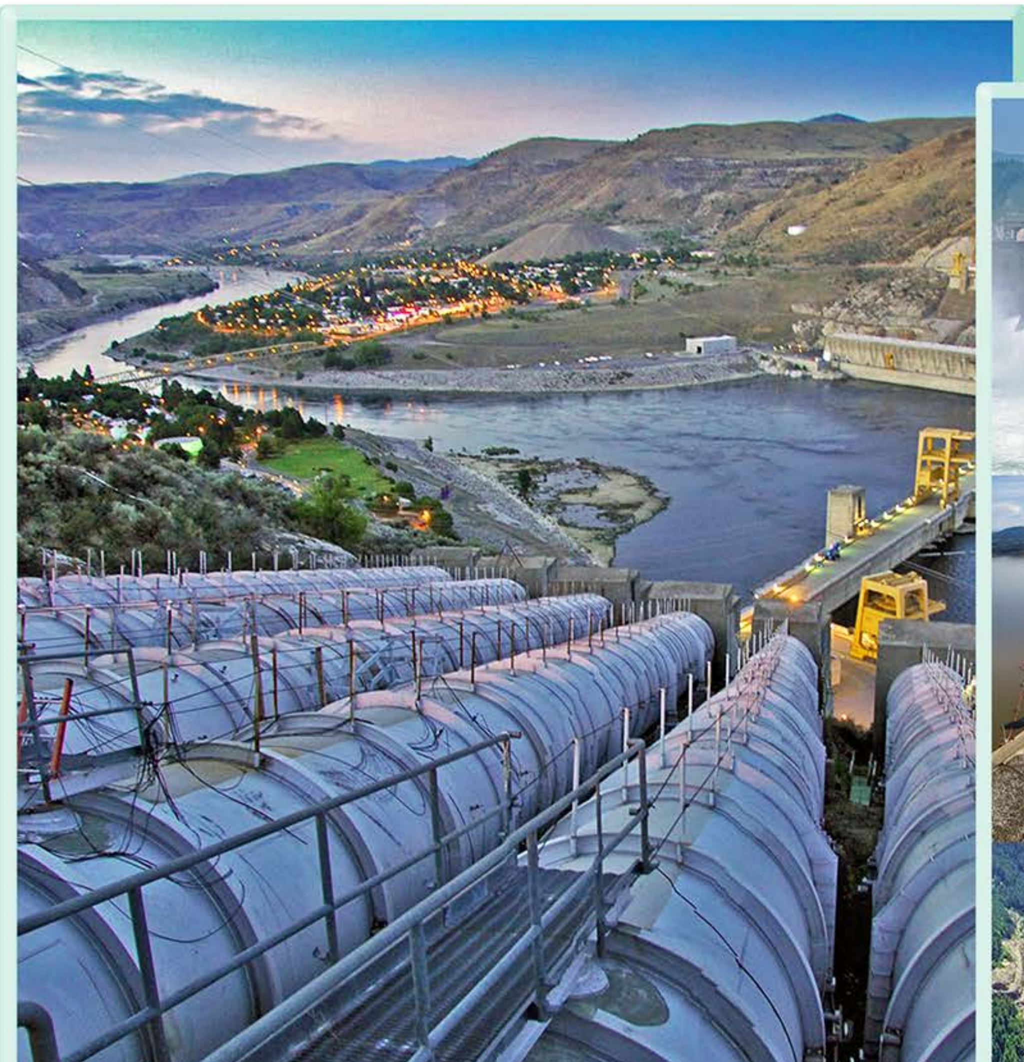
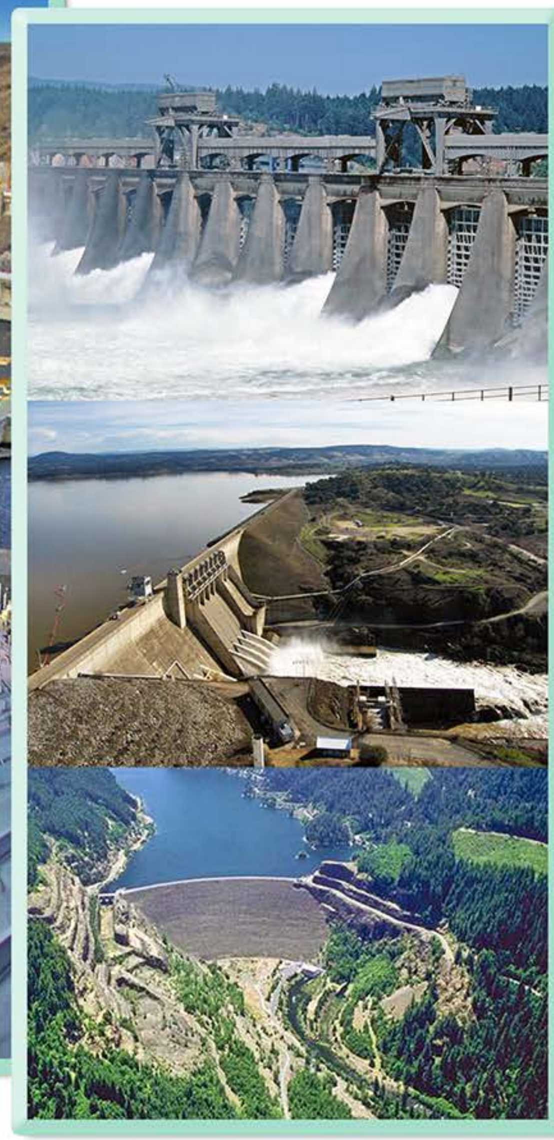
RECLAMATION
Managing Water in the West

SECURE Water Act Section 9503(c)—Reclamation Climate Change and Water 2016

Chapter 4: Columbia River Basin





U.S. Department of the Interior
Bureau of Reclamation

March 2016

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

SECURE Water Act Section 9503(c) Report to Congress

Chapter 4: Columbia River Basin

Prepared for

United States Congress

Prepared by

U.S. Department of the Interior
Bureau of Reclamation

U.S. Department of the Interior
Bureau of Reclamation
Policy and Administration
Denver, Colorado

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Acronyms and Abbreviations

AF	acre feet
BA	Biological Assessment
BPA	Bonneville Power Administration
CRBIA	Columbia River Basin Impact Assessment
CMIP3	Coupled Model Intercomparison Project Phase 3
DOI	Department of the Interior
ENSO	El Niño/Southern Oscillation
ESA	Endangered Species Act
ESU	evolutionarily significant units
FCRPS	Federal Columbia River Power System
GWh	gigawatt hours
kWh	kilowatt hours
MAF	million acre-feet
MW	megawatt
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	NOAA National Marine Fisheries Service
OCR	Office of the Columbia River
PDO	Pacific Decadal Oscillation
PNCA	Pacific Northwest Coordination Agreement
Reclamation	Bureau of Reclamation
RMJOC	River Management Joint Operating Committee
RPA	reasonable and prudent alternatives
TDG	total dissolved gas
TMT	Technical Management Team
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WACCIA	Washington Climate Change Impacts Assessment
WaterSMART	Sustain and Manage America's Resources for Tomorrow

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with section (§) 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011,[1] which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Columbia River Basin and is organized as follows:

- **Section 1**: Description of the river basin setting,
- **Section 2**: Overview of the implications for various water and environmental resources,
- **Section 3**: Potential adaptation strategies considered to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities within the basin to build climate resilience.

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key studies referenced in this chapter include the Yakima River Basin Study Integrated Water Resource Management Plan, Henrys Fork of the Snake River Basin Study (Henrys Fork Basin Study), Hood River Basin Study, Upper Deschutes Basin Study, and Columbia River Basin Impact Assessment. Additional information, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

Columbia River Basin Setting

States: Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

Major U.S. Cities: Boise, Missoula, Yakima, Portland, Spokane

International: Canada

River Length: 1,243 miles

River Basin Area: 258,000 square miles

Major River Uses: Municipal (8 million people), Agricultural (7.8 million acres of land), Hydropower (400 dams provide 60 to 70% of the electrical needs in the northwest, with 31 major federal dams comprising the Federal Power System), Recreation, Flood Control (39.7 million acre-feet of flood storage), Navigation, and Fish and Wildlife including anadromous salmon and steelhead

Notable Reclamation Facilities: Hungry Horse and Grand Coulee

[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

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1 Basin Setting

The Columbia River Basin is located in the Pacific Northwest region of the United States, extending over seven U.S. states and parts of southern British Columbia, Canada (Figure 4–1). The Columbia River is the largest river in the Pacific Northwest, traveling more than 1,240 miles and draining roughly 260,000 square miles. Beginning at its headwaters in the Rocky Mountains of British Columbia, the river first flows northwest before heading south into the State of Washington. It then continues west along the boundary between Oregon and Washington until it drains into the Pacific Ocean. Where the river meets the coast, saltwater intrusion from the Pacific Ocean extends approximately 23 river miles upstream from the mouth; tidal effects can be experienced up to Bonneville Dam, located 146 river miles inland.

The Columbia River has an annual average runoff of approximately 200 million acre-feet per year (AF/year), with roughly 25 percent of that volume originating in the Canadian portion of the basin (Bonneville Power Administration [BPA], 2011). Major tributaries (shown in Figure 4–1) to the Columbia River include:

- The Snake River, which originates in Wyoming and flows primarily through Idaho;
- The Yakima, Spokane, and Methow Rivers in Washington;
- The Kootenai River, which originates in British Columbia, Canada and flows through Montana and Idaho, and joins the Columbia River in British Columbia;
- The Pend Oreille River, which includes the Clark Fork and Flathead Rivers as tributaries, originates in Montana and Canada and flows through Idaho and Washington before joining the Columbia River in British Columbia; and
- The Willamette, Deschutes, and John Day Rivers in Oregon.

Reclamation manages more than 50 dams and reservoirs in the Pacific Northwest Region, with a combined active capacity of more than 18 million acre-feet (AF). Federal and non-Federal entities work together to coordinate reservoir operations for multiple objectives, including flood risk management, irrigation water supply, hydropower production, and ecosystem requirements. Sixty to 70 percent of Pacific Northwest energy supplies come from hydropower in the Columbia River Basin, including both Federal and non-Federal hydropower facilities. The Federal portion alone, referred to as the Federal Columbia River Power System (FCRPS), generates approximately 40 percent of the electricity used in the Northwest (approximately 75,700 gigawatts annually).

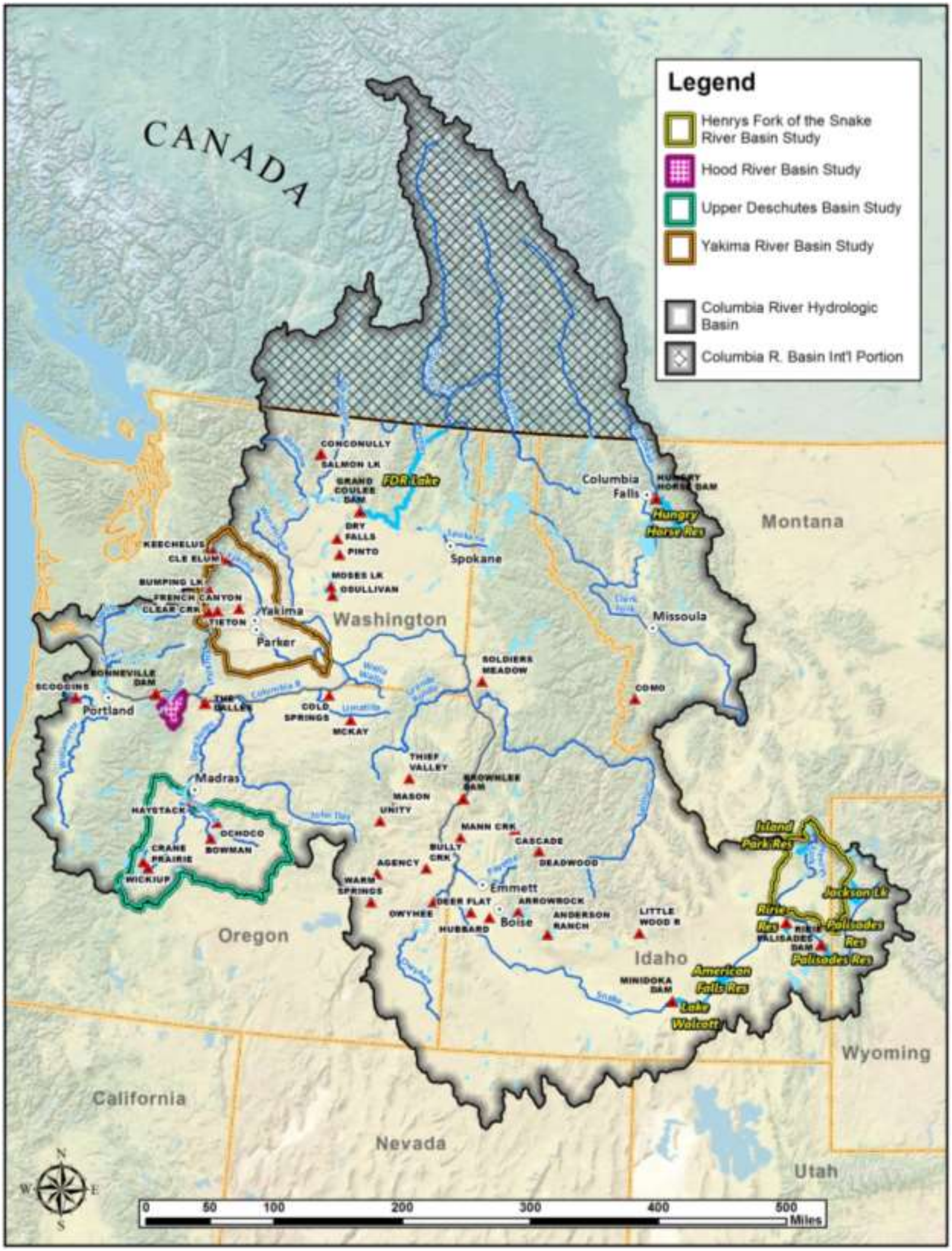

Figure 4–1. Columbia River Basin map.

Within the Columbia River Basin, Reclamation works with other Federal agencies, state government departments (e.g., departments of water resources, fish and wildlife/game, and ecology in Montana, Oregon, Idaho, and Washington), Native American tribes, local entities, and water users on a variety of water resource planning activities. Such activities include water supply analysis, water quality assessments, renewable energy production, and water conservation activities.

Reclamation and the basin states have documented the challenge of ensuring a sustainable water supply and meeting future demands in a complex and highly variable system such as the Columbia River in several studies over the past several decades. Looking ahead, there is growing concern over the ability of the Columbia River system to continue to meet water resource needs[2] due to the likelihood of increasing demands for water throughout the basin and the projected changes in water supply due to climate change.

1.1 Columbia River Basin Studies

Impact Assessments and Basin Studies are funded through the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. Reclamation conducts these assessments/studies in coordination with stakeholders in a specific basin or sub-basin for the purpose of defining current and long-term imbalances in water supply and demand in a basin or sub-basins, and developing adaptation and mitigation strategies to resolve those imbalances. Since 2009, five impact assessment and basin studies have been completed or are ongoing in the Columbia River Basin. These include the following:

Columbia River Basin Impact Assessment: Reclamation conducted the Columbia River Basin Impact Assessment to evaluate the potential effects of future climate change on river flows at 158 locations across the basin.

Yakima River Basin Study: Reclamation collaborated with the Washington Department of Ecology – Office of the Columbia River (OCR) to complete the Yakima River Basin Study in south-central Washington. This study was completed in 2011.

Henrys Fork of the Snake River Basin Study: Reclamation collaborated with the Idaho Water Resource Board to complete the Henrys Fork of the Snake River Basin Study (also referred to as the Henrys Fork Basin Study). This study, completed in 2015, included an evaluation of the surface water and groundwater

[2] Water resource needs include water allocations and deliveries for municipal, industrial, and agricultural use; hydroelectric power generation; recreation; fish, wildlife, and their habitats (including candidate, threatened, and endangered species); water quality, including temperature and dissolved gas; flow- and water-dependent ecological systems; and flood control.

resources in an area upstream of the confluence of the Henrys Fork and the Snake River in central Idaho.

Hood River Basin Study: Reclamation collaborated with the Hood River County Water Planning Group to complete a study of climate change impacts to surface water and groundwater in the basin. The study area encompasses a 339-square-mile region in Hood River County in north-central Oregon. This study was completed in 2015.

Upper Deschutes Basin Study: Reclamation is currently collaborating with the Deschutes Basin Board of Control (DBBC)[3] and Basin Study Work Group to complete the Upper Deschutes Basin Study. The study includes an investigation of surface water and groundwater resources upstream of the confluence of the Deschutes, Crooked, and Metolius River systems in Oregon's Deschutes River Basin.

Reclamation is also involved in ongoing climate change studies that the River Management Joint Operating Committee (RMJOC) is conducting. This committee includes representatives from the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (USACE), and Reclamation and functions as a forum for the coordination of FCRPS dam operations and other river management activities within the Columbia River Basin. With respect to addressing climate change impacts in the Columbia River Basin, Reclamation is working with the RMJOC on the continued development of up-to-date climate change projections in support of long-range planning activities performed by Federal agencies, states, tribes, local governments, and nonprofits. The latest iteration of this effort is referred to as the RMJOC-II Climate Change Study.

[3] DBBC is acting as the fiscal agent for the Basin Study Work Group, with non-Federal contributions coming from State of Oregon funds.

2 Analysis of Impacts to Water Resources

Climate varies considerably in the Columbia River Basin, both temporally (year-to-year, month-to-month, etc.) and spatially (geographically). The El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) have a strong influence on winter weather patterns in the Columbia River Basin and drive much of the year-to-year variability. The warm-phase ENSO (referred to as El Niño) is generally associated with warmer and drier conditions in the basin, while cooler and wetter conditions are typically associated with the cool-phase ENSO (referred to as La Niña). Similarly, warm-phase PDO winters tend to be warmer and drier than average, while cool-phase PDO winters tend to be cooler and wetter than average. When these two events occur at the same time (El Niño and warm-phase PDO, or La Niña and cool-phase PDO), the potential for temperature and precipitation extremes increases. Such conditions often translate into significant shifts in the distribution of January-through-July runoff at The Dalles Dam (Barton and Ramirez, 2004).

Geographically, the north-south Cascade Mountain Range, the Blue-Wallowa Mountains of northeast Oregon, and the Rocky Mountains at the eastern and northern boundaries of the basin strongly influence climate in the Columbia River Basin. These geographic features play an important role in creating the cooler and wetter climate that is characteristic of the western, or windward, side of these mountain ranges, and the warmer and drier climate that is more characteristic of the eastern, or leeward, side (Oregon Climate Change Research Institute, 2010). The variation in precipitation and temperature patterns from one year to the next, combined with the geographic complexity of the basin, result in highly variable Columbia River flows from year to year (Figure 4–2).

Recent studies by Reclamation (including the Henrys Fork Basin Study, Hood River Basin Study, Yakima River Basin Study, Columbia River Basin Impact Assessment, and River Management Joint Operating Committee (RMJOC) Climate Change Study [RMJOC-Phase I][4]) provide more detailed insight into the range of impacts that are expected across the region. Key findings related to projected changes in temperature, precipitation, snowpack, and runoff are presented below.

[4] RMJOC-Phase I refers to the 2011 studies (primarily Brekke et al., 2010) conducted for RMJOC using CMIP3 climate models to develop hydrologic projections and run river system models (the entire set of reports is at: http://www.usbr.gov/pn/climate/planning/reports). The 2011 RMJOC-I study is being updated with CMIP5 climate models as RMJOC-Phase II.

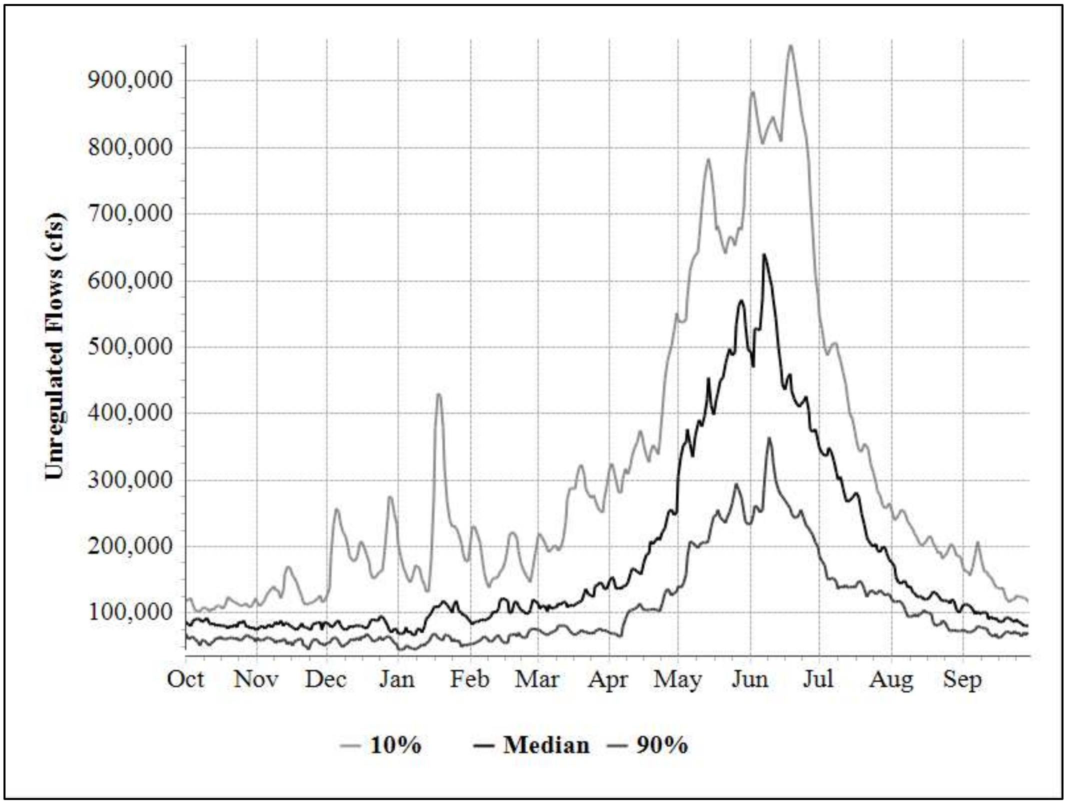

Figure 4–2. Daily summary of historical unregulated inflows for the Columbia River at The Dalles for water years 1967–2015.

Shown here are the 10 percent, median, and 90 percent exceedance values (or the flow rates that are exceeded 10 percent, 50 percent, and 90 percent of the time). Source: Pacific Northwest Region Hydromet, 2015.

- **Temperature** is projected to increase steadily over the next century in the Pacific Northwest, with the greatest changes occuring during the summer months.
- **Precipitation** projections are less certain, but models generally agree in the potential for drier summers and wetter autumns and winters.
- **Snowpack** accumulation is projected to decline as a result of increasing temperatures. Rising temperatures will also cause earlier snowmelt in many subbasins. In areas where water resource systems have been designed around historical hydrologic patterns, this shift toward earlier snowmelt and runoff has the potential to stress flood control and irrigation supply as more water runs off in the late winter and early spring and less water runs off during the irrigation season.
- Decreased snowpack could also result in decreased **groundwater** infiltration, potentially reducing river base flows during the summer season.
- Precipitation falling as rain instead of snow at lower elevations will result in increased winter **runoff** and decreased summer runoff, potentially reducing the overall water availability during the irrigation season.

The multitude of processes (e.g., economic, behavioral, and biological) that play into agricultural, municipal, industrial, and in-stream water demands makes it difficult to quantify the impacts of climate change on water demands from these sectors. However, changes are expected to occur due to increased air temperatures and atmospheric carbon dioxide levels, as well as changes in precipitation, winds, humidity, and atmospheric aerosol and ozone levels. Key findings related to projected changes in demand are summarized below.

- Agricultural demands associated with plant water consumption and surface water evaporation are projected to increase in a warming climate. Additionally, longer growing seasons are expected to result in increased irrigation demands.
- In-stream water demands, including those associated with ecosystem requirements, hydropower and thermoelectric power production, industrial cooling, navigation, and recreation, may increase due to rising temperatures.
- Diversions of water for thermoelectric power production and industrial cooling are predicted to increase as warmer air and water temperatures cause these processes to function less efficiently.
- Demand for hydropower during the warm season is expected to increase over the next century, due in part to increased use of air conditioners and increased cooling degree-days (number of days with temperatures over 65° F) as people adapt to a warming climate.
- In addition to these natural system changes, socioeconomic changes (including those related to infrastructure, land use, technology, and human behavior) will also affect future water demands.

Reservoir systems in the Columbia River Basin were designed under the assumption that snowpack would act as an additional reservoir, holding water (in the form of snow) during the cool season and gradually releasing it in the summer months. Similarly, ecosystems have evolved to depend on specific hydrologic regimes to support important life-cycle events. Climate change impacts to water supplies and demands will stress these systems and may require more tradeoffs among reservoir management objectives (e.g., irrigation, municipal and industrial use, hydropower production, flood control, recreation, flow augmentation for ESA-listed fish, and preservation of habitat for aquatic species).

2.1 Water Delivery

Recent Reclamation water resource studies have examined the projected changes to hydrologic regimes, reservoir operational constraints, and ecological requirements. Although projected impacts vary across the basin, studies suggest the potential for marked decreases in runoff during the irrigation season, causing increased reliance on water storage (where available) and other supplies, such as groundwater. Shifts in runoff timing, lengthening growing seasons, and greater reliance on limited water storage will increase the potential for water supply shortages throughout the agricultural portions of the basin. Specific examples of impacts to water delivery in the Columbia River Basin include the following:

- The Henrys Fork Basin Study points out the potential for climate change to worsen current supply-and-demand imbalances throughout the area due to changes in the phase of precipitation, shifts in runoff timing, a lengthening of the growing season, and greater reliance on storage water (as declining summer flows become less sufficient for the fulfillment of natural flow water rights).
- The Yakima River Basin Study suggests that shifts in runoff quantity and timing are expected to cause significant impacts to water supply. Reservoir operations models indicate that such shifts will correspond to increased cool-season storage, decreased warm-season storage, and decreased end-of-season storage.
- For the Snake River basin above Milner Dam, results from the recent Columbia River Basin Impact Assessment (CRBIA) indicate increases in water delivery shortages across all periods and scenarios (with the exception of the 2020s Less Warming/Wet scenario), with the largest shortages occur during July and August, when demands are at their peak (Figure 4–3).
- The Hood River Basin Study revealed the potential for greater shortages for potable water districts and major irrigation districts within the basin. The study also points out that most irrigation districts in the basin are already operating at very high efficiencies, meaning there are limited opportunities for conservation in terms of water delivery.
- The RMJOC-Phase I Climate Change Study results suggest that under extremely dry conditions, increased withdrawals from reservoirs during the summer and fall may be so significant that refill the following year may not be possible.

2.2 Hydropower

Hydropower provides a significant portion (60 to 70 percent) of the electricity consumed in the northwest (BPA, 2001); however, the impacts of climate change may reduce hydropower generation capacity and flexibility. Climate modeling indicates that a shift to earlier runoff could result in increased generation capability during the winter and early spring months, but reduced generation capability during the late-summer periods. Currently, customers in the Northwest use more electricity during the winter than in the summer, so projected changes to increased winter and spring flows may not negatively affect generation to meet demand during those periods. Decreases in summer flows may be problematic, however, as warming over the next century results in increased energy requirements for cooling.

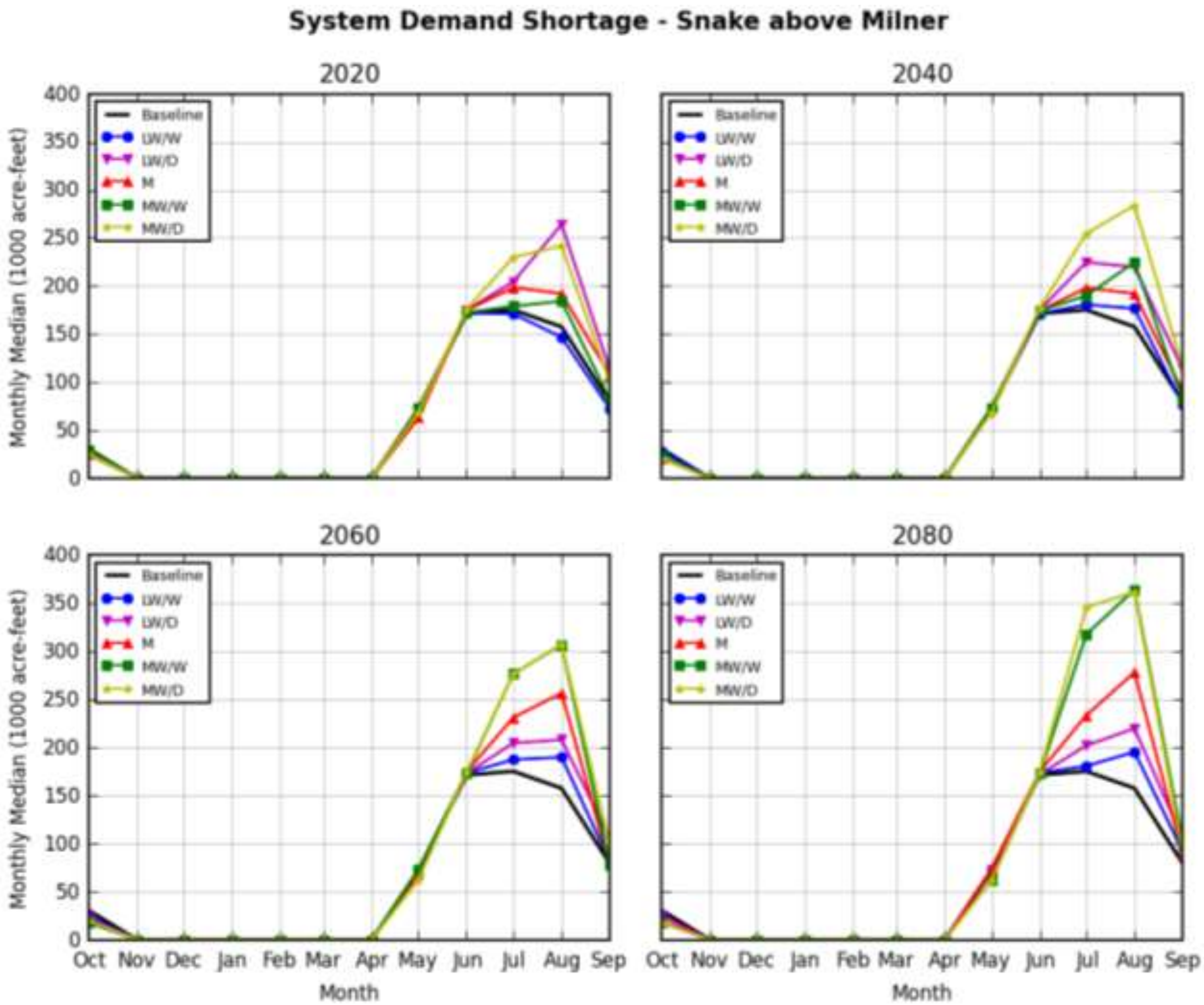

Figure 4–3. Water delivery shortages (i.e., inadequate water supply relative to water demands) in the Upper Snake River Basin above Milner Dam for the 2020s, 2040s, 2060s, and 2080s.

The solid black line represents the historical baseline (1990s), while colored lines represent each of the modeled scenarios (LW/W - LessWarming/Wet, LW/D - LessWarming/Dry, M - Median, MW/W - MoreWarming/Wet, and MW/D - MoreWarming/Dry) considered in the Columbia River Basin Impacts Assessment.

To a certain extent, reservoir systems can be operated to help correct for the discrepancy between the timing of supply and demand by storing water when it is not needed for hydropower production and releasing it when it is. The extent to which this is possible is already limited by a number of (often competing) operational objectives. In the Columbia River Basin, BPA, USACE, and Reclamation collaborate on the operations of the Federal Columbia River Power

System (FCRPS),[5] balancing operations for hydropower, fish and wildlife, irrigation, navigation, cultural resources, and flood-risk management.

Historically, requirements under the Columbia River Treaty with Canada, which recognizes only flood control and power production, served as the primary influence on system operations; however, starting in the 1990s, several species of fish were listed as threatened or endangered under the Endangered Species Act (ESA), adding further constraint to power operations. Biological Opinions, formalized through a series of consultations by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA Fisheries) and U.S. Fish and Wildlife Service (USFWS), now serve to guide BPA, Reclamation, and USACE to perform operations in ways that protect endangered and threatened species. Based on these guidelines, the current strategy calls for increased storage in the fall and winter with increased flows and spill during the spring and summer (BPA, 2001). However, this strategy can conflict with hydropower demand.

The impact of climate change on individual FCRPS hydropower facilities and their ability to adapt and meet future hydropower demands will vary between facilities, depending upon their unique set of operational limitations. At Hungry Horse, flood-control obligations, transmission limitations, and downstream flow requirements for several ESA-listed fish species limit hydropower operational flexibility more significantly than hydrologic conditions do; however, other facilities have more flexibility to respond to hydrologic conditions.

At Grand Coulee Dam, increased inflows from November to May resulting from climate change may be sufficient to operate the facility at or near maximum turbine capacity. However, under existing operating criteria, satisfaction of flood-risk management objectives, which take priority over hydropower production, may result in decreased storage for hydropower production during the summer period. This, combined with the projected decrease in summer and fall flows, may have important consequences for summer hydropower production.

2.3 Flood Management

Reclamation reservoirs in the Pacific Northwest Region range from coastal (fed primarily from rainfall) to alpine (fed primarily from snowmelt); however, most of Reclamation's reservoirs are located in the transitional zone (receiving a mixture of rain and snow as their primary water source and with average winter temperatures near the freezing threshold). Projects in these mixed rain-and-snow

[5] The FCRPS as defined here is consistent with the National Marine Fisheries Service's FCRPS Biological Opinion and only refers to 14 Federal projects: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Little Goose, Lower Monumental, Lower Granite, Dworshak, Chief Joseph, Grand Coulee, Albeni Falls, Hungry Horse, and Libby.

basins are projected to exhibit the largest increase in flood risk due to a combination of warming and increased winter precipitation. For example:

- Studies in the Upper Snake River basin indicate that flows will increase during the cool season and decrease during the summer, with peak flow timing shifting to earlier in the spring. Given these projected changes and current flood-risk management requirements, the probability of passing floodwaters downstream is projected to increase in this basin.

- Similarly, in the Yakima River basin, studies note that higher air temperatures are projected to result in earlier snowmelt and a shift in peak runoff timing to earlier in the season.

Flood-risk management requirements are unique to each project or reservoir system and were developed using individual historical datasets, risk assumptions, flood-protection criteria, and rule-curve development techniques. While many of the reservoirs' operating criteria were developed to account for a wide range of natural variability, operating rules will need to be examined and potentially modified to ensure their adequacy for any changes brought by climate change.

2.4 Recreation at Reclamation Facilities

The Columbia River Basin offers a number of water-dependent recreational activities (Figure 4–4) that are expected to be influenced by climatic changes that affect hydrologic conditions. The reservoirs and rivers in the Columbia River Basin provide recreational opportunities such as camping, boating, swimming, fishing, nature study, and hunting. Potential impacts to recreation due to climate change in the Columbia River Basin include the following:

- Increased summer and winter temperatures may increase the popularity of these water-based recreation activities.
- Changes in the hydrologic regime and project operations may alter the timing of boat ramp availability and flows associated with floating rivers.
- Climate change may cause fluctuations in water depth and surface acreage, which may affect recreation use and economic value in a variety of ways. For instance, extended periods of low reservoir levels may decrease overall visitor numbers.
- Water-based recreation is susceptible to events such as debris flows caused by rainstorms over fire scars. Such impacts may become more common as the climate becomes hotter and drier and rainstorms become more intense.

These examples are in addition to the climate change impacts on fish and wildlife, which will affect associated recreational hunting, fishing, and wildlife viewing. Overall, reduced supplies, altered timing of flows, and increased variability will change the availability and nature of recreational opportunities.

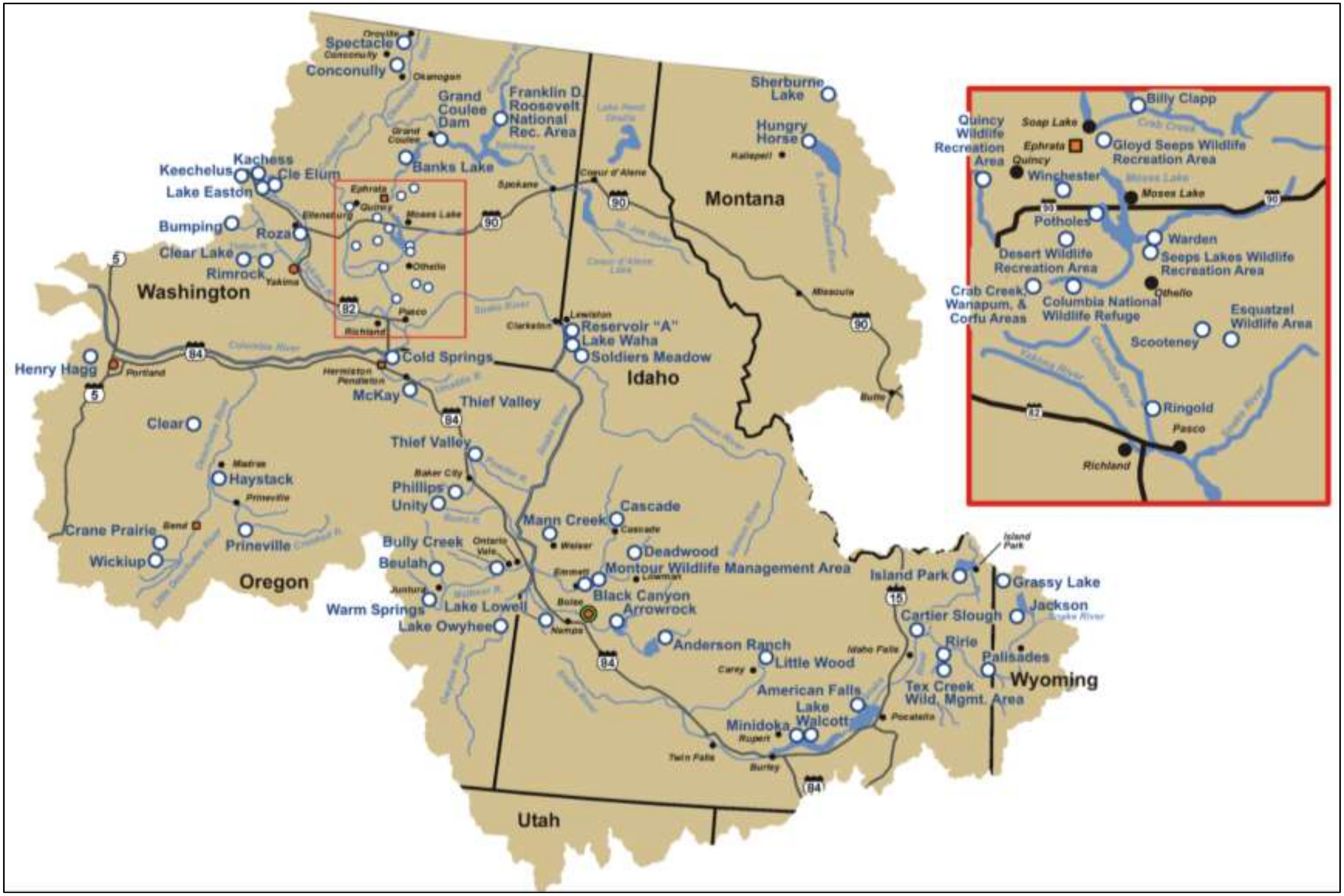

Figure 4–4. Maps of recreation locations in the Columbia River Basin.
Source: Reclamation, 2008.

2.5 Fish and Wildlife Habitat

The Columbia River Basin provides important habitat to a variety of fish and wildlife. The basin is home to small mammals such as beavers, mice, muskrats and otters, and large mammals such as deer, elk, moose, wolves, sheep and bears. The basin also serves as a migration corridor for small birds, raptors, and waterfowl. The lower Columbia River and estuary provide habitats for green sturgeon, eulachon, and leatherback turtles. The Columbia River and tributaries[6] comprise a wide range of fish habitat for resident fish such as bull trout, cutthroat trout, and white sturgeon and are home to six species of anadromous Pacific salmonids: Chinook, Coho, sockeye, chum, pink salmon, and steelhead.[7] In addition to anadromous fish, the Columbia River and its tributaries are home to sturgeon, lamprey, whitefish, and rainbow, cutthroat, and bull trout (char), among other species. Many animals, including bald eagles, osprey, and bears, rely on fish from the Columbia River and its tributaries to survive and feed their young.

Climate change is projected to have an array of interrelated and cascading ecosystem impacts, many of which are primarily associated with increases in air and water temperatures. These include:

- increased stress on fisheries that are sensitive to a warming aquatic habitat,
- increased risk of watershed vegetation disturbances due to increased fire potential,
- shifts in the geographic range of various species (Isaak et al., 2012)
- impacts on migration timing, and
- effects on the distribution and abundance of pests and pathogens in ecosystems.

Instances of high stream temperatures causing hundreds or thousands of adult salmon to die when their thermal tolerances are exceeded have been documented (Isaak et al., 2012) and are projected occur more frequently. The Washington Climate Change Impacts Assessment (WACCIA) (Mantua et al., 2009) reports that rising stream temperatures will likely reduce the quality and extent of freshwater salmon habitat and suggests that the duration of periods that cause thermal stress and migration barriers to salmon is projected to at least double by the 2080s. These findings are consistent with the results of other studies in the region (e.g., Battin et al., 2007).

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[6] Major tributaries include the Kootenai, Flathead/Clark Fork/Pend Oreille, Kettle, Okanogan, Methow, Spokane, Wenatchee, Yakima, Snake/Clearwater/Salmon, Owyhee, Grande Ronde, Walla Walla, Umatilla, John Day, Deschutes, Hood, Willamette, Klickitat, Lewis, and Cowlitz Rivers.

[7] Pink salmon are not listed and are not part of the FCRPS Biological Opinion.

Aquatic ecosystems are also expected to be impacted by the potential for increased winter flood frequency and intensity and decreased summer flows. Increased winter flooding would affect incubating eggs and juvenile Coho, Chinook, and steelhead survival (Hatten et al., 2014), while decreased summer flows will result in shallower and less suitable aquatic habitat, specifically reducing the availability of sections of river that are important for rearing. Climate change also has the potential to trigger synergistic effects (such as temperature influences on metabolism, growth rate, and population impacts) and exacerbate invasive species problems. Allan et al. (2005) suggest that although freshwater ecosystems will adapt to climate change, native biodiversity in these ecosystems could diminish.

2.6 Endangered, Threatened, or Candidate Species

There are 13 Evolutionarily Significant Units (ESU) of salmonids and one char (bull trout) listed as threatened or endangered under the ESA in the Columbia River Basin. The Columbia River Basin salmonids were first listed in the 1990s and include Chinook, chum, Coho, sockeye, and steelhead. Table 4–1 provides more complete list of ESA-listed species with habitat in the Columbia River Basin. As these species are already at risk, climate change has the potential to have detrimental impacts to their survival.

The ESA requires agencies to ensure that their actions are not likely to jeopardize the continued existence of a listed species and that they do not result in the destruction or adverse modification of habitat designated as critical to its conservation. Reclamation currently operates according to several biological opinions (including those on the FCRPS, the Upper Snake, Deschutes, Tualatin, and Umatilla Rivers, and the Lewiston Orchards Project) to protect the continued existence of anadromous species (NOAA Fisheries, 2008) and bull trout (USFWS, 2005).

The FCRPS biological assessment (BA) and associated BiOp take into account the mainstem effects from Reclamation projects in the Deschutes, Umatilla, Okanogan, and Yakima basins, as well as the effects of diversions directly from the Columbia River. The FCRPS BiOp guides the agencies in operating the FCRPS and requires a series of Reasonable and Prudent Alternative (RPA) actions to reduce or offset impacts to salmon and steelhead. The FCRPS RPAs include an aggressive program of actions to improve tributary habitat and survival through system operations.

Tributary habitat actions typically aim to improve spawning and rearing habitat, provide habitat access, and enhance in-stream flows. Since 1992, consultations between Reclamation and NOAA Fisheries under Section 7(a)(2) of the ESA have included the consideration of flow augmentation from Reclamation's Upper Snake Projects to increase flows in the Lower Snake and Columbia Rivers.

Table 4–1. ESA-Listed Species with Habitat in the Columbia River Basin
Source: Columbia River Basin Impact Assessment

Amphibians
- Oregon spotted frog

Birds
- Marbled murrelet (CH)
- Northern spotted owl (CH)
- Red knot
- Streaked horned lark (CH)
- Western snowy plover
- Yellow-billed cuckoo

Fish
- Bull trout (CH)
- Chinook salmon (CH; 5 populations)
- Chum salmon (CH)
- Coho salmon (CH)
- Eulachon
- Green sturgeon (CH)
- Lahontan cutthroat trout
- Sockeye salmon (CH)
- Steelhead (CH; 5 populations)
- White sturgeon (CH)

Mammals
- Canada lynx
- Columbian white-tailed deer
- Gray wolf
- Grizzly bear
- Northern Idaho ground squirrel
- Orca
- Pygmy rabbit
- Woodland caribou (CH)

Plants
- Applegate's milk-vetch
- Bradshaw's desert parsley
- Golden paintbrush
- Howell's spectacular thelypody
- Kincaid's lupine (CH)
- Macfarlane's four-o'clock
- Nelson's checkermallow
- Showy stickseed
- Spalding's catchfly
- Umtanum desert buckwheat (CH)
- Ute ladies'-tresses
- Water howellia
- Wenatchee Mountains checkermallow (CH)
- White bluffs bladderpod (CH)
- Willamette daisy (CH)

Insects
- Fender's blue butterfly (CH)
- Taylor's checkerspot (CH)

Snails
- Banbury springs limpet
- **Bliss Rapids snail**
- **Bruneau hot springsnail**
- **Snake River physa sn**ail

Reptiles
- Leatherback turtle

CH = Critical Habitat has been designated for the species.

Population = A population of individuals that are more or less alike, and that are able to breed and produce fertile offspring under natural conditions (USFWS 2015).

Flow augmentation is important to improving anadromous fish migration in the Lower Snake and Columbia Rivers and relies on adequate storage supplies in the spring and summer months. In the reservoirs that require minimum pools or flows, it may be more difficult to meet these augmentation objectives in the driest conditions.

2.7 Water Quality

Climate change is also expected to have important consequences for water quality conditions across the Columbia River Basin. In addition to causing increased temperatures and altered flow regimes, climate change also has the potential to alter stream networks and erosion regimes (Lettenmaier et al., 2008 and USFS, 2010). Changing weather patterns and the projected increase in fire potential are expected to affect forested watersheds adversely, which generally act to reduce storm runoff, stabilize streambanks, shade surface water, cycle nutrients, and filter pollutants. In many locations, reservoir spill (over spillways or through outlet tubes) generates total dissolved gas (TDG) at levels that are potentially lethal to downstream fish populations. Projections for larger and/or earlier peak flows may require increased spill, having the potential to affect downstream fisheries adversely.

Grand Coulee operational configurations have been studied as a potential mechanism to moderate high temperatures downstream during the summer (projected to become more extreme in the future). However, these investigations have found that Grand Coulee has little flexibility to influence downstream temperatures due to the short residence time water has in the reservoir and the lack of stratification in the reservoir pool.

2.8 Flow- and Water-Dependent Ecological Resiliency

The impacts to fish populations (Section 2.5), and on endangered and threatened species (Section 2.6), will largely depend on the resiliency of the aquatic ecosystems and the specific species. The effects of a changing climate on salmon populations will depend upon the species, local conditions, habitat characteristics, and the ability of specific populations to adapt (Schindler and Rogers, 2009). In addition to increasing mortality rates and creating thermal barriers, warming stream temperatures are also expected to affect the growth and development of juveniles, although this impact will vary substantially with latitude (Schindler and Rogers, 2009).

Restoring floodplain connectivity, restoring stream flow regimes, and re-aggrading incised channels are most likely to ameliorate stream flow and temperature changes and increase habitat diversity and population resilience (Beechie, et al., 2013). Reclamation currently works extensively with partners to improve salmonid spawning and rearing habitat, improve habitat access, and enhance in-stream flows in tributaries across the Columbia River Basin. In addition to being important in helping to reduce the impacts of climate change on ecosystems, the success of these efforts is also directly vulnerable to climate change impacts. For this reason, it is important that climate change impacts must be considered in the identification and planning process for habitat restoration and improvement efforts.

3 Potential Adaptation Strategies to Address Vulnerabilities

The Department of the Interior's (DOI) Climate Change Adaptation Policy requires Reclamation to effectively and efficiently adapt to the challenges posed by climate change using Best Available Science to increase understanding of climate change impacts, inform decision-making, and coordinate an appropriate response to impacts on land, water, wildlife, cultural and tribal resources, and other assets. The Basin Studies conducted in the Columbia River Basin identify potential adaptation strategies that could help reduce the supply and demand imbalances that are projected to result from climate change. Following is a summary of the adaptation strategies considered.

3.1 Reservoir Operations and Modifications

Increased water management flexibility is a core strategy in the Bureau of Reclamation's Climate Change Adaptation Strategy. As climate change alters the hydrologic regime, reservoir operations (e.g., refill schedules, flood risk management rule curves, and flood operating criteria) may need to be adjusted in order to maintain reliable water deliveries, power generation, support for environmental needs, and flood risk management. In response, Reclamation has convened a team of regional reservoir operations experts, planners, climate scientists, and hydrologists to develop a process for evaluating reservoir-operating criteria to determine whether adjustments are needed in response to climate change. As part of this effort, the Pacific Northwest Region of Reclamation will initiate a pilot operations study examining a specific river basin in 2016-2018.

The State of Idaho is also addressing the need to adapt to potential water shortages in the Upper Snake River Basin by conducting an ongoing investigation on the potential for a pool raise (increased reservoir storage capacity) at Island Park Reservoir. Among the list of alternatives presented in the Henrys Fork Basin Study to increase water-delivery reliability under a changing climate, the Island Park pool-raise alternative had low or beneficial environmental impacts, and the lowest cost for additional water. Upon completion of the Henrys Fork Basin Study, the Idaho Water Resource Board secured state funding to move forward on a more detailed study of this alternative.

3.2 Hydropower Modernization

As discussed in Section 2, the impacts of climate change on hydropower will reduce hydropower generation capacity in the region during summer months. Although not identified specifically to address the anticipated impacts of climate change, the Pacific Northwest Region is undergoing modernization efforts on aging infrastructure to provide increased reliability and efficiency that may provide improved resilience to some impacts from climate change.

As the largest hydroelectric facility in the U.S., the 6,809-megawatt (MW) Grand Coulee Dam on the Columbia River is integral to power generation in the Pacific Northwest. If implemented, rehabilitation and potential uprating of generating units at Grand Coulee (currently a proposed action that is undergoing the National Environmental Policy Act [NEPA] process) will ensure continued reliable operation of this valuable asset and provide an additional 510 MW in generating capacity.

The turbines at Palisades Dam and Reservoir on the Upper Snake River have been in service since 1957 and have experienced a 1.6 percent decrease in efficiency. Due to the winter minimum flow requirements and the rough-zone characteristics of the original turbines, two units are required to operate at low efficiency from October through March, which decreases power generation. Reclamation will replace the two units with new turbines that will have a 4.5 to 6.0 percent efficiency improvement and a 30 percent efficiency improvement during winter operations, translating to approximately 44 gigawatt hours (GWh) per year in additional generation. After all work is completed, the four hydroelectric generating units will operate with optimized efficiencies and increased generation capacity and will have a life expectancy of at least 50 years.

Similarly, at Hungry Horse Dam on the Flathead River in Montana, proposed modernization efforts (currently undergoing the NEPA process) will improve the reliability and efficiency for power generation at this facility. The proposal includes the replacement and/or overhaul of the entire powertrain (all four generating units) during the 10-year modernization program. The capstone of the modernization effort will be the replacement of the turbines with a new design that improves efficiency and reduces cavitation. Because of this effort, there will be improved reliability and less need for maintenance.

On the Payette River, a tributary of the Snake River, Reclamation is planning the construction of a third hydroelectric generating unit at Black Canyon Dam. The proposed 12.5 MW hydroelectric unit will expand the capacity of the two existing 5 MW units to generate 105 million kilowatt-hours (kWh)—enough to power 9,359 homes a year. The additional generating unit will take advantage of water that is currently being bypassed and use it for the generation of hydroelectric power.

3.3 Aquatic Ecosystem Restoration

In addition to these modernization efforts, the Pacific Northwest Region is a leader in aquatic ecosystem restoration, specifically targeting critical habitat improvements for anadromous salmon and steelhead and benefitting other resident species as well. Tributary habitat rehabilitation efforts typically aim to improve spawning and rearing habitat, provide habitat access, and enhance in-stream flows. These rehabilitation efforts, which provide increased fish passage, thermal refugia, and refuge from predators, can help reduce the impacts of climate change on ecosystems; however, projected changes in climate and hydrologic regime will likely influence their success. Careful planning and consideration of climate change impacts is important in ensuring the success of these efforts.

Ongoing habitat rehabilitation efforts are taking place in the Methow Basin in Washington and the Salmon River drainage in Idaho. On the Methow River, Reclamation has worked with partners to reconnect a side channel and provide vegetative cover, creating thermal refuge and rearing habitat for salmon and steelhead. The Yankee Fork, a tributary of the Salmon River in Idaho, is also undergoing an extensive rehabilitation, including flood plain reconnection, side-channel development, and large-wood placement, all of which will contribute to improved spawning and rearing habitat for salmonids.

The Appraisal Investigation of the Lewiston Clearwater Exchange Project is a Rural Water Supply Program study of options for removing the Lewiston Orchards Project in Idaho from the watershed and developing alternative water supplies, namely groundwater, while maintaining minimum stream flows necessary for the Nez Perce Tribe to manage steelhead recovery efforts. The Lewiston Orchards Project diverts water from streams on the Nez Perce Indian Reservation that are occupied by ESA-listed steelhead. Warming climate trends have shifted the water supply from a snowpack-driven system to a system dependent primarily on rainfall. Earlier runoff, higher flows in winter, lower summer flows and warmer stream temperatures are expected in the future. Minimum stream flow requirements (established in a Biological Opinion for the Lewiston Orchards Project to limit impacts to steelhead and avoid impacts to critical habitat) should mitigate some impacts due to climate change.

4 Coordination Activities

Since 2010, Reclamation has led multiple collaborative efforts to address climate change impacts in the Columbia River Basin. These include the studies and coordination discussed below.

- Operations of the FCRPS are reviewed by the RMJOC, which comprises representatives from BPA, USACE, and Reclamation and functions as a forum for the coordination of FCRPS dam operations and other river management activities within the Columbia River Basin. With respect to addressing climate change impacts in the Columbia River Basin, Reclamation is working with the RMJOC on the continued development of up-to-date climate change projections in support of long-range planning activities performed by Federal agencies, States, tribes, local governments, and nonprofits. Information from the RMJOC-I climate change study (Brekke et al., 2010) was used in the three completed Basin Studies in the Pacific Northwest Region to assist local entities in addressing water imbalances and the potential impacts of climate change. RMJOC Phase II will assist further coordination and study of the FCRPS.
- Operation of the Columbia River is also coordinated through the Pacific Northwest Coordination Agreement (PNCA), an agreement for coordination of reservoir operations among power systems of the Pacific Northwest. USACE, BPA, Reclamation, and the major generating utilities in the Pacific Northwest signed the PNCA in 1964 to optimize the amount of usable power from the system.
- The wide variations of flows and the need to coordinate for flood risk management and hydropower benefits led to the development of the Columbia River Treaty, an agreement between Canada and the United States. Because of this agreement, several dams[8] were constructed in the Upper Columbia River Basin for the purposes of power generation and flood control.
- Reclamation is an active member of the Columbia River Technical Management Team (TMT). The TMT is an interagency group responsible for making in-season recommendations on dam and reservoir operations to optimize passage conditions for juvenile and adult anadromous fish. In addition to Reclamation, the TMT comprises representatives from BPA, USACE, NOAA Fisheries, USFWS, and various other State and Tribal entities. The TMT was established to implement the reasonable and prudent alternatives (RPA) under the NOAA Fisheries FCRPS BiOp for anadromous salmonids, starting with the 1995 BiOp. The FCRPS is currently operating under the 2014 NOAA Fisheries FCRPS BiOp.

[8] Four dams were constructed under the Treaty: Duncan, Mica, and Keenleyside Dams in Canada and Libby Dam in Montana.

The Basin Studies and the Columbia River Basin Impact Assessment, mentioned in Section 1, are good examples of past and ongoing efforts that involve multiple stakeholder groups. One of the purposes of the basin studies is to engage stakeholders in a collaborative investigation of potential mitigation actions by providing relevant climate and hydrologic analysis. For example:

- The Henrys Fork Basin Study identified alternative actions to help mitigate for a changing climate, including a pool raise at Island Park Reservoir. While the Idaho Water Resource Board will lead the effort to complete the pool raise, Reclamation will continue coordination, as Island Park is a Reclamation facility.
- The Hood River Basin Study found that the occurrence of flows below the established minimum flow requirements would increase under the simulated climate change conditions. These minimum flow shortages are most severe in the summer months and are a direct impact of changes in the basin's hydrologic regime, where spring runoff is projected to peak earlier in the season. Reclamation has made Basin Study results and water recourse models available to study partners to assist better-informed decision-making.
- In the Yakima River basin, Reclamation is coordinating with partners to evaluate better water management options and provide flows for endangered fish. In 2009, Washington Department of Ecology and Reclamation gathered representatives from the Yakama Nation, irrigation districts, environmental organizations, and other Federal, state, and local stakeholders to develop a consensus-based solution to current and future water issues, referred to as the Integrated Water Resources Management Plan. Some of the strategies outlined in the plan were directly related to the Reclamation Yakima River Basin Study, which identified that snowpack (often referred to as the sixth reservoir) is in jeopardy due to current and projected temperature increases and changes in precipitation timing and form.
- Reclamation has also been working collaboratively with a diverse group of stakeholders to initiate the Upper Deschutes River Basin Study in central Oregon. Reclamation and its non-Federal cost-share study partners finalized a Plan of Study in May 2015, and a comprehensive analysis of water supply and demand that addresses the impacts of climate change is now underway. The study will use integrated surface water and groundwater models to apply climate change scenarios to future water-resource-management alternatives. Outcomes will include a tradeoff analysis of the options identified in terms of their ability to address agricultural, environmental, and municipal water supply interests.
- Reclamation has generated reconnaissance-level hydrologic data and analysis on the potential effects of climate change on water supply and demand as part of the Columbia River Basin Impact Assessment. Results from the CRBIA provide important information to the water management community and establish a foundation for stakeholders to develop more

in-depth analyses and adaptation strategies through basin studies, operations planning, feasibility-level analyses, or any other activity that can benefit from the results.

Reclamation also coordinates with, and provides technical review and information to, the Columbia Basin Development League. This group is a 501(C)(6) nonprofit organization incorporated in 1964 with the mission to provide support for the Columbia Basin Irrigation Project and its future development, protect its water rights, and educate the public on the renewable resource and multi-purpose benefits of the project. Reclamation is also a member of the Columbia River Water Resources Program Policy Advisory Group, formed in 2006 to provide a forum for communication among stakeholders and the State of Washington's Department of Ecology with respect to key water-resource management issues in the Columbia River Basin. Reclamation and the Columbia River Water Resources Program Policy Advisory Group work with the State of Washington to identify policy issues associated with implementing water-resource management programs for the Columbia River and assist in setting criteria for funding of storage and conservation projects.

5 References

Allan et al., 2005	Allan, J.D., M.A. Palmer, and N.L. Poff, 2005. Climate Change and Freshwater Ecosystems. In T.E. Lovejoy and L. Hannah (eds.), Climate Change and Biodiversity. p. 274-290, Yale University Press.
Barton and Ramirez, 2004	Barton, S.B., and J.A. Ramirez, 2004. Effects of El Niño Southern Oscillation and Pacific Interdecadal Oscillation on Water Supply in the Columbia River Basin. Journal of Water Resources Planning and Management, 130(4), p. 281-289. Retrieved from http://cedb.asce.org/cgi/WWWdisplay.cgi?142058.
Battin et al., 2007	Battin, J., M.W. Wiley, M.H. Ruckleshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki, 2007. Projected Impacts of Climate Change on Salmon Habitat Restoration. Proceedings of the National Academy of Sciences of the United States of America, 104(16), p. 6720-6725. Retrieved from http://www.pnas.org/content/104/16/6720.abstract.
Beechie et al., 2013	Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, and N. Mantua, 2013. Restoring Salmon Habitat for a Changing Climate. River Research and Applications, 29(8), pp. 939–960. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/rra.2590/abstract.
BPA, 2001	Bonneville Power Administration (BPA), 2001. The Columbia River System Inside Story, Second Edition. Bonneville Power Administration, Portland, Oregon. Retrieved from https://www.bpa.gov/power/pg/columbia_river_inside_story.pdf.
Brekke et al., 2010	Brekke, L., B. Kuepper, and S. Vaddey, 2010. Climate and Hydrology Datasets for use in the RMJOC Agencies' Longer-Term Planning Studies: Part I – Future Climate and Hydrology Datasets. Bureau of Reclamation. Retrieved from http://www.usbr.gov/pn/climate/planning/reports/part1.pdf.

Hatten et al., 2014	Hatten, J.R., T.R. Batt, P.J. Connolly, and A.G. Maule, 2014. Modeling Effects of Climate Change on Yakima River Salmonid Habitats. Climatic Change, 124(1–2), p. 427-439. Retrieved from http://link.springer.com/article/10.1007%2Fs10584-013-0980-4.
Isaak et al., 2012	Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler, 2012. Climate Change Effects on Stream and River Temperatures Across the Northwest U.S. from 1980-2009 and Implications for Salmonid Fishes. Climatic Change, 113(2), p. 499-524. Retrieved from http://link.springer.com/article/10.1007%2Fs10584-011-0326-z.
Lettenmaier et al., 2008	Lettenmaier, D., D. Major, L. Poff, and S. Running, 2008. Water Resources. In M. Walsh (ed.). The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. Synthesis and Assessment Product 4.3, p. 121-150. Retrieved from http://www.usda.gov/oce/climate_change/SAP4_3/CCSPFinalReport.pdf.
Mantua et al., 2009	Mantua, N.J., I. Tohver, and A.F. Hamlet, 2009. Impacts of Climate Change on Key Aspects of Freshwater Salmon Habitat in Washington State. In M. McGuire Elsner, J. Littell, and L. Whitely Binder (eds.), The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, p. 217-253. University of Washington Climate Impacts Group, Seattle, Washington. Retrieved from http://cses.washington.edu/db/pdf/wacciareport681.pdf.
NOAA Fisheries, 2008	National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2008 Upper Snake Biological Opinion, Consultation for the Operation and Maintenance of 10 Bureau of Reclamation Projects and 2 Related Actions in the Upper Snake River above Brownlee Reservoir.
Oregon Climate Change Research Institute, 2010	Oregon Climate Change Research Institute, 2010. Oregon Climate Assessment Report. Corvallis, Oregon: College of Oceanic and Atmospheric Sciences, Oregon State University.
Pacific Northwest Region Hydromet, 2015	Pacific Northwest Region Hydromet, 2015. Retrieved from http://www.usbr.gov/pn/hydromet/

Reclamation, 2008	Bureau of Reclamation (Reclamation), 2008. Recreation Opportunities at Bureau of Reclamation Projects Map.
Reclamation, 2016 (CRBIA)	Bureau of Reclamation (Reclamation), 2016. Columbia River Basin Impact Assessment.
Schindler and Rogers, 2009	Schindler, D.E., and Rogers, L.A., 2009. Responses of salmon populations to climate variation in freshwater ecosystems. In C.C. Krueger and C.E. Zimmerman (eds.), American Fisheries Society Symposium 70, p. 1127–1142.
USFS, 2010	U.S. Forest Service (USFS). 2010. Water, Climate Change, and Forests: Watershed Stewardship for a Changing Climate. General Technical Report PNW–GTR-812, Portland, Oregon. Retrieved from http://www.fs.fed.us/pnw/pubs/pnw_gtr812.pdf