RECLAMATION
Managing Water in the West

West-Wide Climate Risk Assessment

Columbia River Basin

Climate Impact Assessment

Interim Report

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Regional Office

July 2015

Mission Statements

U.S. Department of the Interior

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.

Bureau of Reclamation

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.

Notes Regarding this West-Wide Climate Risk Assessment – Impact Assessment

The Columbia River Basin Impact Assessment is a reconnaissance-level assessment of the potential hydrologic impacts of climate change in the Columbia River Basin. For this study it was necessary to isolate the impacts of climate change from other changes that may occur within the basin. Therefore, Reclamation has assumed that current water operations by all water management entities acting in the Columbia River Basin would continue unchanged in the future. This assessment does not consider any operational changes that may or may not be made by basin stakeholders in the future and does not reflect the position of any entity regarding future operational changes. The results should not be interpreted as an indication of actions that Reclamation or other entities may or may not take to maintain compliance with environmental laws such as the Endangered Species Act or National Environmental Policy Act. Possible adaptation and mitigation strategies to address imbalances in future water supply and demand in the basin may be considered in a subsequent Basin Study, which would include interested stakeholders.

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Abbreviations and Acronyms

Abbreviation or Acronym	Definition
°C	degrees Centigrade
°F	degrees Fahrenheit
aMW	average Megawatts
Assessment	Columbia River Basin Impact Assessment
BCSD	Bias Corrected Spatially Downscaled
BPA	Bonneville Power Administration
CH	Critical Habitat
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
ESA	Endangered Species Act
ET	Evapotranspiration
FCRPS	Federal Columbia River Power System
GCM	Global Climate Models or General Circulation Models
GIS	Geographic Information System
HD	Hybrid-Delta
LCCs	Landscape Conservation Cooperatives
LW/D	Less Warming/Drier
LW/W	Less Warming/Wetter
M	Median
MW/D	More Warming/Drier
MW/W	More Warming/Wetter
NIWR	Net Irrigation Water Requirements
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
PN Region	Reclamation's Pacific Northwest Region
PNRO	Pacific Northwest Regional Office
R&D	Research and Development
Reclamation	Bureau of Reclamation
RMJOC	River Management Joint Operating Committee
RMJOC Study	RMJOC Climate Change Study, Parts I–IV
SECURE	2011 SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water Report

Abbreviation or Acronym	Definition
SWA	2009 SECURE Water Act Subtitle F of P.L. 111-11
TSC	Reclamation's Denver Technical Service Center
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UW CIG	University of Washington Climate Impacts Group
VIC	Variable Infiltration Capacity (Hydrologic Model)
WACCIA	Washington Climate Change Impacts Assessment
WaterSMART	Water (Sustain and Manage America's Resources for Tomorrow)
WCRP	World Climate Research Programme
WRM	Water Resources Model
WWCRA	West-Wide Climate Risk Assessment

EXECUTIVE SUMMARY

Background and Purpose

The Bureau of Reclamation is taking a leading role in assessing the risks and impacts of climate change to Western U.S. water resources, and in working with stakeholders to identify climate adaptation strategies. Adequate and safe water supplies are fundamental to the health of citizens, strength of the economy, and protection of the environment and ecology in the Western U.S. Global climate change poses a significant challenge to the protection of these resources. Section 9503 of the SECURE Water Act, Subtitle F of Title IX of P.L. 111-11 (2009) (SWA), authorizes Reclamation to evaluate the risks and impacts of climate change in each of the eight major Reclamation river basins identified in the Act, and to work with stakeholders to identify climate adaptation strategies.

The Columbia River Basin was one of the basins identified for evaluation in the SWA. The basin is in the Pacific Northwest region of the United States and extends over seven U.S. states (Washington, Oregon, Idaho, Montana, Wyoming, Nevada, and Utah), 13 Federally recognized Indian reservations, and southern British Columbia, Canada. The Columbia River is the largest river in the Pacific Northwest at over 1,240 miles long and drains roughly 260,000 square miles, 15 percent of which is within Canada. The Columbia River Basin has numerous Federal and non-Federal hydropower production facilities which account for nearly 80 percent of the energy development in the Pacific Northwest. Additionally, the basin supplies water from 61 reservoirs that have a total active capacity of over 18 million acre-feet (Reclamation 2011). The basin provides habitat for various fish and wildlife species including Endangered Species Act (ESA) species such as bull trout, steelhead, white sturgeon, and other salmonids.

The 2011 SECURE Report (Reclamation 2011) found that the basin's average mean-annual temperature has increased by approximately 2 °F since the late 1800s. No apparent trend in precipitation exists over the period of record. However, between the mid- and late-20th century, the Columbia River Basin has experienced a general decline in spring snowpack due to more precipitation coming as rain instead of snow and earlier snowmelt runoff (Knowles et al. 2007 and Regonda et al. 2005; as cited in Reclamation 2011, p. 45). To further understand climate change impacts in the Columbia River Basin, the purpose of this Assessment is to generate reconnaissance-level hydrologic data and analysis on the potential effects of climate change in the basin, and how those effects relate to water supply and demand.

Objectives and Scope

In the Columbia River Basin, water management challenges exist in the form of competing water demands for agriculture; power production; environmental requirements; municipal, industrial, and recreational uses compounded by increasing populations; and other uses. Results from this Assessment will provide important information to the water management community in the Columbia River Basin on the scale of the challenges that climate change is likely to pose in the basin. The Assessment establishes a foundation for stakeholders to develop more in-depth analyses and adaptation strategies through more detailed Basin Studies; operations planning; feasibility level analyses; and other activities that may benefit from the results. The Assessment is intended to be another step in a continuing process to characterize the future climate and hydrology in the Columbia River Basin, which we anticipate will be refined many times over the years, as tools are improved and more information becomes available.

The Final Report will document the evaluation of past, current, and potential future climate and hydrology of the Columbia River Basin. It will quantitatively analyze the impacts associated with climate change as they relate to the mission of Reclamation, including effects on water supplies (e.g., snowpack, surface water, and ground water) and demands for the Columbia River Basin. These impacts will be evaluated in terms of the following eight components outlined in the SWA:

- Water and power infrastructure/operations
- Water delivery
- Flood control operations
- Water quality
- Fish and wildlife habitat
- ESA listed species and critical habitat
- Flow and water-dependent ecological resiliency
- Recreation

The Assessment builds upon the modeling and evaluation conducted along the mainstem of the Columbia River and select tributaries summarized in both the 2011 SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water Report, and the River Management Joint Operating Committee (RMJOC) Climate Change Study Reports, Parts I–IV (2011) (RMJOC Study). Certain generalized results about climate change, and the analysis approach from these earlier studies informed the Assessment. However, the Assessment also included refinements based on lessons learned.

At the time of the RMJOC Study, it was known that areas further upstream in the watershed (e.g., Henrys Fork) would need additional analysis and would likely require more routed inflow locations in the basin to better capture potential future changes. The

Assessment evaluated 157 additional future climate change inflow data sites from across the Columbia River Basin. In particular, the Assessment focused efforts on generating new data to evaluate the Upper Snake River Basin. The modeling effort for the Upper Snake River Basin is important to provide a comprehensive perspective for the entire Columbia River Basin.

This Interim Report summarizes research and analyses completed for the Assessment to date. Analyses cited in this report are drawn from the draft technical memorandums developed for each of the Assessment's primary study areas. Final technical memorandums will be included as appendices in the Final Report. All of the results included in this Interim Report are preliminary in nature and do not include the in-depth analyses, conclusions, or refinements that will be present in the Final Report. An internal preliminary review was conducted on all of the included information; however, due to the interim nature of this report, a complete review has not been conducted at this time.

Please note that this Interim Report does not include the bulk of the Assessment's anticipated results, and the subsequent analysis of those results. This is particularly notable in the following sections:

- Impacts of Climate Change on Water Supply
- Impacts of Climate Change on Reservoir Storage and Delivery
- Water Management Implications of Climate Change sections
- Summary of Findings

Assessment results were completed but not analyzed at the time of this Interim Report given the time required to verify and validate the data generated. Results, analysis, and implications of the Assessment's hydrologic projections will follow in the Final Report.

Assessment Approach

Climate Change Analysis and Hydrologic Modeling

This Interim Report will provide a sample of the regional maps that will be included in the Final Report to demonstrate historical data for Pacific Northwest (1) mean annual precipitation, (2) maximum temperature, and (3) minimum temperature (from Livneh et al. 2013), along with the 2080 projected mean annual change relative to each modeled climate scenario. The Final Report will include maps for these three climate metrics developed for the 2020, 2040, 2060, and 2080 period averages.

In addition, climate change impacts from the Assessment's 157 inflow data sites are currently being analyzed to determine any variation across the region, and identify any changes in the magnitude or timing of runoff. The Final Report will include sections on runoff conditions under simulated future climate for four main areas: the Columbia River Basin at the Dalles, the Snake River Basin (including Snake River Basin at Brownlee

Dam; Snake River near Heise, ID; Boise River Lucky Peak Inflow; and Payette River near Payette, ID), the Deschutes River Basin (including Deschutes River near Madras, OR and Crooked River below Opal Springs near Culver, OR), and the Yakima River Basin (including the Yakima River near Parker, WA).

Also, a comparison of the Assessment's climate change projections with previous RMJOC Study results will be performed across the Columbia River Basin. Multiple figures will be developed to provide side-by-side illustrations of the Assessment and RMJOC monthly runoff projections for specific locations.

Water Resource Modeling

A monthly water resources model (WRM) of the Snake River Basin above Brownlee Reservoir was used for this analysis. The WRM data was used to determine the potential effects of climate change scenarios on five major metrics—inflow to reservoirs, reservoir elevation, reservoir volume, flow at specific locations, and flow augmentation impacts. The Snake River Basin above Milner, Boise River Basin, and Payette River Basin were further evaluated in terms of regulated flow, system demand delivery, system demand storage, natural versus stored flow delivery, system inflow, and system reservoir contents.

Agricultural Demands

Methods were developed to adjust the simulated future net irrigation water requirement data from the Reclamation report entitled West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections. The adjusted data can be used in water resources modeling analysis of future climate in more detailed studies, such as Basin Studies. Details on this effort are included in this Interim Report.

Public Affairs

There were coordinated outreach efforts to internal and external stakeholders throughout the 2 year Assessment period to raise awareness of the Assessment. Activities included attending public meetings, writing and distributing quarterly updates, producing a website for the Assessment (http://www.usbr.gov/pn/climate/crbia/), and hosting a webinar series (available on the website created for the Assessment).

GIS

As part of the Assessment, Reclamation's existing Intranet web mapping application, *Tessel*, will be extended to provide context for visualizing previous and ongoing climate and hydrology modeling work in the Pacific Northwest Region. In addition to the internal web mapping application, the existing public web mapping application, *Streamflow Projections for the Western United States*

(http://gis.usbr.gov/Streamflow_Projections) will be updated to efficiently share data generated from the Assessment and previous studies with internal and external partners.

Next Steps

Moving forward, the modeling, analyses, and final reporting for the Assessment will be completed. Specific tasks to be completed include the following:

1) Finalize Assessment Technical Memorandums including:
   - Climate Change Analysis and Hydrologic Modeling Technical Memorandum
   - Water Resource Model Technical Memorandum
   - Determining Agricultural Demands for Use in Water Resources Models Technical Memorandum
   - GIS Coordination and Data Management Technical Memorandum
2) Conduct analyses of completed information and compare to prior work.
3) Refine summary of findings and identify additional next steps or future uses.
4) Complete Final Report by December 30, 2015, to include the items above.

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1 STUDY INTRODUCTION

1.1 Study Background and Purpose

The Bureau of Reclamation is taking a leading role in assessing the risks and impacts of climate change to Western U.S. water resources, and in working with stakeholders to identify climate adaptation strategies. Adequate and safe water supplies are fundamental to the health of citizens, strength of the economy, and protection of the environment and ecology in the Western U.S. Global climate change poses a significant challenge to the protection of these resources.

Section 9503 of the SECURE Water Act, Subtitle F of Title IX of P.L. 111-11 (2009) (SWA), authorizes Reclamation to evaluate the risks and impacts of climate change in each of the eight major Reclamation river basins identified in the Act, and to work with stakeholders to identify climate adaptation strategies. The Columbia River Basin was one of the basins identified for evaluation in the SWA. The purpose of this Assessment is to generate reconnaissance-level hydrologic data and analysis on the potential effects of climate change in the basin, and how those effects relate to water supply and demand.

1.2 Study Objectives and Scope

In the Columbia River Basin, water management challenges exist in the form of competing water demands for agriculture; power production; environmental requirements; municipal, industrial, and recreational uses compounded by increasing populations; and other uses. Results from this Assessment will provide important information to the water management community in the Columbia River Basin on the scale of the challenges that climate change is likely to pose in the basin. The Assessment establishes a foundation for stakeholders to develop more in-depth analyses and adaptation strategies through more detailed Basin Studies; operations planning; feasibility level analyses; and other activities that may benefit from the results. The Assessment is intended to be another step in a continuing process to characterize the future climate and hydrology in the Columbia River Basin, which we anticipate will be refined many times over the years, as tools are improved and more information becomes available.

The Final Report will document the evaluation of past, current, and potential future climate and hydrology of the Columbia River Basin. It will quantitatively analyze the impacts associated with climate change as they relate to the mission of Reclamation, including effects on water supplies (e.g., snowpack, surface water, and ground water) and demands for the Columbia River Basin. These impacts will be evaluated in terms of the following eight components outlined in the SWA:

- Water and power infrastructure/operations
- Water delivery

- Flood control operations
- Water quality
- Fish and wildlife habitat
- ESA listed species and critical habitat
- Flow and water-dependent ecological resiliency
- Recreation

The Assessment builds upon the modeling and evaluation conducted along the mainstem of the Columbia River and select tributaries summarized in both the 2011 SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water Report, and the River Management Joint Operating Committee (RMJOC) Climate Change Study Reports, Parts I–IV (2011) (RMJOC Study). Multiple Basin Studies have been completed in the Columbia River Basin, including the Henrys Fork Basin Study, the Yakima River Basin Study leading to the Yakima Integrated Plan, and the Hood River Basin Study (completed but public release is pending). The Upper Deschutes River Basin Study is currently in progress. Certain generalized results about climate change, and the analysis approach from these earlier studies informed the Assessment. However, the Assessment also included refinements based on lessons learned. To maintain consistency across Reclamation's regions, the Sacramento and San Joaquin Basins Impact Assessment (2014) and the Upper Rio Grande Impact Assessment (2013) were used as resources for this Assessment.

At the time of the RMJOC Study, it was known that areas further upstream in the watershed (e.g., Henrys Fork) would need additional analysis and would likely require more routed inflow locations in the basin to better capture potential future changes. The Assessment evaluated 157 additional future climate change inflow data sites from across the Columbia River Basin. In particular, the Assessment focused efforts on generating new data to evaluate the Upper Snake River Basin. The modeling effort for the Upper Snake River Basin is important to provide a comprehensive perspective for the entire Columbia River Basin.

Specific activities in this Assessment, many of which were selected to fill in gaps in RMJOC data, include the following:

- Presented an overview of the current climate and hydrology of the Columbia River.
- Analyzed observed trends in temperature and precipitation.
- Compared observed trends in temperature and precipitation over the past decade to Global Climate Models (GCMs) projections.
- Used the Hybrid Delta Ensemble approach to generate Variable Infiltration Capacity (VIC) input at the 1/16th degree scale.
- Developed simulated future streamflow for the Columbia River Basin using VIC.
- Bias-corrected VIC simulated future streamflow using the method applied in the RMJOC Study.

- Used the resulting bias-corrected VIC simulated future streamflow as water supply inputs to a Water Resources Model (WRM) to simulate regulated streamflow and operations for the 2020, 2040, 2060, and 2080 periods. The 2060 and 2080 periods were not simulated in the RMJOC Study.
- Used Coupled Model Intercomparison Project Phase 5 (CMIP5) projections and refined climate change scenarios that each represented the combined trend of 10 CMIP5 projections. This is in contrast to the one projection for one climate change scenario ratio used in RMJOC. The trend of 10 used in the Assessment provided a smoother, improved representation of the climate change signal.
- Created internal and external web mapping applications to make Assessment data available for use by stakeholders.

The Assessment evaluated the potential impacts of climate change on water supply and demand over the entire Columbia River Basin and does not attempt to project what future development or management actions may be, including how population may change, how power generation may evolve, or how land use may change due to the level of detail necessary for those type of analyses. While factors such as these will undoubtedly be affected by climate change, they are also changing due to societal factors and management actions that are independent of climate change. Reclamation does not presume to know what management actions will be taken by other entities operating in the Columbia River Basin. For these reasons, the results presented in the Assessment should be considered estimates of the hydrologic impacts of climate change only and not predictions of the future operation of facilities in the Columbia River Basin.

This Interim Report summarizes research and analyses completed for the Assessment to date. Analyses cited in this report are drawn from the draft technical memorandums developed for each of the Assessment's primary study areas. Final technical memorandums will be included as appendices in the Final Report. All of the results included in this Interim Report are preliminary in nature and do not include the in-depth analyses, conclusions, or refinements that will be present in the Final Report. An internal preliminary review was conducted on all of the included information; however, due to the interim nature of this report, a complete review has not been conducted at this time.

Please note that this Interim Report does not include the bulk of the Assessment's anticipated results, and the subsequent analysis of those results. This is particularly notable in the following sections:

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- Water Management Implications of Climate Change sections
- Summary of Findings

Assessment results were completed but not analyzed at the time of this Interim Report given the time required to verify and validate the data generated. Results, analysis, and implications of the Assessment's hydrologic projections will follow in the Final Report.

1.3 Study Document Organization

This report begins with a discussion of the purpose, basis, and authorizations for this Assessment. Next it provides a description of the basin, which provides the context for the study, followed by analyses methods, and initial study results. The following list breaks down which information is presented in each chapter of this report.

- Chapter 1 introduces the Assessment and describes the motivations for this work, the objectives and scope, and the programs supporting the study.
- Chapter 2 provides context for the study and presents the historical climate and hydrology of the basin.
- Chapter 3 presents the methods used for the analysis of current trends in climate and hydrology in the basin as well as the use of climate and hydrologic models to develop projections of what the climate and hydrology are likely to look like over the next century.
- Chapter 4 describes impacts to climate, hydrology, and water supply and demand.
- Chapter 5 describes impacts to water management, including: water and power infrastructure/operations, water delivery, flood control operations, water quality, fish and wildlife habitat including species listed under the ESA, flow and water-dependent ecological resiliency, and water-related recreation.
- Chapter 6 summarizes these impacts and provides a description of the next steps for Reclamation in its efforts to characterize the hydrologic impacts of climate change, as well as ways that local water-management entities might get involved in this effort.

1.4 Reclamation's Programs Supporting the Study

A key component of Reclamation's implementation of the SWA is the Basin Study Program. Reclamation's Basin Study Program is managed under the Department of Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program, which is working to achieve a sustainable water strategy to meet the Nation's water needs now and for the future. To learn more about WaterSMART, please visit: (http://www.usbr.gov/WaterSMART/).

The Assessment is an activity of the West-Wide Climate Risk Assessments (WWCRAs), which is a component of Reclamation's WaterSMART Basin Study Program. WWCRA

activities include identifying climate change water-related information needs of water resource managers, compiling climate data for water resources, and developing adaptation tools and guidance for water resource managers. The WWCRAs include three separate activities:

1) Consistent, west-wide assessment of climate-change impacts to water supplies
2) Consistent, west-wide assessment of climate-change impacts to water demands
3) Impact assessments for individual basins or sub-basins

Individual basin Impact Assessments, such as this one, address the potential risks of climate change to Reclamation facilities and operations, including water and power delivery, recreation, flood control, and ecological resources. These Impact Assessments are conducted to provide:

- A baseline analysis of climate change impacts that can be used to support future Basin Studies, in cooperation with local partners, in which impacts to multiple water uses are evaluated, and potential adaptation and mitigation strategies are developed and assessed.
- A more in-depth analysis of climate-change impacts as they relate to Reclamation facilities and operations.

Since the WWCRA Impact Assessments emphasize impacts to Reclamation facilities and operations and are not focused on the development of adaptation strategies, they are conducted by Reclamation alone and are not cost-shared with non-Federal partners. This allows Reclamation to develop consistent baseline information in a time frame consistent with the reporting requirements of SWA 9503(c). Results from all three WWCRA activities contribute to Reclamation's SECURE Reports to Congress every 5 years.

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2 LOCATION AND BACKGROUND

2.1 Basin Description

The Columbia River Basin is in the Pacific Northwest region of the United States and extends over seven U.S. states (Washington, Oregon, Idaho, Montana, Wyoming, Nevada, and Utah), 13 Federally recognized Indian reservations, and southern British Columbia, Canada. The Columbia River is the largest river in the Pacific Northwest at over 1,240 miles long and drains roughly 260,000 square miles, 15 percent of which is within Canada. The Columbia River headwaters are within the Rocky Mountains of British Columbia and the U.S., and its mouth is at the Oregon coast in Astoria. The river flows northwest into Canada before heading south into the State of Washington and continues westerly forming the boundary between Oregon and Washington before it drains into the Pacific Ocean.

The Columbia River has an annual average runoff of approximately 200,000,000 acre-feet (275,000 cubic feet per second) with roughly 25 percent of that volume originating in the Canadian portion of the basin (BPA 2001). Major tributaries to the Columbia River include the Snake River in Idaho (largest tributary to the Columbia River with a drainage area of 108,000 square miles); the Yakima, Spokane, and Methow rivers in Washington; the Kootenai, Clark Fork, and Flathead rivers originating in Montana; and the Willamette, Deschutes, John Day, Klamath, and Cowlitz rivers in Oregon. The Columbia River flows through diverse landforms including mountains, arid plateaus, rolling uplands, deserts, rainforests, and deep gorges. The river provides habitat for various fish and wildlife species including ESA species such as bull trout, steelhead, white sturgeon, and other salmonids.

The Columbia River Basin is home to six species of anadromous Pacific salmonids: Chinook, coho, sockeye, chum, pink salmon[1], and steelhead. The basin's salmon and steelhead runs were once among the largest in the world, with an estimated average of between 10–16 million fish returning to the basin annually. In addition to anadromous fish, the Columbia River and its tributaries are home to sturgeon, lamprey, whitefish, rainbow and cutthroat trout, and bulltrout (char) among other species. Many animals, including bald eagles, osprey, and bears, also rely on fish from the Columbia River and its tributaries to survive and feed their young.

Figure 1 shows the location of major dams in the Columbia River Basin that are owned and operated by Reclamation, U.S. Army Corps of Engineers (USACE), Canada and others. The

[1] Pink salmon are not listed under the Endangered Species Act.

Federal Columbia River Power System (FCRPS) has 14 facilities located on the Columbia River's mainstem, two of which are owned and operated by Reclamation, including Grand Coulee, the largest hydropower generating facility in the United States. The Columbia River also has numerous non-Federal hydropower production facilities. The combination of these facilities and the FCRPS facilities accounts for nearly 80 percent of the energy development in the Pacific Northwest. Many other facilities located on Columbia River tributaries, including 11 on the Snake River, are also authorized for uses such as water delivery, flood control, ecological resource support, and recreation. These facilities are primarily owned and/or operated by Reclamation, the USACE, other agencies, public utility districts, and private entities. Overall, the Columbia River supplies water from 61 reservoirs that have a total active capacity of over 18 million acre-feet (Reclamation 2011).

Reclamation's Pacific Northwest Region has a significant presence throughout the Columbia River Basin, with several offices working in response to actions affecting hydrology, power generation, and ecological resources in the basin. These include Grand Coulee Dam and Power Office, the Columbia-Cascades Area Office with field offices in Washington (Yakima and Ephrata) and Oregon (Bend and Umatilla/Hermiston); the Columbia Snake Salmon Recovery Office Tributary Habitat Program; various programs at the Snake River Area Office with field offices in Boise and Heyburn, Idaho; and multiple Regional Resource and Technical Services programs.

Figure 1. Map of major Dams in the Columbia River Basin (Reclamation 2015b)

2.2 Surface Water Flows

There is a high degree of variability in surface water flows in the Columbia River Basin as water flows through dry and wet areas of the diverse landscape. The basin is generally cooler and wetter on the western side of the Cascades and warmer and drier to the east. The

basin has dramatic elevation changes ranging from sea level to mountains over 14,000 feet. The headwaters of the Columbia River and its major tributaries are in high elevation and snow dominant watersheds. Snow dominant watersheds are sufficiently cold in the winter to allow for precipitation to fall in the form of snow, and for that snow to accumulate and remain until temperatures rise in the spring and summer. High elevation summers tend to be short and cool while the lower elevation interior regions are subject to greater temperature variability. As the effects of climate change increase overall temperatures in the Columbia River Basin, several watersheds are vulnerable to changing from snow dominant to rain dominant, especially tributaries in lower elevations.

This shift in precipitation type and its effect on runoff timing will affect Columbia River storage ability. Barton et al. (2012) found that reservoirs in the Columbia River Basin can only store approximately 20 percent of the average annual runoff. Table 1 shows that the estimated surface water use in 2010 was over 23 million acre-feet, which is just over 10 percent of the average annual runoff of 200 million acre-feet. While Table 1 is 1 year compared to a long period of record for the Columbia River Basin, it demonstrates that the basin's surface water is used for many purposes, including withdrawals.

Table 1. Total surface water use in Idaho, Oregon and Washington in 2010 (USGS 2014).

	Ground water (in million gallons/ day)	**Surface water (in million gallons/ day)**	**Groundw ater (acre-feet/day)**	**Surface water (acre-feet/day)**	**Groundw ater (acre-feet/year)**	**Surface water (acre-feet/year)**	**Total (acre-feet/year)**
Idaho	4,250	13,000	13,042.83	39,895.70	4,760,631	14,561,931	19,322,562
Oregon	2,130	4,300	6,536.76	13,196.27	2,385,916	4,816,639	7,202,555
Washin-gton	1,600	3,350	4,910.24	10,280.82	1,792,238	3,752,497	5,544,735
TOTAL	7,980	20,650	24,490	63,373	8,938,785	23,131,067	32,069,852

2.3 Groundwater Supply

Groundwater is an important source of water to the overall water supply in the Columbia River Basin. It is used to support agriculture in addition to providing a large portion of drinking water supply for some urban populations and most rural populations. In 2010, groundwater withdrawals made up about 30 percent of total water withdrawals in Idaho, Oregon and Washington (USGS 2014). In addition to providing water supply, groundwater return flows support baseflows in rivers throughout the Columbia River Basin.

Eight of the 62 primary aquifer systems in the U.S. identified by the U.S. Geological Survey are located within the Columbia River Basin. Reclamation projects are associated with the Columbia Plateau, Pacific Northwest, and Snake River Plain primary aquifer types, along with other local systems. The three primary aquifer types are comprised of fractured basalt at depth with interbedded and overlying sediments.

Many aquifer systems in the Columbia River Basin receive a large amount of seasonal recharge from the irrigated agriculture system, including canal seepage and excess water applied to crop land. In the Snake River Plain and Columbia Plateau systems, groundwater storage volumes increased from the early 1900s through the 1960s after which point groundwater storage volumes decreased due primarily to increased pumping (USGS 2013). Since that time, both groundwater systems have experienced depletions in groundwater storage.

2.4 Basin Development History

Humans have inhabited the Columbia River Basin for more than 15,000 years, with a transition to a sedentary lifestyle based mainly on salmon starting about 3,500 years ago (U.S. National Research Council 2004). Starting in the 19th and 20th centuries, Columbia Basin rivers were engineered for navigation, flood control, irrigation, hydropower generation and other uses. Dam construction, construction of irrigation and drainage systems, changing land use patterns, and river channelization, as well as ground-water pumping, has significantly altered flows and sediment distribution in the basin. These activities have also affected the relationship between surface water and groundwater throughout the basin. Operation of flood control and water storage dams alters the amount of water that is conveyed through the river.

The Columbia River Basin and its tributaries have 61 major dams (see Figure 1 for locations) along with numerous minor dams and diversion structures that have been constructed by Reclamation, USACE, Canada, and others. These facilities alter flows by storing and releasing water in a manner that generally decreases flood peaks and alters the distribution of the timing of the flows. The major dams also trap significant amounts of sediment, causing buildup and increases in channel elevation upstream, and riverbed degradation (lowering of the riverbed) and coarsening of riverbed sediment in the reaches below the dams.

Another noteworthy basin development is the significant population growth that has been changing the Pacific Northwest. Between the 2000 and 2010 U.S. Census the population of Idaho, Oregon and Washington increased 21.1 percent, 12.0 percent and 14.1 percent respectively (U.S. Census Bureau 2011). The increasing populations place increased pressure on infrastructure, residential and business development, agricultural demands, energy production, and recreation. These pressures underscore the need for water delivery and hydropower from Reclamation facilities.

3 ASSESSMENT APPROACH

Since the RMJOC Climate Change Study was the primary basis for the Assessment's analysis approach, a background of the RMJOC process is provided in this section to clarify which refinements were made in the Assessment. The RMJOC Climate Change Study was a collaborative effort among the USACE, Bonneville Power Administration (BPA), and Reclamation. The study documents the impact of climate change on the Federal hydropower system, and flooding on the mainstem Columbia River. The RMJOC Study, Parts I–IV was a 2-year effort completed in 2011 in which the mainstem Columbia River and the Upper Snake River sub-basin above Brownlee Reservoir (including the Boise and Payette rivers), Deschutes River Basin, Yakima River Basin, and other tributaries to the Columbia River were analyzed. The three agencies completed a four-part series of reports:

1. *Climate and Hydrology Datasets for Use in the River Management Joint Operating Committee Climate Agencies' Longer-Term Planning Studies: Part I - Future Climate and Hydrology Datasets (December 2010)*

2. *Climate and Hydrology Datasets for Use in the RMJOC Climate Agencies' Longer-Term Planning Studies: Part II - Reservoir Operations Assessments for Reclamation Tributary Basins (January 2011)*

3. *Climate and Hydrology Datasets for Use in the RMJOC Climate Agencies' Longer-Term Planning Studies: Part III - Reservoir Operations Assessment: Columbia Basin Flood Control and Hydropower (May 2011)*

4. *Climate and Hydrology Datasets for Use in the RMJOC Climate Agencies' Longer-Term Planning Studies: Part IV - Summary (May 2011)*

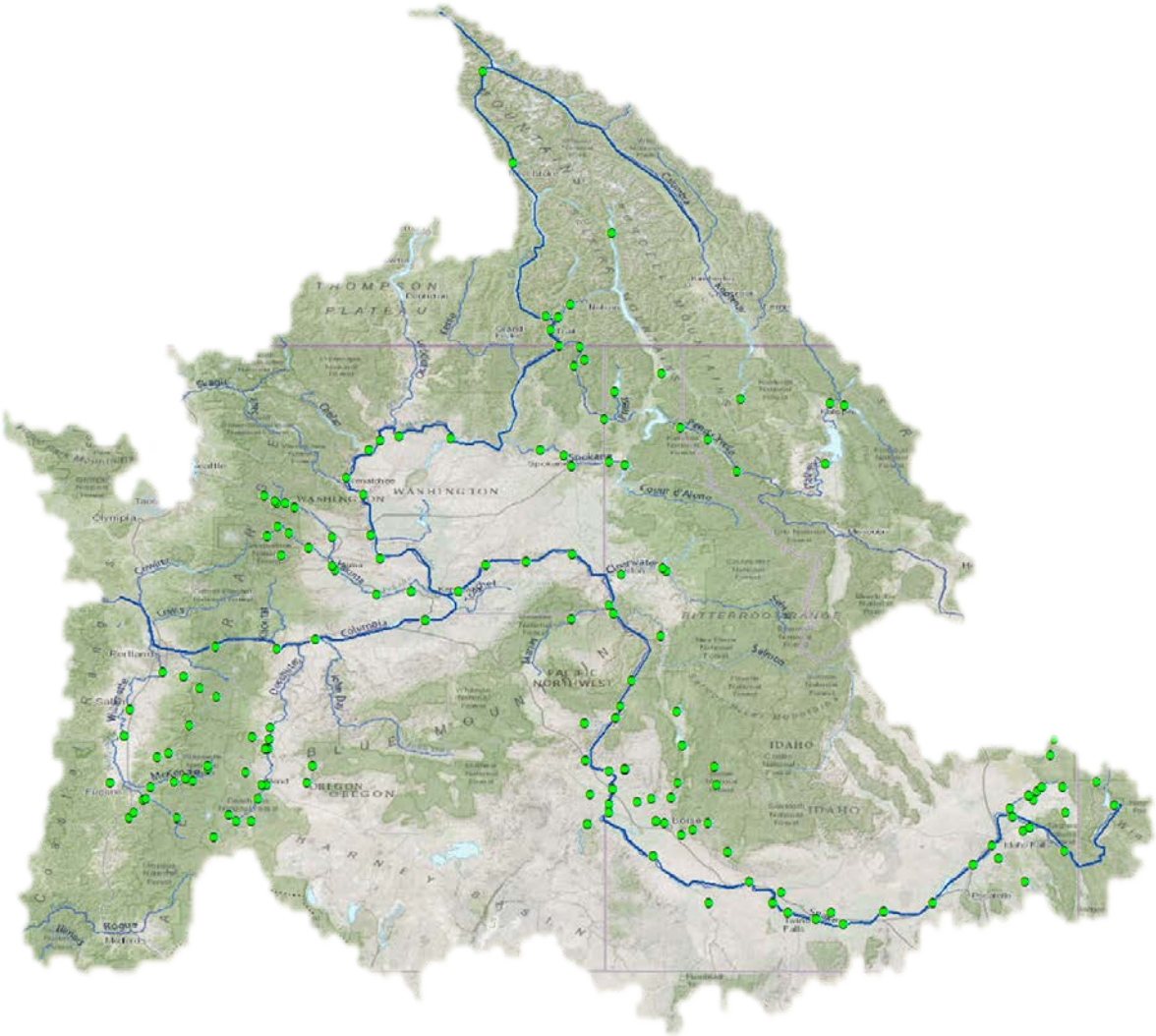
The RMJOC Study used climate and hydrologic data developed by the University of Washington Climate Impacts Group (UW CIG). In turn, the RMJOC Study developed climate change scenarios using bias corrected and spatially downscaled (BCSD) Coupled Model Intercomparison Project Phase 3 (CMIP3) climate change projections (e.g., temperatures, precipitation). The RMJOC Study then used two techniques to evaluate climate change scenarios—Hybrid-Delta (HD) and Transient. Two future time periods of the HD scenarios were defined as the 30-year period surrounding the 2020s (2010 to 2039) and the 30-year period surrounding the 2040s (2030 to 2059), while Transient projections were evaluated from 1950 through 2099.

At the time of the RMJOC Study it was known that locations further upstream in the watershed (e.g., Henrys Fork) would need additional analysis and would likely require more routed inflow locations in the basin to better capture potential future changes. In the Assessment, flows were generated using the VIC hydrologic model at additional points to

total 157 future climate change inflow data sites from across the Columbia River Basin. Data was bias corrected and spatially downscaled. This additional analysis is included in this Assessment. In particular, the Assessment focused efforts on generating new data to evaluate the Upper Snake River Basin. The modeling effort for the Upper Snake River Basin is important to provide a comprehensive perspective for the entire Columbia River Basin.

3.1 Climate Change Analysis and Hydrologic Modeling

As part of the Assessment, almost 300 locations were originally selected for VIC model generation of future flow time series; however, this inventory had to be scaled back due to a lack of available historic flow data to allow for accurate bias correction. Therefore, the VIC model was used to generate simulated historic and future climate change flows at 157 locations throughout the Columbia River Basin (see map of locations in Figure 2).


THOMPSON
PLATEAU
WASHINGTON
Olympia
Seattle
Tacoma
Spokane
Wenatchee
Yakima
Kennewick
Pasco
Columbia
Clearwater
Coeur d'Alene
Lewiston
Cascade
Salmon
BITTERROOT RANGE
PACIFIC
NORTHWEST
IDAHO
Boise
Twin Falls
Pocatello
Idaho Falls
Portland
Salem
Eugene
Medford
Roseburg
Coos Bay
Bend
Klamath Falls
Rogue
Umpqua
Willamette
Deschutes
Crooked
Malheur
Owyhee
Snake
Clearwater
Salmon
Lewis
Cowlitz
Nooksack
Skagit
Okanogan
Methow
Pend Oreille
Kootenai
Flathead
Bitterroot
Clark Fork
Spokane
Palouse
Tucannon
Yakima
Wenatchee
Entiat
Chelan
Methow
Okanogan
Similkameen
Kettle
Colville

climate to be evaluated in each 30-year period. The five scenarios, used in the RMJOC Study and continued in the Assessment, include:

- Less Warming Wetter (LW/W) – a cluster of 10 future projections around the 20th percentile of temperature and 80th percentile of precipitation;
- Less Warming Drier (LW/D) – a cluster of 10 future projections around the 20th percentile of temperature and 20th percentile of precipitation;
- Median (M) – a cluster of 10 future projections around the 50th percentile of temperature and 50th percentile of precipitation;
- More Warming Wetter (MW/W) – a cluster of 10 future projections around the 80th percentile of temperature and 80th percentile of precipitation; and,
- More Warming Drier (MW/D) – a cluster of 10 future projections around the 80th percentile of temperature and 20th percentile of precipitation.

Since the RMJOC study, an additional suite of GCM simulations known as Coupled Model Intercomparison Project Phase 5 (CMIP5) has become available. The Assessment developed hydrologic scenarios based on a cluster of 10 projections from these updated CMIP5 model runs. A total of 231 CMIP5 monthly climate projections were considered in this Assessment. In its climate change analyses, the Pacific Northwest (PN) Region Project Team also used the Climate Analysis Toolkit (a free plugin for HydroDesktop) to analyze downscaled climate projection data and develop future climate data for subsequent hydrological modeling. Details on this work will be provided in the Final Climate Change Analysis and Hydrologic Modeling Technical Memorandum.

The following table outlines the PN Region Project Team's methodology selections for the Assessment by describing the Assessment's steps, the choices available for each step, the PN Region Project Team's selections, and guidance for the decisions.

Table 2. Columbia River Basin Impact Assessment methodology selections.

Step	Description of Step	Choices	Selection for use in Assessment	Guidance for Selection Decisions
1	Select Global Climate Projection Context	CMIP3 or CMIP5	Selected CMIP5	WWCRA, Research and Development (R&D)
2	Select how future climate will be characterized	Period-change (Delta or Hybrid Delta) or transient	Selected Hybrid Delta ensemble method	WWCRA & R&D
3	Select number of change scenarios	Selections by 80/20 percent, 10/90 percent, 25/75 percent leading to MW/W, MW/D, LW/W, LW/D, C	80/20 percent was selected. Selected five change scenarios bracketed by Less Warming/Drier (LW/D), Less Warming/Wetter (LW/W), More Warming/Wetter (MW/W), and More Warming/Drier (MW/D). A fifth scenario indicating the central change (50 percent) or Median (M) was selected as well.	WWCRA, R&D, Pacific Northwest Regional Office (PNRO)

Step	Description of Step	Choices	Selection for use in Assessment	Guidance for Selection Decisions
4	Select whether change scenarios informed by a single projection or an ensemble of several	Single projection or ensemble	Ensemble (nearest 10 to intersection)	R&D, PNRO
5	Based on the decisions above, determine options for generating hydrology	Use existing available future hydrology or generate new future hydrology consistent with climate assumptions made above with original modeling	Generated new future hydrology	WWCRA, PNRO
5a	If generating new hydrology, select model	VIC 1/16th or 1/8th degree grid and routing tool (other hydrologic models are available)	Selected VIC 1/16th degree grid model and routing tool for routing flow to selecting locations (VIC model has been applied to Columbia River Basin already through the RMJOC Climate Change Study) For generating future climate-adjusted weather under each climate change scenario, 1/8th degree precipitation and temperature changes computed from the 1/8th degree BCSD CMIP5 climate projections were interpolated to 1/16th degree before being used to adjust the 1/16th degree “base historical” weather data developed by UW CIG.	WWCRA, PNRO

Step	Description of Step	Choices	Selection for use in Assessment	Guidance for Selection Decisions
5b	If generating new hydrology, determine flow routing locations of interest	Identify locations in the sub-basin of interest that have gages with long-term Periods of Record to "train" simulated historical and future climate change flows to.	Several key locations have been identified in previous efforts (RMJOC Climate Change Study) and will continue to be used. The PN Region Project Team also identified additional sites. Initially 300 VIC flow routing points were identified for study. However, several points were excluded because it was determined that there was not sufficient historical gage data to bias correct them. Therefore, only 157 points with sufficient historical flow data were retained for analysis.	WWCRA, R&D, PNRO

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3.1.1 Identification of Groundwater Dominated Systems

In the Columbia River Basin, several streams have a large component of flow supplied by groundwater (baseflow). Since climate change has the potential to impact groundwater supplies, streamflows may also be affected. VIC is limited in its ability to simulate runoff in basins that have a large baseflow component, so it may be necessary to use an alternate tool to develop simulated future hydrologic flows for these streams.

In order to determine if an alternate tool should be used when developing simulated future hydrologic flows, monthly mean summary hydrographs were examined for the 157 flow points in the Columbia River Basin. Monthly mean summary hydrographs tend to have a flatter signature than hydrographs in snowmelt driven systems. Figure 3 shows an example of this behavior for the gage at Boise River at Glenwood Bridge, a snowmelt driven system, and the gage at Deschutes River at Benham Falls, a baseflow driven system.

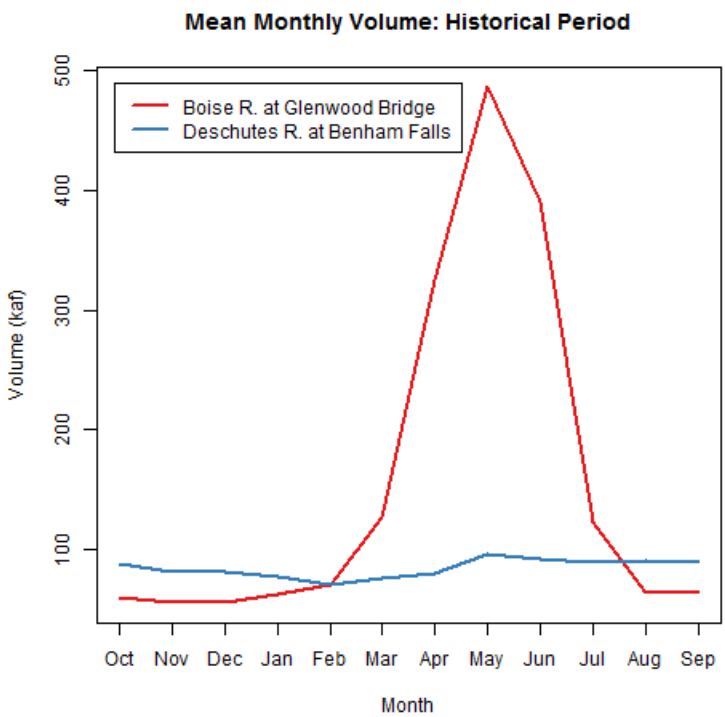

Figure 3. Mean monthly volume for the historical period of naturalized flow at (1) Boise River at Glenwood Bridge (red) and (2) Deschutes River at Benham Falls (blue).

Given this hydrograph behavior, a ratio was developed for each of the 157 gages of the minimum flow divided by the maximum flow. Larger ratios reflect a flatter hydrograph which indicates the system may be dominated by baseflow, and therefore an alternate tool

may be necessary to develop simulated future hydrologic flows. Since this work directly applies to determining an appropriate hydrologic model for developing simulated future hydrologic flows, this task was combined with the hydrologic modeling section. Details on this work will be provided in the Final Climate Change Analysis and Hydrologic Modeling Technical Memorandum.

3.2 Water Resource Modeling

A monthly water resources model (WRM) of the Snake River Basin above Brownlee Reservoir is being used for this analysis. The WRM includes the Boise River Basin, Payette River Basin, and the Owyhee River Basin as well as the Snake River Basin from its headwaters at Jackson Lake down to Brownlee Reservoir. The WRM has been used for multiple purposes, including the RMJOC analysis. For this Assessment, the WRM was used to evaluate potential impacts from climate change.

In the RMJOC Study, the upper Snake River MODSIM model (version 8.1) was used to determine the potential effects of climate change scenarios on five major metrics in the Upper Snake River sub-basin (i.e., inflow to reservoirs, reservoir elevation and volume, flow at specific locations, and flow augmentation impacts). In this Assessment, the model was updated to MODSIM version 8.4.2 and re-calibrated and validated before it was used to evaluate the same five major metrics as in RMJOC.

The Baseline simulation represents a regulated MODSIM simulation using a simulated historical water supply from VIC. Simulated flows generated by VIC, which use simulated historical inputs of precipitation and temperature, were bias-corrected using the same process described in RMJOC Part I to remove bias on both a monthly and annual basis. The observed historical (unregulated) and the VIC simulated historical (Baseline) and simulated future climate change flows generated in the climate change analysis and hydrologic modeling task were used as input to the upper Snake River MODSIM model. Next, analyses were conducted of associated output.

Output parameters analyzed in this Assessment include:

- Monthly median natural reservoir inflow
- Monthly median regulated reservoir outflow
- Monthly median streamflow
- Monthly median irrigation delivery and shortage
- Impact to natural flow and stored water rights

Details on this work will be provided in the Final Water Resource Modeling Technical Memorandum.

3.3 Agricultural Demands

Agricultural demands (also called diversions) are a large subset of water use in the Columbia River Basin and are a necessary set of information when modeling water resources. For historical analysis, historical diversions can be quantified by looking at actual diversion rates that are typically measured by various entities.

In 2015, Reclamation completed an analysis of future projected water demands for eight major river basins in the Western U.S. (Reclamation 2015a). The analysis focused on required crop evapotranspiration (ET), the amount of water required by the crop to grow, and net irrigation water requirement (NIWR)—the amount of precipitation subtracted from the required evapotranspiration. The demand quantity required for the WRM is the total amount of water that is diverted from the river, of which ET and NIWR are only a portion. The remaining part of the demand can be made up of canal seepage, on-farm losses, and surface return flows, and is referred to as system loss. Therefore, the data in the Reclamation study must be adjusted to reflect the total demand prior to using it in the water resources model.

This portion of the Assessment focused on developing methods to adjust the simulated future NIWR data from the Reclamation study so that it could be used in water resources modeling analyses of future climate in more detailed studies, such as Basin Studies. Two methods were developed and tested using MODSIM nodes from the upper Snake River model—the Total Irrigated Acres method and the Linear Regression method. Both methods used a relationship between historical diversion and historical NIWR to obtain an estimate of system loss that could be applied to the future projected NIWR data. Details on this work will be provided in the Final Determining Agricultural Demands for Use in Water Resources Models Technical Memorandum.

3.4 Public and Stakeholder Outreach

Reclamation Public Affairs staff coordinated outreach efforts to internal and external stakeholders throughout the 2 year Assessment period to raise awareness of the Assessment. External stakeholders include BPA, USACE, U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service, the Federal Caucus, the public, non-governmental organizations, and interested Tribes. Activities included attending public meetings, writing and distributing quarterly updates, producing a website for the Assessment (http://www.usbr.gov/pn/climate/crbia/), and hosting a webinar series (available on the Assessment website).

3.5 GIS Coordination and Data Management

As part of the Assessment, Reclamation's existing Intranet web mapping application, *Tessel*, is being extended to provide context for visualizing previous and ongoing climate and hydrology modeling work in the PN Region. A number of interactive data-driven layers are available in the internal web mapping including, but not limited to, Reclamation features (dams, diversions, hydropower plants, reservoirs, canals, etc.), major hydrography, terrain, imagery, jurisdictional boundaries, and watershed boundaries. Custom functionality is also being created to support download of observed historical, simulated historical, and simulated future climate change flow data for locations where modeling has been conducted for the Assessment.

In addition to the internal web mapping application, the existing public web mapping application, *Streamflow Projections for the Western United States* (http://gis.usbr.gov/Streamflow_Projections) is being updated to efficiently share data generated from the Assessment and previous studies with internal and external partners. This work is being coordinated with Reclamation's Policy and Administration Office to establish an approach that will be used west-wide. Details on this work will be provided in the Final GIS Coordination and Data Management Technical Memorandum.

3.6 Sources of Uncertainty

The simulations presented in the Assessment are based on reasonable assumptions about our future. Since we do not actually know how humans are going to behave, what energy sources they will be using, or how much carbon dioxide they will emit into the atmosphere, there is uncertainty associated with any projection of future climatic changes. Also, output from each model used in the Assessment carries with it uncertainties associated with simplification and lack of understanding of the modeled system, and each statistical transformation of the output increases these uncertainties. By definition, these uncertainties are difficult to quantify, but can have significant effects on the hydrologic simulations generated. The modeling tools are continually being refined, and, as planning moves forward, the hydrologic simulations developed by these tools will have to be reexamined as well.

This section will be updated in the Final Report based upon output results.

4 IMPACT ASSESSMENT: PROJECTED CLIMATE AND WATER SUPPLY, DEMAND AND DELIVERY

This section will provide an overview of the climate characteristics of the Columbia River Basin along with observed trends and estimated future changes. Also, it will evaluate how the projected impacts of climate change will affect water supply including groundwater, surface water, and natural basin inflows. Lastly, the section will discuss reservoir storage and delivery in terms of regulated and general water delivery and consumption.

4.1 Climate in the Columbia River Basin: Past, Present, and Future

4.1.1 Discussion and Overview of the General Climate Characteristics of the Columbia River Basin

Climate is distinguished from weather by a longer timescale, years as opposed to days or weeks, over which meteorological conditions are viewed. Meteorological conditions include temperature, precipitation, solar radiation, wind, atmospheric pressure, and humidity, among others. Evaluations of changes in climate include both natural variability and human-induced long term changes in climate.

The year-to-year variability is driven, in-part, by the El Niño (a.k.a. Southern Oscillation), which has a strong influence on the Columbia River Basin. El Niño causes dryer conditions in the basin and has a long-term average return interval of 4-years. Natural variability also includes other multi-year ocean cycles such as La Niña, as well as cycles that can occur on even longer time scales (for example, the Pacific Decadal Oscillation). Naturally driven variation in climate will continue into the future along with changes due to increased greenhouse gas concentrations from human activities.

Geographically, the basin has a wide variety of climates that is strongly influenced by highly varied topography over a large area. A maritime climate occurs in most coastal areas, typically between the ocean and high Cascade Mountain Range; an alpine climate in the highest mountains; and semi-arid and arid climates east of the higher mountains (Oregon Climate Change Research Institute 2010). The climate within the basin generally varies from cooler and wetter on the western “windward” side of the Cascades

to warmer and drier on the eastern "leeward" side (Reclamation 2011). Approximately two-thirds of the region's precipitation occurs in just half the year between October and March. From late spring to early fall, high pressure to the west generally keeps the region fairly dry; however, extended severe droughts are relatively rare.

4.1.2 Observed Trends in Climate Conditions over the Columbia River Basin

The 2011 SECURE Report (Reclamation 2011) included the finding that, over the course of the 20th century, warming has been prevalent in the Columbia River Basin (Figure 4). The mean annual temperature in the basin has increased by approximately 2 °F since the late 1800s. Basin moving-mean annual precipitation, depicted within Figure 4 (bottom panel), ranges from 20 to 25 inches. No apparent trend in precipitation over the period of record exists. Between the mid- and late-20th century, the Columbia River Basin has had a general decline in spring snowpack due to more precipitation occurring as rain instead of snow and earlier snowmelt runoff (Knowles et al. 2007 and Regonda et al. 2005; as cited in Reclamation 2011, p. 45). Luce and Holden (2009) evaluated the distribution of streamflow reductions from 1948-2006 and revealed significant trends in annual streamflow reductions during dry years and suggests that dry years have been getting increasingly "dry."

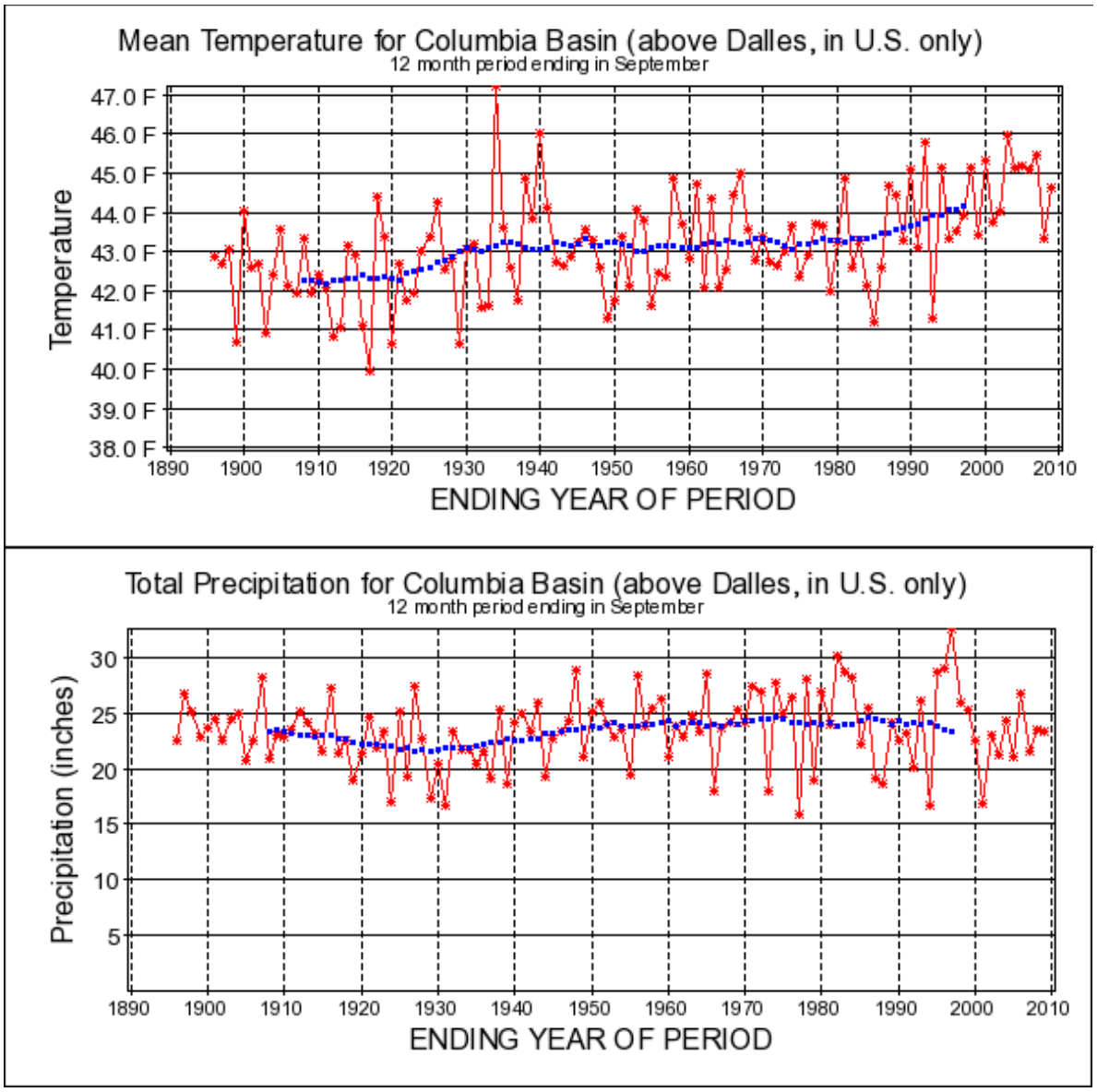

Figure 4. Observed annual (red) and moving-mean annual (blue) temperature and precipitation, averaged over the Columbia River Basin above The Dalles.

Source: Western Climate Mapping Initiative (WestMap) available at: http://www.cefa.dri.edu/ Westmap/. Red line indicates annual time series for the given geographic region. Blue line indicates 25-year moving annual mean values, where each value is plotted on the center year of its respective 25-year period. WestMap data are derived from the PRISM climate mapping system (Daly et al. 2004 and Gibson et al. 2002; as cited in Reclamation 2011, p. 44).

4.1.3 Future Changes in Climate Conditions over the Columbia River Basin

Figure 5 – Figure 7 show historical data for Pacific Northwest (1) mean annual precipitation, (2) maximum temperature, and (3) minimum temperature (from Livneh et al. 2013), along with the 2080 projected mean annual change relative to each modeled climate scenario. The Final Report will include maps for these three climate metrics developed for the 2020, 2040, 2060 and 2080 period averages. These figures illustrate the general trend characterized by the Assessment towards warmer and wetter across the region, as well as the spatial variation of the change magnitude.

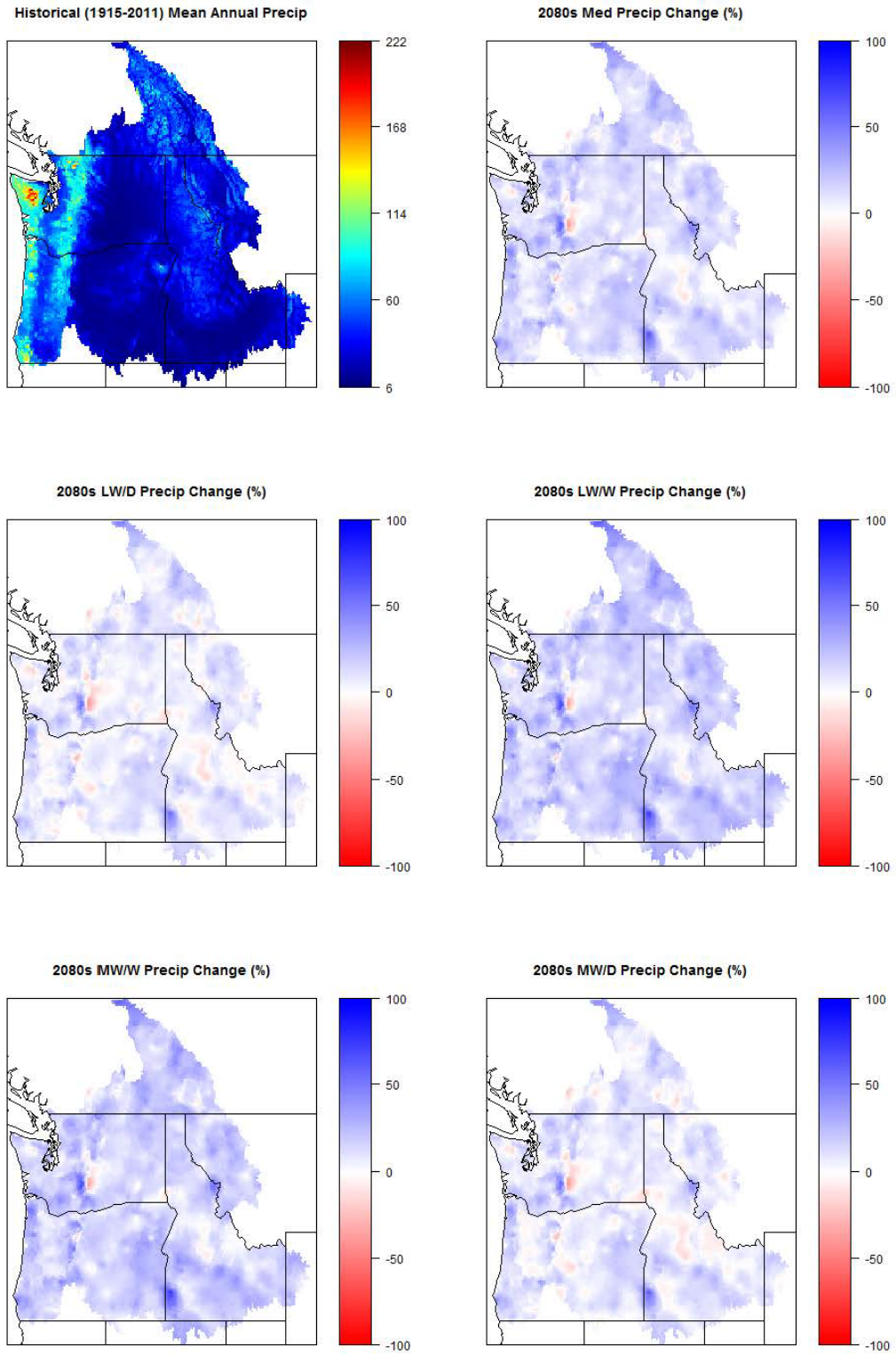

Figure 5. Mean annual precipitation in inches for the period of January 1915 through December 2011 (from Livneh et al. 2013) and maps of percent change between historical and 2080 period averages for each Hybrid-Delta climate scenario. Note: LW/W = Less Warming Wetter; LW/D = Less Warming Drier; M = Median; MW/W = More Warming Wetter; MW/D = More Warming Drier

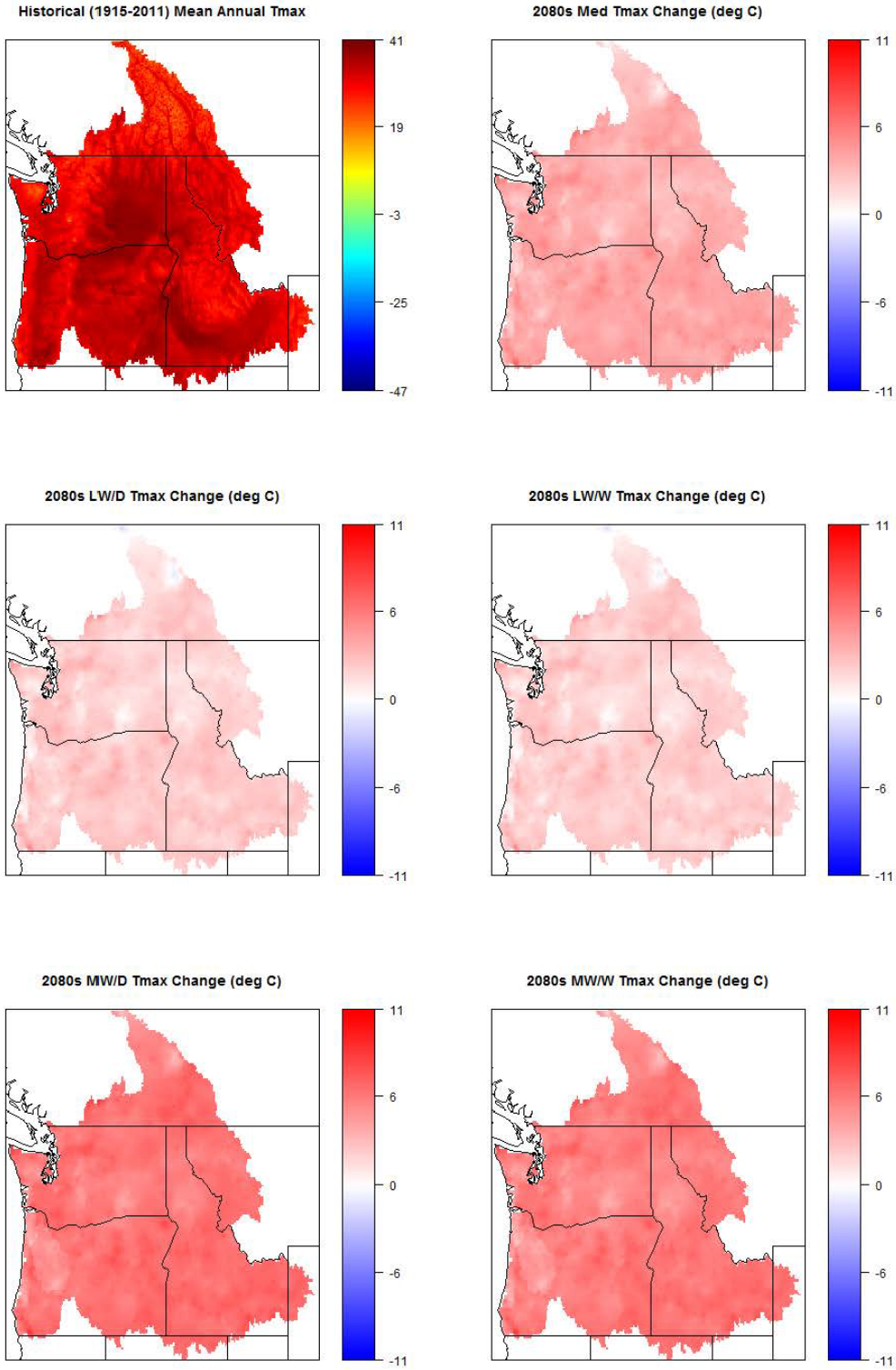

Figure 6. Mean annual maximum temperature for the period of January 1915 through December 2011 (from Livneh et al. 2013) and maps of the change in degrees Celsius between historical and 2080 period averages for each Hybrid-Delta climate scenario. Note: LW/W = Less Warming Wetter; LW/D = Less Warming Drier; M = Median; MW/W = More Warming Wetter; MW/D = More Warming Drier

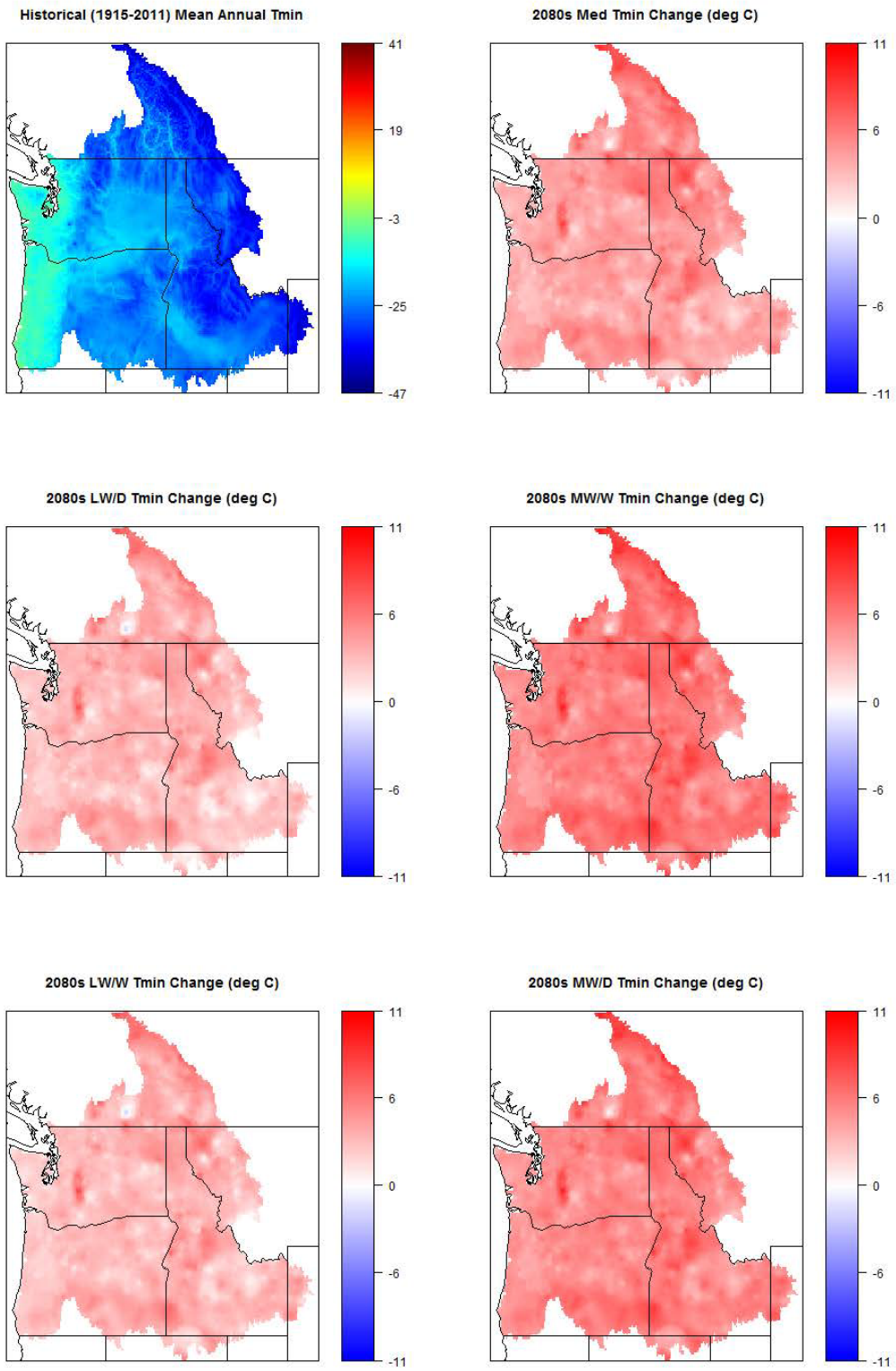

Figure 7. Mean annual minimum temperature for the period of January 1915 through December 2011 (from Livneh et al. 2013) and maps of the change in degrees Celsius between historical and 2080 period averages for each Hybrid-Delta climate scenario. Note: LW/W = Less Warming Wetter; LW/D = Less Warming Drier; M = Median; MW/W = More Warming Wetter; MW/D = More Warming Drier

In future years, more pronounced changes are anticipated in the climate of the Columbia River Basin, including greater increases in average temperature, earlier snowmelt runoff, increased variability in streamflow, and other hydrologic variables. Projected changes in temperature are generally uniform across the Columbia River Basin and increase steadily over time. Observed temperatures are generally cooler in the north and along the mountainous rims, while warmer temperatures are observed in the lower-lying areas of the Columbia River Basin interior and throughout the Snake River plain of southern Idaho.

As shown in Figures 5 through 7, precipitation and temperature is expected to increase throughout the basin over the 21st century. Changes in temperature and precipitation will have important and varied consequences for water resources across the region, with hydrologic response (for example, timing and magnitude of runoff) depending upon the dominant form of precipitation in the basin and other local characteristics such as elevation, aspect, geology, vegetation, and changing land use (Melillo et al. 2014).

4.2 Impacts of Climate Change on Water Supply

This section of the report identifies the locations that are being simulated in the Assessment. In the Final Report, this section will summarize model simulation results that describe climate change impacts on water supply. At the time of this Interim Report, the results were completed but not yet analyzed given the time required to verify and validate the data generated.

4.2.1 Groundwater Discharge to Surface Water

Reduced mountain snowpack, earlier snowmelt, and reductions in spring and summer streamflow volumes originating from snowmelt likely would affect surface water supplies and could trigger heavier reliance on ground water resources. However, warmer, wetter winters could increase the amount of water available for ground water recharge, but this area needs further study. Also, according to Lettenmaier et al. (2008; as cited in Reclamation 2011, p. 59), depletions to natural groundwater recharge are sensitive to climate warming.

4.2.2 Natural Basin Inflows

The Assessment generated average monthly stream flows for 157 locations throughout the Columbia River Basin. Climate change impacts are currently being analyzed to determine any variation across the region, and any identified changes in the magnitude or

timing of runoff. The Final Report will include sections on runoff conditions under simulated future climate for four main areas: the Columbia River Basin at The Dalles, the Snake River Basin (including Snake River Basin at Brownlee Dam; Snake River near Heise, ID; Boise River Lucky Peak Inflow; and Payette River near Payette, ID), the Deschutes River Basin (including Deschutes River near Madras, OR and Crooked River below Opal Springs near Culver, OR), and the Yakima River Basin (including the Yakima River near Parker, WA).

Also, a comparison of the Assessment's climate change projections with previous RMJOC Study results will be performed across the Columbia River Basin. Multiple figures will be developed to provide side-by-side illustrations of the Assessment and RMJOC monthly runoff projections for specific locations.

4.3 Impacts of Climate Change on Reservoir Storage and Delivery

In the Final Report, this section will summarize model simulation results that describe climate change impacts on Columbia River Basin regulated water delivery and consumption, and general Columbia River Basin water delivery and consumption. For this Interim Report, the results were completed but not analyzed given the time required to verify and validate the data generated.

4.3.1 Columbia River Basin Regulated Water Delivery and Consumption

Figure 8 identifies the WRM locations by code that were used during the selection of climate projections. Analyses of the model data will include identifying seasonal flows, storage and refill, and demand delivery for the Columbia River Basin. The results for the WRM effort and figures will be included in the Final Water Resource Model Technical Memorandum in the Final Report.

Figure 8. Map showing Water Resource Modeling locations by code (e.g., DALLE) of Columbia River Basin subbasins used during the selection of climate projections.

4.3.2 General Columbia River Basin Water Delivery and Consumption

Columbia River Basin water delivery and consumption is predominantly agricultural. Therefore, the Assessment focused its analysis on agricultural consumption, the details of which are further described below. In addition, this section covers other uses of Columbia River Basin water; however, these delivery and consumption amounts are poorly quantified compared to those of agricultural use.

4.3.2.1 Agricultural Consumption

As noted in the 2011 SECURE Report (Reclamation 2011), given that the moisture holding capacity of the atmosphere increases when air temperature increases, it may not simply lead to higher plant water consumption and surface water evaporation with a warming climate. Crop water demand responds to atmospheric carbon dioxide ozone and potential evapotranspiration as a result of temperature and precipitation (e.g., Baldocchi and Wong 2006 and Bloom 2010; as cited in Reclamation 2011, p. 60). In addition to the physical atmospheric drivers affecting water demands, there may be other, even more difficult to quantify, drivers. For instance, agricultural water demand could decrease on average due to crop failures caused by changes in pests and diseases (Reclamation 2011).

Also mentioned in the 2011 SECURE Report (Reclamation 2011), the seasonal volume of agricultural water demand could increase if growing seasons become longer and if farmers' practices and legal constraints adapt to this opportunity by introducing more

crop cycles per growing season. According to Gutowski et al. (2008; as cited in Reclamation 2011, p. 60), this possibility is based on studies suggesting that the average North American growing season increased by about 1 week during the 20th century; and it is projected that, by the end of the 21st century, it may be more than 2 weeks longer than typical of the late 20th century. A 2009 Pacific Institute study (as cited in Reclamation 2011, p. 60) suggests that agricultural lands requiring irrigation may increase by up to 40 percent due to climate change, and livestock water demands will increase significantly. Figure 9 shows the spatial distribution of the change in net irrigation water requirement for the Columbia River Basin for five scenarios (S1 = less warm/dry, S2 = less warm/wet, S3 = more warm/dry, S4 = more warm/wet, S5 = central tendency/median) for three future time periods, the 30 years surrounding the 2020s, 2050s, and 2080s (Reclamation 2015a).

In order to apply this information to water resources models, it requires that the projected future NIWR values be adjusted for system losses. This was tested on two water resource model nodes in the upper Snake River WRM using the Total Irrigated Acreage Method and the Linear Regression Method, described in section 3.3. Since the nodes in the upper Snake River model had substantial system loss, the change in total diversion was small relative to the total diversion.

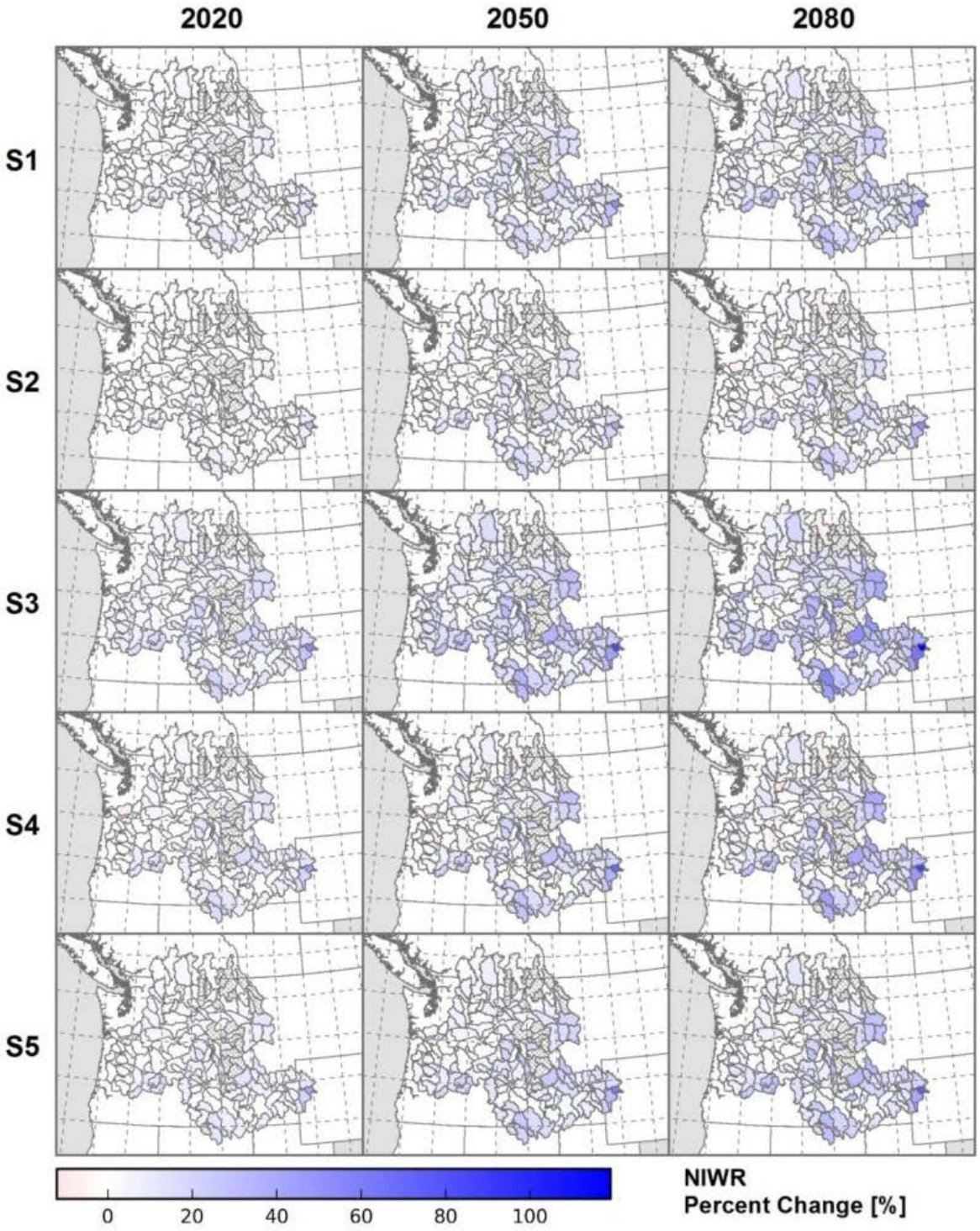

Figure 9. Spatial distribution of projected net irrigation water requirements (NIWR) percent change for different climate scenarios and time periods, assuming static crop distribution for annual crops (S1 = less warm/dry, S2 = less warm/wet, S3 = more warm/dry, S4 = more warm/wet, S5 = central tendency/median) (adapted from Reclamation 2015a).

This is illustrated in the following comparison between the two nodes. The A_BPump demand node supplies surface water to an average 12,223 acres in the A and B Irrigation District, with a maximum monthly diversion rate of approximately 14,000 acre-feet. The PeopAber demand node supplies surface water to an average 43,649 acres in the Aberdeen-Springfield and Peoples irrigation districts with a maximum monthly diversion rate of approximately 110,000 acre-feet. Using the Total Irrigated Acreage Method, the change in demand for both nodes was greatest in the summer months for the MW/D scenario. This is consistent with the idea that crops would require more irrigation water in dryer and warmer conditions. The maximum change for A_BPump, approximately 2,000 acre-feet, is roughly 15 percent of the total maximum diversion. The maximum change for PeopAber, approximately 20,000 acre-feet, is roughly 20 percent of the total maximum diversion. The changes are smallest for the LW/W scenario, which is also consistent with the idea that crops would require less irrigation water in less warm and wetter conditions (see Figure 10 and Figure 11).

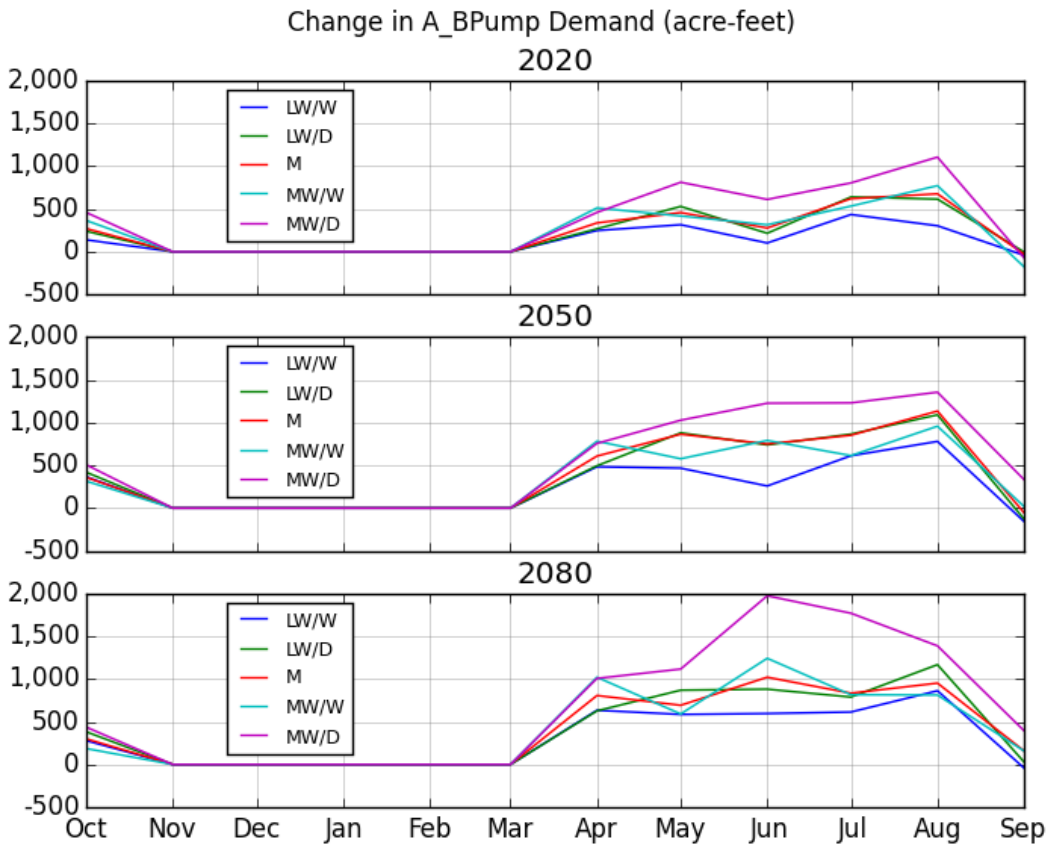

Figure 10. Total Irrigated Acreage Method: Average difference between the calculated future demand and the baseline for the A_BPump water resources node. Note: LW/W = Less Warming Wetter; LW/D = Less Warming Drier; M = Median; MW/W = More Warming Wetter; MW/D = More Warming Drier

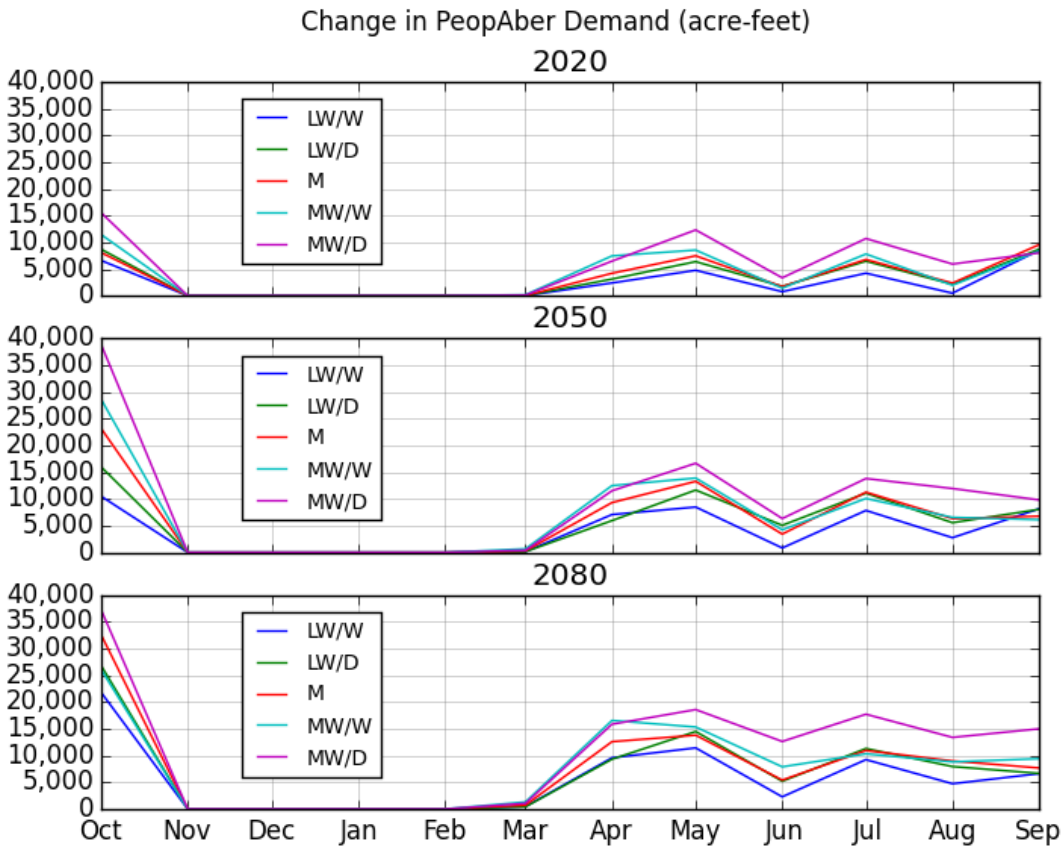

Figure 11. Total Irrigated Acreage Method: Average difference between calculated future demand and baseline for the PeopAber water resources model node. Note: LW/W = Less Warming Wetter; LW/D = Less Warming Drier; M = Median; MW/W = More Warming Wetter; MW/D = More Warming Drier

As in the Total Irrigated Acreage Method, in the Linear Regression Method the greatest change in future projected demand is also in the MW/D scenario and the smallest change is in the LW/W scenario (see Figure 12 and Figure 13). While both methods predicted similar results, the Total Irrigated Acres method predicted the historical demand slightly better than the Linear Regression Method.

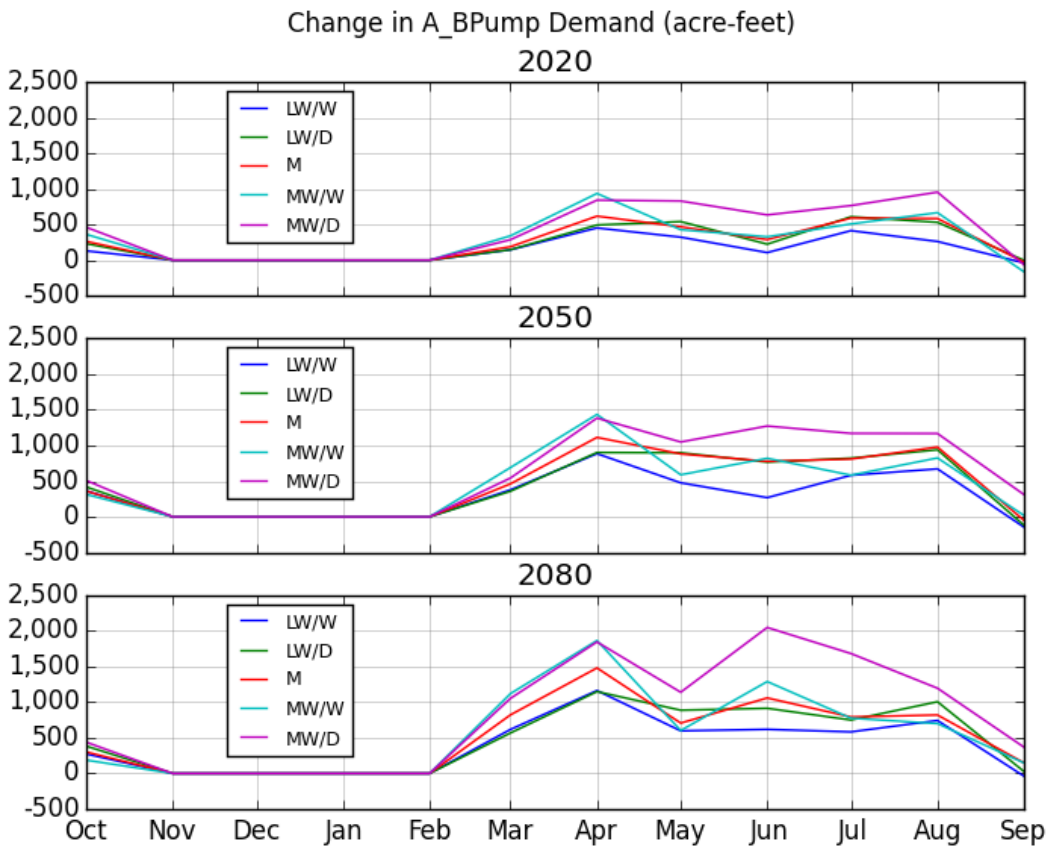

Figure 12. Linear Regression Method: Average difference between the calculated future demand and the baseline for the A_BPump water resources node.

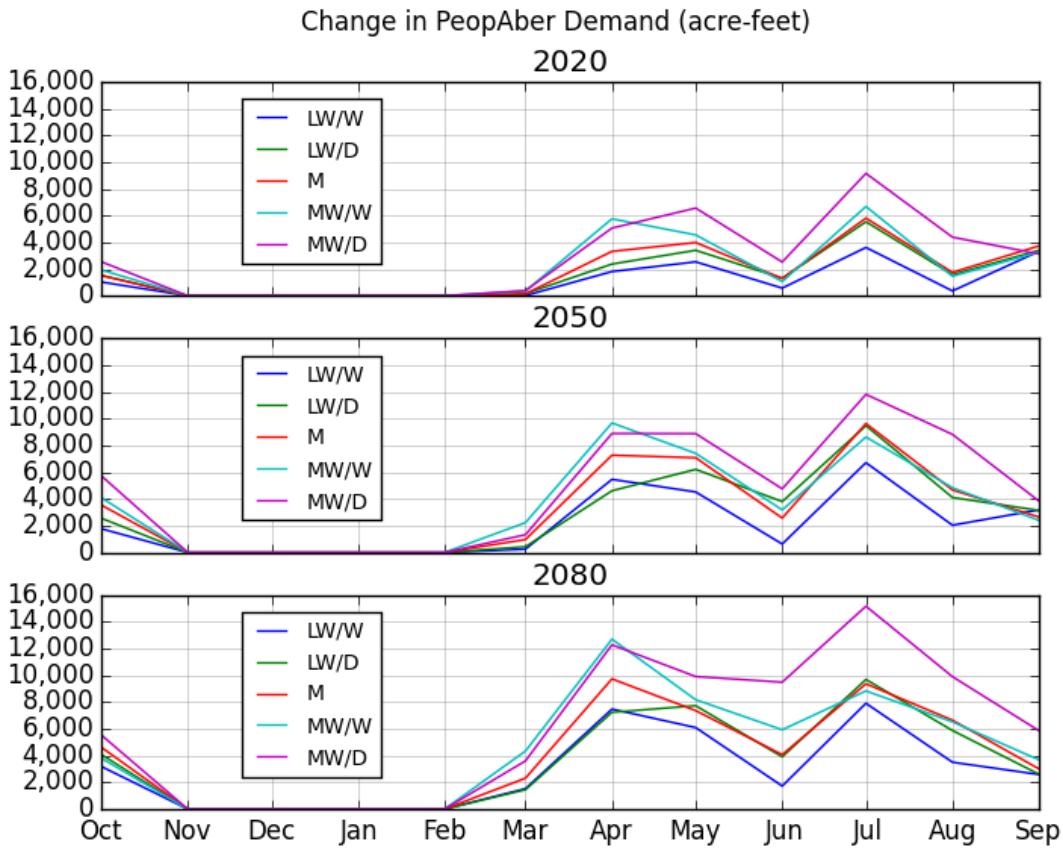

Figure 13. Linear Regression Method: Average difference between the calculated future demand and the baseline for the PeopAber water resources node.

The changes in diversion volumes noted in this Assessment are simply due to changes in NIWR that result from projected future climate conditions. Other systematic changes may occur if crop distribution, land use, or system efficiencies change with the changing climate. All diversion increases are currently limited by legal water right diversion rates. To understand the impacts of these changes on the system, the demands could be included in a water resource model application. This more extensive level of analysis was not conducted for this study.

4.3.2.2 Water Delivery and Consumption for Miscellaneous Water Uses

Potential instream water demand increases resulting from climate change within the Columbia River Basin could include ecosystem demands, hydropower production, industrial cooling, navigation, and recreational and municipal uses. Water demands for endangered species and other fish and wildlife could increase with ecosystem impacts due to warmer air and water temperatures and the resulting hydrologic impacts (i.e., runoff timing).

The timing of diversions for hydropower production could also be a factor in ecosystem demands and navigation and recreational water uses. Hamlet et al. (2010) project that demand for hydropower during the warm season is also expected to increase over the next century in part due to increased use of air conditioners as people adapt to higher temperatures and increased cooling degree days (number of days over 65 °F). Wilbanks et al. (2012) found that increases in energy demand are also expected to occur in response to increased groundwater pumping for irrigated agriculture and the pumping and treatment of water for municipal uses.

Climate change may affect water supplies and reservoir operations, and the resultant effects on water allocations from year-to-year could trigger changes in water use (e.g., crop types, cropping dates, environmental flow targets, transfers among different uses, hydropower production, and recreation) (Reclamation 2011). Such climate-related changes in water use would interact with market influences on agribusiness and energy management, demographics, land use changes, and other non-climate factors (Reclamation 2011).

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5 WATER MANAGEMENT IMPLICATIONS OF CLIMATE CHANGE

The following sections summarize the implications of the hydrologic projections developed in the Assessment for management of the Columbia River system in terms of the parameters defined in the SWA.

- Section 5.1 discusses the water infrastructure and operations, including reservoir conditions and water delivery and hydropower generation impacts.
- Section 5.2 discusses flood control operations impacts.
- Section 5.3 discusses water quality impacts.
- Section 5.4 discusses fish and wildlife habitat, including environmental flow targets, ESA-listed species, and critical habitat impacts.
- Section 5.5 discusses flow and water-dependent ecological resiliency impacts.
- Section 5.6 discusses impacts to recreation.

5.1 Water and Power Infrastructure and Operations

5.1.1 Hydropower Generation

The FCRPS consists of 14 Federal hydroelectric dams operated by either Reclamation or USACE. Additionally, the Columbia River houses hydroelectric dams owned by Canada, private entities, and others. In the climate change models studied in the RMJOC Study (RMJOC Part IV 2011), the anticipated change of runoff patterns with higher winter flows and lower spring and summer flows would result in a change in the regulated outflows from the projects. The increase in the January through April outflows would result in higher hydropower generation during this period and an increase in the frequency of forced spills at most of the projects. However, the reduced outflows during July and August are particularly problematic in that hydropower production would be reduced at the same time as increased temperatures caused by climate change trigger the demand for greater summer power loads (as cited in RMJOC Part IV 2011). Hydropower operations also are affected indirectly when climate change affects air temperatures, humidity, or wind patterns (Bull et al. 2007; as cited in Reclamation 2011, p. 58).

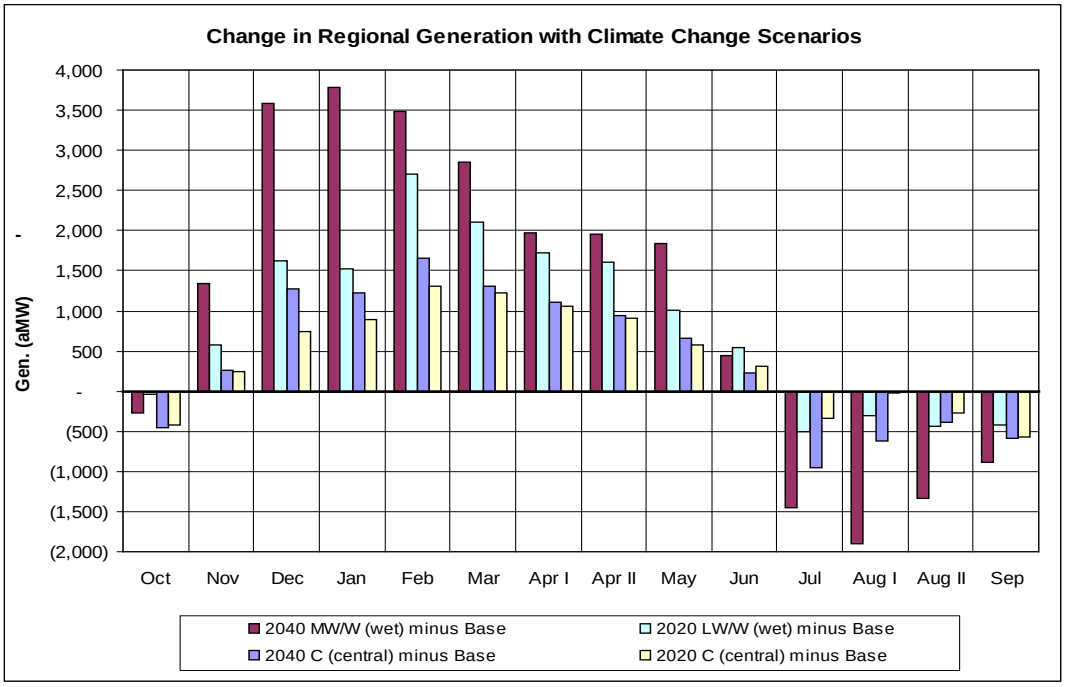

Figure 14. Climate change average changes in regional hydro-electric power generation (RMJOC Part III 2011).

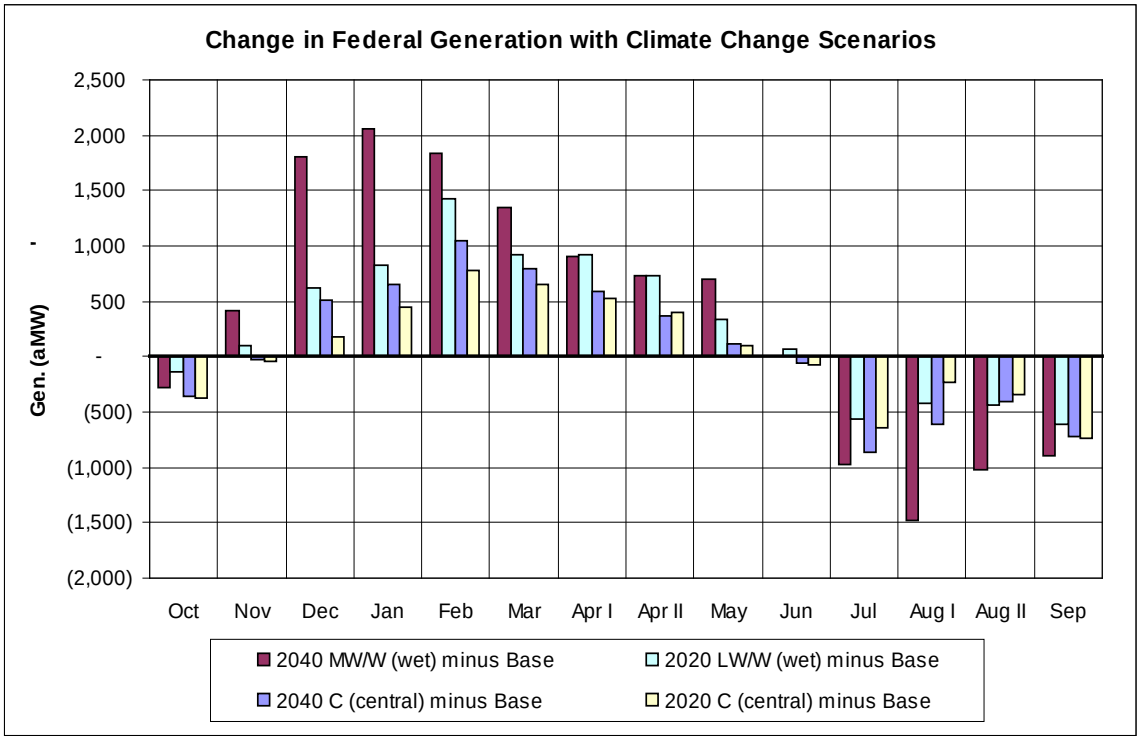

Figure 15. Climate change average changes in Federal hydro-electric power generation (RMJOC Part III 2011).

5.1.2 Reservoir Conditions and Water Delivery

In the climate change models evaluated in the RMJOC Study (RMJOC Part IV 2011), the increase in January through April precipitation falling as rain rather than snow would result in reservoirs filling more quickly and at a greater frequency. This characteristic led to a number of periods when project outflows were significantly higher during the late spring period because the reservoirs refilled to full pool too quickly (as cited in RMJOC Part IV 2011). Peak flows would occur earlier in the year and possibly necessitate earlier drawdowns[2] of the reservoirs.

According to the RMJOC Study (RMJOC Part III 2011), future river management procedures would likely need to be revised through a combination of deeper December reservoir drafting, (to better accommodate higher winter flows), and possibly deeper reservoir drafts in the August-September period to compensate for the reduced natural flows in the late summer (as cited in RMJOC Part III 2011). Increased drawdowns could also result in lower carryover volumes, thus increasing the potential for water shortages in drought years. Considerations to develop modifications of reservoir operations in advance would be a project-specific proactive measure as the projections are realized.

5.2 Flood Control Operations

In the mainstem Columbia River, snowpack in the unregulated portions of the basin is referred to as another reservoir for the system and is key to providing adequate irrigation supplies. Climate change would cause fall and winter inflow to reservoirs to increase as a result of more precipitation falling as rain rather than snow. The RMJOC Study (RMJOC Part III 2011) notes that, with current procedures, conflicts may arise between drafting earlier for spring snowmelt and the need to reduce winter flooding. This is because flood control Projects draft in the period January through April to meet their April flood control requirements for spring flood protection while higher winter flows are occurring. Any consideration of an earlier draft period might also have implications on Project refill and other spring-summer objectives such as fish flow objectives (as cited in RMJOC Part III 2011). It would also increase the reliance on storage for irrigation as more water will be lost to flood control that was previously available for those with natural flow rights.

As cited in the RMJOC Study (RMJOC Part III 2011), it is notable that some Projects may have operating constraints that limit reservoir draft rates due to dam safety, downstream safety, or other non-power operational reasons. Also, it may be desired to

[2] Drawdowns are defined as releasing water from reservoirs to lower the water surface levels and decrease the volume of water in the reservoirs, often done in anticipation of high inflows.

limit spill for water quality purposes and power purposes. These constraints will need to be considered if there is a need to draft to the maximum evacuation point earlier in the season (as cited in RMJOC Part III 2011, p. 105).

5.3 Water Quality

In the 2011 SECURE Report (Reclamation 2011) it was determined that whether water quality conditions improve or deteriorate under climate change depends on several variables including water temperature, flow, runoff rate and timing, and the physical characteristics of the watershed (Lettenmaier et al. 2008; as cited in Reclamation 2011, p. 59). Climate change has the potential to alter all of these variables. Climate change impacts on surface water ecosystems very likely will affect their capacity to remove pollutants and improve water quality; however, the timing, magnitude, and consequences of these impacts are not well understood (Lettenmaier et al. 2008; as cited in Reclamation 2011, p. 59).

According to the climate change models for the Columbia River Basin evaluated in the RMJOC Study (RMJOC Part III 2011), the increase in the January through April flows could result in higher power generation and increased spill at most dams. This additional spill may increase the total dissolved gas levels that could negatively impact fish (as cited in RMJOC Part III 2011).

5.4 Fish and Wildlife Habitat, Including Species Listed under the Endangered Species Act

5.4.1 Fish and Wildlife Habitat

Projected climate changes are likely to have an array of interrelated and cascading ecosystem impacts with feedbacks to runoff volume, water quality, evapotranspiration, and erosion (e.g., Janetos et al. 2008; Lettenmaier et al. 2008; Ryan et al. 2008). As stated in the 2011 SECURE Report (Reclamation 2011), other projected impacts are primarily associated with increases in air and water temperatures and include increased stress on fisheries that are sensitive to a warming aquatic habitat, potentially improved habitat for invasive species including quagga mussels (which bear further implications for maintenance of hydraulic structures), and increased risk of watershed vegetation disturbances due to increased fire potential. Additional warming-related impacts include poleward shifts in the geographic range of various species, impacts on the arrival and departure of migratory species, amphibian population declines, and effects on pests and

pathogens in ecosystems. Climate change can also trigger synergistic effects in ecosystems and exacerbate invasive species problems (Reclamation 2011).

Specific climate change implications for salmon fisheries in the Pacific Northwest include rising stream temperatures that will likely reduce the quality and extent of freshwater salmon habitat (Washington Climate Change Impacts Assessment (WACCIA) (Mantua et al. 2009; as cited in Reclamation 2011, p. 59)). WACCIA also suggests that the duration of periods that cause thermal stress and migration barriers to salmon is projected to at least double by the 2080s which is consistent with other studies in the region (e.g., Battin et al. 2007; as cited in Reclamation 2011, p. 59).

5.4.2 ESA Listed Species

The historic development of the Columbia River Basin has had impacts on listed species and their habitats, and climate change promises to exacerbate those impacts, primarily through decrease in streamflows. Reclamation currently operates under several biological opinions in the Columbia River Basin, including opinions on the Federal Columbia River Power System, Upper Snake, and Deschutes, Umatilla, and Lewiston Orchards Projects.

ESA listed species with habitat in the Columbia River Basin include the following:

Species Group and Species	Species Group and Species
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 snail **Reptiles** • Leather back turtle
Notes: 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).	

As indicated, total dissolved gas levels due to additional spill could negatively impact listed salmon and steelhead. Climate change impacts to the timing of Federal hydropower system operations could also affect the amounts of flows released for listed salmon and steelhead. The reduced flows during July and August may undercut Federal agencies' efforts to augment summer flows under the National Oceanographic and Atmospheric Administration (NOAA) Fisheries FCRPS Biological Opinion. Another impact to aquatic ecosystems is the potential for increases to winter flood frequency and intensity. According to Hatten et al. 2013, increases in winter flooding would impact incubating eggs and juvenile coho, Chinook, and steelhead survival. Because of the uncertainties associated with climate change analysis, the full extent of potential impacts on listed species would require further review. For instance, it appears that some NOAA Fisheries FCRPS Biological Opinion objectives would benefit and some would not in a changing climate.

5.5 Flow- and Water-Dependent Ecological Resilience

The impacts to fish populations will largely depend on the resiliency of the aquatic ecosystems and specific species. Schindler and Rogers state that the effects of changing climate on salmon populations depend on the species and life history of interest, local expressions of climate change, characteristics of habitat, and the adaptation of specific populations to geographic variation in habitat characteristics. In addition to the potential for mortality and thermal barriers, another impact from warming in freshwaters is a positive growth response in juveniles, although this will vary substantially with latitude (2009).

The effects of changes in thermal conditions on salmon populations throughout their range will likely show substantial variation both among and within climatic regions, and among species, populations, and life history strategies. Schindler and Rogers identify protection of biocomplexity of viable habitats and stock diversity as a key to resiliency of aquatic ecosystems in the face of a changing climate; where a stock characterized by a high diversity of populations and their associated dynamics is less sensitive to the variation in an individual population compared to a stock with low diversity (2009). Several studies have shown the importance of life history variability, or biocomplexity, to the resilience of salmonids in dynamic environments (Rieman and Dunham 2000). Evidence from this work suggests three important elements are necessary for resilience of Pacific salmon in fresh water: (1) the capacity to recover, (2) the diversity of habitats necessary to support the range of salmon life histories, and (3) connectivity. Additionally, Beechie et al. found that restoring floodplain connectivity, restoring stream flow regimes, and re-aggrading incised channels are most likely to improve stream flow and temperature changes and increase habitat diversity and population resilience (2013).

Reclamation's tributary habitat actions are typically geared to improving salmonid spawning and rearing habitat, providing habitat access, and enhancing in-stream flows. Reclamation's Columbia-Snake Salmon Recovery Office has ongoing work throughout the Columbia River Basin and these efforts should improve spawning and rearing habitat, including providing improved fish passage, refuge from predators, and thermal refugia, all of which could be impacted by, or in some cases help reduce, the impacts of the projected changes to climate and the hydrologic regime.

5.6 Recreation

The Columbia River Basin offers a number of water-dependent recreational activities, which are likely to be affected by climatic changes that affect the system hydrology. The reservoirs and rivers in the Columbia River Basin provide recreational opportunities such as camping, boating, swimming, fishing, nature study, and hunting. Increased summer and winter temperatures may increase the popularity of these water-based activities. Changes in the hydrologic regime and Project operations may alter the timing of boat ramp availability and flows associated with floating rivers. This is in addition to the impacts to fish and wildlife discussed in previous sections which will impact the associated recreational hunting, fishing, and wildlife viewing.

Climate change may also 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 also susceptible to impacts of cascading changes, such as from debris flows caused by rainstorms over fire scars, changing water quality, and changes to species presence/absence and abundance. Such impacts may become more common as the climate becomes hotter and drier. Overall, reduced supplies, altered timing of flows, and increased variability will change the availability and nature of recreational opportunities.

6 SUMMARY AND NEXT STEPS

6.1 Summary of Findings

The Assessment findings for climate and basin hydrology and potential water management implications will follow in the Final Report once the results and subsequent analyses are completed.

6.1.1 GIS

As part of the Assessment, internal and public web-mapping applications are being developed to share the climate and hydrology modeling work from the Assessment and previous studies. The Final GIS Coordination and Data Management Technical Memorandum will detail the data structure, organization, naming conventions, metadata, and delivery. The memorandum will also include methods, functions, and processes developed for processing and managing data, as well as the web-based discovery and delivery of data products.

6.1.2 Public and Stakeholder Outreach

Reclamation Public Affairs staff have coordinated outreach efforts to internal and external stakeholders throughout the 2 year Assessment period. Specific outreach efforts include the following:

Quarterly Updates

To spread the word about Reclamation's efforts on the Assessment, the PN Region Project Team releases quarterly e-newsletter updates on the project. The e-newsletter is sent to an expanding list of interested internal and external individuals. The first issue came out on August 30, 2014, and gave a summary of the Assessment and what could be expected in terms of results and timing. Subsequent issues, distributed January 30 and May 4, 2015, updated readers on the Assessment's progress and released preliminary results.

Webinar Series

To raise awareness about the Assessment, Reclamation hosted a five-part webinar series with presentations on September 4 and 25, October 8 and 22, and November 5, 2014. The series introduced the Assessment to Reclamation staff and external individuals involved in the Columbia River Basin. The series was created to highlight the processes used in the Assessment and to demonstrate the Assessment's high level of scientific integrity. A total of 240 participants attended at least one webinar in the series. These

webinars provided an opportunity for questions, feedback, and active participation from participants. Videos of the webinar presentations are posted on the Assessment website for access by all stakeholders.

Website

The PN Region Project Team also set up a website to inform partners about the Assessment. The website (http://www.usbr.gov/pn/climate/crbia/) includes an overview of the Assessment, related web links, a map of the study area, timelines, and a library of the Assessment webinars and quarterly updates. This Interim Report will be added to the website.

6.2 Next Steps and Future Uses of Assessment Information

Moving forward, the modeling, analyses, and final reporting for the Assessment will be completed. Specific tasks to be completed include the following:

1) Finalize Assessment Technical Memorandums including:
   - Climate Change Analysis and Hydrologic Modeling Technical Memorandum
   - Water Resource Model Technical Memorandum
   - Determining Agricultural Demands for Use in Water Resources Models Technical Memorandum
   - GIS Coordination and Data Management Technical Memorandum
2) Conduct analyses of completed information and compare to prior work.
3) Refine summary of findings and identify additional next steps or future uses.
4) Complete Final Report by December 30, 2015, to include the items above.

6.2.1 WaterSMART Basin Study Program Activities

As mentioned in section 1.4, this WaterSMART WWCRA Impact Assessment establishes a baseline characterization of how climate change may impact water supply, demand and key water-management activities, as called for in the SWA. This Assessment allows Reclamation to fulfill requirements under the SWA to better understand how its facilities, operations, and water delivery commitments to its customers may be affected by climate change.

Several WaterSMART Basin Study Program activities are available for stakeholders to pursue next steps:

- **Basin Studies.** Fully understanding risks and impacts of climate change will require a study team to evaluate not just the direct impacts of climate change, as projected in this study, but the secondary impacts that result from human responses to these changes, and the other developments that will go on with or without climate change. These other changes will need to be evaluated through a collaborative process that includes all of the necessary stakeholders in a basin. Reclamation's WaterSMART Basin Study Program has been developed to provide a framework for this collaborative process, and includes various options for stakeholders to build upon the results from a WWCRA Impact Assessment.

  The Basin Studies are in-depth water supply, demand, and operations analyses that are cost-shared with stakeholders and selected through a competitive process. Through the Basin Studies, Reclamation works collaboratively with stakeholders to evaluate the ability to meet future water demands in a particular basin and to identify mitigation and adaptation strategies to address potential climate change impacts. More information about Basin Studies is available at: http://www.usbr.gov/WaterSMART/bsp/.

- **Landscape Conservation Cooperatives.** In addition to the WWCRA Impact Assessments and the Basin Studies, the Basin Study Program includes Landscape Conservation Cooperatives (LCCs). The LCCs are partnerships of governmental (Federal, State, Tribal, and local) and non-governmental entities, and are an important part of the Department of the Interior's efforts to coordinate climate change science activities and resource management strategies.

  The Columbia River Basin is part of the Great Northern LCC, Great Basin LCC, and North Pacific LCC. Currently, Reclamation is a steering committee member for the Great Northern LCC.

  Reclamation participates in LCCs encompassing the 17 Western states to identify, build capacity for, and implement shared applied science activities to support resource management at the landscape scale. More information on LCCs is available at: http://www.usbr.gov/WaterSMART/lcc/.

All of the existing and proposed activities within the WaterSMART Basin Study Program are complementary and represent a multi-faceted approach to the assessment of climate change risks to water supplies, and impacts to activities in Reclamation's mission, as well as the identification of adaptation strategies to meet future water demands.

Reclamation will continue to refine these preliminary Columbia River Basin results through detailed Basin Studies under its WaterSMART program. Several WaterSMART Basin Studies have been completed or are currently being conducted in the Columbia River Basin. These include:

- Yakima River Basin
- Henrys Fork Basin
- Hood River Basin
- Willamette River Basin Plan of Study
- Upper Deschutes River Basin

Results of these efforts will continue to be monitored and reported in this Assessment as appropriate.

6.2.2 Other Research Activities

Additionally, other studies, analyses, assessments, and research have been conducted or are currently in progress in the Columbia River Basin and its subbasins. These efforts include the following:

Completed Efforts

Studies

- Boise River Climate Change Study (2009)
- RMJOC Climate Change Study 1 — Parts I–IV (2011)
- Icicle Creek Climate Change Qualitative Analysis (2011)
- Upper Snake River Bull Trout Biological Assessment (2013)

SECURE Water Act

- 2011 Report to Congress (2011)
- Ecosystem Resiliency Guidance (2013)

Current Efforts

Studies

- SECURE Water Act
    - Report to Congress (anticipated March 2016)
    - Agricultural Demands Analysis
    - Reservoir Evaporation Analysis
- RMJOC Climate Change Study 2 (anticipated 2016/2017)

Research

- Climate Analysis Toolkit using HydroDesktop
- Evaluating Future Agricultural Water Needs using Integrated Modeling Methods in the Boise River Basin

6.2.3 Reservoir Operations Pilot Initiative

As part of Reclamation's Climate Change Adaptation Strategy, a Reservoir Operations Pilot Initiative (Initiative) was identified to increase water management flexibility. As climate change alters the hydrologic regime, reservoir operations may need to be adjusted in order to maintain reliable water deliveries, power generation, support for environmental needs and flood control management. In future years, the Initiative will develop Reclamation guidance for making reservoir operations more flexible to adapt to projected climate impacts.

The Reservoir Operations Team (Team), a Reclamation-wide group of regional reservoir operations experts, planning engineers, climate scientists, and hydrologists was established under this Initiative. The Team has outlined a three step process to identify risks, determine impacts, and formulate alternatives for reservoir operations that will be used in developing the guidance. Moving forward, these three steps will be applied to selected pilot studies and associated reservoir operation systems.

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