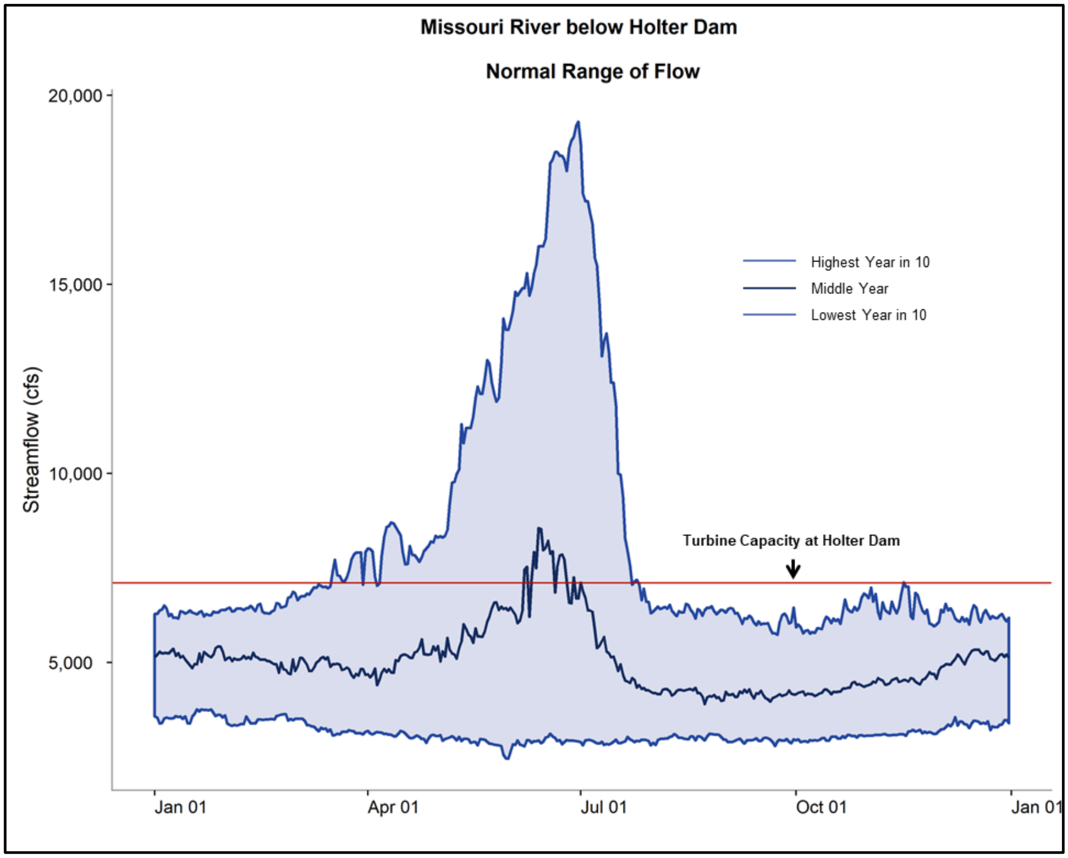

Figure 6.—Normal range of flow for Missouri River compared to turbine capacity at Holter Dam.

1.3.3. Municipal and Domestic

The Missouri River and its tributaries in the study area are the primary water source for about 318,000 people (Montana DNRC 2014). Much of the population live in Gallatin, Madison, and Lewis and Clark counties in the southwestern portions of the study area (Figure 7). These counties have been growing rapidly over the past 20 years and this growth is expected to continue. Larger communities, including Bozeman, Helena, and Great Falls, rely on surface water sources for most of their supply. Smaller communities and rural populations more commonly use groundwater sources for their supply.

Housing development in the Helena Valley.

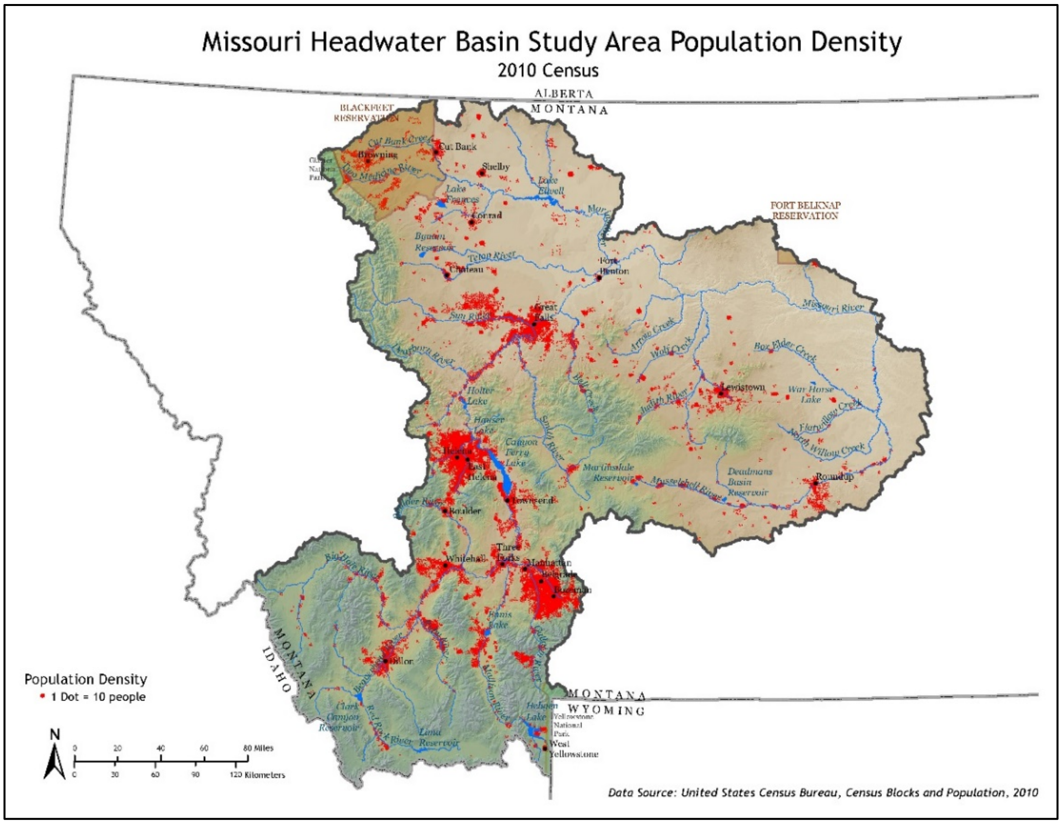

Figure 7.—Missouri Headwaters Basin Study area population density.

1.3.4. Environment

Upper Missouri River, National Wild and Scenic portion.

The study area includes the Missouri Headwaters blue-ribbon trout fisheries of the Big Hole, Gallatin, Beaverhead, Jefferson, Madison, Smith, and Missouri Rivers. The Upper Missouri River and its reservoirs provide some of the highest value recreation areas in the state. Federal and State-owned reservoirs provide much of the flat-water recreational opportunities, with Canyon Ferry Reservoir ranking number one in a recent survey of lakes and reservoirs in Montana. The Missouri River between Holter Dam and Cascade and the Madison River rank second and third respectively amongst Montana streams for recreational use (Montana Department of Fish, Wildlife and Parks [Montana DFWP] 2013).

The Upper Missouri River basin also offers other water-dependent recreational activities which are likely to be affected by changes in hydrology and/or water management and operations, such as fishing, white-water rafting, reservoir boating, camping, swimming, nature study, and hunting. Downstream, the Missouri National Wild and Scenic River in the lower portion of the study area is a common destination for recreational floaters and boaters. Changes in the hydrologic regime and reservoir operations may alter the timing of boat ramp availability and flows associated with floating rivers.

1.3.4.1. Instream Flow

Montana DFWP holds instream flow rights within the Upper Missouri River basin for fish, wildlife, and aquatic habitat. The major rights fall under two general categories:

1) **Murphy Rights**. In 1969, the Montana legislature enacted a law allowing the Montana Fish and Game Commission to file for water rights on the unappropriated waters of 12 streams to maintain stream flows necessary for the preservation of fish and wildlife habitat (Section 89-901 (2), Revised Codes of Montana [RCM] 1947). In the Missouri Headwaters, Montana DFWP filed for Murphy Rights for the Madison, Gallatin, West Gallatin, Missouri and Smith Rivers, and Big Spring Creek. These rights have December 1970 priority dates.
2) **Water Reservations.** In 1992, Montana DFWP was granted water reservations for minimum instream flows for 245 streams or stream reaches in the study area to protect fisheries, aquatic habitat, and associated recreational values. In the Missouri River Headwaters, instream reservations generally were based on the amount of instream flow required to protect riffle habitat in the streams as quantified by the Wetted Perimeter Inflection Point method (Montana DFWP 1989). By §85-2-316 Montana Code Annotated (MCA) these rights were limited by statute to one-half the average annual flow for gaged streams.

For the Basin Study, the greater of either Murphy Rights or Water Reservations were used to characterize instream flow objectives and as metrics for characterizing changes to instream flow at key locations in the Missouri Headwaters. These locations and instream flow rates are summarized in Table 5 with rates based on Murphy Rights shaded in grey.

Table 5.—Preferred Minimum Instream Flows for Select Locations in the Missouri Headwaters

River Basin	Location	Flow (cfs)	Period	River Basin	Location	Flow (cfs)	Period
Beaverhead River basin	Upper Beaverhead River	200	annual	**Missouri River Mainstem**	Upper Missouri River	1,500	Jan 1 - Jan 31
	Lower Beaverhead River	200	annual		Upper Missouri River	3,000	Feb 1 - May 15
	Red Rock River	60	annual		Upper Missouri River	4,000	May 16 - Jun 30
Big Hole River basin	Lower Big Hole River	573	annual		Upper Missouri River	3,816	Jul 1 - Jul 15
	Upper Big Hole River	160	annual		Upper Missouri River	1,500	Jul 16 - Sep 14
Gallatin River basin	Upper Gallatin River	800	May 16 - Jul 15		Upper Missouri River	3,000	Sep 15 - Dec 31
	Upper Gallatin River	400	Jul 16 - May 15		Middle Missouri River	3,327	annual
	East Gallatin River	170	annual		Lower Missouri River	4,652	annual
	Lower Gallatin River	947	May 1 - May 15		Dearborn River	110	annual
	Lower Gallatin River	1,278	May 16 - May 31	**Musselshell River basin**	Upper Musselshell River	80	annual
	Lower Gallatin River	1,500	Jun 1 - Jun 15		Middle Musselshell River	80	annual
	Lower Gallatin River	1,176	Jun 16 - Jun 30		Lower Musselshell River	70	annual
	Lower Gallatin River	850	Jul 1 - Aug 31		Musselshell River at Mosby	70	annual
	Lower Gallatin River	800	Sep 1 - Apr 30	**Ruby River basin**	Ruby River below Reservoir	40	annual
Jefferson River basin	Upper Jefferson River	50	annual		Ruby River near mouth	40	annual
	Lower Jefferson River	1,095.5	annual	**Smith River basin**	Lower Smith River	372	May 1 - May 15
	Boulder River	47	annual		Lower Smith River	400	May 16 - Jun 15
Judith River basin	Upper Judith River	25	annual		Lower Smith River	398	Jun 16 - Jun 30
	Lower Judith River	160	annual		Lower Smith River	150	Jul 1 - Apr 30

Table 5.—Preferred Minimum Instream Flows for Select Locations in the Missouri Headwaters

River Basin	Location	Flow (cfs)	Period	River Basin	Location	Flow (cfs)	Period
Madison River basin	Madison River below Ennis Lake	825	annual		Upper Smith River	150	May 5 - Jun 30
	Madison River below Ennis Lake	1,200	Jan 1 - May 31		Upper Smith River	90	Jul 1 - Apr 30
	Madison River below Ennis Lake	1,500	Jun 1 - Jun 30	**Sun River basin**	Upper Sun River	100	annual
	Madison River below Ennis Lake	1,423	Jul 1 - Jul 15		Middle Sun River	130	annual
	Madison River below Ennis Lake	1,300	Jul 16- Dec 31		Lower Sun River	130	annual
Marias River basin	Birch Creek	10	annual	**Teton River basin**	Upper Teton River	35	annual
	Upper Marias River	200	annual				
	Lower Marias River	488.5	annual				

Rates based on Murphy Rights are shaded in grey. All other rights are based on water reservations.

1.3.4.2. Fish Species of Concern

Pallid sturgeon.
Photo by Hagerty Ryan. Courtesy of USFWS.

Pallid sturgeon inhabit the Missouri River between the mouth of the Marias River and Fort Peck Reservoir and have been listed as endangered by the U.S. Fish and Wildlife Service (USFWS). Currently, the pallid sturgeon is the only federally-listed fish species under the ESA within the study area. Montana designated the pallid sturgeon with the second highest rank on the Global Conservation Status, G2,[1] and highest rank on the Montana Species Ranking Codes scale S1,[2] on the internationally recognized system for ranking rare, threatened and endangered species throughout the world. According to the 2014 Revised Recovery Plan, the overall status of the species has improved since the original 1990 listing and is currently stable, although population estimates of wild pallid sturgeon within some reaches of the Missouri River indicate that wild populations may be declining or extirpated.

Arctic grayling.
Courtesy of USFWS.

The last fluvial Arctic grayling population in the contiguous United States resides in the Big Hole River basin of the study area. This Arctic grayling population is genetically distinct from those in Alaska and Canada (Cayer and McCullough 2013). Due to declining numbers, the USFWS was petitioned in 1991 to list this grayling population under the ESA. Throughout the 1990s and early 2000s, an ESA listing of Arctic grayling was considered warranted, but precluded. In 2014, the USFWS found that this distinct population segment in the Upper Missouri River basin does not warrant protection under the ESA, due largely to significant conservation efforts in the past decade. (USFWS 2014). Led by the multi-agency Arctic

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[1] G2 is imperiled—At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors. See the ranking at http://explorer.natureserve.org/granks.htm.

[2] S1 is at high risk because of extremely limited and/or rapidly declining population numbers, range and/or habitat, making it highly vulnerable to global extinction or extirpation in the state. See ranking at http://fieldguide.mt.gov/statusCodes.aspx.

Grayling Recovery Program, these conservation efforts include habitat protection and restoration, and reintroduction and recolonization. A drought action plan for the Big Hole River has been a part of this effort. Restoration and reintroduction areas include the Red Rock River and Red Rock Lakes National Wildlife Refuge, the Ruby River, and the North and South Forks of the Sun River.

1.4. Groundwater Resources

Wells and springs in the study area yield water from aquifers in shallow alluvium, deeper semi-consolidated to consolidated basin-fill sediments, and bedrock. They may be recharged by direct infiltration of precipitation, leakage from irrigation ditches, irrigation return flows, and seepage from streams.

Alluvial aquifers are by far the most common sources of groundwater for irrigation, municipal, industrial, household, and livestock purposes. They exist along floodplains of major streams. These aquifers are typically less than 100 feet thick and therefore, are accessible by shallow wells at relatively low expense and have hydraulic properties favorable to groundwater production.

Aquifers in the plains portion of the Upper Missouri River basin include thin surficial sediments that overlie bedrock and top benches. The Greenfields Bench and Burton Bench terrace aquifers have relatively high permeability and are the primary sources of water for domestic and public water supply use in the area. They are both primarily recharged by irrigation water.

Groundwater within bedrock aquifers in the study area occurs in discontinuous fractures and faults in sandstone, siltstone, shale, and carbonate rocks. The most productive bedrock aquifer in the basin is the Madison Group aquifer which is especially important in the City of Great Falls area and is the source of Lyman Springs, which is an important municipal water source for the City of Bozeman. On a regional scale, groundwater in the bedrock often is in hydraulic communication with alluvial aquifers and discharge in topographically lower areas by upward leakage to shallower aquifers and streams.

The Basin Study incorporates groundwater contributions to surface water based on previous studies of the regions aquifers from the Montana Bureau of Mines and Geology (MBMG), USGS, and other sources. Details of how groundwater contributions to surface water were quantified in different parts of the study area are discussed in the Impacts Assessment, Reclamation (2019a).

2. Characterization of Historical and Projected Future Conditions

This section summarizes historical and projected future water supply and demand in the study area and impacts of projected changes in hydrology and population on water resources management and operations within the study area. Water supply, demand, and potential risks to future water supplies were analyzed and documented in the Impacts Assessment (Reclamation 2019a). Results of the Impacts Assessment were subsequently used to identify and evaluate strategies in the Basin Study.

This summary provides foundational information for the discussion and evaluation of strategies that were developed to alleviate the impacts of potential future supply and demand scenarios. As part of the discussion of historical water supply and demand, observed droughts occurring in the last one hundred years or so help to identify areas where water shortages were particularly severe. Conversely, observed pluvial (wet) periods help to identify where flooding and other associated impacts (e.g., loss of hydropower production due to spilling) may be an issue.

2.1. Historical Challenges and Considerations

In the Impacts Assessment, historical water supply and demand were evaluated over the 50-year period from 1950 to 1999 (termed the historical scenario). Daily average temperatures in the study area increased by about 1.4 degrees Fahrenheit (°F) over the historical scenario; however, average annual precipitation did not exhibit a significant trend. Average snowpack on April 1, which is an indicator of seasonal snowmelt runoff, decreased during this period, corresponding with observed warming. Thus, the volume of annual runoff has not changed, but the timing of snowmelt and seasonal runoff peak has shifted toward earlier in the year.

Most of consumptive water demands in the Upper Missouri River basin have historically been agricultural water use, comprising about 85 percent of the total consumptive use, or about 1.7 million acre-feet per year. Reservoir evaporation comprises about 12 percent of the total consumptive use, while M&I use comprises just one percent of the total consumptive use. Most of the agricultural lands are within the valleys of river basins, while precipitation falls primarily in the mountainous headwaters of the study area, resulting in reliance on the regions snowpack and storage reservoirs for water supply.

Meeting the needs of various water users in the study area has historically been a challenge due to variability in climate in addition to long-term climate changes. The Dust Bowl Drought, which lasted from 1929 to 1943 (15 years) was the drought of record[1] for the Missouri River basin draining to Fort Benton. The late century drought from about 1985 to 1992 was almost as severe and part of more recent management memory. The Millennium Drought from 2000 to 2010 was the drought of record for the Musselshell River basin draining to Mosby. On many Upper Missouri River tributaries, during these droughts, irrigation demands have exceeded the late-summer water supply, and this has led to stream dewatering. In 1988, both the Big Hole and Jefferson Rivers were dewatered to meet irrigation demands and at the time there were no minimum instream flow requirements. The historical scenario period used was limited by naturalized streamflow data availability and consequently does not include either the Dust Bowl Drought (before the period in the 1930s) or the Millennium Drought (after the period in the 2000s). In some instances, to provide context to simulated historical conditions, the historical scenario flows are compared to observed conditions during these two droughts of record.

Some adaptation to historical changes in water supply and demand related to warming, as well as changes in the timing and duration of droughts and wet periods, have already been occurring within the study area. Some examples include modification of crop planting or harvest dates.

Water managers and farmers consider uncertain future conditions. Use of paleohydrology data, such as in the form of tree rings analyses, can provide additional historical context to existing conditions and may factor into operational or planning decisions. The Impacts Assessment analyzed tree rings and other data to examine conditions from 1100 - 1950 Common Era (CE) as well as analyzing the historical record. The paleohydrology analysis included extreme events: the Most Intense Drought (MID), Most Intense Pluvial (MIP), Longest Drought (LD), Longest Pluvial (LP). The historical record included severe droughts: the Dust Bowl Drought, the Mid-Century Drought of the 1950s, and the Millennium Drought. This analysis showed that the range in annual streamflow over the last 900 years is greater than the range over the historical scenario period. This is to be expected, in part because of the larger number of years contributing to the range.

[1] Drought of record is defined as the worst recorded drought since compilation of historical hydrologic data began in the region in the late 19th century.

2.1.1. Population Growth

Montana has a growing population, and much of this growth is occurring in a few concentrated areas in the Missouri Headwaters study area, such as the Gallatin Valley. Communities in the headwaters already face challenges in providing water for a growing population because most of the flow in the basin has been appropriated for irrigation, hydropower, and municipal uses along with instream flows needed to support fisheries and recreation. Rural water users in Gallatin Valley and other areas have increasingly relied on groundwater sources to meet demands.

2.1.2. Closed to Further Water Appropriations

In 1993, due to large senior hydropower rights and late-season water shortages on tributaries, the Montana Legislature closed the Missouri River drainage above the Great Falls, including all tributaries, to further appropriations of water, with some exceptions for groundwater, storage of high spring flow, and domestic, municipal and stock use (§85-2-343, MCA) (Figure 8). A similar, overlapping closure is specific to the Jefferson and Madison River basins (§85-2-341, MCA). The Teton River basin below the Great Falls is also closed to most new appropriations (§85-2-330, MCA). There is an administrative closure on the North and South Forks of the Musselshell River, and the Musselshell River downstream to the mouth of Flatwillow Creek that applies to consumptive uses during the period July 1 through August 31 (36.12.1016, Administrative Rules of Montana [ARM]). Stipulations in the Upper Missouri Wild and Scenic Compact will close much of the lower portion of the study area to new appropriations when designated volumes available for new depletion are reached (§85-20-501, MCA).

The basin closures create administrative constraints that emphasize the need for additional data and modeling of historical and future water supply and demand, which was done as part of the Impacts Assessment (Reclamation 2019a).

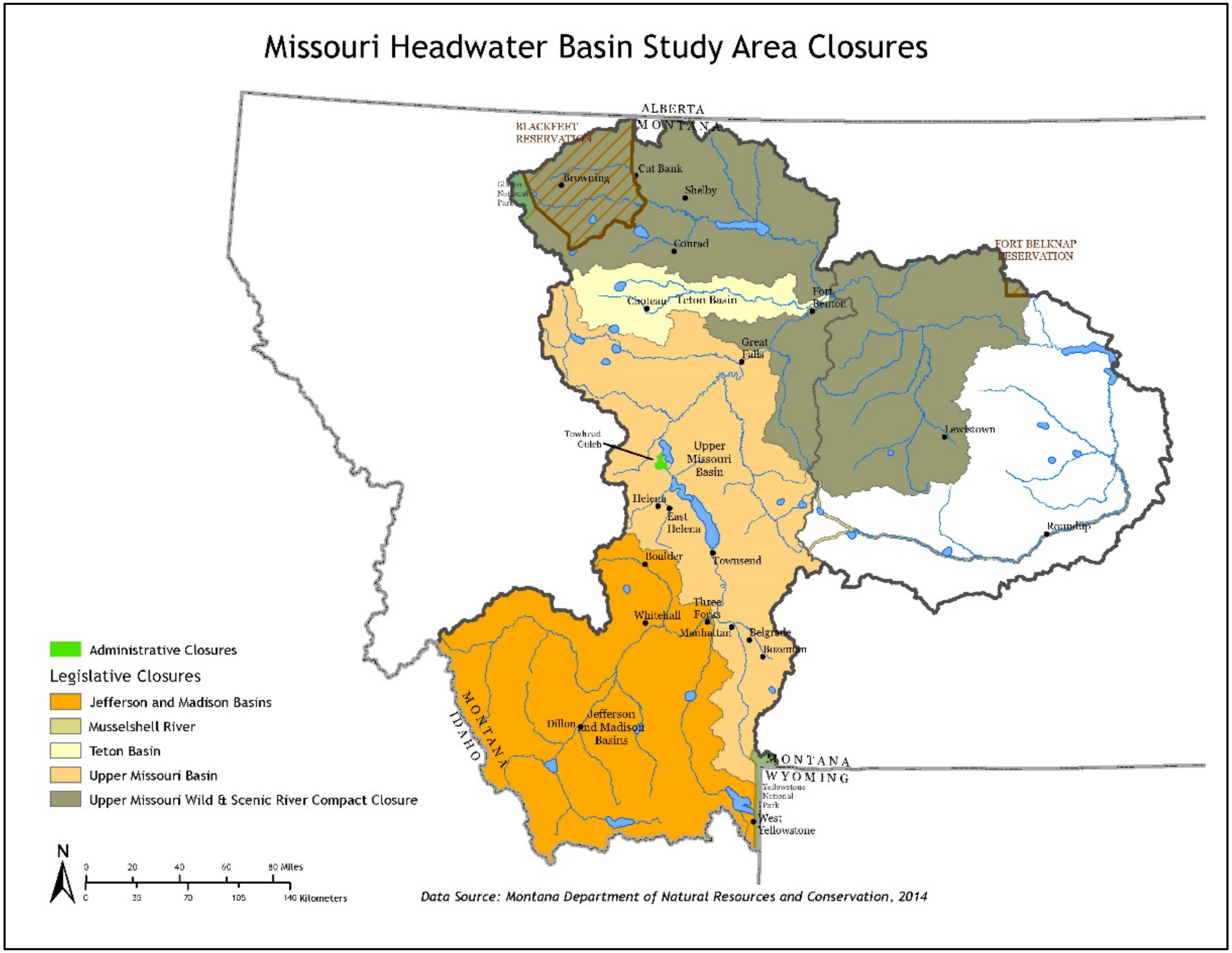

Figure 8.—Water rights closures in the Missouri Headwaters Basin study area.

2.2. Future Challenges and Considerations

Changes in either water supply or demand can have a significant impact on communities, irrigators, hydropower plant owners, recreation interests, wildlife, and federally-listed species and their habitat.

Water shortages are common and increasing in the study area overall (as summarized in the Impacts Assessment), and it is likely that the current imbalances between supply and demand will be intensified in the future due to the following factors:

1) **A warming climate and increased consumptive-use demands.** Reservoir storage decreases correspond with projected increases in agricultural demand and reservoir evaporation. Most scenarios indicate an increase in reservoir evaporation, coupled with decreases in precipitation for most scenarios. Reservoir evaporation may be offset by precipitation increases in other months.
2) **Changes in snowpack in headwater mountains with resulting changes in the amount and timing of snowpack runoff.** The timing of inflow is projected to be earlier as one looks further into the future for most of the region's reservoirs. Shifts in the volume and timing of snowpack storage will impact the region's reservoir operations, particularly during spring when operations must balance competing objectives of flood control and water storage for irrigation deliveries later in the season. End-of-water year storage is projected to decrease in the future for most reservoirs modeled.
3) **Population growth and associated increased water demands.** Communities in the headwaters already face challenges in providing water for a growing population, such as the Gallatin Valley, because most of the flow in the basin has been appropriated for irrigation, hydropower, and municipal uses along with instream flows needed to support fisheries and recreation.
4) **Other water demands.** Water supplies for fish, wildlife, and recreation, and to conserve threatened and endangered species are also needed.

Future scenarios combined with paleohydrology show that future managed river conditions may be beyond the range of historical conditions and even conditions of the distant past, as suggested by comparisons between future scenarios and paleohydrology scenarios in the Impacts Assessment. Resource categories for four different regions within the study area are illustrated in Figure 9. Table 6 summarizes results from the Impacts Assessment for these categories.

Rocky Mountain Front	
Water Deliveries	Irrigation water shortage in the Sun River basin and in the upper Marias River basin are projected to increase because reservoirs will fill earlier, deliveries will begin earlier, and overall irrigation demands are expected to increase.
Hydropower	Annual hydropower production is projected to decrease at Tiber Dam; however, for February through April the wetter future scenarios project a modest increase in projection.
Flood Control	Lake Elwell is projected to have an increase in the average number of days in the flood pool.
Ecological Resources	Winter streamflow may increase while summer flows may increase or decrease depending on the scenario. Any decreases in summer streamflow would negatively affect ecological resources.
Recreation	Usable days for boat ramps from April to October are projected to decrease for Lake Elwell.

Headwaters	
Water Deliveries	Irrigation water shortage may increase for most irrigators except for Clark Canyon water users where shortages may decrease.
Hydropower	Canyon Ferry annual hydropower production may increase in wetter future scenarios and decrease in drier future scenarios.
Flood Control	Canyon Ferry Reservoir is projected to have more days in the flood pool. Clark Canyon reservoir is projected to have more days in the flood pool in wetter future scenarios, and fewer in drier future scenarios.
Ecological Resources	Winter streamflow may increase, while summer streamflow may decrease under most future scenarios, except in the Beaverhead watershed where summer flows are projected to increase under most future scenarios. Lower summer streamflow could further stress ecological systems.
Recreation	Boat ramps will have fewer accessible days from April through October at Clark Canyon under all but the wettest future scenario. Boat ramps will have more usable days at Canyon Ferry under wetter future scenarios and fewer under drier future scenarios.

Lower Missouri Mainstem	
Water Deliveries	Risk factors such as drought and climate change may have a smaller impact at these facilities because the reservoirs are maintained at constant pool elevations.
Hydropower	Future scenarios suggest greater annual hydropower production under wetter scenarios and reduced hydropower production under drier scenarios, and may experience shifts in production timing.
Flood Control	Reservoirs in this region are not formally operated for flood control.
Ecological Resources	Potential increases in high flows may indicate greater opportunities for bank full streamflow release events that may improve ecological resources in the Upper Missouri Wild and Scenic River.
Recreation	The Smith River's popular recreational boating season may shift toward earlier in the year, corresponding with higher peak flows from December to May and lower peak flows during the rest of the year.

Musselshell	
Water Deliveries	Irrigation water shortages may remain about the same or even decrease on average for those users in the Musselshell River and Judith River basins. At the same time, crop water consumption will increase. Shortages are about 45 percent of demand in the Musselshell River historically. Any additional projected shortages would compound existing shortage issues.
Hydropower	NA
Flood Control	NA
Ecological Resources	All future scenarios indicate a higher maximum peak streamflow in the lower Musselshell River basin. Minimum streamflow is likely to decrease under most future scenarios in the Judith River basin, while it will decrease under drier future scenarios and increase under wetter future scenarios in the upper Musselshell River basin.
Recreation	Average monthly reservoir levels may increase for wetter scenarios and decrease for drier scenarios, which may impact recreation access.

Figure 9.—Summary of Impacts Assessment results by region.

Table 6.—Summary of Impacts Assessment Results by Region within the Study Area

		Rocky Mountain Front	Upper Missouri Headwaters	Musselshell and Judith River Basins	Lower Missouri Mainstem
Water Deliveries	Centroid of streamflow timing	At least 35 days earlier for the 2050s and 2080s.	5 to 15 days earlier on average by the 2080s for most future scenarios.	15 to 25 days earlier on average by the 2080s.	Generally smaller changes because flows are managed by upstream reservoirs.
	November—March Streamflow	Increases with earlier peak.	Increases for wetter scenarios and decreases for drier scenarios.	Substantial increases for wetter scenarios and modest decreases or modest increases for drier.	Modest increases for wetter scenarios and modest decreases or modest increases for drier scenarios.
	Snowpack	Substantial decrease and much earlier date of peak snowpack.	Highest percent decrease in snowpack compared with other regions.	Modest decreases are anticipated. Mountainous areas that produce snowpack are relatively small.	Smaller decreases because region is primarily located plains where snowpack typically is low.
Water Demands	Agricultural Irrigation Demands	Increases are anticipated due to rising temperatures. Precipitation increases under most scenarios will not be sufficient to offset increasing demands.	Larger increases are anticipated than in other parts of the study area.	Increases due to increasing temperatures, particularly Box Elder and Flatwillow sub-basins.	Increases are anticipated with the Smith River basin increases projected to be more substantial increases.
	Reservoir Evaporation	Increases are generally anticipated, although increased precipitation for wetter scenarios could offset some evaporation increases.	Increases are generally anticipated, although for wetter scenarios increased precipitation could result in net evaporation decreases.	Increases are generally anticipated, although for wetter scenarios increased precipitation could result in net evaporation decreases.	Increases are generally anticipated, although for wetter scenarios increased precipitation could result in net evaporation decreases.
Reservoir Operations and Water Deliveries	Reservoir Storage	Greater inflow to Lake Elwell (Tiber Dam) for most months other than June through August; higher storage from January through June.	Higher or lower depending on the scenario at Canyon Ferry, Clark Canyon, Lima, and Ruby Reservoirs. Paleohydrology scenarios indicate a broader range of potential change than has occurred historically.	Higher or lower for Deadman's Basin, Flatwillow, Bair, and Martinsdale Reservoirs, depending on the scenario. Paleohydrology scenarios indicate a broader range of potential change than has occurred historically.	Little effect on mainstem, run-of-the-river hydropower facilities. Higher or lower for North Fork of Smith, and Newlan Creek, depending on the scenario.
	Deliveries and Shortages	Delivery shortages in the Sun River basin and in the Upper Marias River basin upstream are projected to increase because reservoirs will fill sooner, deliveries will begin earlier, and overall irrigation demands are expected to increase.	Reservoirs are likely to fill and release stored water earlier in the year, leaving storage generally lower at the end of the season. Most headwaters irrigators with access to reservoir storage are expected to see increases in shortages. However, water shortages are projected to remain about the same or even decrease on average for Clark Canyon water users.	Water shortages are projected to remain about the same or even decrease on average under wetter scenarios for reservoir users in the Musselshell and Judith River basins. Paleohydrology scenarios suggest that a greater range of reservoir inflows is possible than has occurred historically and much greater inflows are possible for some reservoirs, such as Flatwillow Reservoir.	Scenarios suggest earlier filling of reservoirs due to streamflow timing changes and earlier drawdown to meet increased irrigation demands. Water shortages are projected to remain about the same or even decrease on average for those users of stored water in the mainstem Upper Missouri River and Smith River basins.
Hydropower	Production	Annual hydropower production is projected to decrease at Tiber Dam. Seasonally, decreases are projected for all months except for February through April, where the wetter future scenarios indicate a modest increase in production.	Average annual hydropower production at Canyon Ferry Dam may increase according to wetter future scenarios and decrease according to drier scenarios. Decreases are projected for most scenarios in July through December, while increases are projected for most scenarios in April and May.	*Reservoirs in the Musselshell River and Judith River basins do not have hydropower facilities.*	Future scenarios suggest greater annual hydropower production at NorthWestern Energy facilities for the wetter scenarios and reduced hydropower production for the drier. Production is expected to decrease under most scenarios during June through October and increase during January through April.

Table 6.—Summary of Impacts Assessment Results by Region within the Study Area

		Rocky Mountain Front	Upper Missouri Headwaters	Musselshell and Judith River Basins	Lower Missouri Mainstem
Flood Control	Reservoir Storage in Flood Pool	Lake Elwell is projected to have more days on average in the flood pool.	At Clark Canyon Reservoir, the average number of days above flood pool elevation may increase under wetter future scenarios and decrease in the near term under drier scenarios. At Canyon Ferry Reservoir, the average number of spring days per month above flood pool elevation is expected to increase, while the number of days during summer is projected to decrease. Further evaluation under the paleohydrology scenarios suggests that Clark Canyon and Canyon Ferry may go into the flood control pool more frequently in April through June and for longer periods of time (i.e., multiple years in a row).	*Reservoirs in the Musselshell River and Judith River basins do not have hydropower facilities, nor are they formally operated for flood control.* Flooding will likely be an increasing challenge in the region because average annual runoff is generally projected to increase.	*Hydropower reservoirs on the mainstem upper Missouri River and the smaller irrigation reservoirs in the Smith River basin are not formally operated for flood control.*
Ecological Resources	Monthly Streamflow	Summer flows are likely to increase under wetter future scenarios and decrease under drier future scenarios. Flows during winter months are likely to increase. Lower summer streamflow could further stress ecological systems.	Summer flows are likely to decrease under most future scenarios and locations, except in the Beaverhead River basin where summer flows are largely projected to increase under most scenarios. Flows during winter months are likely to increase. Lower summer streamflow could further stress ecological systems.	Mean monthly flows during spring and early summer months in the Judith River basin are likely to increase or decrease depending on the future scenario, while flows outside these months are projected to experience small changes. Mean monthly flows in the Musselshell River, on the other hand, are likely to increase for most months under future scenarios.	At Missouri River mainstem streamflow gage locations, flows are expected to increase during winter and spring months and decrease during summer and autumn months. High flows are projected to increase substantially by the 2050s and 2080s. Increases in high flows may provide benefits to ecological resources.
Ecological Resources (Continued)	7-day Average Maximum Streamflow	Likely to increase for the Sun River, Teton River, Marias River, and Dearborn River, particularly under wetter scenarios, and possibly decrease under drier scenarios. Increases in high flows may provide benefits to ecological resources.	Likely to increase for the Sun River, Teton River, Marias River, and Dearborn River for wetter future scenarios and even some of the drier future scenarios like at Red Rocks River.	Projected to decrease under drier future scenarios and increase under wetter future scenarios in the Judith and upper Musselshell River basins. However, in the lower Musselshell River basin, all future scenarios indicate an increase.	For the Missouri River mainstem, high flows are expected to increase by almost twice as much by the 2050s and 2080s [check this]. For the Smith River, drier scenarios project decreases while wetter scenarios point towards increases.
	7-day Average Minimum Streamflow	Projected to decrease in the Dearborn River under most future scenarios but increase in the Marias and Teton basins. In the Sun River basin, future scenarios show decreases under drier scenarios and increases under wetter scenarios.	May be higher under wetter scenarios or lower under drier future scenarios, except in the Beaverhead where increases are projected under most future scenarios. Theses minimums for some streams can occur during the winter and increases could be beneficial to ecological resources.	For the Musselshell River basin, decreases are projected under drier future scenarios and increase under wetter future scenarios. In the lower Musselshell River basin, most future project an increase. Projected to decrease under most scenarios in the Judith River basin.	Drier future scenarios project decreases while wetter future scenarios indicate increases. For the Smith River, drier future scenarios indicate lower 7-day average low flows, while wetter future scenarios indicate increases.
Recreation	Flatwater Recreation and River Floating	The future scenarios indicate a decrease in the average number of usable days at the boat ramps on Lake Elwell for all scenarios (assuming use is from April through October). This could result in reductions of overall recreational opportunities.	At Clark Canyon (Beaverhead South, Lone Tree, and Horse Prairie boat ramps), more unusable days on average are projected for the future under all but the wetter future scenarios. At Canyon Ferry, there may be more unusable days overall under the wetter future scenarios and fewer unusable days under the drier future scenarios.	Boat ramp access for recreation has also not been quantified for reservoirs within this region.	In the upper reach of the Smith River, between Sheep Creek and Eden, results indicate increases in higher flows from December - May and overall reductions during the remainder of the year. This could shift the popular recreational floating season on this stream to earlier in the year. Boat ramp access for recreation has not been quantified for reservoirs within this region

3. Collaboration and Outreach

3.1. Background and Preliminary Outreach

Stakeholder outreach was a principal component of the Basin Study because it provided Montana DNRC and Reclamation the opportunity to explain current operational procedures and water management strategies in the study area and to engage stakeholders in planning for the future. Outreach for this Basin Study and the associated Impacts Assessment began in 2015 to inform stakeholders of study goals and objectives as well as to solicit input on technical aspects of the studies. This included future climate and runoff projections, construction of the Upper Missouri RiverWare planning model, and the identification of impacts measures. In addition to fostering technical developments, this initial outreach helped the study team to establish contacts and informed Montana DNRC and Reclamation of the many ongoing related activities in the basin. For example, the collaboration on paleo-hydrology streamflow scenario aspects of the study with the USGS Northern Rocky Mountain Science Center was established during this initial outreach phase.

Following this, other centralized meetings were held in Helena and Bozeman, with stakeholders from throughout the basin invited to attend. These meetings targeted agencies, researchers, non-governmental organizations (NGO) and watershed group coordinators. Other meetings were held in smaller communities. These were hosted by watershed groups or conservation districts to engage stakeholders who were knowledgeable and active in local water resource issues. Discussions at these meetings focused on study methods and results, identifying important issues, and developing strategies.

Some of the key meetings and other stakeholders outreach activities are summarized in the following subsections.

3.1.1. Upper Missouri Impacts Assessment Technical Meeting in Bozeman, Montana, July 9, 2015

This meeting primarily was attended by agency, university, and other water resources professionals to discuss and to solicit input on the technical aspects of the project. Participants were encouraged to present and discuss related activities that they were conducting in the basin. About 30 people attended the meeting. Key topics included:

- West-wide Climate Risk Assessment
- Future scenario analysis for the Upper Missouri Basin Impacts Assessment
- Hydrology modeling, including model inputs and calibration

- Upper Missouri RiverWare planning model development
- National Drought Resilience Partnership (NDRP) parallel efforts
- Metrics for evaluating potential water supply and demand impacts

3.1.2. Missouri Headwaters Impacts Assessment and Basin Study Workshop in Helena, Montana, December 1, 2016

December 1, 2016, stakeholder meeting in Helena, Montana.

About 35 people attended the meeting, and about another 10 participated via the web and conference call. The attendees primarily were from agencies, universities, conservation districts, watershed groups, and non-profit organizations. During this meeting, the study partners presented preliminary future climate and runoff projections. Development and calibration of the Upper Missouri RiverWare planning model also was described. A discussion of future impacts on water supplies, demands and associated resources, and potential strategies followed. The participants also updated the group on their related activities in the basin.

3.1.3. Upper Missouri Headwaters (UMH) Basin Task Force Meeting in Bozeman, November 8, 2017

Representatives of local watershed groups, non-profits, State and Federal agencies, the Montana State University system, the City of Bozeman, and drought coordinators for major watersheds in the Missouri Headwaters attended this meeting. Montana DNRC organized this meeting in conjunction with a WaterSMART program effort to produce a drought contingency plan for the Missouri Headwaters. The purpose was to share science and information on activities occurring in the Missouri Headwaters related to climate, water supply and drought. A portion of the meeting agenda was devoted to discussing the Basin Study and Impacts Assessment, with emphasis on potential strategies. The remainder of the meeting was a facilitated group discussion by the Science for Nature and People Partnership (SNAPP) ecological drought working group team. This included small-group discussions on resilience and adaptation to drought in the Missouri Headwaters.

3.2. Local Meetings

This outreach generally was conducted in conjunction with the regularly scheduled watershed group or conservation district meetings. Table 7 summarizes these meeting.

Table 7.—Local Meetings Attended during the Basin Study Process

Group	Meeting Date	Topics Presented and Discussed
Sun River Watershed Group (Great Falls)	11/12/2014	Study and analyses overview, timelines, and opportunities for participation
	06/28/2016	Conference call to discuss operational procedures for Upper Missouri RiverWare planning model development
	09/14/2016	Study progress report, discussion of Upper Missouri RiverWare planning model calibration, integration with group's 10-year planning process
	03/20/2017	Presentation of Impacts Assessment results, discussion of issues and strategies
Musselshell Watershed Coalition (Roundup)	06/13/2017	Presentation of Impacts Assessment results and preliminary modeling of strategies and discussion of issues
	04/10/2018	Discussion of proposed off-stream storage strategy results
Beaverhead Watershed Committee (Dillon)	09/20/2017	Presentation of Impacts Assessment results, and identification and preliminary modeling of strategies and discussion of issues
Ruby Watershed Council (Sheridan)	01/17/2018	Presentation of Impacts Assessment results, adaptation for anticipated future drought conditions, 2017 water budget, and potential future equivalents
Liberty County Conservation District (Chester)	01/18/2018	Presentation of Impacts Assessment results with focus on Marias River basin, Lake Elwell operations and modeling, potential strategies, and water for the Blackfeet Compact.

The Blackfeet Tribe was contacted by the study team to identify possible needs for strategies related to tribal water rights and use. Although no strategies were identified to meet specific needs of the Blackfeet Tribe, one identified strategy does explore additional water use from Lake Elwell in the Marias River basin (Section 6.5.1: *Providing Water for Future Consumptive Uses Through Canyon Ferry Reservoir and Lake Elwell*).

3.3. NDRP Montana Pilot Project

Partly due to the working efforts established for the Basin Study and Impacts Assessment, the Missouri Headwaters in southwest Montana was selected as one of two NDRP pilot projects, a collaboration of Federal and State agencies, NGOs, and watershed stakeholders. Several of the same Reclamation and Montana DNRC staff participated in this Drought Resilience project and Impacts Assessment/Basin Study, and many of the same stakeholders contributed to both processes. NDRP participants were interested in how the Impacts Assessment and Basin Study could inform future drought planning. Montana DNRC received Reclamation funding in 2018 through the WaterSMART program to produce a drought contingency plan for the Missouri Headwaters upstream of Canyon Ferry Dam which is in progress. This includes developing individual drought resilience plans for nine Missouri Headwaters tributary watersheds, and then incorporating these into a regional plan. Key meetings which Reclamation and Montana DNRC staff participated in included:

- November 13 and 14, 2014 NDRP kick-off meeting in Bozeman
- March 17-18, 2015 workshop in Bozeman
- September 9-11, 2015 work plan development meeting in Dillon
- May 23, 2018 drought contingency planning meeting in Helena

3.4. Meetings with Other Entities

Informal meetings were held with other entities to gather information for the technical aspects of the studies and to solicit input on strategies. These meetings are summarized in Table 8.

Table 8.—Informational Meetings Held with Other Entities

Group	Meeting Date	Topics Discussed
Montana DNRC State Water Projects Bureau (Helena)	09/20/2017	Presentation of Impacts Assessment results with emphasis on State-owned dams and reservoirs, and potential use in upcoming Toston Dam Broadwater Hydropower Facility relicensing.
East Bench Irrigation District and local DFWP fisheries biologist (Dillon)	06/17/2016	Discussion of attributes to be considered in Upper Missouri RiverWare planning model, potential strategies, and fisheries considerations.
Helena Valley Irrigation District (Helena Area)	07/19/2017	Background on Basin Study, tour of District facilities, and discussion of operations.
Great Northern LCC (Bozeman)	04/27/2017	Great Northern LCC activities and climate change at the large landscape level. Modeling and strategy considerations.

3.5. Professional Meetings and Presentations

Presentations connected with the Impacts Assessment and Basin Study were given at professional meetings and conferences, including:

Montana Section of the American Water Resources Association Conference, October 19, 2017, Helena, Montana:

- Missouri Headwaters Impacts Assessment and Basin Study (Montana DNRC)
- Applied paleohydrologic information for improved water management in the Upper Missouri River basin (USGS)

Missouri River Natural Resources Council Conference, March 24, 2016, Great Falls Montana: Missouri Headwaters Basin Study:

- Modeling future water supplies and demands, and operations of the basin upstream of Fort Peck Dam (Montana DNRC)

University Council on Water Resources, Fort Collins Colorado June 13-15, 2017:

- Upper Missouri Basin Impacts Assessment and Missouri Headwaters Basin Study (Reclamation)

2017 UCOWR/NIWR Annual Conference "Water in a Changing Environment", June 14, 2017, Colorado State University, Fort Collins, Colorado:

- Applied paleohydrologic information for improved water management in the Upper Missouri River basin (Montana State University)
- Upper Missouri River Basin Impacts Assessment and Missouri Headwaters Basin Study (Reclamation)

3.6. Learning and Collaboration Opportunities

The outreach and collaboration process provided Reclamation and Montana DNRC an opportunity to inform the public, listen to their thoughts and concerns, and to learn about all the other interrelated activities in the study area. This was the first occasion for some people to learn about projected future water supplies and demands in a quantitative way. While the study partners found much interest in projections of future water supplies and demands, there also was some apprehension concerning our ability to meet future needs while maintaining existing resource values. Representatives of agencies, universities, and non-profit groups that attended the meetings were interested in all the overlapping projects and eager to coordinate corresponding work efforts. The study partners also found a strong foundation for collaboration in the basin, especially through the established network of watershed groups and conservation districts.

It was apparent from the collaboration and outreach process that changes to future operations and management will be constrained by existing contracts, commitments, and water rights considerations. On the other hand, it was evident that the stakeholders are willing to work together where they can to manage the system in a way that shares benefits across resources.

4. Interrelated Activities

4.1. Montana State Water Plan

The 2015 Montana State Water Plan (State Water Plan) set out a progressive program for the conservation, development, use, and sustainability of Montana's water resources. In the State Water Plan, it was recommended that Montana DNRC:

> "*work with local water users and other government agencies to conduct a basin-wide physical water availability and water management assessment in the Upper Missouri Basin. The study will assess and analyze how the basin's existing water and power operations and infrastructure will perform under different water supply scenarios. The study will also analyze the effectiveness of adaptation and mitigation strategies for meeting the challenges of supplying adequate water in the future.*"

The Basin Study closely aligns with this objective of the State Water Plan recommendation. The Basin Study and the resulting Upper Missouri RiverWare planning model will be used by Montana DNRC as a planning and educational tool to help guide State Water Plan responsibilities under §85-1-203 MCA. In addition, Montana DNRC has other collaborative efforts in the Missouri Headwaters area with objectives that overlap with those of this Basin Study.

4.2. The Montana Climate Assessment

The Montana Climate Assessment is an effort to synthesize, evaluate, and share credible and relevant scientific information about climate change in Montana with the citizens of the State (Whitlock et al. 2017). It is an assessment on climate trends and their potential consequences on Montana's water, forests and agriculture. The Montana Climate Assessment is intended to be a sustained effort, with plans to regularly incorporate new information to address the needs of Montana.

Because the Montana Climate Assessment was compiled during the same time as the Impacts Assessment and early phase of the Basin Study, there was some dialogue and overlap between the two efforts. For instance, hydrologic projections for the Montana Climate Assessment were developed using the Variable Infiltration Capacity (VIC) hydrology model web-based application, of which Reclamation was one of the developers. During a Musselshell Watershed Coalition meeting on June 13, 2017, which the Basin Study team presented at, the Montana Climate Assessment was also presented. The Montana Climate

Assessment report likewise contained a short description of the Basin Study. To validate some of the Impacts Assessment results, Reclamation compared them with the corresponding results from the Montana Climate Assessment.

4.3. City of Bozeman Integrated Water Resources Plan

The City of Bozeman is growing and recognizes that its available water supply could be surpassed in the future as the population and water demands increase. Also, the city is in a basin that is closed to many types of new appropriations. The city also is concerned about the susceptibility of its water supply to drought and climate change.

In response to these concerns, the City of Bozeman has completed a detailed Integrated Water Resources Plan (IWRP) to address water supply requirements over the next 30 to 50 years (Advanced Engineering and Environmental Services [AEES] 2013). The study estimates that its water supply/demand imbalance gap might range from 6,842 acre-feet to 17,752 acre-feet by the year 2062. These estimates were adjusted for projected climate change impacts on the water supply.

In the IWRP, the City identified and evaluated various alternatives and alternative portfolios for meeting the additional projected future water needs. These included: implementing water conservation measures, adding water storage capacity, developing groundwater, purchasing senior water rights and water storage contracts, optimizing the capacity of existing sources, and developing non-potable sources for outdoor irrigation.

4.4. Drought Planning

4.4.1. National Drought Resilience Partnership

The NDRP is a collaborative effort by Federal and State agencies, watershed stakeholders, and NGOs working to leverage and deliver technical, human, and financial resources to help address drought in the arid West.

NDRP selected the Missouri Headwaters upstream of Canyon Ferry Dam in southwest Montana as one of two national drought resilience pilot projects. The basin was selected because the basin experiences frequent drought and faces rapidly increasing population and resource and land use changes. The NDRP Missouri Headwaters pilot study built on the Federal and State partnerships established for the Impacts Assessment (Reclamation 2019a) and this Basin Study, but this effort focused more on building resiliency to drought at the local watershed level.

One purpose of the NDRP was to link drought information (e.g., monitoring, forecasts, outlooks, and early warnings) to longer-term drought resilience strategies in critical sectors such as agriculture, municipal water systems, energy, recreation, tourism, and manufacturing. The pilot initiative focused on how improved drought preparedness at the local, State, and Tribal levels could be achieved through enhanced coordination with Federal agency and resources.

The partners worked collaboratively to engage and train community-based drought coordinators to lead planning, mitigation, and project implementation in eight watersheds in the Missouri Headwaters. A project goal was to produce a model for information sharing, efficient water use, and community collaboration. It also prepared people to mitigate for drought while preserving cultural and ecological values in the face of a drier future.

The project partners identified collective goals for developing community-based drought preparedness plans and long-term mitigation strategies to:

1) Organize and engage watershed communities for local drought planning
2) Provide tools for drought monitoring, assessing and forecasting
3) Initiate local projects to build regional drought resiliency

4.4.2. WaterSMART Drought Contingency Planning

To build on the work of the NDRP Missouri Headwaters Project, Montana DNRC received Reclamation funding in 2018 through the WaterSMART Drought Program to produce a drought contingency plan for the Missouri Headwaters. The project is assisting communities with drought planning efforts with the support of local watershed drought coordinators and their Big Sky Watershed AmeriCorps members. These individual watershed planning efforts will provide the basis for a scaled-up, integrated regional Headwaters Basin Plan that considers watershed connections. These efforts are bringing together partners and resource agencies which have been collecting, analyzing, mapping, and sharing natural resource data in the Missouri Headwaters through the NDRP Montana Demonstration Project.

4.5. Water Compacts

4.5.1. Blackfeet Tribe Compact

The 2009 Montana Legislature passed a Compact settlement between the Blackfeet Tribe, the United States, and the State of Montana (§85-20-1501:1511, MCA). The Compact quantifies the reserved water right for the Blackfeet Tribe while protecting the rights of non-tribal water users locally and downstream on Birch Creek, Badger Creek, Cut Bank Creek, the Two Medicine River and the Milk River. The Compact was first introduced in Congress in 2010 and signed into law by President Obama on December 16, 2016. On April 20, 2017, Blackfeet Tribal members voted to approve the Compact. Interior Secretary Zinke executed the Compact on June 12, 2018.

Blackfeet Indian Reservation.

The Compact encompasses streams in the upper Marias River basin, including the Birch Creek, the Two Medicine River, and Cut Bank Creek. In general terms, the Compact quantifies the water rights for the existing and future needs of the Blackfeet Tribe while minimizing impacts to the water supply available to other users. It specifies minimum flows for some streams. The Compact also provides a process for the Tribe to lease a portion of its water to off-reservation users. There is a specific stipulation for the Birch Creek drainage which provides for coordinated management between Tribal and non-tribal users. Provisions for the rehabilitation of the Four Horns Reservoir in the Badger Creek drainage would allow for water to be brought from there for use in the Birch Creek drainage. The Compact settlement also provides the Blackfeet Tribe an allocation to store water in Lake Elwell (Tiber Dam) of 45,000 acre-feet per year which is available for the Tribe to use or market.

4.5.2. Chippewa Cree Tribe-Montana Compact

This Compact covers the water rights of the Chippewa Cree Tribe of the Rocky Boy's Reservation. Because the reservation mostly is within the Milk River basin, most of the Compact provisions apply to that drainage (§85-20-1001:1008, MCA). Pertinent to the study area, the Compact contains provisions to support Federal legislation that has passed and provides an allocation of 10,000 acre-feet per year of stored water from Lake Elwell (Tiber Dam) for any beneficial purpose, either on or off the reservation.

4.5.3. Missouri Wild and Scenic River

This Compact between the State of Montana and the Bureau of Land Management (BLM) includes water for instream flow purposes in the Upper Missouri National Wild and Scenic River from Fort Benton to the Fred Robinson Bridge (§85-20-501, MCA) and an instream flow stipulation for the Madison River within the Bear Trap Canyon Public Recreation site. The Compact provides for protection of all existing water rights under State law with a priority date before June 1, 2012, and for capped levels of new depletions (priority after December 31, 1987) in the Missouri River basin upstream, ranging from 35,000 acre-feet per month in October to 219,000 acre-feet per month during May. The stipulations for the Bear Trap Canyon Recreation Site provide a 1,100 cubic feet per second (cfs) year-round water right for the site with a June 9, 1971 priority date.

4.5.4. Upper Missouri River Breaks National Monument

This Compact was entered into by Montana and the United States to settle Federal reserved water rights claims for the Upper Missouri River Breaks National Monument, administered by the BLM (§85-20-1801, MCA). Relevant to the Basin Study are the minimum flows for the Judith River of 160 cfs, to be measured near the confluence with the Missouri River, and 5 cfs for lower Arrow Creek. The priority date for these rights is June 1, 2012.

4.5.5. United States National Park Service

This Compact between the State of Montana and the U.S. National Park Service covers five park units within Montana, three of which are in the Upper Missouri River basin study area, including Yellowstone National Park, the Big Hole National Battlefield, and Glacier National Park. The Compact generally provides surface water and groundwater for administrative purposes, instream flow, irrigation use, and emergency fire suppression (§85-20-401:402, MCA). Relevant to the study area are stipulations for instream flow water rights for the Big Hole National Battlefield, flows to Marias River tributary streams in Glacier National Park, and flows to Gallatin and Madison River tributary streams in Yellowstone National Park.

4.5.6. United States Fish and Wildlife Service

Compacts between the State of Montana and USFWS provide water in the study area for the Benton Lake National Wildlife Refuges as well as the Red Rock Lakes National Wildlife Refuge and Wilderness Area (§85-20-701, and §85-20-801, MCA). In general terms, these Compacts allow for natural flow rights to fill refuge water bodies and for consumptive use, primarily by evaporation from water bodies and wetlands that provide wildlife habitat. Provisions are also included for the Red Rock Lakes Refuge for minimum flows in some streams and for the water needed to maintain lake levels. Administrative uses, such as wildfire suppression, also are protected.

4.5.7. U.S. Forest Service

This Compact encompasses Federal reserved water rights for National Forest System Lands within the State of Montana and was approved in April 2007 (§85-20-1401, MCA). This Compact recognizes reserved water rights for the U.S. Forest Service for administrative and emergency firefighting needs. The compact also uses Montana law to create state-based water rights for instream flow on the National Forest System lands, including those in the Missouri Headwaters. The Montana Water Court issued a final decree for this compact in October 2012.

5. Scenarios and Analysis

Water resource managers across the Missouri Headwaters balance water supply and demand under complex rules and uncertain conditions. In long-term planning, managers must consider how investments made today could influence their ability to manage for both current and future challenges. Scenario planning offers multiple benefits for water resources planning, as it allows for the development of flexible, long-term plans and decision making where future conditions are uncertain. Development and analysis of scenarios are ways of systematically characterizing and combining different variables, events, conditions, or trends to reveal future problems or challenges and help to identify potential responses. The central purpose of scenario development is to understand the full range of possibilities for how future conditions may unfold.

The Impacts Assessment and Basin Study use a scenario approach for quantifying water supply and demand, and for evaluating strategies. Scenarios of water supply include paleohydrology, historical conditions, and projected climate change (5 scenarios) under three planning horizons for the 21st century: 2020s, 2050s, and 2080s (Figure 10). The approach, which is described in detail in the Impacts Assessment, uses a modeling framework to identify and evaluate possible water supply and demand imbalances under these different planning scenarios. Analysis includes:

- **Water supply** under these scenarios was developed for surface water through hydrologic and statistical modeling. Scenarios with additional groundwater pumping were modeled to deplete the surface water source based on aquifer characteristics.
- **Water demands** under these scenarios were developed by modeling evaporative demands from reservoirs and agricultural demands via evapotranspiration of crops. Demands also incorporate population estimates for municipal and industrial water use.
- **Management risk** broadly refers to the potential failure of water resources infrastructure and management actions to meet water management objectives. Management risks under 2017 operating procedures were evaluated using the Upper Missouri RiverWare planning model, which incorporate inputs of water supply and demand to simulate river operations under various scenarios.

Water supply and demand scenarios, as well as modeling for evaluation of water management risks, are discussed in following sections and detailed in the Impacts Assessment (Reclamation 2019a). Figure 10 provides an overview of developed scenarios of water supply and demand. These are described in more detail in the following sections.

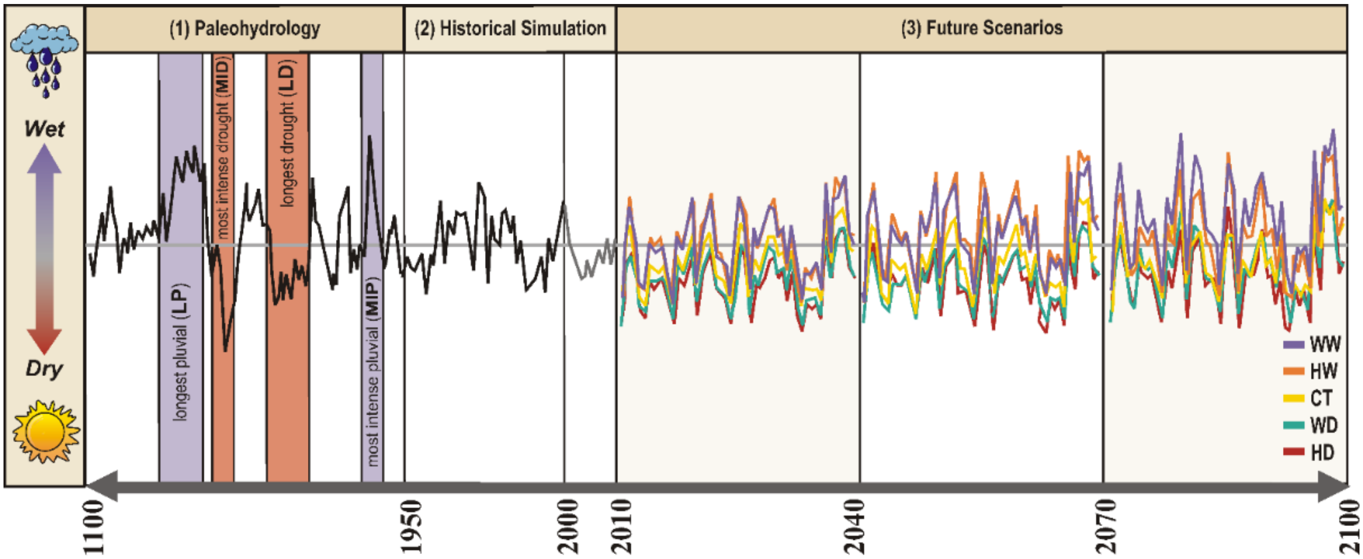

Figure 10.—Components of the Missouri Headwaters Basin Study scenarios.[1]

5.1. Water Supply Scenarios

Scenarios for evaluating possible water supply in the Upper Missouri River basin in the future include historical conditions, paleohydrology, and future scenarios with and without paleohydrology. These scenarios are a key step in understanding future water supply within the study area and are summarized below and described in detail in the Impacts Assessment (Reclamation 2019a).

Events that occurred in the distant past (paleohydrology) are included in the analysis because similar patterns of wet or dry years are likely to occur again. With expertise from the USGS, this Basin Study makes use of paleohydrology (Martin and Pederson 2019), and more specifically extreme droughts (i.e., dry periods relative to the long-term average) and pluvial events (i.e., wet periods relative to the long-term average), to determine if there are conditions that occurred in the distant past that may affect the performance of strategies in ways the more recent historical period has not.

The Basin Study uses paleohydrology in two ways:

1) **Extreme paleo events.** Developing daily streamflow timeseries over 50-year periods that encompass extreme drought and 50-year periods that encompass extreme pluvial events identified from tree rings (Most Intense Drought [MID], Most Intense Pluvial [MIP], Longest Drought [LD], and Longest Pluvial [LP])

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[1] WW: Warm wet future scenario; HW: Hot-wet future scenario; CT: Central tendency future scenario; WD: Warm-dry future scenario; and HD: Hot-dry future scenario.

2) **Future scenarios with paleohydrology.** Identifying the same events combined with future streamflow scenarios (Warm wet [WW], Hot-wet [HW], Central tendency [CT] Warm-dry [WD], and Hot-dry [HD])

A relatively recent historical period (water years 1951 - 1999) simulation was used to provide a baseline for comparisons with paleohydrology and future scenario output. This simulation combines historical hydrology with current (2017) operational rules for river and reservoir management. The historical period (water years 1951 - 1999) was chosen due to the availability of stream gaging data, naturalized streamflow estimates, and hydrologic model data. This period, however, is bracketed by two intense historic droughts: the Dust Bowl drought of the 1930s - 1940s and the Millennium Drought between 2000 and 2010. The paleohydrology records were used to capture and test operation under extreme drought events such as these.

Future scenarios were developed as a way of using the best available science for long-term planning under uncertain future conditions. The future scenarios provide our best estimate of what could occur over the coming century with respect to climate dynamics and warming. For this study, each scenario is considered an equally likely future planning scenario. These scenarios include five climate timeseries developed for the Missouri Headwaters that represent the range of projected changes in temperature (less warming to more warming) and precipitation (from decreases to increases):


Badger Creek in the Marias River watershed headwaters.

- **Warm-wet (WW):** Lower on the range of temperature change and higher on the range of precipitation change
- **Warm-dry (WD):** Lower on the range of temperature change and lower on the range of precipitation change
- **Central tendency (CT):** Middle of the range of temperature change and middle of the range of precipitation change
- **Hot-wet (HW):** Higher on the range of temperature change and higher on the range of precipitation change
- **Hot-dry (HD):** Higher on the range of temperature change and lower on the range of precipitation change

The climate timeseries are developed by adjusting historical climate over water years 1951 - 1999 to reflect projected changes from this baseline period to the 2020s, 2050s, and 2080s future planning horizons. The resulting adjusted climate timeseries match the sequence of drought and pluvial events from the historical period and incorporate the effects of projected future climate. Each climate timeseries is then applied to models that simulate the effect of climate on hydrology in the region, including snow accumulation, snow melt, and surface runoff.

5.2. Water Demand Scenarios

Scenarios for evaluating water demand in the Missouri Headwaters include historical conditions and projected demographic and climate change. These scenarios are a key step in understanding future water demand and thereby the ability of future water supplies to meet this demand. The demands for water quantified for this Basin Study include: agricultural demands via crop evapotranspiration, evaporative losses from the region's reservoirs, and M&I water use.

Water supply and demand scenarios were developed in parallel so that a water demand scenario corresponds to each water supply scenario. These scenarios are input to the Upper Missouri RiverWare planning model to evaluate conditions with or without strategies (described in Section 6). Water supply scenarios using paleohydrology were coupled with water demands over the more recent historical period (including agricultural demands, evaporative demands, and M&I demands). It was beyond the scope of this study to develop paleo-informed demands, which would require reconstruction of precipitation and temperature from the paleo record or substantial research into potential relationships between tree ring widths and historical plant water demand.

The same recent historical period (water years 1951 - 1999) used for the historical water supply scenarios was also used to develop a baseline demand scenario for comparisons with paleohydrology and future scenario output. The recent historical period used as the baseline combines: modeled historical agricultural demands (assuming a crop mix from 2007 in the Upper Missouri River basin and 2009 in the Musselshell River basin), modeled historical reservoir evaporation (assuming average reservoir depth), M&I demands for the largest municipalities (2017 estimates for Bozeman, Butte, Great Falls, and Helena), and current (2017) operational rules for river and reservoir management.

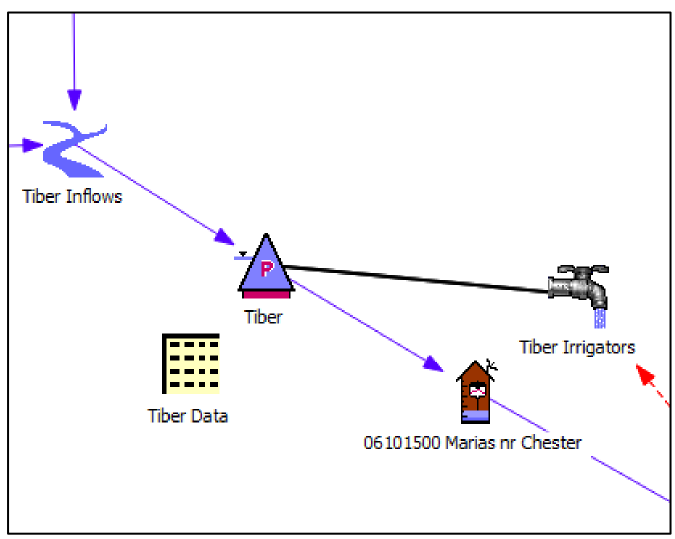

Irrigation on the Greenfields Bench, Sun River. watershed.

Future scenarios of water demand were developed by combining the same five future scenarios for water supply (WW, WD, CT, HW, and HD) with population projections for the largest municipalities for the 2020s, 2050s, and 2080s. More specifically, future scenarios of agricultural demand incorporate future crop demands for water using the crop mix described above, future evaporative demands under a changing climate, and future M&I demands based on population growth. Because M&I demand is a relatively small fraction of overall demand in the region (about one percent), this study used a single future population growth scenario.

As with other aspects of the Basin Study, there is uncertainty about future demand. The rates of regional economic growth, conservation efforts, shifting social preferences, and other factors that cannot be firmly predicted will affect future water demand in the Missouri Headwaters. As with the water supply scenarios, this approach evaluates a range of plausible future conditions regarding how—and how much—water will be used in the Missouri Headwaters into the future.

5.3. Upper Missouri RiverWare Planning Model

The Upper Missouri RiverWare planning model was developed as part of the Impacts Assessment to simulate current river and reservoir operations in the Upper Missouri River and Musselshell River and simulate water supply and demand scenarios, as well as strategies. The model was used to compute agricultural water deliveries, managed river flows, and reservoir levels throughout the study area, among other things. The model was developed using the RiverWare™ software (Zagona et al. 2001).



Upper Missouri RiverWare Planning Model excerpt.

Other basin studies have used RiverWare, including the St. Mary's and Milk Rivers, Colorado River, Truckee River, and Klamath River Basin Studies.

The historical scenario represents historical climate and hydrology alongside current operational and management conditions as of 2017. Various hydrologic and water demands scenarios previously discussed represent a range of plausible future conditions. These scenarios are examined within the current range of water development and management conditions to determine potential impacts of future changes through comparison with paleo-hydrologic scenarios and the historical baseline scenario.

5.4. Strategy Assessment Measures

In the Impacts Assessment and Basin Study, measures are used to evaluate and aid in the comparison of strategies for reduced imbalances in water supply and demand. These measures span numerous resource categories and were identified based on input from study partners, stakeholders, and resource managers in the basin. The measures presented in this study report and the reasoning behind using each measure are summarized in Table 9.

Table 9.—Strategy Assessment Measures

Measure Category	Measure Description	Relevance
Basin-wide Responses	Change in the days of centroid of flow timing	Illustrates change in hydrologic regime
	Change in end of month reservoir storage	Illustrates change in magnitude and timing of reservoir storage and effectiveness of operational policies
	Change in annual reservoir inflow volume	Illustrates change in overall water supply
	Change in April - October reservoir inflow volume	Illustrates change in hydrologic regime
	Change in November - March reservoir inflow volume	Illustrates change in hydrologic regime
Water Deliveries	Change in end of water year reservoir storage	Illustrates ability of reservoir to meet summer storage demands
	Change in irrigation supply shortages	Illustrates impacts to water users
Hydroelectric Power Resources	Change in annual hydropower production at State, Federal, and private facilities	Illustrates impacts to hydropower production
Flood Control Operations	Change in days per month exceeding reservoir flood pool (Canyon Ferry, Clark Canyon, and Lake Elwell)	Illustrates change in potential flood risk

Table 9.—Strategy Assessment Measures

Measure Category	Measure Description	Relevance
Ecological Resources*	Change in monthly streamflow	Illustrates change in hydrologic regime
	Change in the annual maximum 7-day streamflow	Illustrates change in high flows which help move sediment, provide bank and overbank storage, and help alleviate disease
	Change in the annual minimum 7-day streamflow	Illustrates change in low flows which may stress fish and wildlife
	Change in streamflow percentiles (5^{th}, median, 95^{th})	Illustrates change in hydrologic regime
Recreation	Change in median unusable days at boat ramps	Illustrates impacts to flatwater boating recreation

Ecological resources include fish and wildlife habitat; species listed as an endangered, threatened, or candidate species under the ESA; flow and water dependent ecological resiliency; and water quality.

6. Strategies

Strategies were developed to address water resource challenges identified in the Impacts Assessment, to address current issues identified by study partners and through stakeholder outreach, and to examine the impact of increased water demand. Strategies include changes to current water management practices, changes to existing infrastructure, and development of new infrastructure. Simulating the system under existing operations and with the existing infrastructure for various alternatives provides a baseline scenario (typically termed no-action) to which strategies can be compared.

6.1. Formulation of Strategies

Strategies were developed to address future water needs and to adjust future water infrastructure operations to changing hydrologic conditions. The strategies also address 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. Because 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.

6.2. Objectives and Constraints

While strategies were primarily developed to address gaps in water supply and demand, some were formulated to address multiple objectives while others were single purpose. Strategies include management changes, different operations for existing infrastructure, and structural changes, such as new off-stream storage reservoirs. Although a strategies' ability to address water supply imbalances was addressed, they were not evaluated for economic or financial feasibility. Because the Missouri Headwaters is such a large area, not all strategies would affect the entire basin. Many of the strategies included here are specific to the larger Missouri River tributaries. Strategies were developed to be within the framework of the prior appropriation doctrine and how it is implemented through Montana state law, recognizing that water rights changes or new permits might be needed to implement some of the strategies.

6.3. Approach to Strategy Identification

Using Reclamation and Montana DNRC knowledge of managed water resources in the study area as a starting point for considering input from stakeholders, strategies were identified to address present and potential future water supply challenges and investigate the effects of increased water use in the study area and its tributaries.

Known existing water supply/demand imbalances were then evaluated for future water supply and demands scenarios. Future conditions also were evaluated to assess whether there were any new imbalances in supply and demands that needed to be addressed. This was done on the basin and sub-watershed scale with focus on watersheds within Reclamation projects, such as the Beaverhead River, Sun River, and Marias River basins. Stakeholder meetings also were held at the basin and watershed scales to identify and evaluate strategies.

Canyon Ferry Dam.

6.4. Approach to Strategy Analysis

The following sections describe and evaluate the strategies by category or watershed. The first category of strategy presented is "Providing Water for Future Uses." The two strategies within this category were developed to address future growth in the study area and not to alleviate impacts of future conditions. Subsequent presented strategies were developed to address concerns for water supply reliability and needs of fish and wildlife. Table 10 and Figure 11 list the strategies that were evaluated and are discussed below.

Strategies were grouped by watershed if the strategy was focused on a particular watershed, and by strategy intent if the strategy focused on addressing a particular vulnerability. For example, three strategies seeking to improve water deliveries in the Sun River basin were evaluated together, while strategies investigating the effect of increasing irrigation efficiencies to improve water deliveries and investigating targeted high flow releases for ecological purposes were evaluated separately. Sets of performance measures for each strategy or groups of strategies were identified and a set of overview figures present summary information using these measures.

In the analysis that follows, background and objectives for each strategy are presented, followed by the strategy analysis and discussion of performance and tradeoffs. For each strategy, figures and tables may be presented to highlight specific aspects or benefits of the strategy. For each strategy category listed above, an overview figure summarizes impacts on various resource measures (described in Section 5.4. *Strategy Assessment*) under future and paleohydrology scenarios, with key findings highlighted. The overview figure also summarizes the effects of implementing a strategy compared with the current condition. Finally, the overview figure summarizes the effects of implementing the strategy under future and paleohydrology scenarios.

Figure 11.—Overview of strategy locations.

Table 9.—List of Evaluated Strategies

Category	Strategy Description
Providing Water for Future Uses	
1	Providing Water for Future Consumptive Use through Contract Water from Canyon Ferry Reservoir and Lake Elwell
2	Providing Water for Future Municipal, Domestic, and Industrial Use in the Gallatin Valley
	Pumping Groundwater with Corresponding Aquifer Recharge
	Canyon Ferry Water Supply Pipeline
System-wide Water Management Strategies	
3	Increasing Canal and On-farm Irrigation Efficiencies
4	Providing Ecological Flow Releases from Canyon Ferry Reservoir and Lake Elwell
5	**Beaverhead River Basin Strategies**
	Decreasing drawdown for Flood Storage and Clark Canyon Reservoir
	Capping Winter Releases from Clark Canyon Reservoir to 100 cfs
	Decreasing Flood Storage and Capping Winter Releases
6	**Sun River Basin Strategies**
	Increasing Willow Creek Feeder Canal Capacity
	New Off-stream Storage for Sun River Water
	Increasing Pishkun Supply Canal Capacity
	New Off-stream Storage and Increasing Pishkun Supply Canal Capacity
7	**Musselshell River Basin Strategies**
	New Off-stream Storage in Lower Musselshell Watershed
8	**Water Management Strategy for Increased Drought Resilience**

6.5. Providing Water for Future Uses

Increased demand for water in the future is a likely scenario for long term planning, including agricultural water demand and M&I demand. Two significant factors are considered for future demands. The first is increasing irrigated acreage in the Canyon Ferry Reservoir area and in the Marias River basin near Tiber Dam. The second is providing water for new M&I uses in the Gallatin Valley, which is the fastest growing region in Montana.

6.5.1. Providing Water for Future Consumptive Uses through Contract Water from Canyon Ferry Reservoir and Lake Elwell

6.5.1.1. *Background*

Population growth and economic development could increase future water demands in the Missouri Headwaters. Because the study area upstream of the Great Falls and Teton watersheds is closed to most new appropriations of water with state-based water rights, contracting Reclamation-stored water from Canyon Ferry Reservoir and Lake Elwell might provide one of the few opportunities available for new water development in the future. Contract water could be pumped directly from the reservoirs or diverted from the Missouri River or Marias River downstream dams, from which targeted contract releases could be made. With the ability to store and regulate flow into the reservoirs, providing stored water through contracts could be a way to minimize impacts to other resources, when compared to potential impacts from direct flow diversions with no storage.

Current Canyon Ferry water service contracts total approximately 9,100-acre-feet. Analyses by Reclamation indicate that there is about an additional 291,000 acre-feet available in the Canyon Ferry Reservoir for contracting, based on historical flow data (Reclamation 2008). Much of the new development associated with Canyon Ferry Reservoir was anticipated to occur upstream of the reservoir, and this is now unlikely given the basin closures and instream flow rights described in Sections 1 and 2. However, there is the potential to develop new irrigated lands adjacent to the reservoir and along the Missouri River downstream through Reclamation contracts. Reclamation recently received a proposal from a private entity to develop about 12,000 acres of new irrigation on uplands just to the east of Canyon Ferry Reservoir. For this study, contracting of 50,000 acre-feet to supply 16,667 acres of irrigation was selected as a more realistic future maximum.

One of the original purposes for constructing Tiber Dam and Lake Elwell was to provide water for irrigation. Earlier analyses by Reclamation indicate that there is about 236,000 acre-feet available for contracting in Lake Elwell (Reclamation 2008). Current irrigation water service contracts for the project total approximately 13,841 acre-feet, indicating that much of the demand estimated when Tiber Dam was constructed did not come to fruition. In 2005, Montana DNRC and Reclamation assessed the economic potential of a proposal by local irrigation proponents to pump water directly out of Lake Elwell to 20,000 to 40,000 acres of bench lands to the northeast of the reservoir near Chester (Aquoneering 2005).

Stored water from these reservoirs also could be used to meet future municipal and domestic water needs. The Rocky Boy’s North Central Regional Water Project is under development and is critical to fulfilling reserved water rights with the Chippewa Cree Tribe of the Rocky Boy’s Reservation and would provide water to other communities and rural water users in north-central Montana. The

City of Helena already has a water service contract for Canyon Ferry Reservoir water. Water service contracts from Canyon Ferry Reservoir also might provide opportunities for other municipalities and rural water users, including areas upstream.

Releases from Reclamation reservoirs might also be used to offset some of the impacts associated with the eventual development of irrigated lands from state-based water rights. In 1992, the Montana Board of Natural Resources and Conservation issued an Order granting water reservations to Conservation Districts in the Upper Missouri River basin for developing irrigated land in the future. The water reservation process identified lands with the best potential to be developed in the future. Although 18,675 acre-feet was reserved for the future development in the Upper Missouri River basin, only about 2,000 acre-feet of this water has been developed, due to basin closures and economic factors.

6.5.1.2. Objectives

The objectives of this strategy are to identify a realistic potential expansion of future consumptive water demands for the Missouri Headwaters during the planning period (to 2099) and to investigate the potential role of contract water from Canyon Ferry Reservoir and Lake Elwell in meeting these demands and in mitigating potential impacts to other resources. This analysis is a starting point in developing strategies for meeting future consumptive use demands while sustaining other important resources. The additional developments considered in this strategy are summarized in Table 11. Because demands for water are a function of many factors, these demands may not fully be realized in the future or could be exceeded.

This scenario includes adding 109,203 irrigated acres to the estimated 1.1 million acres currently irrigated. It is possible that irrigated acreages in other parts of the basin, such as the Gallatin Valley, could decline due to residential development and thereby offset some of the increases. The municipal/domestic pipeline projects were modeled to serve an additional 238,330 people.

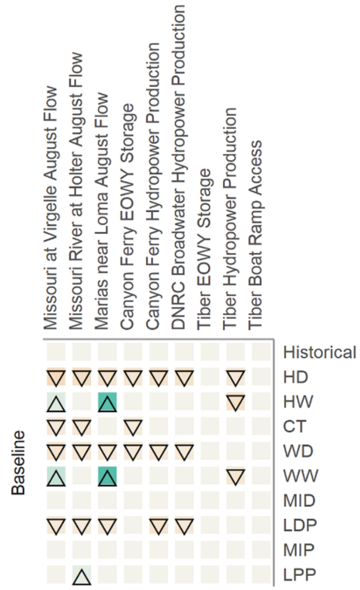
Table 10.—Future Developments Included in the Strategy

Potential Development	Source	Description
Irrigation by contract from Canyon Ferry Reservoir	Canyon Ferry Reservoir	This was modeled as pipe-to-sprinkler irrigation that would be pumped from the reservoir. The modeled maximum annual volume was 50,000 acre-feet to supply 16,667 acres of irrigation.
Irrigation by contract from Lake Elwell	Lake Elwell	This was modeled as pipe-to-sprinkler irrigation that would pumped from the reservoir. The modeled maximum annual volume was 200,000 acre-feet to supply 85,400 acres of irrigation.
Irrigation for State-based water reservations	Missouri River in lower portion of study area	This is the modeled future expansion based on current rates of development. It would include an additional 4,523 acres of sprinkler irrigation by 2050, and 7,136 acres by 2080.
Gallatin Valley pipeline for municipal and domestic use	Canyon Ferry Reservoir	This would include the pipeline described in the Gallatin Valley strategies. The maximum volume diverted per year would be 20,900 acre-feet.
Rocky Boy's North Central Regional Water Project	Lake Elwell	This would provide water to the Rocky Boy's Indian Reservation and other small communities and rural areas in North-Central Montana. Annual contract volumes would be 4,640 acre-feet by 2020 and increase to 8,870 acre-feet by 2050.

6.5.1.3. Performance and Trade-Offs

The new irrigation development and water for municipal and rural growth could provide economic benefits, although these potential benefits are not quantified in this study. On the other hand, potential increased withdrawals from the reservoirs and associated water depletions could impact fisheries and aquatic resources, hydropower production, and recreation. There also is the potential for reductions to downstream flows and associated fisheries and hydropower benefits. Figure 12 presents modeled changes to resource measures with and without the strategy by scenario.

Baseline



Key Findings for the 2050s:

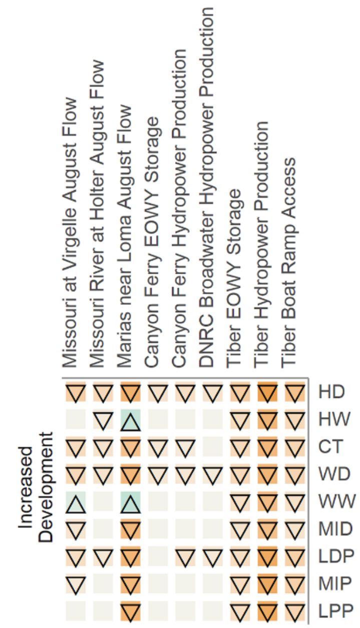
- **Under drier future scenarios (HD, CT, WD)**, average August flows are projected to decrease at the Missouri at Virgelle, the Missouri at Holter, and the Marias near Loma.
- **Under wetter future scenarios (WW, HW),** average August flow are projected to increase, with the Marias at Loma flows increasing more substantially than the Missouri at Virgelle.
- **All scenarios** indicate small impacts to EOWY storage in Tiber Reservoir and Canyon Ferry Reservoir as well as to hydropower production.

Historical

Key Findings for the historical scenario:

- **Increased water development** results in decreases in Marias August flows downstream of Tiber Dam as well as Tiber hydropower production, according to historical simulations.
- **Increased water development** results in only moderate impacts to Tiber EOWY storage and to boat ramp access, as well as to Missouri River August flows at Virgelle.

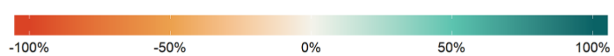
Scenarios



Key Findings for the 2050s:

- **Increased water development is not a strategy developed to alleviate impacts of changes in future water supply**. Instead, it may be considered a scenario of increased water demand.
- **Selected measures will not be impacted more substantially according to future and paleo scenarios than in the historical scenario**.

Providing Water for Future Consumptive Uses



Boxes marked with a dot exceed +/-100%. Changes less than +/-5% are marked as 0. Shortage changes are reversed as an increase in shortage has a negative effect on the system.

Figure 12.—Resource benefit changes comparison chart for Providing Water for Future Consumptive Uses through Contract Water from Canyon Ferry Reservoir and Lake Elwell strategy (2050s futures).

6.5.1.3.1. Figure Orientation

In Figure 12, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios, as well as with different strategies, are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability. The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

The middle panel shows how different strategies affect the performance measures under historical conditions. The reader may explore in these figures: *had the strategy been implemented under current conditions, what effect does it have?*

The third panel shows the effect of strategies under future and paleoclimate scenarios. The reader may explore in these figures: *do the strategies have a noticeable effect on the vulnerabilities identified in the first panel, and are the effects of the strategies seen under historical conditions in the second panel still evident under a range of scenarios?*

6.5.1.3.2. Figure Discussion

Canyon Ferry Reservoir end of water year storage was modeled to be a bit lower under most scenarios, compared with the baseline no strategy, while Lake Elwell (Tiber) end of water year storage was modeled to be substantially lower across scenarios.

Modest reductions to flow were simulated for the Missouri River below Canyon Ferry (USGS Missouri River below Holter Dam gauge) and in the lower river (USGS Missouri River at Virgelle gauge) due to the increased development. The Holter gauge is downstream of Canyon Ferry Reservoir and indicates modeled reductions due to the Canyon Ferry water developments. The Virgelle station is below the mouth of the Marias River and reflects the combined developments associated with both reservoirs. More substantial flow reductions were modeled for the Marias River at Loma associated with the new modeled water developments from Lake Elwell. Because the Marias River is a much smaller river than the Missouri River and increases in consumptive use are larger, the modeled effects of the new development on other resources are more pronounced.

Modeled hydropower production decreased some for Canyon Ferry and the NorthWestern facilities with the strategy. This likely is due to an increase in the amount of water depleted from the system. The model results showed more substantial reductions to hydropower production at Lake Elwell, where relative depletions are greater.

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

6.5.2.1. Background

Rapid growth is occurring in the City of Bozeman and the surrounding Gallatin Valley, and additional water likely will be needed to supply the increases in demand. The Missouri Headwaters are closed to applications for new permits to appropriate water, with some exceptions for surface water use by municipalities and applications to store water during high spring flows (§85-2-343, MCA). Moreover, local and downstream senior irrigation, storage, and instream flow water rights would generally preclude surface water development for new uses without more storage or changing an existing use. Groundwater is physically available in most valley areas, but because almost all accessible groundwater is connected to surface water, high-capacity wells without mitigation plans generally are precluded, although smaller wells (less than 35 gallons per minute and 10 acre-feet per year) are mostly exempt from permit requirements (§85-2-306, MCA). These same constraints generally pertain to other areas in the Missouri Headwaters where domestic and M&I demands are increasing, although presently to a lesser extent than in the Gallatin Valley. At the same time, groundwater dynamics in the valleys are changing as agricultural land is developed for residential use. Irrigation recharge to aquifers is an important component to the hydrology of the Gallatin Valley, and reducing irrigation will decrease aquifer recharge.

Table 12 illustrates potential increases in water demands (including indoor and outdoor) for the City of Bozeman and the remainder of Gallatin County over the Basin Study planning period. These demand projections presume an increase in water use efficiency and corresponding decrease in per-capita water diversion based on percentage decreases from AEES (2013: Table 27. Medium Conservation, High Growth Reductions).

Table 11.—Projected Increases in Populations and Demands for the City of Bozeman and Other Communities and Rural Users in Gallatin County, Montana

Demands	2010	2020	2050	2080
Bozeman population	37,280	49,900	89,714	120,921
Smaller communities and rural population	47,204	63,184	113,596	153,111
Per-capita daily water demand (gpcd)	165	135	116	116
Annual demand all users (acre-feet)	15,615	17,100	26,417	35,607

gcpd = gallons per capita per day

In its integrated water resources plan (AEES 2013), the City of Bozeman has considered a number of options for meeting future water demands including: implementing water conservation measures, acquiring additional shares of Hyalite Reservoir storage, acquiring water rights with older priority dates, optimizing water use from existing sources, using non-potable water for irrigation, developing storage on Sourdough Creek, developing groundwater, aquifer recharge and recovery, importing water from the Yellowstone River basin, and importing water from Canyon Ferry Reservoir. However, Bozeman only accounts for less than half of the existing and projected population of the greater Gallatin Valley area. Future residents outside of the City of Bozeman generally will depend more on groundwater and may not have alternative water supplies such as the additional storage being considered by the City of Bozeman.

6.5.2.2. Objectives

The objectives are to explore strategies that provide potential sources of water for future domestic and M&I demands in the City of Bozeman 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

For this Basin Study, 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 which have more limited water supply options.

6.5.2.3. Strategy 1: Pumping Groundwater with Corresponding Aquifer Recharge

Under this strategy, high capacity wells drilled into Gallatin Valley aquifers would serve as the direct water source for increased domestic water demand. Although groundwater use has advantages, such as resilience to seasonal shortage or drought and reduced treatment, withdrawals could affect existing water rights, including those for surface water. The source aquifer would be recharged with surface water during times of higher flow or through existing water rights purchases. These recharges could offset later depletions from the additional well pumping.

The surface water diverted for aquifer recharge might be diverted from the Gallatin River, East Gallatin River, or tributaries and added to the aquifer through infrastructure such as existing irrigation canals, infiltration basins, injection wells, or green infrastructure (e.g., infiltration via permeable pavement). Aquifer recharge water might be secured from the following sources or from a combination of these sources:

- **Irrigation water rights:** This potential source of mitigation water would be from purchasing, leasing, or changing irrigation surface water rights and then using the water to recharge the source aquifer storage rather than irrigating with it. Recharge water can be injected or infiltrated into the source aquifer through wells or engineered infiltration galleries or structures. Irrigation canals also are potential means for recharging aquifers or conveying water to aquifer recharge sites. Recharging with senior irrigation water rights would allow aquifer recharge to occur throughout the irrigation season, possibly providing greater ability to offset depletion to surface water during the winter and early spring. However, recharge with junior irrigation water rights might provide similar offsets with proper design of an aquifer recharge system and are more likely to be more available and less costly.

- **Canyon Ferry Reservoir water service contracts:** During most years, all available flow from the Missouri Headwaters is captured, stored, and regulated by Reclamation at Canyon Ferry Dam. An upstream exchange of storable flow (where water would be stored in the aquifer rather than Canyon Ferry Reservoir) might be possible during times of high spring runoff by securing a contract for Canyon Ferry Reservoir water. As shown in Figure 13, during most years water is available for the Lower Gallatin River near Logan above senior Montana DFWP instream flow rights from April through early July. However, during the driest years, there is little, if any, water available above these rights.

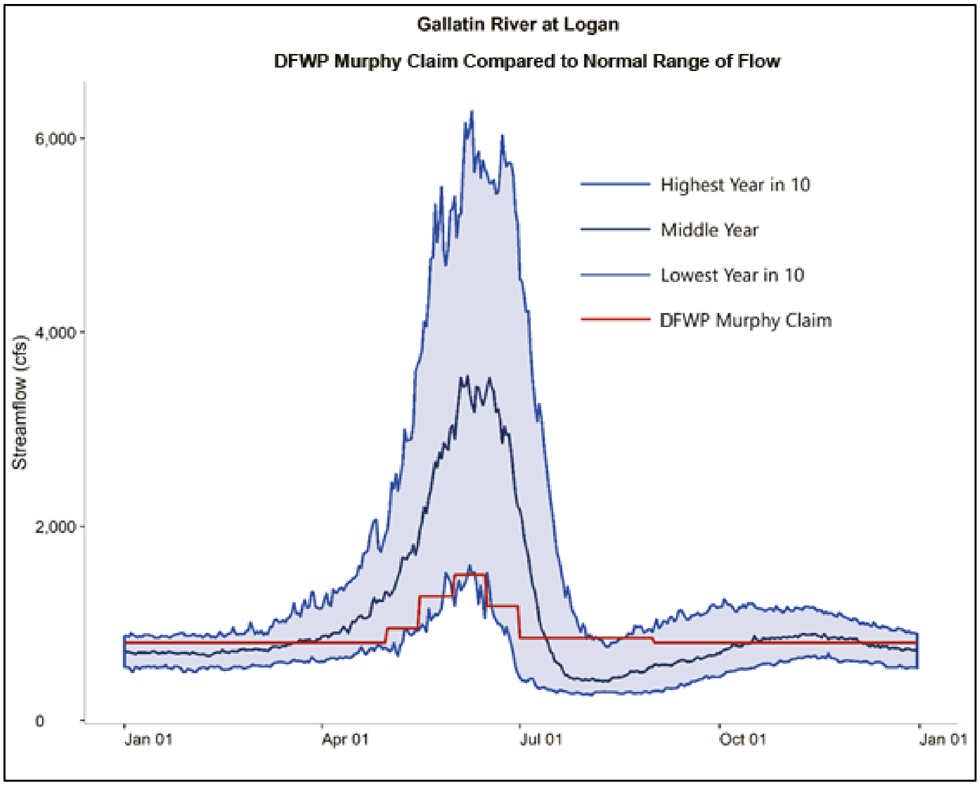


Figure 13.—Normal range of streamflow for the lower Gallatin River near Logan compared to senior Montana DFWP instream flow rates.

6.5.2.3.1. Performance

The model was used to evaluate the potential of using groundwater pumping in conjunction with aquifer recharge to: (1) supply water for future population growth in the greater Gallatin Valley, and (2) offset reductions to streamflow in the lower Gallatin River and Missouri River due to groundwater pumping.

The rates of new demand were determined using projected per capita use rates and population growth. For the City of Bozeman, water would be pumped from groundwater wells if existing surface water supply is not sufficient to meet demands. The rate and timing of depletions to surface waters was determined using the assumed efficiencies in the baseline model and lag factors consistent with the basin-wide return flow factors used for irrigation. Because the other Gallatin Valley users generally do not have access to alternative water supplies, future needs above and beyond use by the present-day population were all modeled to be met through groundwater. Due to distance from the source and well depth, pumping effects were modeled to result in constant year-round depletions, consistent with the assumed return flow patterns in the baseline. Depletions and the volume of water required for mitigation were assumed to be 52.5 percent of the pumped volume (Newfields and RESPEC 2017). The model results found that about 20,200 acre-feet would need to be pumped from groundwater annually to meet projected future needs by the 2050s.

Correspondingly, about 10,600 acre-feet per year of surface water on average would need to be recharged to groundwater to offset depletions. Aquifer recharge was modeled to occur through infiltration to the shallow aquifer at or near surface facilities for close to the annual volume depleted through aquifer pumping. Water was not added in the spring until irrigation demands commence, assuming that initial crop growth is a reasonable indicator that the ground is thawed for infiltration operations. When using high spring flow for aquifer recharge, the availability of high spring flow water is checked at Logan against the Montana DFWP instream flow right. When high spring flow is not available above this flow right, irrigation water is used as the source. To meet the aquifer volume recharge goals, water rights for up about 11,000 acres of irrigated land might need to be acquired by the 2050s (assuming irrigation water requirement of 1 acre-foot per acre; a greater consumptive use per acre would require acquiring less acreage). Water from aquifer recharge was modeled to return to surface water with a similar time lag as that used in the Upper Missouri RiverWare planning model for groundwater return flow from Gallatin Valley irrigation. The return flow factors were based on generalized aquifer characteristics for the Gallatin Valley.

Figure 14 graphs rates of: (1) aquifer recharge, (2) recharge returns to surface water, and (3) modeled depletions to surface water due to groundwater pumping for a sample two-year sequence for the City of Bozeman component of the strategy. Aquifer recharge was generally modeled to start in April and continue through the late summer. Modeled returns of this recharge water to surface water exceeded depletions until the early spring when recharge again commenced. On an annual volumetric basis, more water was added to the aquifer than was needed to offset depletions due to pumping in the model, mostly because modeled percentages of the water pumped from groundwater consumed were less than initial expectations. However, as seen in Figure 14, this volume of mitigation might be required to ensure that winter flow depletions are fully covered. Additionally, some level of recharge above the depleted volume may be required to adequately mitigate any more local impacts to streamflow in individual streams, a level of analysis which has not been covered by this investigation.

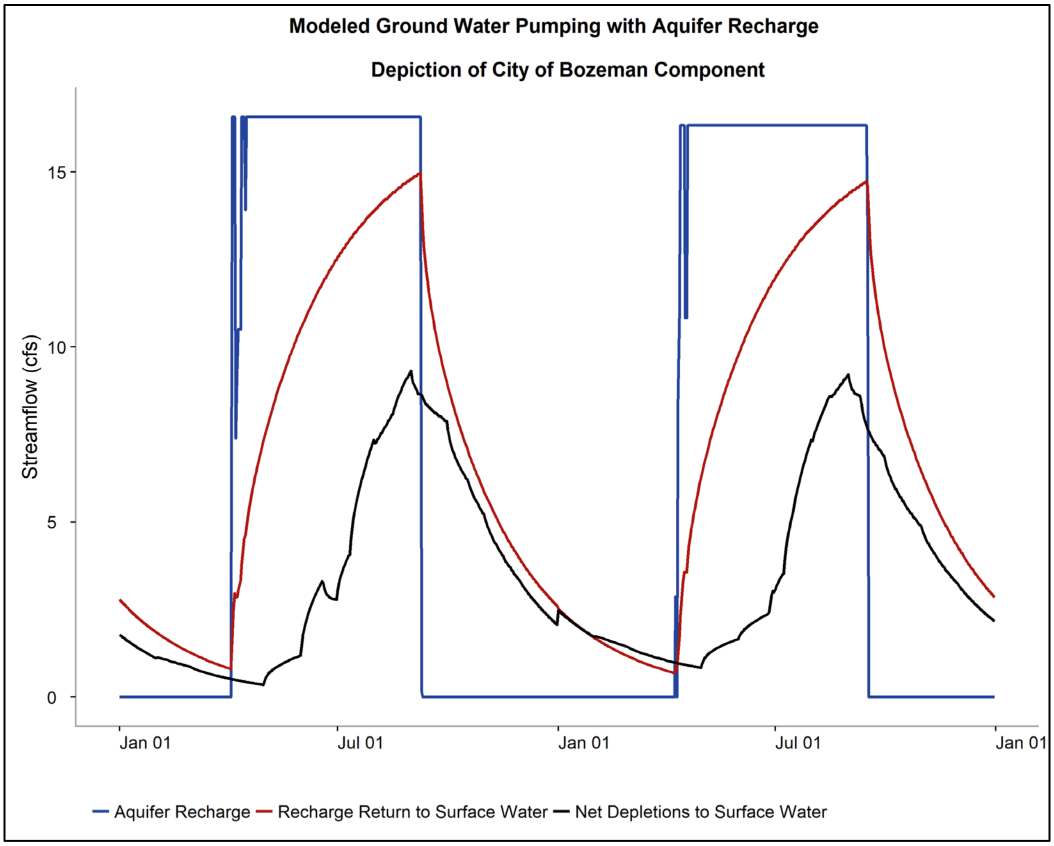


Figure 14.—Modeled depletions to surface water compared to aquifer recharge rates and outflows from recharge to surface water.

6.5.2.3.2. Other Considerations

6.5.2.3.2.1. Well Sites

Kendy and Bredehoeft (2006) investigated the effects of groundwater pumping and surface-water-irrigation returns on streamflow in the Gallatin Valley. They found that by strategically timing and locating artificial recharge within a basin, groundwater and surface water may be managed conjunctively to help maintain desirable streamflow conditions as land uses and irrigation practices change. They found that the most important factor in estimating stream depletion from pumping is the distance from the well to the stream and that artificial recharge near the pumping site is one way to achieve mitigation that conserves the quantity and timing of the stream depletion.

Kendy and Bredehoeft (2006) used average aquifer characteristics for the Gallatin Valley. Moving aquifer recharge sites as far as possible from the surface water source would be one way to potentially further delay aquifer recharge returns. Artificial recharge could be sited most effectively to offset the effects of pumping if the aquifer materials are similar and the recharge site is the same distance from the stream as the pumping site. The shallow aquifer to 45 - 60 feet, where recharge might occur, is highly permeable while at depth, where water might be pumped for M&I use, the aquifer materials become finer and it is less transmissive. Injection wells might be a way to add recharge water deeper in the aquifer and further attenuate returns to surface water.

6.5.2.3.2.2. Institutional Framework

During stakeholder outreach, questions were raised concerning whether the institutional framework exists to implement this type of strategy. Utility Solutions LLC, a privately held water and waste-water utility serving unincorporated areas near Four Corners in Gallatin County and recently purchased by Four Corners Water and Sewer District, has successfully mitigated new public water supply wells with existing junior irrigation water rights using an aquifer recharge basin (Montana DNRC 2015).

Montana passed a state law in 2011 that allows existing water rights holders to change all or part of an appropriation for use as aquifer recharge or mitigation (§85-2-420, MCA). Part of the appropriation may be marketed (e.g., leased) or sold. A Gallatin Valley water exchange has been suggested as a way to facilitate water transactions for mitigating new groundwater use (Bren School of Environmental Science and Management 2016). Aquifer recharge mitigation with water rights and selling mitigation credits to new water users to offset effects of groundwater pumping was identified as a potential type of transaction a water exchange could facilitate.

Given the physical and legal challenges associated with this strategy, aquifer recharge might be developed incrementally through multiple, dispersed recharge areas throughout the Greater Gallatin Valley, rather than as a single large facility. Mitigation facilities would likely be sited in areas of the valley where aquifer conditions and other factors are most conducive.

6.5.2.3.2.3. Applicability

The strategy concept has been developed with the Gallatin Valley as a model, but it could be applicable to other Missouri Headwaters valleys to supply water for growing populations. Anticipated future changes to runoff timing would need to be considered in developing this strategy. This type of concept might be furthered developed and pursued by a city, NGO, or private entity.

6.5.2.4. Strategy 2: Developing a Water Supply Pipeline from Canyon Ferry Reservoir Pipeline

This option models a 60-mile pipeline from Canyon Ferry Reservoir to deliver water upstream to the Greater Gallatin Valley. In its Integrated Water Resources Plan, the City of Bozeman considered a 36-inch diameter pipeline from Canyon Ferry Reservoir. The City also investigated the possibility of a shorter 30-mile pipeline which would divert water from the Missouri River upstream, near Three Forks. During the integrated water resources planning process, the technical advisory committee chartered by the Bozeman City Commission recommended against importing water from outside the Gallatin River basin due to costs, legal hurdles, and environmental concerns (AEES 2013). This would be a long-range regional option, and it may only be practicable with support from the City of Bozeman and the other communities and rural water users in the Gallatin Valley, as well as possibly the State and Federal government.

6.5.2.4.1. Performance

The model was used to evaluate pipeline water deliveries and potential impacts to other resources. Pipeline diversion demands were determined based on projected City of Bozeman and Gallatin Valley populations and per-capita use rates to follow the patterns shown in Figure 15. Modeled water demand from Canyon Ferry Reservoir for the City of Bozeman is that needed by the future population above what is modeled to supply the City under future climate scenarios from the City's existing water sources. Other Gallatin Valley users were modeled to have their future water needs above historical be met solely with imported Canyon Ferry water.

The pipeline was modeled to import about 20,200 acre-feet of water per year to the Gallatin Valley at an average rate of about 28 cfs. As with the previous strategy, the additional water would be diverted when existing water supplies were insufficient to meet demand. The rate ranged from a summer peak of up to about 58 cfs to a low in the winter of about 17.5 cfs (Figure 15). The water users outside of the City of Bozeman account for about half of the modeled diversions.

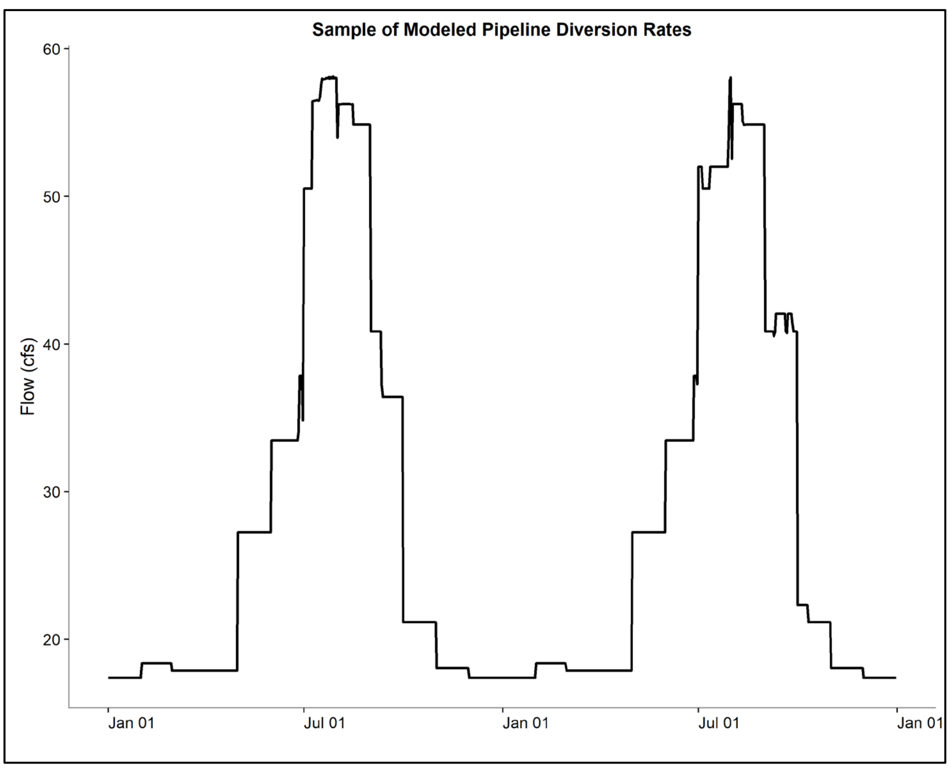


Figure 15.—Modeled Canyon Ferry pipeline seasonal diversions for a sample two-year sequence.

A consideration with importing Canyon Ferry water for municipal and domestic use is that it would need to be treated to remove arsenic to current water quality standards. This arsenic primarily originates from the Madison River headwaters in the geothermal areas of Yellowstone National Park. The City of Helena Missouri River Water Treatment Plant has been successful at treating Canyon Ferry Reservoir water to water quality standards (Helena Water Treatment Division 2015). Water might be treated at the diversion site or elsewhere on the pipeline system.

A water service contract from Reclamation would be needed for this type of development. Water in Canyon Ferry Reservoir in the amounts need for this strategy was available for contracting under all future scenarios and extreme paleo event scenarios. The contract and features associated with the project, such as pumping facilities from the reservoir, would require a special use permit and compliance with the National Environmental Policy Act (NEPA) and National Historic Preservation Act (NHPA). Additional requirements typically associated with pipeline infrastructure (rights-of-way) would also need to be considered.

6.5.2.4.2. Trade-Offs for Gallatin River Basin Strategies

Because these two strategies were developed to mitigate depletions to surface water, model results did not show appreciable changes to East Gallatin River and Lower Gallatin River streamflow (Figure 16).

6.5.2.4.2.1. Figure Orientation

In Figure 16, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel in Figure 16 shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability. The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

The middle panel shows how different strategies affect the performance measures under historical conditions. The reader may explore in these figures: *had the strategy been implemented under current conditions, what effect does it have?*

The third panel shows the effect of strategies under future and paleoclimate scenarios. The reader may explore in these figures: *do the strategies have a noticeable effect on the vulnerabilities identified in the first panel, and are the effects of the strategies seen under historical conditions in the second panel still evident under a range of scenarios?*

6.5.2.4.2.2. Figure Discussion

An important consideration for Strategy 1: Pumping Groundwater with Corresponding Aquifer Recharge is that irrigated acres were reduced to supply the water needs for the municipal and rural domestic growth. This would substantially reduce irrigated acres in the Greater Gallatin Valley.

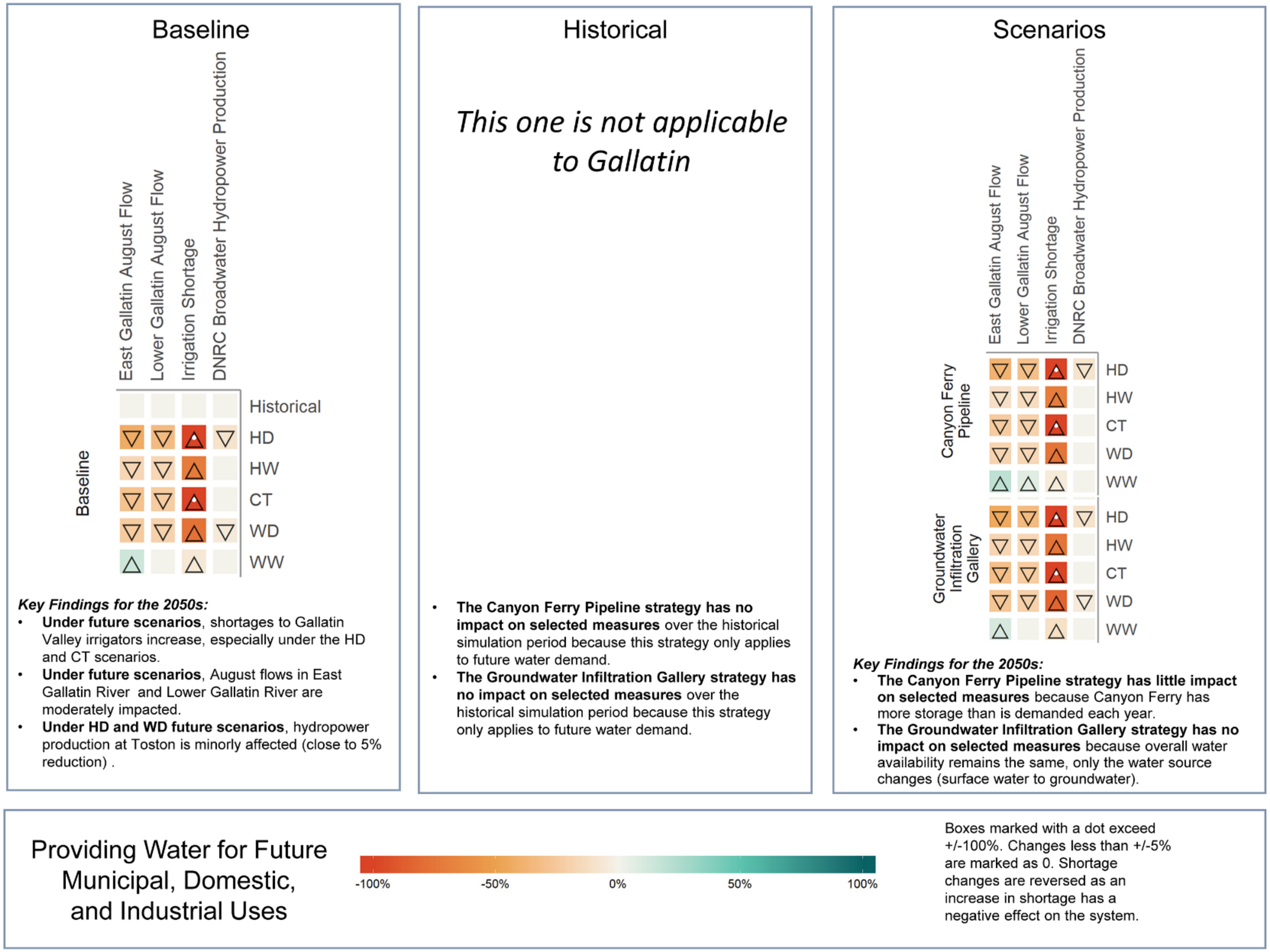


Figure 16.—Resource benefit changes comparison chart for the Providing Water for Future Municipal, Domestic, and Industrial Uses in the Gallatin Valley strategies (2050s futures).

6.6. System-Wide Water Management Strategies

The strategies discussed in this section were developed as ways of alleviating current and possible future challenges related to water supply availability. There were two strategies identified that have implications for water supply and demand across much of the study area. These strategies include:

1) Increasing on-farm and irrigation conveyance system efficiencies for all agricultural water users.
2) Introducing ecological flow releases from Canyon Ferry and Tiber Dam.

These strategies are further described in the sections that follow. Strategy performance and trade-offs were evaluated according to the assessment measures discussed previously.

6.6.1. Increasing Canal and On-farm Irrigation Efficiencies

6.6.1.1. Background

There are about 1.1 million acres of land irrigated in the study area upstream of Fort Peck Reservoir. While much of this irrigation originated as gravity flood systems, the percentage of irrigation under center pivot and other sprinkler irrigation systems in Montana statewide increased between 1977 and 2008 from about 25 percent to about 45 percent (Figure 17). Conversions to sprinkler irrigation are expected to continue, although there are limits to the conversion because not all lands are suitable for sprinkler irrigation. Changes also have been made to decrease losses from the delivery systems that convey water to the irrigated fields from the source, such as converting open ditches to pipelines and lining ditches.

A flood irrigation system in the Ruby River valley.

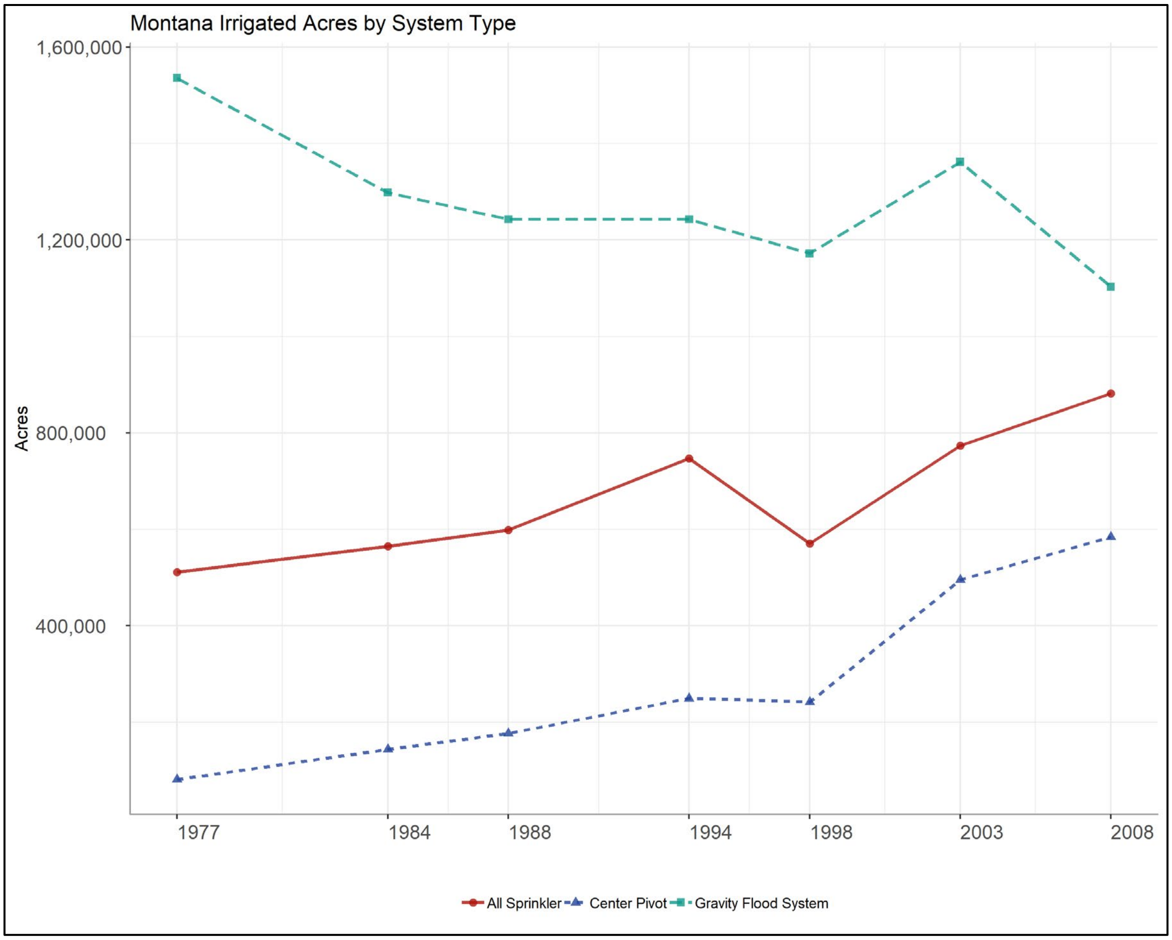


Figure 17.—Montana irrigation trends (source data: U.S. Department of Agriculture [USDA] undated).

6.6.1.2. Objectives

The objectives of this strategy are to investigate how trends towards increasing irrigation efficiencies might affect resources in the Missouri Headwaters (including the availability of water for irrigation and irrigation production, reservoir operations, hydropower production, recreation, and ecological resources) in the future and to investigate challenges and opportunities that this might create. Efficiency increases would include both on-farm and conveyance efficiencies.

A sprinkler irrigation system in the Missouri River Valley near Townsend, Montana.

On-farm efficiencies: These conservation measures could include conversions from flood to sprinkler irrigation and more efficient flood irrigation water distribution, such as gated pipe, surge valves, land leveling, or shorter field runs. More efficient irrigation systems generally result in a larger percentage of the water applied on the field effectively meeting the crop's evapotranspiration requirements.

Conveyance efficiency: These conservation measures involve the conveyance system—from the point of diversion on the stream or canal to the field. Efficiencies could include reducing losses to canal seepage and decreasing operational water spills off the end of the ditch system. Conveyance system improvements could include lining canals and laterals, putting lateral ditches into pipe, reducing operational spills by incorporating water measurement and automation into operations, reusing spills, and improving water management.

For this strategy, modeled irrigation efficiencies (combined on-farm and conveyance) were increased for each individual user group by 25 percent over the baseline (Reclamation 2019b), or to a minimum of 35 percent and maximum of 72 percent. Table 13 summarizes the composite baseline efficiency and modeled increased efficiency by major sub-basin. Sub-basins with large acreages operating with higher initial efficiencies or acres irrigated by groundwater would have percentage increases less than 25 percent.

6.6.1.3. Performance and Trade-Offs for Increasing Canal and On-farm Irrigation Efficiencies

Although more efficient irrigation systems usually require less water to be diverted, more water generally will be depleted from the system through evapotranspiration, as irrigation water is delivered in a more uniform and timely manner. Table 14 compares irrigation depletion shortages for the Missouri Headwaters area above Three Forks, with and without the strategy. The reductions to depletions in the fourth column of the table correspond with the overall increase in the volume of water modeled to be depleted from the system.

Table 12.—Modeled Increases in Irrigation Efficiencies Compared to Baseline by Sub-basin

Sub-basin	Baseline Percent Efficiency	Strategy Percent Efficiency	Percent Increase
Beaverhead	36.6	46.7	27.5
Big Hole	20.0	35.0	75.0
Boulder	26.0	35.0	34.6
Gallatin	39.6	49.2	24.3
Helena Valley	48.2	54.7	13.4
Jefferson	33.0	41.3	25.0

Table 12.—Modeled Increases in Irrigation Efficiencies Compared to Baseline by Sub-basin

Sub-basin	Baseline Percent Efficiency	Strategy Percent Efficiency	Percent Increase
Judith	29.3	36.6	25.0
Madison	35.2	44.0	25.0
Upper Missouri	36.6	45.8	25.0
Marias	46.1	57.6	25.0
Missouri Below Great Falls	28.0	35.0	25.0
Upper Musselshell	22.2	35.0	57.7
Middle Musselshell	31.5	39.4	25.0
Lower Musselshell	35.3	44.1	25.0
Ruby	30.0	37.5	25.0
Smith	40.6	50.8	25.0
Sun	44.0	54.5	23.9
Upper Teton	56.0	70.0	25.0
Lower Teton	31.0	38.8	25.0
Area Weighted Average	**36.2**	**46.8**	**29.3**

Table 13.—Comparison of Irrigation Depletion Shortages for the Missouri Headwaters Upstream of Three Forks under the Increasing Canal and On-Farm Irrigation Efficiencies Strategy

Scenario	Shortage without Strategy (acre-feet)	Shortage with Strategy (acre-feet)	Increased Depletions with Strategy (acre-feet)	Change with Strategy (%)
Historical	202,957	154,961	47,996	23%
HD 2050s	363,341	293,699	69,642	19%
HW 2050s	275,857	211,470	64,387	23%
CT 2050s	311,547	246,061	65,486	21%
WW 2050s	213,121	160,093	53,028	25%
WD 2050s	282,260	223,040	59,220	21%

6.6.1.3.1. Figure Orientation

Figure 18 summarizes modeled changes to resource measures at select locations due to the strategy for the period centered on the 2050s. In Figure 18, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel in Figure 18 shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability. The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

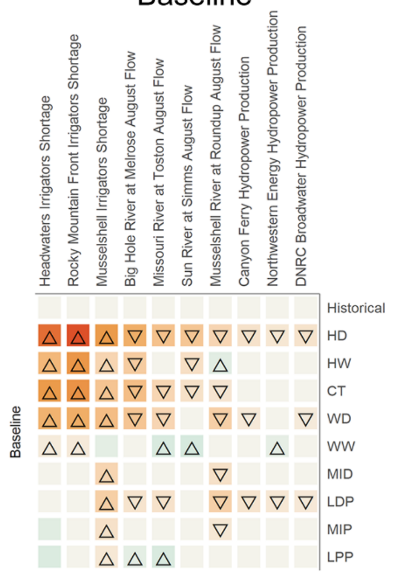
The middle panel shows how different strategies affect the performance measures under historical conditions. The reader may explore in these figures: *had the strategy been implemented under current conditions, what effect does it have?*

The third panel shows the effect of strategies under future and paleoclimate scenarios. The reader may explore in these figures: *do the strategies have a noticeable effect on the vulnerabilities identified in the first panel, and are the effects of the strategies seen under historical conditions in the second panel still evident under a range of scenarios?*

6.6.1.3.2. Figure Discussion

Irrigation shortages, as measured by the amount of water supplied to the crop relative to the demand, increase under future scenarios, but improved irrigation efficiencies lessen the impact, with shortage reductions being greatest under the HD and HW scenarios. There are some differences in the performance of the measure between watersheds. For instance, modeled decreases to irrigation depletion shortages in the Musselshell River basin are not as large as in the Rocky Mountain Front or Headwaters regions, possibly because the lengthy reach of this river allows irrigation returns from inefficient systems to continually be recycled and eventually depleted as water flows down the system.

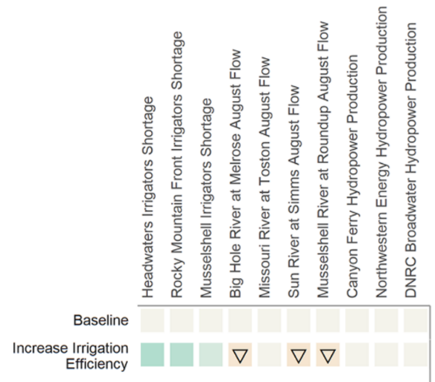
Baseline



Key Findings for the 2050s:

- **Under future scenarios**, shortages increase to irrigators in all regions. These increases are especially pronounced for irrigators in the Rocky Mountain Front (Sun) and Headwaters (Gallatin) regions.
- **Under future scenarios (except HW),** decreases in August flows are projected.
- **Under drier future scenarios**, small reductions in hydropower production are projected, otherwise tere is no noticeable change.
- **Under the longest paleo drought period (LDP),** shortages to all irrigators were larger than for this historical scenario, but not as large as in future scenarios.

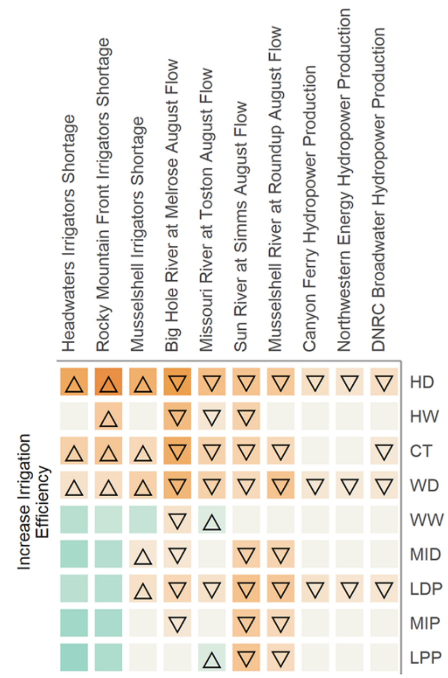
Historical



Key Findings for the historical scenario:

- **Increasing irrigation efficiencies** under historical conditions decreases shortages to irrigators in all regions.
- **Increasing irrigation efficiency** decreases average August flow at Big Hole River at Melrose, Sun River at Simms, and Musselshell River at Roundup, but does not affect August flows at Missouri River at Toston.
- The strategy no noticeable effect on average annual hydropower production.

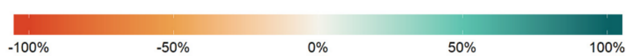
Scenarios



Key Findings for the 2050s:

- **Increasing irrigation efficiency** lessens the impacts of future scenarios on irrigation shortages.
- **Increasing irrigation efficiency** does not noticeably affect the impacts of future change on average August flows.
- **Increasing irrigation efficiency** may result in slightly less average annual hydropower production under drier future scenarios.

Increasing Canal and On-Farm Irrigation Efficiencies



Boxes marked with a dot exceed +/-100%. Changes less than +/-5% are marked as 0. Shortage changes are reversed as an increase in shortage has a negative effect on the system.

Figure 18.—Resource benefit changes comparison chart for the Increasing Canal and On-farm Irrigation Efficiencies strategy (2050s futures).

For the Sun River in the Rocky Mountain Front, the water supply for most of the irrigated land is diverted in the upper portion of the Sun River basin and then is conveyed a considerable distance down the watershed by irrigation canals. It is not possible to re-capture most of irrigation returns because they flow into the very lower portion of the river, where there is a much smaller irrigated land base. Modeled shortage decreases were more pronounced here because of the limited opportunities to recycle water and because more efficient irrigation systems would consume more water overall.

The results from a representative sample of river monitoring stations indicate that increasing irrigation efficiencies would generally decrease or not have a noticeable impact on average August streamflow (middle panel in Figure 18), due to a combination of modeled increases in the amount of water depleted and reductions to irrigation return flow. Streamflow reductions were modeled to be greater under the future climate scenarios (left panel). Reductions would be most notable in streams such as the Big Hole River, where baseline efficiencies are low and groundwater return flows, which contribute to late season flows would be reduced most. Lower late summer streamflow could have adverse effects on ecological resources and recreational opportunities. Overall, modeled percentage changes to August streamflow due to increased efficiencies were modest (right panel) because the efficiency increases were relatively small and because the hydrology model tends to overestimate late summer streamflow for most headwater streams.

The model results also indicate some modest reductions to hydropower production across future scenarios at Canyon Ferry Dam and the NorthWestern Energy facilities downstream. Increasing irrigation efficiency may result in slightly less average annual hydropower production under drier future scenarios. This likely is due to an overall increase in the amount of water depleted from the system and corresponding decrease in the flow of water through the turbines.

6.6.1.4. Other Considerations

In some locations, it might be possible to achieve multiple resource objectives through irrigation efficiency improvements. For instance, in a highly regulated sub-basin, such as in the Sun River basin, as irrigation systems become more efficient there might be opportunities to mitigate potential late-season streamflow reductions through refinements to reservoir and delivery system operations. Linstead (2018) states that “A key first step should be to establish quantitatively (e.g., using modelling and field observations) whether, in the specific context being considered, there is potential for increased irrigation efficiency to deliver ecologically relevant improvements to the timing of flows.” Evaluating these types of opportunities more specifically at the watershed scale would be a next step towards implementing this strategy.

6.6.2. Ecological Flow Releases from Canyon Ferry Reservoir and Lake Elwell

6.6.2.1. Background

There is concern that flow regulation at Canyon Ferry Reservoir and Lake Elwell have reduced the magnitude and frequency of downstream peak streamflow. Higher streamflow can mobilize streambed gravel and flush out accumulated sediment, which helps to provide an oxygen rich environment for fish eggs to incubate and provide habitat for aquatic insects which provide food for fish such as trout and whitefish. The Upper Missouri Watershed Alliance (UMOWA) suggested that pulse flow releases from Canyon Ferry Reservoir, or periodic high-flow events, would create a more natural state of the river and generally improve river health (UMOWA 2017). Further, these pulse flows might dislodge some of the excess aquatic vegetation on the streambed. UMOWA has begun a conversation with Reclamation, NorthWestern Energy, and the Montana DFWP concerning the possibility of providing an annual large pulse flow to flush the Missouri River below Holter Dam. Ramping releases up to a peak of 14,000 cfs was suggested as a starting point.

The Marias River immediately below Tiber Dam contains a trout fishery, and the river below the Highway 223 Bridge contains a variety of warm-water fish and serves as a spawning area for fish from the Missouri River. Tiber Dam (Lake Elwell) regulates the Marias River for flood control and for augmenting downstream flow when reservoir inflows are low. There has been interest in periodically releasing higher flows from Lake Elwell to mimic some of the pre-dam variability of the natural flow regime downstream to benefit fisheries and riparian habitat. During 2006 when the reservoir was nearly full, Reclamation took the opportunity to make a pulse flow release from the reservoir, resulting in a June peak flow of about 4,800 cfs. An assessment after the release documented improved fisheries and riparian habitat (USGS 2008). Reclamation also made a pulse flow release for downstream fisheries, with a peak flow of about 4,000 cfs, during June 2014.

Within the study area, the main stem of the Missouri River below the Great Falls and the Marias River represent the upstream extent of the Great Plains Management Unit (GPMU), one of four major management units identified in the 2014 Pallid Sturgeon Revised ESA Recovery Plan. While the Great Falls of the Missouri River are believed to have represented a natural boundary above which pallid sturgeon could not migrate, dams such as Fort Peck Dam on the Missouri River and Tiber Dam on the Marias River now present migratory barriers that did not exist historically.

Additionally, the dams upstream of the Great Falls, including Canyon Ferry, affect river flow, temperature, and sediment and nutrient transport regimes which are believed to affect the various life stages of pallid sturgeon. Within the Upper Missouri River basin, specifically, recovery strategies have focused on adaptive management of reservoir flow releases, habitat protection, and restoration. Instream flow criteria specific to pallid sturgeon life history within important reaches of the Mainstem Missouri River and critical tributaries may be developed and implemented (USFWS 2014).

6.6.2.2. Objectives

The objectives of this strategy are to evaluate the potential of ecological pulse flow releases from Canyon Ferry Reservoir and Tiber Dam to improve aquatic habitat in the Missouri and Marias Rivers, and potentially trigger pallid sturgeon 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 ramped-up 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 (Figure 19).

Confluence of the Marias and Missouri Rivers near Loma, Montana.

Modeled releases from each reservoir were simulated when the forecasted snowmelt season runoff volume exceeds the 20th percentile based on historical volumes. In years when the Canyon Ferry and Tiber Dams' targeted flow releases were modeled to overlap, there would be more potential for benefits to ecological resources in the Missouri River downstream of the mouth of the Marias River due to the combined increase in flow. These benefits might include habitat and spawning conditions for the endangered pallid sturgeon, shovelnose sturgeon, paddle fish, sauger, and other warm-water species.

It is important to note that only streamflow in the Missouri River system above Fort Peck Reservoir was considered in modeling this strategy. 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.

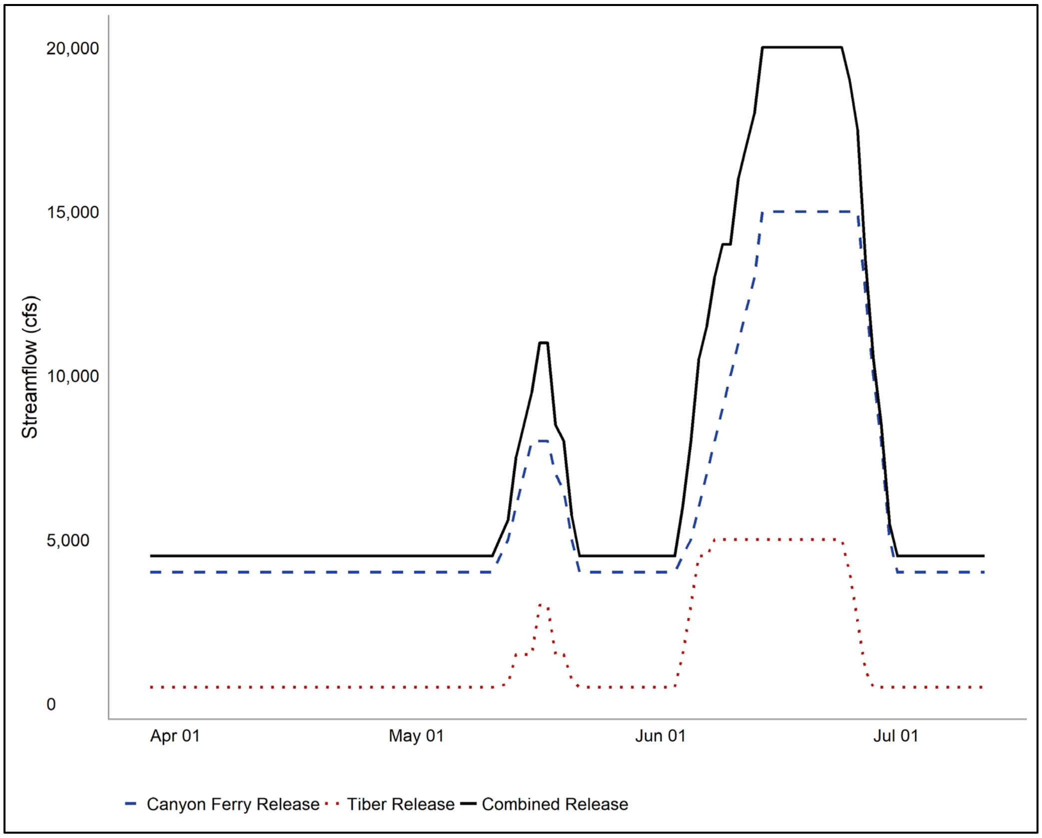


Figure 19.—Example of Canyon Ferry and Tiber Dams coordinated release scenario.

Table 14.—Example Ecological Flow Release Scenarios Where Synchronized Releases were Modeled

Release Timing	Reservoir	Peak (cfs)	Duration* (days)	Volume of Release (acre-feet)**
May and June	Canyon Ferry	15,000	50	462,039
	Lake Elwell	5,000	50	207,025
	Combined Release***	20,000	50	669,064

*This is the duration of the entire ecological flow releases, not just the peak.
**This is the volume of the release above the 4,000 cfs base release for Canyon Ferry Reservoir and the 500 cfs base release for Lake Elwell.
***This would not include additional tributary inflow that would occur downstream of the reservoirs.

Because most future scenarios predict increased runoff and inflow to Canyon Ferry Reservoir and Lake Elwell, this strategy might be able to take advantage of some of that inflow to make more frequent targeted releases to maintain downstream channel characteristics for fisheries and aquatic and riparian habitat and provide high flows for spawning fish. As shown in Table 15, a substantial volume of water would be required for these flow releases.

6.6.2.3. Performance and Trade-Offs for the Ecological Flow Releases from Canyon Ferry Reservoir and Lake Elwell

Figure 20 depicts an example modeled release based on hydrologic conditions for the year 1956 when Canyon Ferry outflow was at the 15,000 cfs during the entire month of June and a release was made from Lake Elwell. The graph also shows how inflows from other tributaries, which were peaking at about the same time, contributed to boost the total flow at the Missouri River at the study area outlet at Landusky to over 30,000 cfs.

Although the strategy did not appreciably increase the modeled highest peak flow rates for the lower Missouri River, it did demonstrate the potential to accomplish a couple of objectives:

- First, it would allow for a controlled one-month release, which might be long enough to allow for native fish spawning. The relatively abrupt modeled drop in the flow at the time larval fish are emerging could increase the downstream drift time and might allow these larvae time to develop in the river where they are more likely to survive rather than getting swept into Fort Peck Reservoir. With a substantial inflow from the Marias River, some native fish might be impelled to ascend that stream during the time of the release, which could increase spawning habitat overall.

- Second, as the timing of spring runoff shifts earlier in the future, a managed release could be made that corresponds more closely with the long-established timing of fish migration and spawning.

Projected future flow conditions might provide more opportunities for these types of ecological pulse flow releases.

Figure 21 depicts the frequency for which these releases were modeled during a sample of 50-year periods which were developed with paleohydrology data to account for the range of flow conditions that occurred in the past and could occur again during the future. The black line overlaying each historical bar summarizes the number of qualifying releases made during the historical simulation period (water years 1951 - 1999). To further describe results shown in Figure 21 during a 50-year period under historical conditions, targeted pulse flow releases were modeled to be made from Canyon Ferry reservoir from 1 to 12 years, from Tiber Dam in 5 to 16 years, and targeted releases from the two reservoirs were only modeled to overlap, at best, during only 1 of those year. For the HW future scenario, Canyon Ferry Dam releases were modeled to occur from 13 to 36 times during a 50-year period, Tiber Dam releases made ranged from 18 to 32, and releases overlapping releases were modeled to occur from 7 to 25 times.

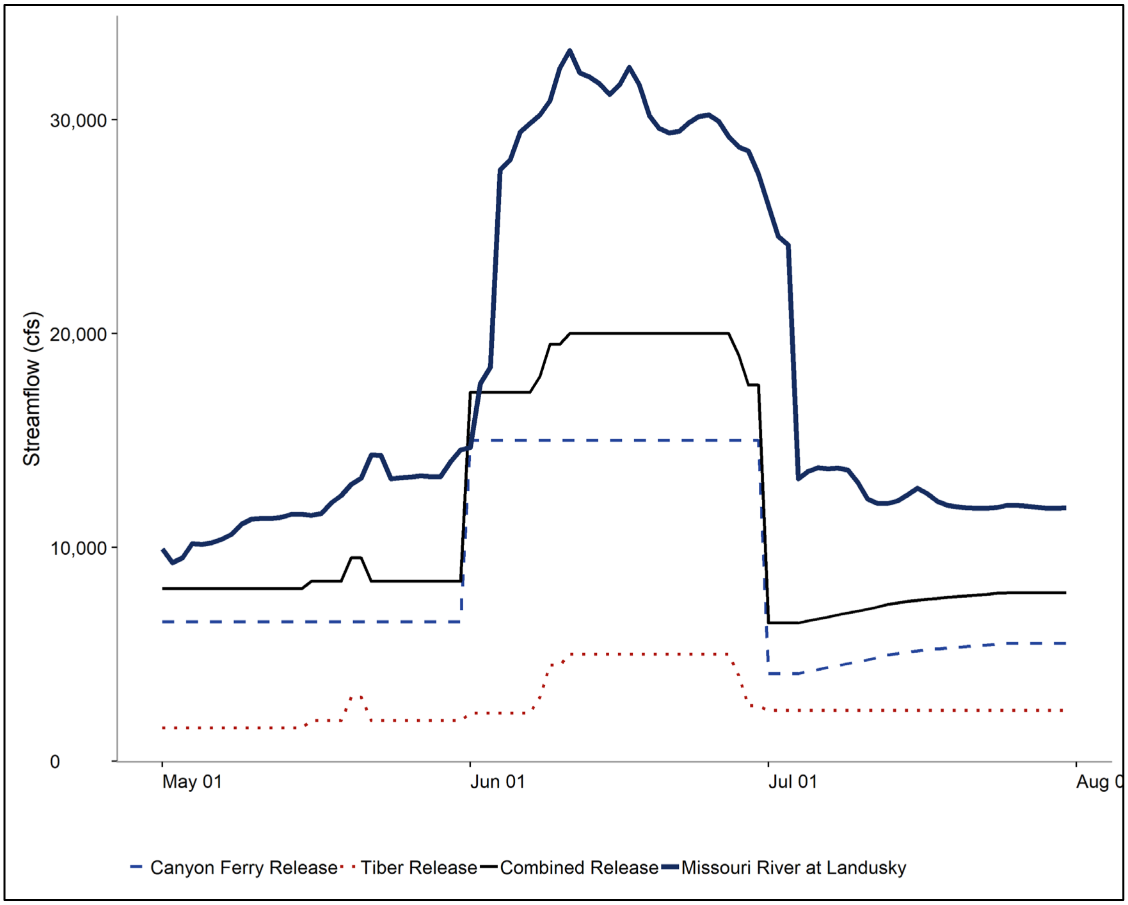


Figure 20.—Example of a modeled ecological flow release based on 1956 conditions.

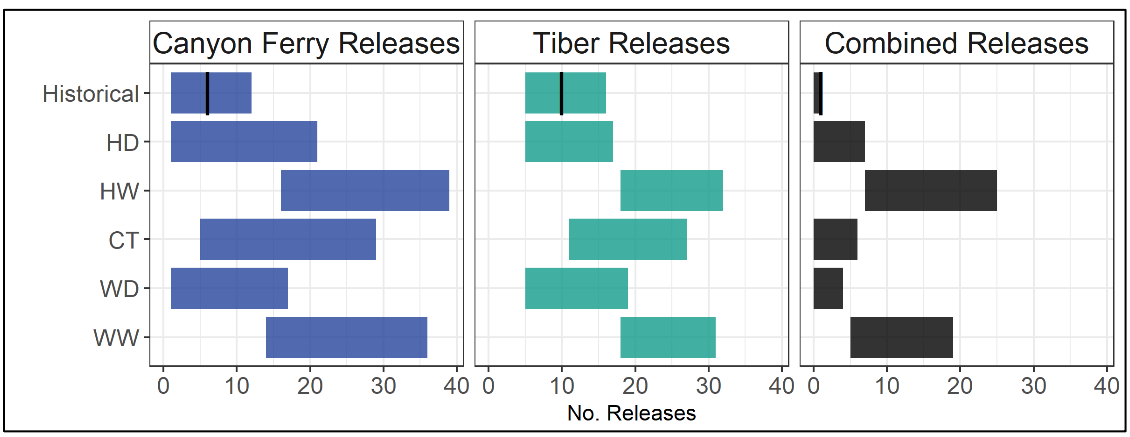


Figure 21.—Comparison of number of ecological flow releases for each reservoir and combined flow releases under historical and future scenario conditions.

6.6.2.3.1. Figure Orientation

Figure 22 summarizes how ecological flow releases may impact other resources in the study area. In Figure 22, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability. The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

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6.6.2.3.2. Figure Discussion

The ecological flow releases were modeled to result in some decreases to late summer flow for the Marias River at Loma and to Lake Elwell's end-of-water-year (EOWY) storage (right panel in Figure 22 compared with left panel). Modeled hydropower production at Tiber did not change appreciably. Changes to other Canyon Ferry resources measures (e.g., hydropower production, reservoir levels, and streamflow at other times of the year) were modest but more than 5 percent. These changes may be because the releases were limited to a maximum of 15,000 cfs due to downstream flooding concerns and were modeled to be made during wetter years, when similar releases would most likely be required under current reservoir operation procedures anyway.

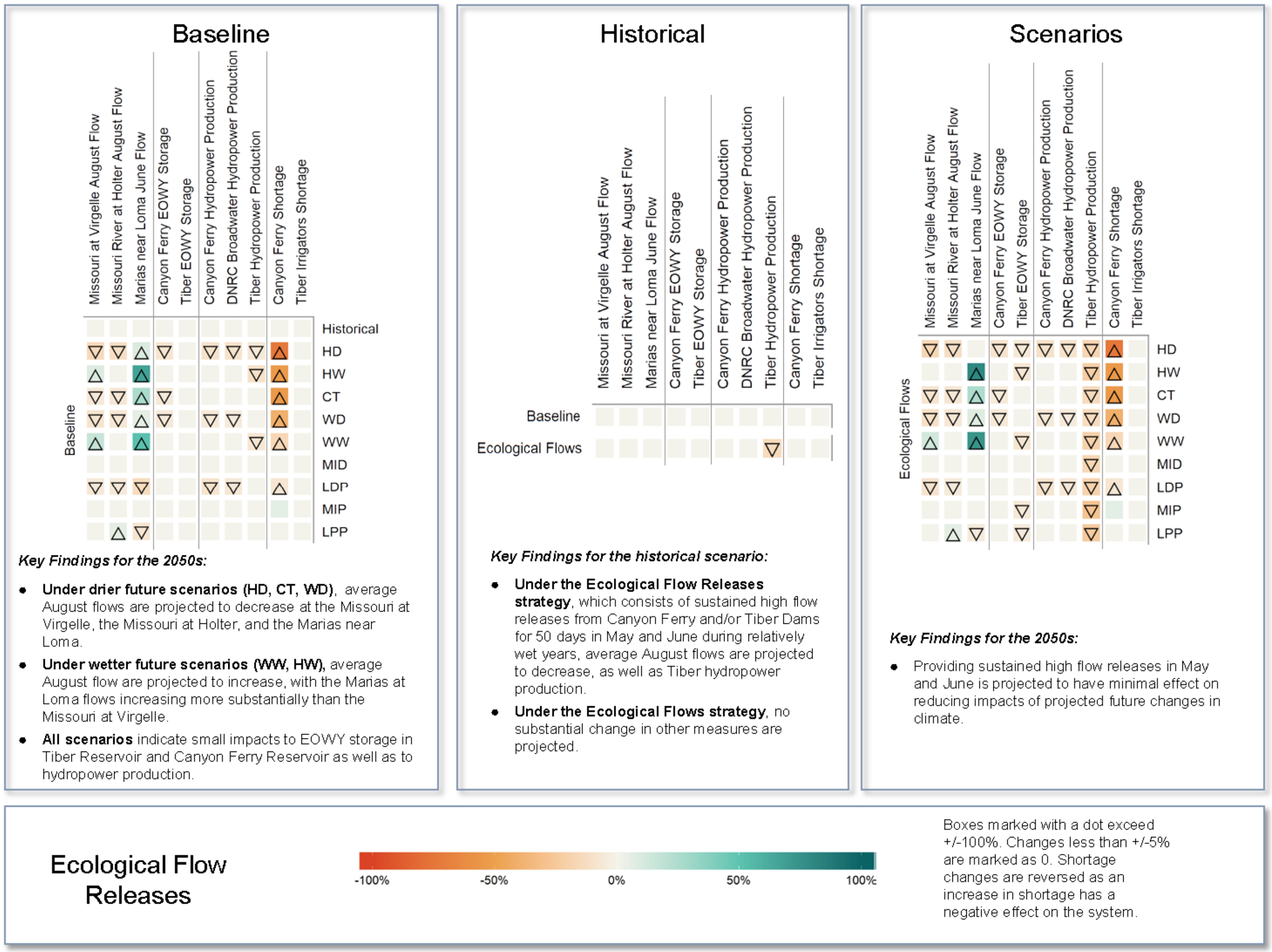

Figure 22.—Resource benefit changes comparison chart for the Ecological Flow Releases from Canyon Ferry Reservoir and Lake Elwell strategy (2050s futures).

6.7. Beaverhead River Basin Strategies

Irrigation water shortages are common in the Beaverhead River basin and late summer streamflow in the Beaverhead River between Clark Canyon Reservoir and the Barret's Diversion Dam are projected to decrease under most future scenarios. This section investigates potential strategies for storing more water in Clark Canyon Reservoir to increase irrigation allocations during dry years and possibly improve Beaverhead River instream flow.

Clark Canyon Dam and Reservoir.

6.7.1. Decreasing the Drawdown for Clark Canyon Reservoir Flood Storage

Currently, 79,075 acre-feet of Clark Canyon Reservoir storage are allocated for exclusive flood control. 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 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.

6.7.2. Capping the Clark Canyon Reservoir Winter Release at 100 cfs

Minimum winter releases from Clark Canyon Reservoir are set by following guidelines based on the September 1 storage volume plus what the inflow volume was during July and August (Table 16). The maximum winter release of 200 cfs can result in a substantial reduction to the amount of water stored during the winter and it is thought that this could, in some cases, result in a reduced winter release rate during subsequent years.

Table 15.—Clark Canyon Winter Release Guidelines

September 1 Clark Canyon Reservoir storage plus July-August Inflow Volume (acre-feet)	Minimum Winter Release (cfs)
Less than 80,000	25
80,000 - 130,000	50
130,000 - 160,000	100
160,000 or greater	200

This strategy's objective is to provide a more consistent winter instream flow rate by reducing the maximum rate to 100 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.

6.7.3. Decreasing Flood Storage and Capping Winter Releases

This strategy would combine the decreased flood storage drawdown and winter instream flow release cap options described above.

6.7.4. Performance and Trade-Offs for the Clark Canyon Reservoir Operational Strategies

The benefits from these strategies in reducing irrigation water shortages for the two water user groups that have contracts to Clark Canyon Reservoir Water, the East Bench Irrigation District and Clark Canyon Water Supply Company, might be subtle overall, but this strategy could provide important benefits during some drought years when water is at a premium. Figure 23 illustrates modeled results from the historical data set for a sequence of drought years in the late 1980s and early 1990s. Modeled annual water allocations, as a percentage of full allocation, increased noticeably during drought years with the strategies, except during 1991 which was the worst drought year and near the middle of the sequence. For that year, the East Bench users were not modeled to have any water available to them, with or without the strategy. Because the plots in the graph for the capped winter release and combined strategies line up, it appears that most of the benefits would be attributable to the cap in the winter flow release from the reservoir.

East Bench Irrigation District Canal.

6.7.4.1. Figure Orientation

Figure 24 shows changes to various resources by scenario associated with the three strategies discussed in this section. In Figure 24, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (∆) for positive change and a down arrow (∇) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

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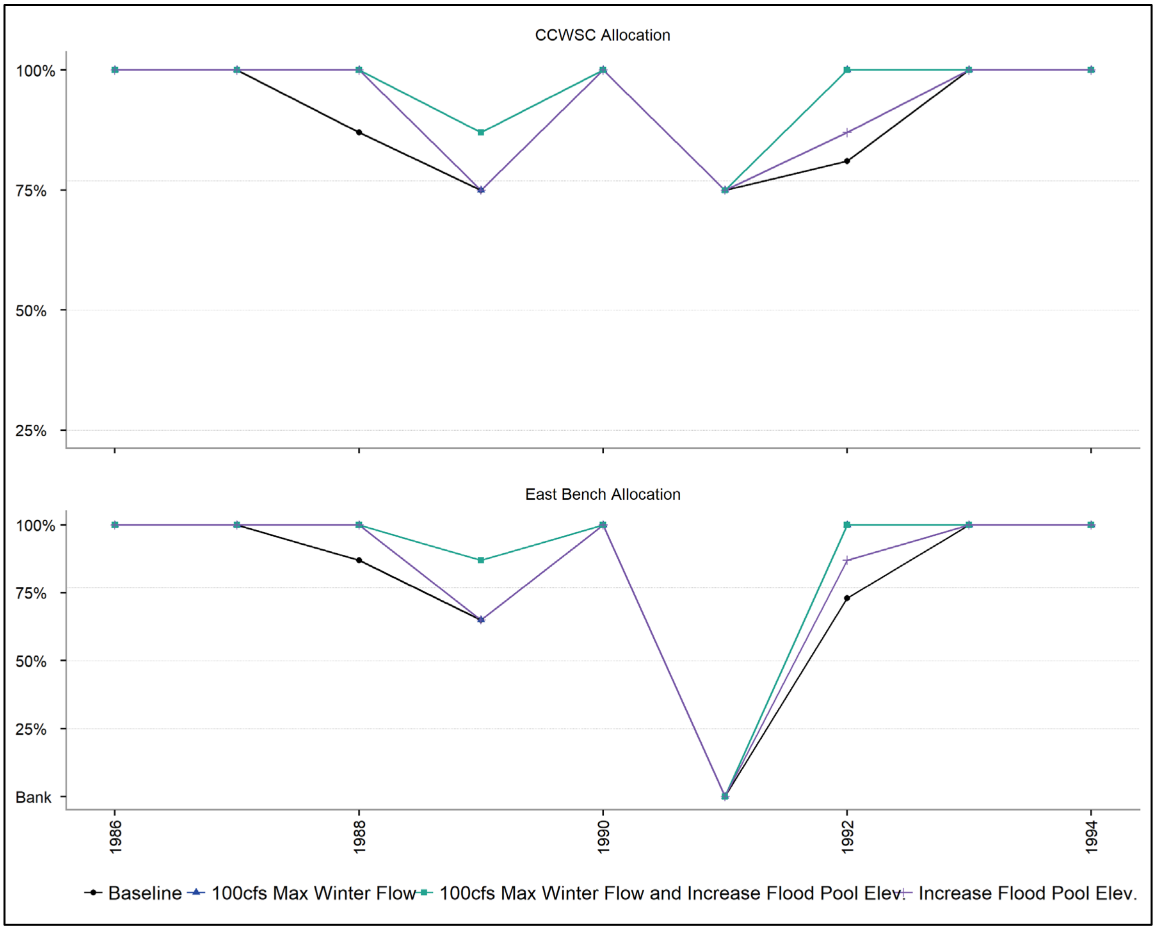


Figure 23.—Modeled percent changes to Clark Canyon Water Supply Company and East Bench Irrigation District allocation fractions for a sample drought year sequence.

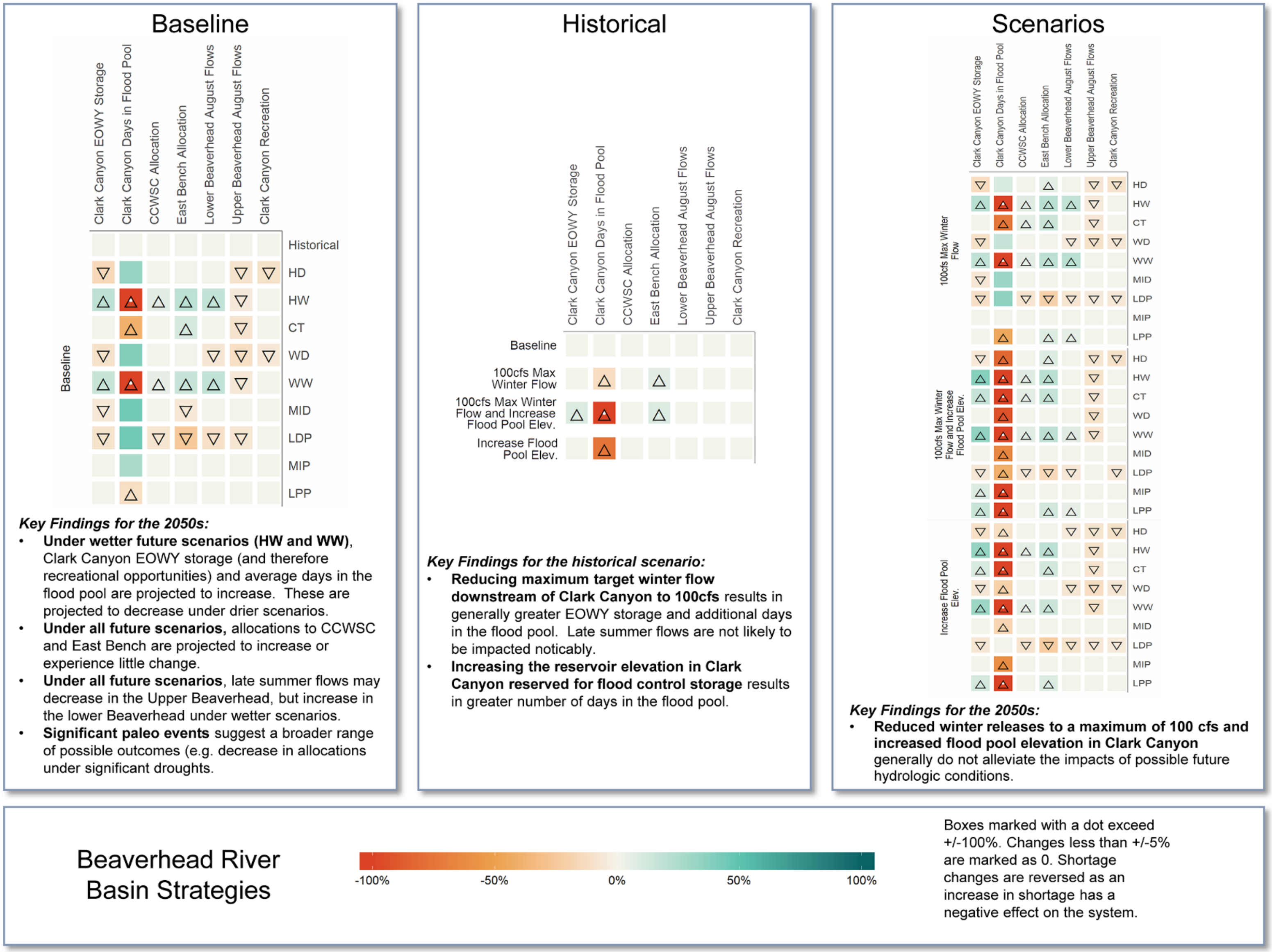


Figure 24.—Resource benefit changes comparison chart for the Beaverhead River basin strategies (2050s futures).

6.7.4.2. Figure Discussion

There would be some instream flow increases below Clark Canyon Dam during drought years in the river below Clark Canyon Dam associated with delivering water to the irrigation contract users (right panel compared with left panel). However, the opportunity for a winter instream flow release above 100 cfs during wetter years and associated benefits would be lost. Reservoir fisheries might benefit as model results showed higher end of water year reservoir levels for some scenarios. Under the increased flood pool and combined strategies, the time that the reservoir was in the exclusive flood control zone would notably increase.

6.8. Sun River Basin Strategies

6.8.1. Background and Objectives

Sun River.

Water shortages are projected to increase for Sun River senior irrigation water users, including the Greenfields Irrigation District (GID), Fort Shaw Irrigation District (FSID), and Broken O Ranch. In particular, late summer streamflow for the Sun River at Simms is projected to decline under most scenarios. A system of canals and reservoirs provide water to Sun River irrigation users (Figure 25). Because the system is heavily regulated, operations are closely monitored through a series of stream and canal flow gaging stations to ensure that minimum streamflow is maintained and that flows for senior water rights and stored water are delivered to the intended users.

These strategies investigate the potential for modifying some of the existing infrastructure associated with GID and FSID to reduce irrigation water shortages and improve the amount of time minimum instream flows are met and increase reservoir storage levels. These strategies include managing water diversions and operations of the Willow Creek Reservoir, increasing the capacity of the Pishkun Supply Canal, and increasing off-stream storage available to GID.

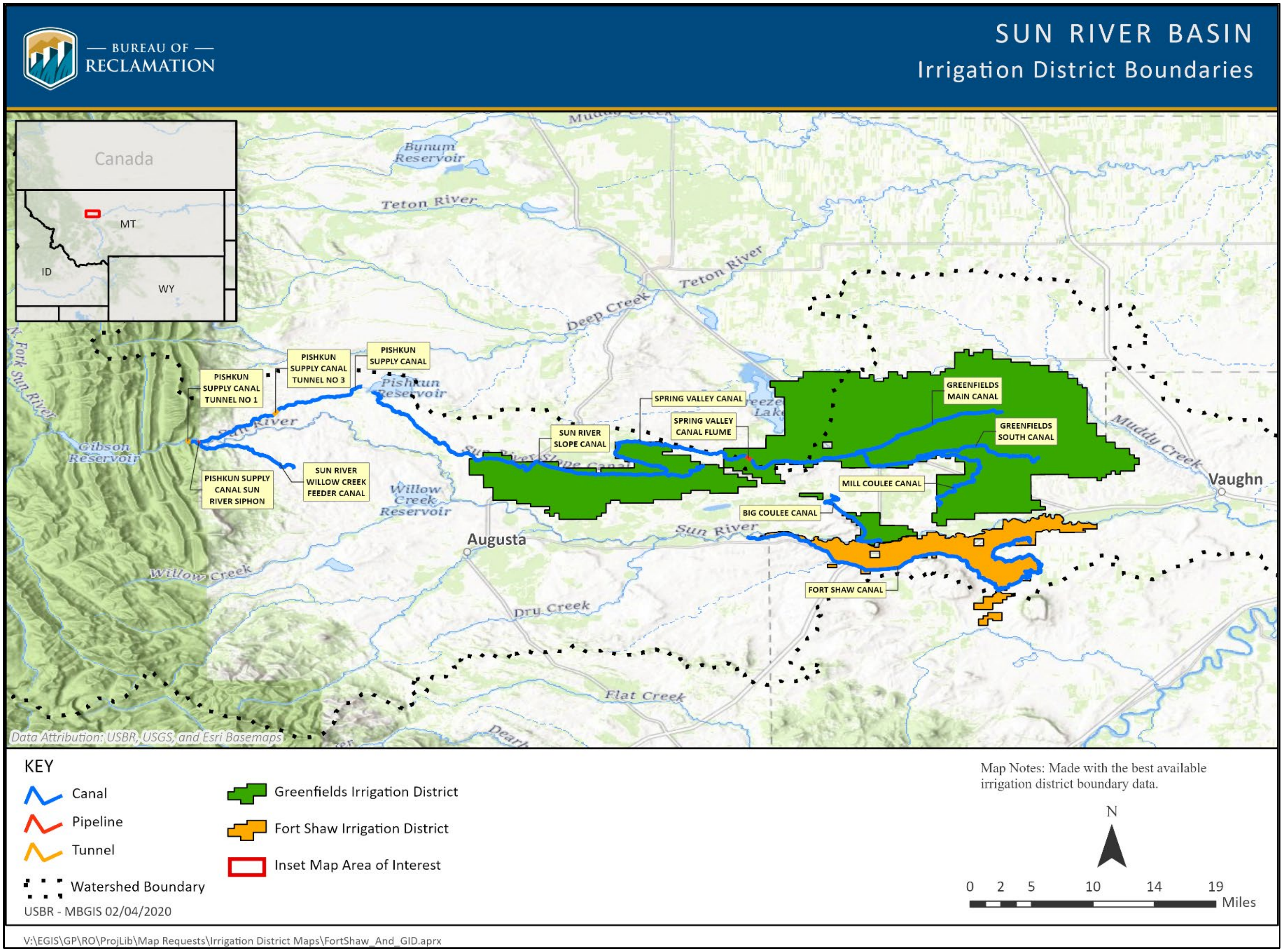


Figure 25.—Map of the Sun River basin showing major hydrologic features, irrigation districts, and flow monitoring stations.

6.8.2. Increasing Willow Creek Feeder Canal Capacity

This strategy's objective is to investigate potential benefits to irrigation and other resources of increasing the effective capacity of the Willow Creek Feeder Canal (WCFC) from 75 to 175 cfs. The analysis was completed by using the Upper Missouri RiverWare planning model to model operations of the system with and without the canal capacity increase and compare resources benefits.

Willow Creek Reservoir is an off-stream storage reservoir for Sun River water. GID operates Willow Creek Reservoir to provide:

1. Exchange water to downstream senior irrigators to offset GID diversions at the Sun River upstream at the Sun River Dam below Gibson Reservoir, primarily the FSID and Broken O Ranch senior users.

Willow Creek Feeder Canal.

2. Stored water to supplement the natural flow supply for FSID—about 5,000 acre-feet of reservoir storage is allocated to FSID.

Willow Creek Reservoir holds about 31,848 acre-feet of water, with a usable capacity of about 30,000 acre-feet. The rest of the storage supports the reservoir fishery. The WCFC is the most important water source to the reservoir and has a design capacity of 500 cfs. The feeder canal receives water from the Sun River but discharges into a natural tributary to Willow Creek, where it flows for about 10 miles before discharging into the reservoir. Substantial erosion has occurred in this natural channel and, as a result, recent operational procedures limit the maximum diversion down the feeder canal to about 75 cfs. The reservoir also receives some natural inflow from Willow Creek, which was included in the modeling analysis. Historical model runs, however, imply that the Willow Creek drainage might contribute about 7,500 acre-feet per year to the reservoir, on average. The maximum Willow Creek Reservoir outlet release, according to GID, is 350 cfs.

Increasing the capacity of the WCFC generally would generally result in more water stored in the reservoir and a fuller reservoir at the end of the irrigation season. Figure 26 illustrates the impact of increasing the WCFC capacity to 175 cfs under one of the HD paleohydrology scenarios for the 2080s future time horizon, which results in the lowest Willow Creek EOWY 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.

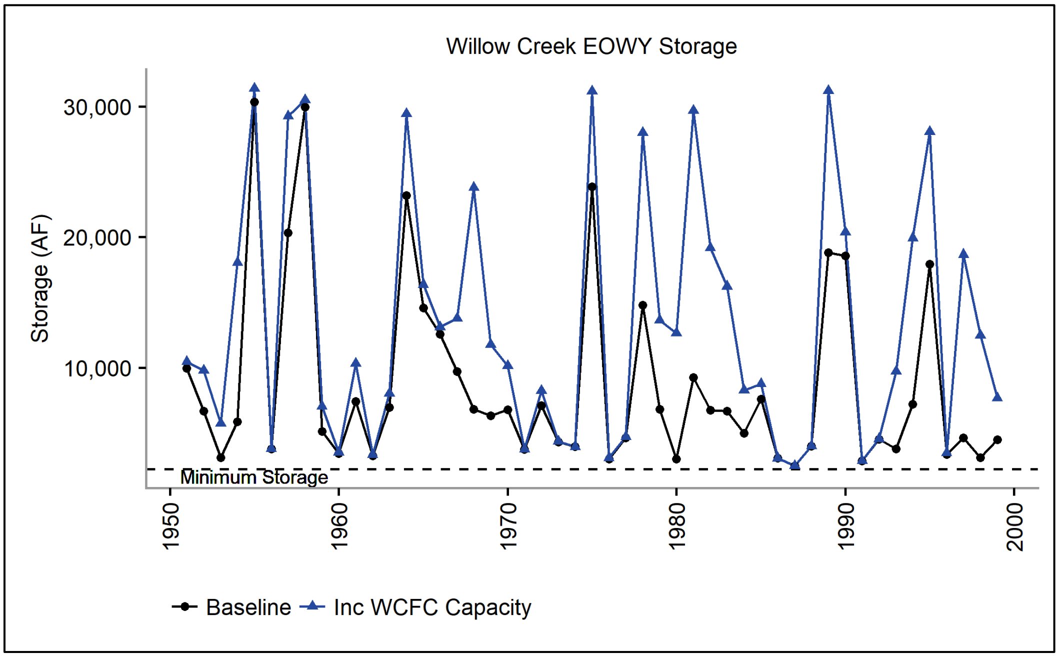


Figure 26.—Modeled Willow Creek end of water year storage for the increased WCFC capacity strategy for the worst case paleohydrology scenario compared to baseline conditions.

6.8.3. New Off-Stream Storage for Sun River Water

The objectives of this strategy are to assess the possibility and potential benefits of storing additional Sun River water off-stream.

Gibson Dam and Reservoir near the end of the irrigation season.

There is currently about 140,000 acre-feet of combined storage capacity in the three major Sun River Reclamation Reservoirs (Gibson, Willow Creek, and Pishkun). Although this is a substantial amount of storage, irrigation storage is mostly depleted by the end of August during many years. Increased storage might provide benefits to irrigation and other resources. During stakeholder outreach, GID envisioned that this new storage might be located on the main GID canal system, either on the Pishkun Supply Canal or upper portion of the Sunny Slope Canal downstream of Pishkun Reservoir. For future scenarios, peak reservoir inflows are projected to be earlier. 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.

This strategy could include new reservoirs or expanding existing reservoirs. For this strategy, the new storage was modeled as located on main GID canal system through expansion of Pishkun Reservoir. An off-stream storage increase of 25,000 to 30,000 acre-feet was suggested by the GID manager.

In simulating this strategy, the modeled maximum storage volume for the Pishkun Reservoir object was increased by 30,000 acre-feet—mimicking a new reservoir that would produce similar modeled results.

6.8.4. 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 Reservoir 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.

6.8.5. New Off-Stream Storage with Increasing Pishkun Supply Canal Capacity

This strategy would combine Sun River Strategies 2 and 3. Modest reductions to irrigation shortages were modeled under the combined strategy, with most of the reduction due to the additional 30,000 acre-feet of off stream storage. This is demonstrated by Figure 27 which compares GID modeled baseline irrigation depletion shortages to those with the additional 30,000 acre-feet of off stream storage, with and without an increase in the capacity of the Pishkun supply canal. Figure 27 illustrates the impact of these two strategies under one of the HD paleohydrology scenarios for the 2080s future time horizon, which results in the highest average GID shortages over a 50-year period. This sequence may be considered the worst-case scenario for GID. Modest reductions are in part due to the limited amount of additional water new off-stream storage could capture, which is explained further below.

If new storage were to be constructed for use by GID, it is advantageous to evaluate how often the new storage would fill in a given scenario. The percentage of total new storage averaged over the simulation period was calculated under the historical scenario, 2050s future scenarios without paleohydrology, and extreme paleo event scenarios (MID, LDP, MIP, and LP) (Figure 28). Relative storage on July 1 was chosen because this is typically when the greatest volume of storage is available to GID, as July 1 is during the typical refilling period and the end of the runoff season.

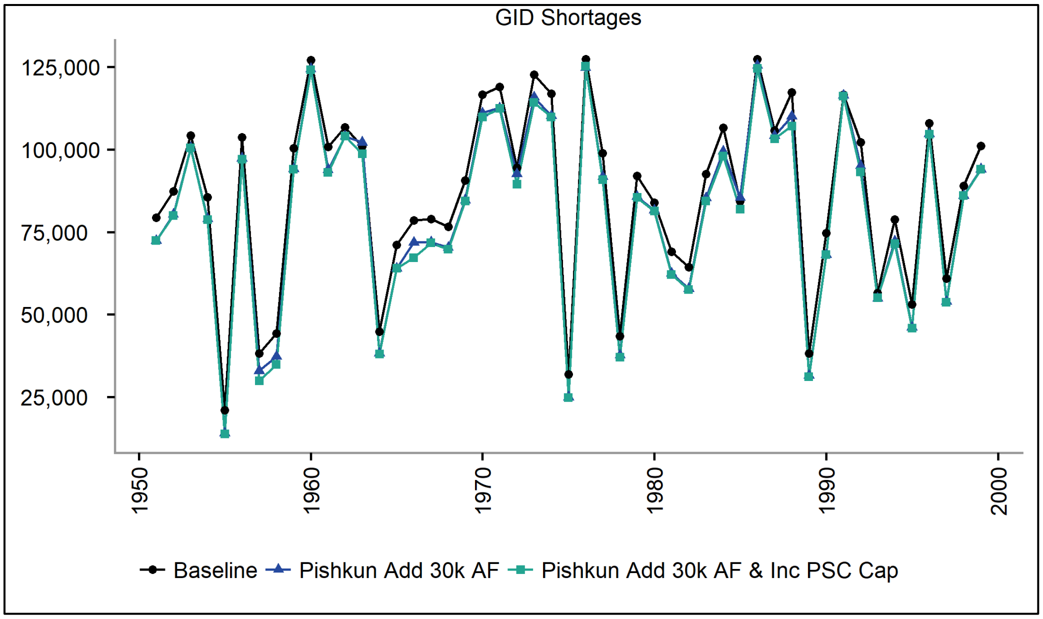


Figure 27.—Modeled irrigation depletion shortages to GID considering additional off-stream storage strategy and additional off-stream storage strategy with an increase in Pishkun Supply Canal capacity for the worst case paleohydrology scenario compared to baseline conditions.

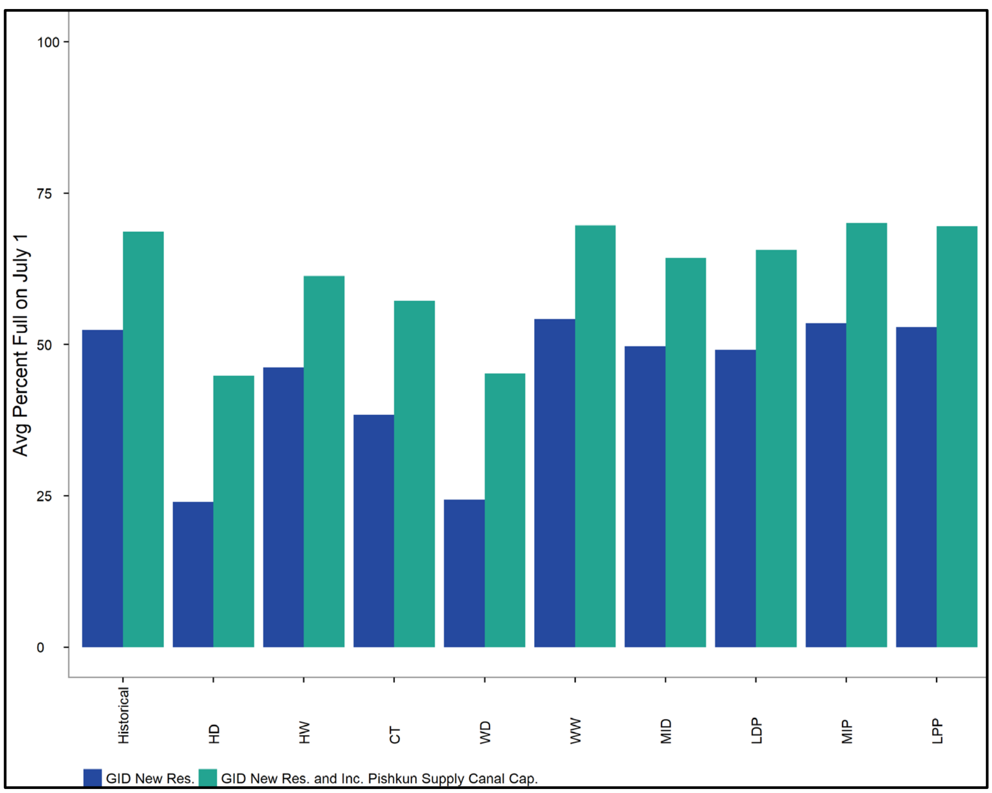


Figure 28.—Modeled average percent full additional 30,000 acre-feet of off-stream storage would be with and without a modeled increase in capacity of the Pishkun Supply Canal, including historical and future 2050s scenarios as well as extreme paleo events.

In Figure 28, the new reservoir would not always be full on July 1. Further, under the historical scenario and most future scenarios, the new reservoir would be less than 50 percent full on July 1 on average. When modeled in conjunction with an increase in the capacity of the Pishkun Supply Canal, the additional storage was near about 10 to 20 percent fuller on July 1—meaning the new reservoir would be at least 50 percent full on average. Modeled July 1 storage was typically less under the future climate scenarios than the historical scenario, possibly due to irrigation demands beginning earlier in the year, with the additional modeled benefits of increasing the supply canal capacity to this measure being more distinct.

6.8.6. Performance and Trade-Offs for the Sun River Basin Strategies

Figure 29 compares modeled changes in benefits provided by selected resource measures, with and without the strategies.

6.8.6.1. Figure Orientation

In Figure 29, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability. The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

The middle panel shows how different strategies affect the performance measures under historical conditions. The reader may explore in these figures: *had the strategy been implemented under current conditions, what effect does it have?*

The third panel shows the effect of strategies under future and paleoclimate scenarios. The reader may explore in these figures: *do the strategies have a* *noticeable effect on the vulnerabilities identified in the first panel, and are the effects of the strategies seen under historical conditions in the second panel still evident under a range of scenarios?*

6.8.6.2. Figure Discussion

Overall, changes in benefits were modeled to be modest with these strategies. Although irrigation water shortages are projected to increase substantially under most future climate scenarios, modeled decreases to water shortages were small for all strategies and under all scenarios. Increases in Willow Creek Reservoir EOWY storage were modeled for the increased Willow Creek Feeder Canal strategy under most scenarios. These increases in storage could result in increased reservoir recreational benefits. The strategies generally were not found to have substantial effects on the flow in the Sun River downstream. Gibson EOWY storage could improve some under the combined additional off-stream storage and increased Pishkun Supply Canal strategies. This could be due to the increased storage and ability to divert higher flows into storage—resulting in less demand on Gibson Reservoir storage during some years.

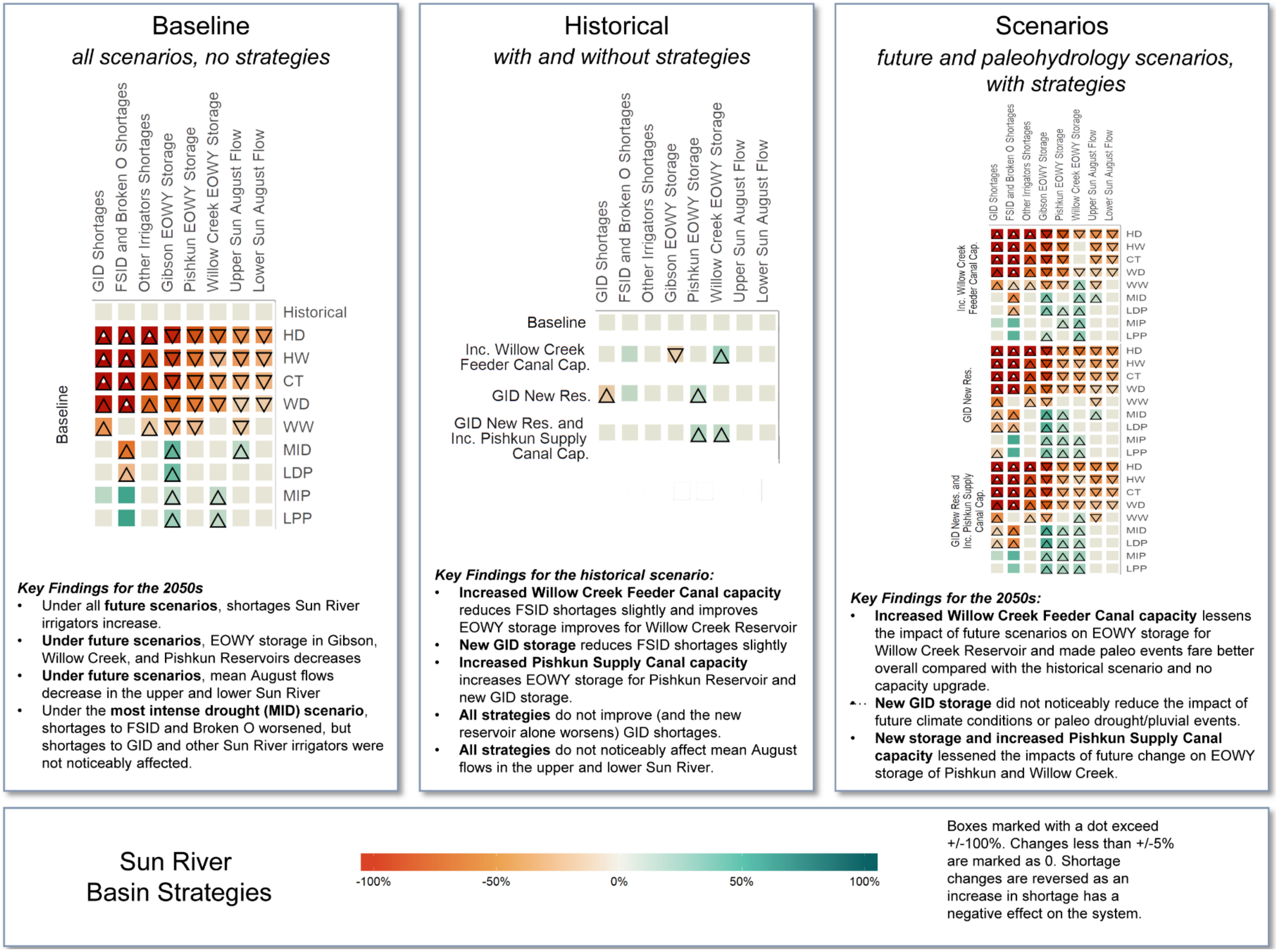


Figure 29.—Resource benefit changes comparison chart for the Sun River basin strategies (2050s futures).

6.9. Musselshell River Basin Strategy

6.9.1. New Off-Stream Storage in the Lower Musselshell River Basin

6.9.1.1. Background

Delphia-Melstone Canal description.

In 2009, Montana DNRC received an application for a beneficial water use permit to construct a dam and reservoir in Horse Creek Coulee, a tributary drainage to the lower Musselshell River near Melstone. The reservoir's primary purpose would be to provide supplemental water to irrigators on the lowermost Musselshell River who are subject to severe water shortages during drier years. This would be an off-stream storage reservoir for Musselshell River water. Flow would be diverted to the reservoir via the Southside Delphia-Melstone Canal. Some upgrades would need to be made to the canal to accommodate the new diversions. The reservoir would also capture some of the natural runoff from the Horse Creek watershed (30.2 square miles of drainage area). In Petroleum County Conservation District's application for a water use permit (2009), the natural runoff was anticipated to be about enough water to offset reservoir evaporation and seepage. Releases from the reservoir would be used to supplement irrigation on the lower Musselshell River, and to enhance late summer instream flow in the lower river. Montana DNRC issued a water right permit for this project in 2011, but this project has yet to be constructed, primarily due to lack of funding. The Musselshell Water Users Association and Montana DNRC are considering funding alternatives.

As described in the water permit applications, the project is anticipated to have a maximum storage capacity of 4,464 acre-feet and to supply about 1 acre-foot of supplemental water to about 2,500 acres of primarily flood irrigation along the Musselshell River downstream. The reservoir would be near the end of the Delphia-Melstone Canal, and improvements would need to be made to the canal to allow a desired diversion rate of 60 to 65 cfs to the new reservoir. As originally proposed, water would typically be stored in the reservoir during the spring and fall, with the specified diversion period being March 1 through November 15, and with the reservoir releases from July 1 to July 31 at a rate of up to about 50 cfs. Potential benefits to streamflow are also identified, with a goal being the Montana DFWP target (water reservation) minimum flow of 70 cfs for the lower river. For recreational benefits, a minimum reservoir dead pool of 500 acre-feet is anticipated.

6.9.1.2. Objectives

The objectives of this strategy are to evaluate the potential benefits of new off-stream storage in the lower Musselshell River basin, using the Horse Creek Coulee Reservoir project as an example. Feasibility and sources of funding for executing this strategy were not considered in this analysis. The reservoir was modeled using the Upper Missouri RiverWare planning model. Water storage was modeled to occur during the fall and early spring and for releases for downstream irrigation 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 DFWP'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.

6.9.1.3. Performance and Trade-Offs for the New Off-Stream Storage in the Lower Musselshell River Basin

The reservoir's primary purpose would be to provide supplemental water to lower Musselshell River irrigators. Table 17 summarizes modeled reductions to irrigation shortages for lower Musselshell River irrigators. During wetter years, the reservoir benefits were smaller, because there typically is adequate direct flow water in the river to support the irrigation and little stored water needs to be released. During moderate flow years, this strategy would help provide water to fill the reservoir outside of the irrigation season and to meet a later demand for the stored water to reduce irrigation shortages. As the years become drier, however, it becomes difficult to fill the reservoir and consequently less water can be released, even though there is a substantial demand for stored water. For the driest 5 years, the strategy provides significant benefit only in the first year of an extended drought.

Table 16.—Modeled Reductions to Irrigation Shortages Associated with the Horse Creek Coulee Reservoir using Historical Streamflow Data

Year Type	Decreases to Irrigation Diversion Shortages (acre-feet)	Decreases to Irrigation Depletion Shortages (acre-feet)
Average for period	1,400	450
Wettest Ten Years (average)	477	134
Middle Ten Years (average)	2,226	782
Driest Ten Years (average)	1,095	324

Year Type	Decreases to Irrigation Diversion Shortages (acre-feet)	Decreases to Irrigation Depletion Shortages (acre-feet)
Driest 5 Years (average)	584	136

For this shortage-reduction assessment (Table 17), modeled conditions were based on historical streamflow data as input to the Musselshell River basin portion of the Upper Missouri RiverWare planning model data. Streamflow data input to the model were based on historical streamflow data because of the uncertainties associated with the modeled streamflows, especially for the 1,900-square mile Flatwillow Creek drainage, which enters the Musselshell River between the reservoir and the targeted irrigation. Flatwillow Creek is a flashy stream which is frequently dry during the summer. Based on gaging station data for the Musselshell River at Mosby, just below the Flatwillow Creek confluence, the hydrology model (VIC) appears to be overestimating contributions from Flatwillow Creek during the latter part of the irrigation season. Also for this analysis, the Upper Missouri RiverWare planning model was run for the period 1950 - 2010 to capture the severe drought of the early 2000s. Local water users are mindful of the effects of that drought.

Figure 30 depicts modeled storage for the reservoir for the 1950 - 2010 period. During about half of the years, the reservoir was filled to capacity and much or all of that stored water (to the minimum reservoir pool) was later released. Because both Martinsdale and Deadman's Basin Reservoirs upstream have considerable off-stream storage capacity and senior water rights, the reservoir was not modeled to fill during dry years. Indeed, during extended drought, there may be sequences of years where the reservoir would be able to store little—if any—Musselshell River water. During the drought of the late 1980s and early 1990s, storage and releases were around 1,000 acre-feet per year or less. For the early 2000s, the simulations showed 5 years in a row where almost no water was modeled as being stored. There were a few years, generally dry years followed by wetter years, where nearly the full active storage capacity of the reservoir (about 4,000 acre-feet) was modeled as being released.

As stated earlier, the proposed reservoir was also intended to provide some instream flow benefits during the latter part of the irrigation season. Thus, increases to flow at Mosby are generally projected for the July through September period, as water is released for supplemental irrigation downstream of this monitoring point. However, there are modeled reductions to flow during times when the reservoir is generally storing water, typically during the fall after the irrigation season and early spring. While reducing flows during these periods, the reservoir was simulated to only store water when flow at Mosby exceeded Montana DFWP's 70 cfs instream flow right.

Figure 31 summarizes changes to resource benefits, for historical conditions relative to future scenarios and extreme paleo events, and with and without the reservoir.

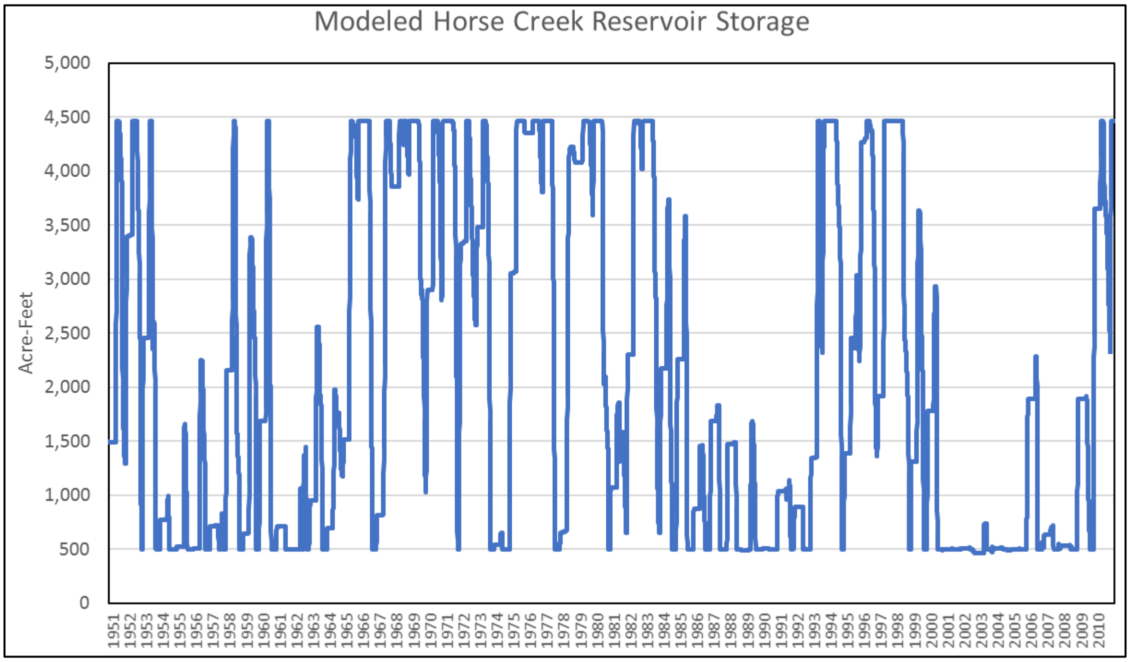


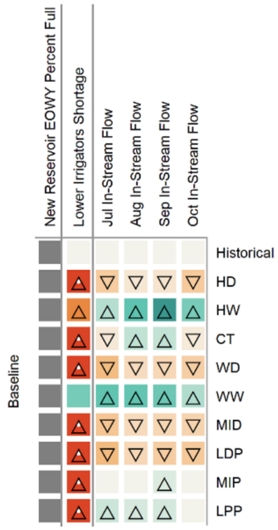
Figure 30.—Modeled Horse Creek Coulee Reservoir storage for 1950 - 2010 historical period.

6.9.1.3.1. Figure Orientation

In Figure 31, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability.

Baseline



Key Findings for the 2050s:

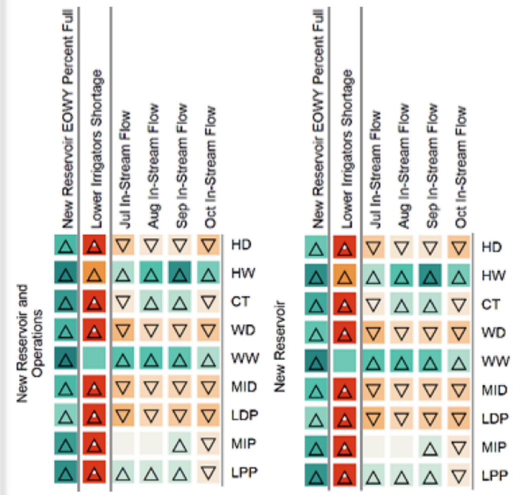
- **Under future scenarios**, irrigation water shortages to lower Musselshell irrigators are projected to increase substantially (except WW).
- **Under drier future scenarios (HD and WD)**, average flows from July through October are also projected to decrease.
- **Under wetter future scenarios (HW and WW)**, summer flows are projected to increase.
- **The longest drought (LDP) and most intense drought (MID)** suggest that summer flows were comparable to those under drier future scenarios (HD and WD).

Historical

Key Findings for the historical scenario:

- **A new reservoir is able to remain close to full at the end of the water year**, according to the historical simulation.
- **A new reservoir reduces irrigation water shortages to lower Musselshell irrigators.**

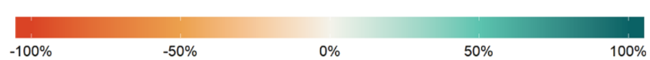
Scenarios



Key Findings for the 2050s:

- **A new reservoir** does lessen the increases in irrigation water shortages to lower Musselshell irrigators that are projected, particularly under drier future scenarios. However, future change is still greater than 100% compared with the historical scenario. Further, historical shortages are not large, so increases may appear large on a percent basis.
- A new reservoir does not noticeably change impacts of future scenarios on average summer flows.

Musselshell River Basin Strategy



Boxes marked with a dot exceed +/-100%. Changes less than +/-5% are marked as 0. Shortage changes are reversed as an increase in shortage has a negative effect on the system.

Figure 31.—Resource benefit changes comparison chart for the Musselshell River basin strategy (2050s futures).

The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

The middle panel shows how different strategies affect the performance measures under historical conditions. The reader may explore in these figures: *had the strategy been implemented under current conditions, what effect does it have?*

The third panel shows the effect of strategies under future and paleoclimate scenarios. The reader may explore in these figures: *do the strategies have a noticeable effect on the vulnerabilities identified in the first panel, and are the effects of the strategies seen under historical conditions in the second panel still evident under a range of scenarios?*

6.9.1.3.2. Figure Discussion

Irrigation shortages for lower Musselshell water users are modeled to increase substantially in the future, with and without the reservoir. The reservoir was modeled to reduce those shortages under historical conditions but not noticeably under the future scenarios. Small changes to streamflow for the lower Musselshell River at Mosby were modeled for the future scenarios. Compared to historical conditions, the average reservoir levels were modeled to be similar to historical under the wetter future scenarios, and lower than modeled historical for the drier scenarios.

6.10. Water Management Strategy for Increased Drought Resilience

6.10.1. Background

Monitoring streamflow on the Ruby River.

Drought has been a regular occurrence in the Missouri Headwaters in the past and will continue to be in the future. Historical droughts have significantly stressed agriculture, recreation, and fisheries and other ecological resources. Even during years when there is a near-average total water volume, late season water shortages can cause significant impacts, such as occurred during the late summer “flash” drought of 2017. The worst drought in the historical record for most areas in the Missouri Headwaters was the Dust Bowl drought of the 1930 - 1940s. As severe as that drought was, the paleohydrology streamflow scenarios indicate that numerous droughts of similar or greater magnitude and duration have occurred in the more distant past (Figure 32), and the drought cycles of the future will be affected by changes in flow timing, precipitation, and temperatures.

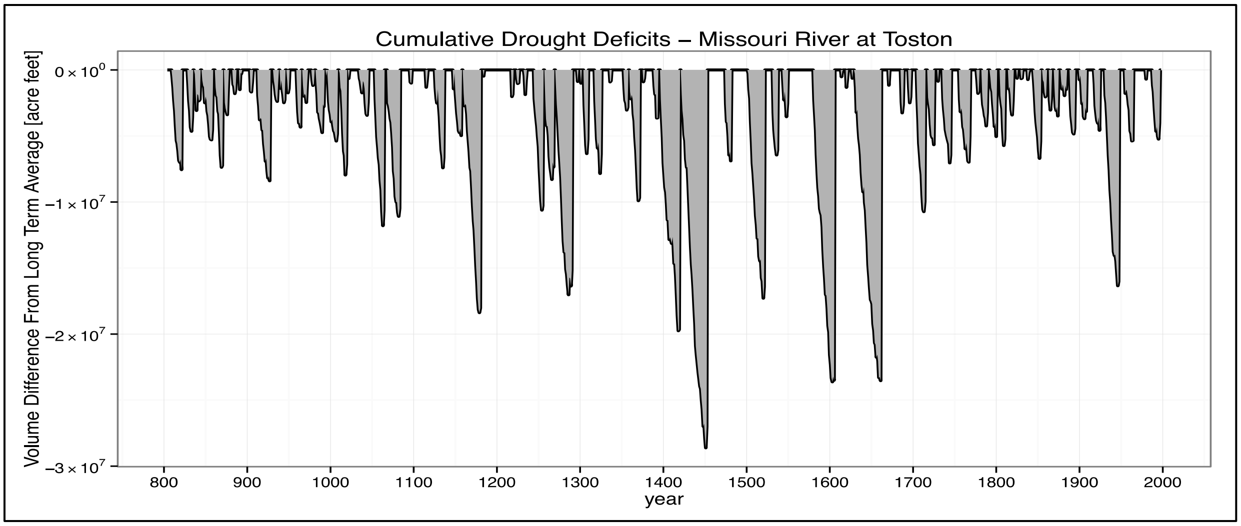


Figure 32.—Droughts in the Missouri Headwaters during the last 1,200 years.

Although future climate projections for the Missouri Headwaters could be interpreted as tilting towards wetter conditions, due to increased average annual streamflow, the annual streamflow measure can be misleading. Summer and early fall streamflow, when water demands typically are highest, generally is projected to decrease in the Missouri Headwaters under future scenarios. In addition, demands are projected to increase and late summer precipitation, which when timely can lessen irrigation demands, generally is projected to decrease as well. The earlier snowmelt and lower late-season flow projected for the future, could lead to increase competition for water during the peak growing season in the future and add to drought vulnerability.

During stakeholder outreach for the 2015 Montana State Water Plan, there was considerable discussion of drought and whether drought intensity, frequency, and duration might increase in the future. With the drought of the early 2000s still fresh in everyone's minds, a paramount concern was how to maintain our water-based resources and economy in the Missouri River Headwater through times of drought.

At about that same time, there was a Federal initiative to demonstrate how communities could plan and prepare for drought, which led to the National Drought Resilience Partnership (NDRP) Pilot Program. The Missouri Headwaters Drought Resiliency Project was initiated in 2014 as part of this National pilot program to engage communities in the development and implementation of local watershed drought resilience plan through a collaborative effort by State and Federal agencies, watershed stakeholders, and NGOs. The pilot study was linked to the State and Federal partnerships established for the Impacts Assessment and Basin Study in the Upper Missouri Headwaters, but with efforts focused more at creating resiliency to drought in the face of a changing future at the local watershed level.

To further build on the work of the NDRP Missouri Headwaters Project, Montana DNRC received Reclamation funding in 2018 through the WaterSMART program to produce a drought contingency plan for the Missouri Headwaters upstream of Canyon Ferry Dam. This includes developing individual drought resilience plans for eight Missouri Headwaters tributaries watersheds and then incorporating these into a regional plan that considers downstream connections and evaluates drought resilience from a regional perspective.

6.10.2. Objectives

This strategy's objectives are to continue ongoing efforts to build drought resilience capacity in the Missouri Headwaters to prepare 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 NDRP and Reclamation 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 Headwaters. These ongoing efforts will prepare stakeholders to mitigate for drought while preserving cultural and ecological values in the face of a changing future.

Specific tasks will include linking drought information (e.g., monitoring, forecasts, outlooks, and early warnings) to longer-term drought resilience strategies in critical sectors such as agriculture, municipal water systems, energy, recreation, and tourism.

The project partners identified collective goals for developing community-based drought preparedness plans and long-term mitigation strategies in the Missouri Headwaters:

1) To organize and engage watershed communities for local drought planning

2) To provide tools for drought monitoring, assessing, and forecasting

3) To initiate local projects to build regional drought resiliency

As part of the project, the Missouri Headwaters Task Force was formed to assist communities with local drought contingency planning efforts and to support local drought coordinators and their Big Sky Watershed AmeriCorps members. The individual watershed planning efforts will provide the basis for a scaled-up, integrated Headwaters Basin Plan. These efforts also are bringing together partners and resource agencies that have been collecting, analyzing, and mapping natural resource data in the Missouri Headwaters. This is a proactive approach to drought as envisioned in Reclamation's WaterSMART Drought Response Program Framework, to implement actions to build long-term resiliency to drought.

Other aspects of this strategy would include:

- *Monitoring system:* The drought monitoring network is being expanded through planning efforts to allow coordinators to better quantify water supplies and establish procedures to identify the onset and severity of drought. As an example, the coordinator in the Ruby River basin has developed a comprehensive tributary gaging project to monitor the contributions of flow to the Ruby River downstream of the Ruby Reservoir. Other participants in the original NDRP process are developing drought monitoring tools that will be used by the coordinators, such as the Montana Climate Office's development of a statewide soil moisture and meteorological information system called the Montana Mesonet (Montana Climate Office 2018).
- *Vulnerability assessment:* Assessing risk requires a review of past drought impacts, an analysis of historical water supply and water use trends, and projections to show how those trends may change over time. The results of the Impacts Assessment will be used in developing the vulnerability assessments, including the range of potential future drought conditions.
- *Mitigation and response actions:* Mitigation actions taken in advance of drought will include conserving water, improving soil health, and taking advantage of and improving the storage capacity of wetland and riparian areas. Response actions will include instream flow minimums at key locations that will trigger water conservation measures.

The process will include tying together the drought plans in the individual watersheds. This is especially important for watersheds such as the Jefferson River basin, where river flows depend on contributions from upstream tributaries, in this case the Big Hole, Ruby, and Beaverhead Rivers.

Evaluation and updating the plan will be ongoing and include testing the effectiveness of the plan under simulated drought conditions. Drought characteristics will be selected that are most relevant and problematic, including single-year and multi-year droughts and late season "flash" droughts. An iterative process could be used and the impacts to resources could be reassessed with the mitigation and response actions in place and subsequently adjusted as appropriate.

6.10.3. Performance

The Big Hole River basin provides an example of how a group can work to build drought resilience through a coordinated long-term effort that includes all stakeholders. The plan includes voluntary conservation targets for all water users and relies on shared sacrifice for shared success. It encourages irrigation and stock water conservation during drought, and fishing restrictions when drought conditions reach critical levels. As an example, Table 18 provides a synopsis of flow targets from the Big Hole River Drought Management Plan for the upper portion of the Big Hole River basin at the USGS Big Hole River below Lake Creek at Wisdom gauge (USGS gauge #06024450). In addition to the actions listed, late afternoon and evening fishing restrictions are also implemented when river temperatures exceed 73 °F for three consecutive days.

Big Hole River watershed Arctic grayling.

Many Big Hole River water users have committed to maintaining these targets through Candidate Conservation Agreements with Assurances (CCAA). These agreements between (USFWS and property owners who voluntarily agree to manage their lands and resources to remove threats to species at risk of becoming threatened or endangered and who in turn receive assurances against additional regulatory requirements should that species be subsequently listed under ESA. The CCAA's conservation goal for the Big Hole River is to secure populations of the native fluvial (river-dwelling) Arctic grayling. In 2014, the USFWS found that this distinct population segment in the Upper Missouri River basin does not warrant protection under the ESA, due largely to significant conservation efforts in the past decade such as the Big Hole River Drought Management Plan.

Figure 33 compares gaged summer flows during 1988, before the flow targets and other conservation measures in the Big Hole River Drought Management Plan were adopted, to modeled streamflow with the targets. Maintaining these targets does come with certain costs to other resources, primarily as some production of irrigated hay crops reductions that result from irrigation water shortages.

Figure 34 is a synopsis of changes to resource benefits associated with three late-summer targeted instream flow rates across projected future climate scenarios and paleo event scenarios. This strategy explores the effects of the various instream flow targets listed in Table 18 but does not capture the dynamic and voluntary nature of the targets. Thus, this strategy helps to understand the sensitivity of irrigation water shortage and summer flow to these targets if they were invoked.

Table 17.—Summary of Flow Targets for the Big Hole River below Lake Creek at Wisdom Gage

Target	Action when flow reaches at or below target
April 1 - June 30	
160 cfs	Water users with conservation plans will implement them. Others will be contacted and encouraged to implement conservation measures. The goal of this target is to maintaining spawning and rearing flow requirements for Arctic grayling.
July 1 - October 31	
60 cfs	Montana DNRC and Montana DFWP officials will work with the Big Hole Watershed Committee to formulate options and prepare to act. This could include conservation plan implementation, voluntary reduction of irrigation and stock water diversions, municipal water use, angling, and encouragement of the use of stock watering wells. A phone tree will be used to notify water users and outfitters and anglers of low water conditions and encourage conservation measures. Information will be posted online and on social media platforms.
40 cfs	A phone tree will be used to provide notice to outfitters and anglers requesting they voluntarily limit their angling activities to earlier, cooler hours of the day. Water users will be asked to contact other water users and encourage water conservation. The Big Hole Watershed Committee will contact the media to inform public of low flow conditions. Information will be posted online as well as on social media platforms.
20 cfs	Montana DFWP will close the upper section of the Big Hole River to fishing and encourage public conservation efforts. The phone tree will be used to contact water users and outfitters/anglers to advise them about the river closure and extreme low water conditions and to encourage conservation measures. Information will be posted online on the Big Hole Watershed Committee (BHWC) website (http://www.bhwc.org/), via BHWC social media platforms, and on the Montana DFWP website.

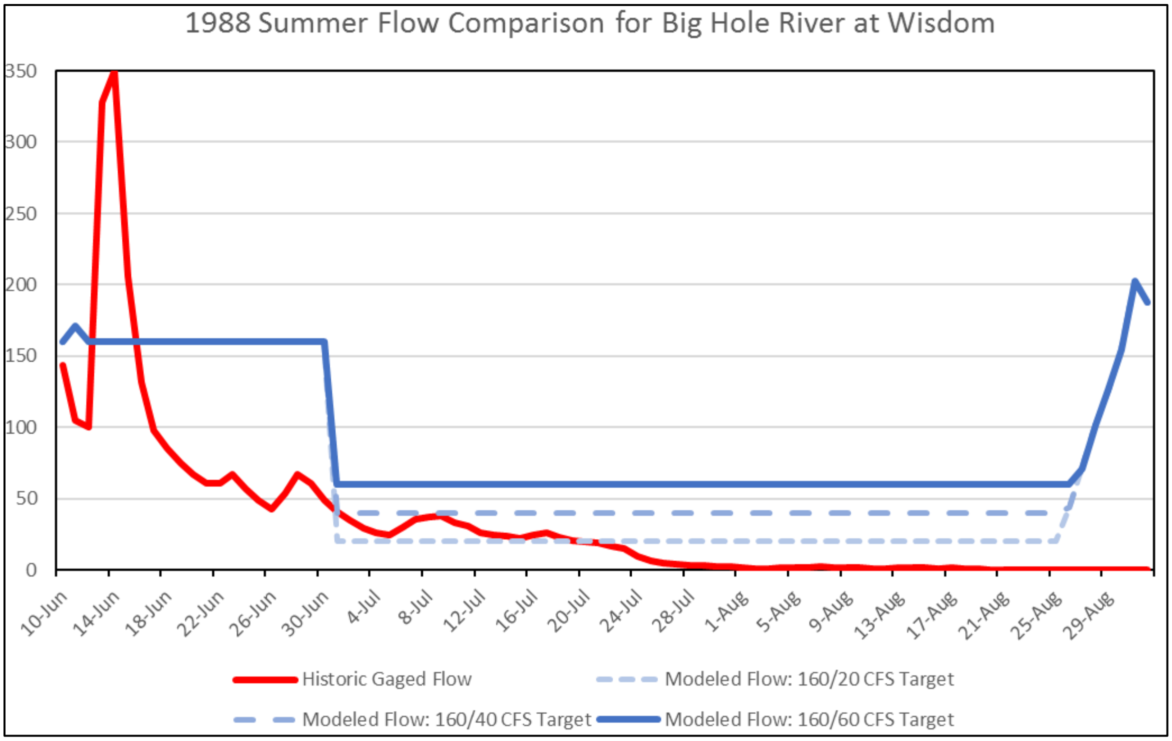


Figure 33.—Modeled flows for Big Hole River near Wisdom gage compared to the historical gaged flow.

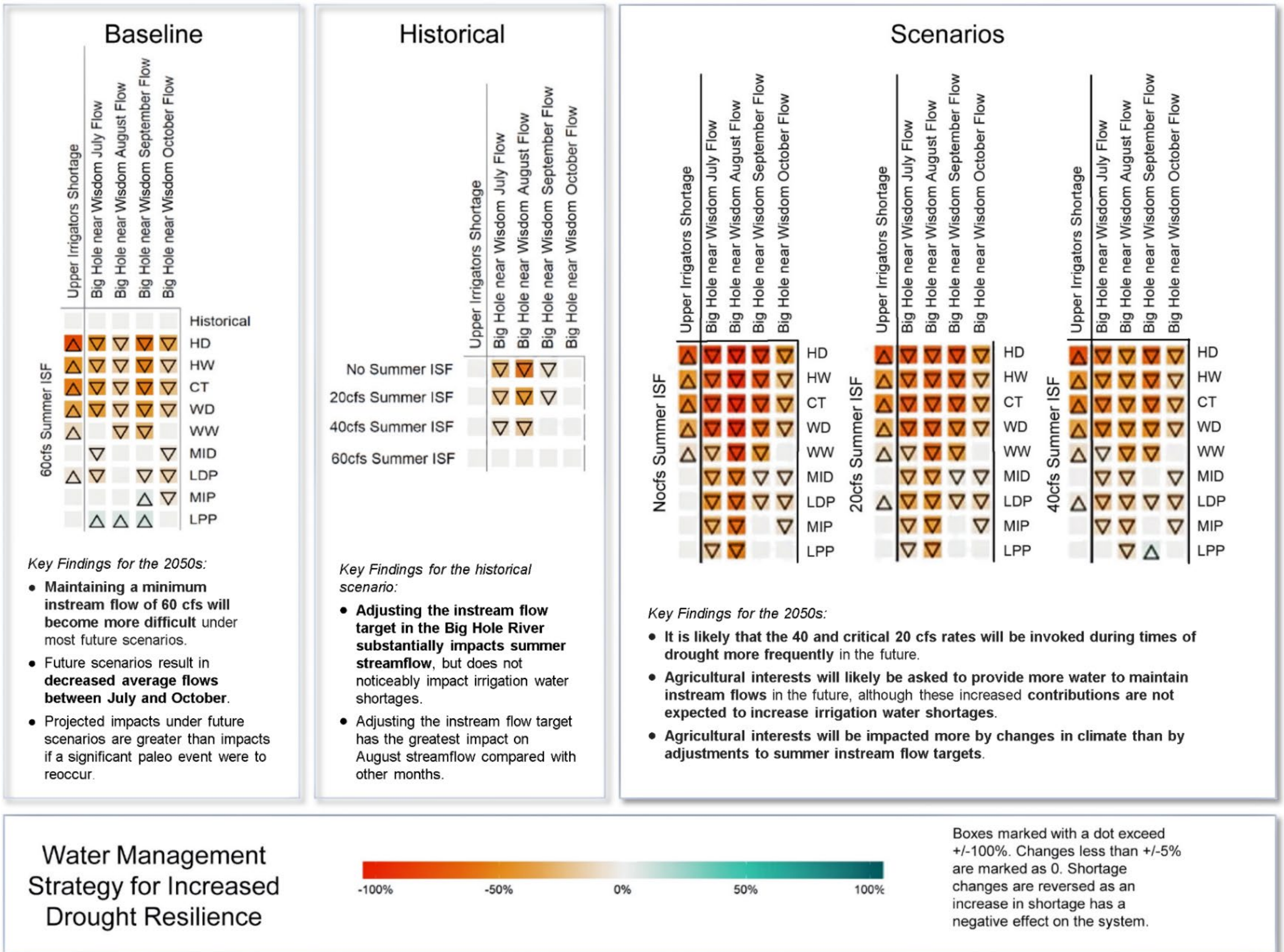


Figure 34.—Resource comparison grid for Water Management Strategy for Increased Drought Resilience strategy. (2050s futures).

6.10.3.1. Figure Orientation

In Figure 34, the percent change in performance measures, shown in the large upper panels, under different future and paleoclimate scenarios as well as with different strategies are presented relative to the historical baseline—which uses historical climate conditions, existing system configuration, and existing system operating rules. These changes are shown on the figures both as colors—increasingly dark red for negative changes, and increasingly dark green for positive changes—and arrows indicating the direction of change—an up arrow (△) for positive change and a down arrow (▽) for negative change. If changes, positive or negative, are less than five percent, they are shown as no change. If changes, positive or negative, exceed one hundred percent, they are shaded as plus or minus one hundred percent and marked with a dot (•).

The left panel shows performance under future and paleoclimate scenarios without strategies (baseline). The HD, HW, CT, WD, and WW future scenarios are shown along with the MID, LDP, MIP, and LP paleoclimate scenarios. This suggests how climate alone will impact system performance and identifies vulnerabilities under a range of different scenarios. Including both the future and paleoclimate scenarios also shows how the range of projected future change compares to historical variability. The reader may explore in these figures: *do the future scenarios stay within the range of the paleoclimate scenarios, or do they exceed it, and in what measures?*

The middle panel shows how different strategies affect the performance measures under historical conditions. The reader may explore in these figures: *had the strategy been implemented under current conditions, what effect does it have?*

The third panel shows the effect of strategies under future and paleoclimate scenarios. The reader may explore in these figures: *do the strategies have a noticeable effect on the vulnerabilities identified in the first panel, and are the effects of the strategies seen under historical conditions in the second panel still evident under a range of scenarios?*

6.10.3.2. Figure Discussion

In the future, especially under the hotter and drier scenarios, the streamflow targets could be expected to be more important in maintaining aquatic resources in this section of the river. The chart also shows increases in irrigation water shortages for future scenarios, although these primarily are attributed to changes in crop demands and flow conditions for the future scenarios rather than the streamflow targets.

6.11. Strategies Considered but not Evaluated

This section summarizes strategies that were identified during the Basin Study process but not further pursued.

6.11.1. Shift Drawdown Operations Timing at Canyon Ferry Reservoir and Lake Elwell

Most future scenarios project an earlier shift of runoff inflow to Canyon Ferry Reservoir and Lake Elwell and projected higher peak inflow during wetter years. A potential strategy would be to shift the timing of reservoir flood control operations to earlier in the season for years with high projected runoff. The strategy was not pursued further because of the complexity of flood control operations associated with these Missouri reservoirs in conjunction with other Mainstem Missouri River reservoirs and the USACE. This is a strategy that could be pursued in the future, with input from USACE.

6.11.2. Beaverhead Valley Aquifer Recharge

This strategy would use existing infrastructure, such as the East Bench Canal, to recharge shallow aquifer storage in the lower Beaverhead Valley for later withdrawal to ease late-season irrigation water shortages through supplemental groundwater pumping. The strategy was not pursued further because initial model runs indicated that there are only short, infrequent periods of time when water is available to recharge groundwater. Typically, during spring runoff when water is most likely to be available, all flow above senior rights is needed to fill Clark Canyon Reservoir. The few years when this water is available tend to be higher flow years when late-season supplemental groundwater pumping is less likely to be needed. Due to the nature of the aquifer and relatively short distances from the Beaverhead River, little aquifer recharge water was modeled to be carried over from one season to the next.

6.11.3. Flushing Flow Releases from Clark Canyon Reservoir

The Beaverhead River below Clark Canyon Reservoir is a valuable trout fishery. Maintaining the quality of this fishery requires not only water, but a clean gravel streambed substrate that provides habitat for the aquatic insects that trout feed on and allows for trout to successfully spawn. Periodically, during times of low releases from Clark Canyon Reservoir, spring storms in downstream tributary drainages, primarily Clark Canyon Creek, will introduce high loads of sediment into the Beaverhead River. Higher flows are required to mobilize these sediments and flush them out of the gravel bed substrate. Reclamation completed a sediment flushing flow study and model (Reclamation 2013) that predicted that flows of 600 cfs would be needed to mobilize river bed gravels and remove the fine sediments. Further work by Applied Geomorphology (2014) recommended the duration and ramp-up and ramp-down rates for flushing flow releases. A successful flushing flow release that followed these recommendations was made during May 2017, with a total of 2,091 acre-feet released. The strategy was not analyzed further because these releases already are being implemented through the cooperation of the East Bench Unit Joint Irrigation Board, Reclamation, Montana DFWP, and Beaverhead Watershed Committee.

6.11.4. Musselshell River Basin Off-Stream Reservoir Fill Sequencing Change

There are two existing off-stream storage reservoirs in the Musselshell River basin: Martinsdale and Deadman's Basin Reservoirs. Because water rights associated with Deadman's Basin Reservoir are senior to those for Martinsdale Reservoir, it typically has priority in filling. At times, this priority order can restrict the filling of Martinsdale Reservoir. An option was preliminarily assessed that would look at the implications of filling Martinsdale Reservoir in priority before Deadman's Basin Reservoir. Model results showed potential decreases in basin-wide irrigation water shortages during drier years, but there was no discernable pattern that could be used to predict when a filling sequence change would be advantageous.

7. Next Steps and Future Considerations

This report has described some of the projected future water resources challenges and opportunities for the Missouri River Headwaters. Although total basin water supplies are projected to increase under most future scenarios, as measured by average annual flow volume, streamflow during the critical late-summer season are projected to decrease on many streams under most scenarios. At the same time, the amount of water consumed by irrigated crops (evapotranspiration) and that which evaporates from reservoirs is projected to increase under most scenarios. As the population in the study area continues to grow, more water will need to be provided for municipal and domestic needs, and economic development. Despite these challenges, the Basin Study describes some opportunities for future adaptation.

There still is water available for contract from Canyon Ferry Reservoir and Lake Elwell to meet future needs while minimizing impacts to other resources, and there may be some flexibility with how these dams can be operated in the future. The United States has determined that a water supply can be made available to water contractors without significantly impacting existing or future authorized purposes of the Canyon Ferry Unit and Lower Marias Unit of the Pick-Sloan Missouri Basin Program. Any future additional contracted water may be subject to restrictions in drought conditions. Most scenarios project increased future annual runoff volumes into these reservoirs, some of which might be available to capture and store for later use. The stored water might provide for new consumptive uses, such as irrigation, or could be used to enhance ecological flow releases. Finally, watershed groups and conservation districts are active in the Missouri Headwaters and provide an opportunity to develop and implement adaptive water management strategies at the local level, such as for drought planning.

The following are some next steps that might be taken to improve the Upper Missouri RiverWare planning mode and apply it to existing and potential future water resources problems. Also included are steps that Reclamation and Montana DNRC can take to continue to promote the collaboration and water resources planning in the basin—which is key to implementing strategies.

7.1. Potential Future Applications of the Upper Missouri RiverWare Planning Model

- Examining alternative strategies for early season reservoir draw-down operations in the future given the potential for higher runoff volumes.
- Using the Upper Missouri RiverWare planning model structure and results to inform and enhance current operational models for Reclamation reservoirs. This could include those for the Beaverhead River basin, Sun River basin, and Canyon Ferry Reservoir and Lake Elwell.
- Facilitating the analysis of water contracting from Reclamation reservoirs, such as at Canyon Ferry and Lake Elwell.
- Facilitating the implementation of water rights compacts, such as those for the Blackfeet Tribe and Chippewa Cree Tribe-Montana Compact.
- Analyzing areas where irrigation efficiency improvements might have the potential to provide multi-resource benefits.

7.2. Potential to Update Models

- Expand and update the naturalized streamflow data set for the major streams in the Missouri Headwaters to include through the year 2018. The current data sets only contain naturalized streamflow estimates through the late 1980s. In the meantime, there have been substantial changes to irrigation depletions and return flow characteristics that affect natural flow computation. Also, lengthening the data set would bring in the severe drought years of the early 2000s and the notable 2011 and 2018 high flow years.
- Improve upon hydrologic model, either through increased spatial resolution of the VIC model, or by exploration of additional modeling approaches.
- Correspondingly, update the lake evaporation and ET demands models to include through the year 2018. This would include irrigation demands and reservoir evaporation rates.
- Run and calibrate the Upper Missouri RiverWare planning model for the historical data set through the year 2018.
- Update the models to include any refinements made to projected future conditions.

7.3. Continued Collaboration and Support

The project partners developed or enhanced working relationships with many agency staff and groups during this Basin Study. This collaboration should be continued, such as through periodic attendance and presentation at watershed group meetings, and presentations at conferences of professional organizations. In addition, the project partners should continue to support, when resources allow, the work of watershed groups and conservation districts, especially for water management activities related to strategies.

8. Uncertainty

The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with the Bureau of Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

Water resources studies are developed in collaboration with basin stakeholders to evaluate potential future scenarios to assess risks and potential actions that can be taken to minimize impacts, including supply and demand imbalances. These types of studies support a proactive approach to water resources management, using the best available science and information to develop scenarios of future conditions within the watershed. This positions communities to take steps now to mitigate the impacts of future water supply management issues, including water shortages, impacts of droughts and floods, variations in water supply, and changing water demands for water for new or different uses.

Because every water resources planning study requires the study partners to make assumptions about future conditions, addressing the uncertainties in those assumptions is an essential component of the planning process. For example, there are uncertainties associated with the characterization of future water supply and demand, demographics, environmental and other policies, economic projections, climate conditions, and land use, to name a few. Moreover, projections are often developed using modeling techniques that themselves are only potential representations of a particular process or variable, and therefore, introduce additional uncertainties into characterizations of the future. The cumulative, interacting uncertainties are not well known in the scientific community and, therefore, are not presented within this study. By recognizing this at each process step, uncertainties are adjusted for and reduced when possible, to allow Reclamation and its stakeholders to use the best available science to create a range of possible future risks that can be used to help identify appropriate strategies, which is fundamental to the planning process. Importantly, scenarios of future conditions should not be interpreted as a prediction of the future, nor is the goal of any water resources planning study to focus on a singular future. Rather the goal is to plan for a range of possible conditions, thereby providing decision support tools for water managers.

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