RECLAMATION

Managing Water in the West

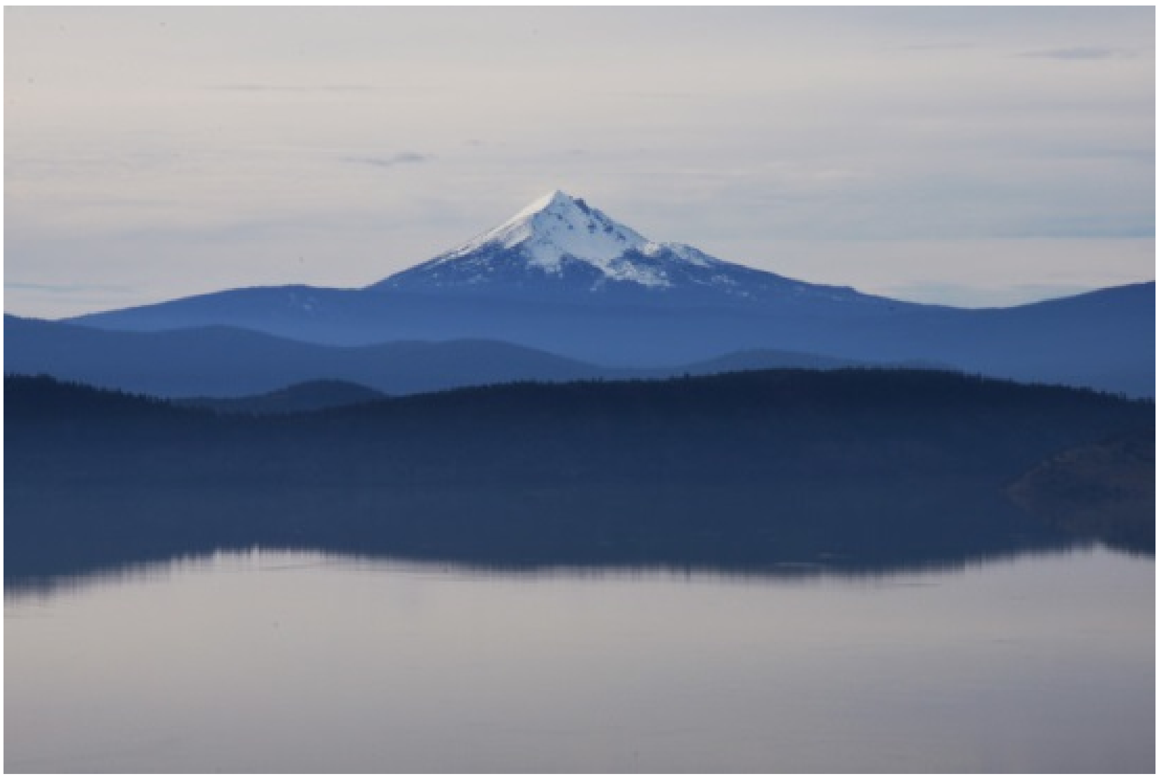
Final Report

Klamath River Basin Study

Technical Memorandum 86-68210-2016-06

Prepared by:

Klamath River Basin Study Technical Working Group



U.S. Department of the Interior
Bureau of Reclamation

State of California
Department of Water Resources

State of Oregon
Water Resources Department

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Mission Statements

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

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

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Abbreviations and Acronyms

AF	acre-feet
AFY	acre-feet per year
BA	Biological Assessment
Basin Study	Klamath River Basin Study
BCSD	bias corrected and statistically downscaled
BiOp	Biological Opinion
BLM	Bureau of Land Management
CDFG	California Department of Fish and Game (became CDFW in 2013)
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CMIP3	Coupled Model Intercomparison Project, Phase 3
CMIP5	Coupled Model Intercomparison Project, Phase 5
COPCO	California Oregon Power Company
CRLE	complementary relationship lake evaporation
CRS	Congressional Research Service
CT	central tendency
CVP	Central Valley Project
degrees C	degrees Celsius
degrees F	degrees Fahrenheit
DPS	distinct population segment
DRI	Desert Research Institute
EIS/EIR	environmental impact statement/environmental impact report
ENSO	El Niño/southern oscillation
EOM	end of month
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ET	evapotranspiration
ET_c	crop evapotranspiration
ET_o	reference evapotranspiration

Abbreviations and Acronyms (continued)

FAO	Food and Agriculture Organization of the United Nations
FERC	Federal Energy Regulatory Commission
GCM	general circulation model
GDD	growing degree days
gpcd	gallons per capita per day
HD	hot-dry
HDe	ensemble hybrid delta method
HUC	hydrologic unit code
HW	hot-wet
Interior	U.S. Department of the Interior
IPCC	Intergovernmental Panel on Climate Change
KAF	thousands of acre-feet
KBPM	Klamath Basin Planning Model
KBRA	Klamath Basin Restoration Agreement
KHSA	Klamath Hydropower Settlement Agreement
LKNWR	Lower Klamath National Wildlife Refuge
M&I	municipal and industrial
MODFLOW	modular finite-difference flow (model)
MWAT	maximum weekly average temperature
NEPA	National Environmental Policy Act
NIWR	net irrigation water requirement
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWR	National Wildlife Refuge
OWRD	Oregon Water Resources Department
PDO	Pacific decadal oscillation
PDSI	Palmer drought severity index
P_e	effective precipitation
PET	potential evapotranspiration
P.L.	Public Law
PM	Penman Monteith dual crop coefficient method

Abbreviations and Acronyms (continued)

Prcp	mean annual precipitation
Project	Reclamation's Klamath Project
PRMS	precipitation runoff modeling system
Reclamation	Bureau of Reclamation
RBM10	River Basin model-10
RO	runoff
SECURE	Science and Engineering to Comprehensively Understand and Responsibly Enhance
SONCC ESU	Southern Oregon/Northern California Coast Ecologically Significant Unit
SWE	snow water equivalent
Tavg	mean daily average temperature
T_{max}	maximum daily air temperature
T_{min}	minimum daily air temperature
TMDL	total maximum daily load
TWG	technical working group
UKL	Upper Klamath Lake
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIC	variable infiltration capacity (model)
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WD	warm-dry
WW	warm-wet
WWCRA	West-Wide Climate Risk Assessments

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Chapter 1
Klamath River Basin Study
Introduction

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Chapter 1
Introduction

1.1 Background

The Klamath River Basin is the second largest watershed in the State of California (approximately 15,700 square miles), after the Sacramento River Basin (approximately 27,900 square miles; see Figure 1-1). Approximately 60 percent of the watershed is public land (U.S. Geological Survey [USGS], 2007). It supports habitats and numerous fish and wildlife species in addition to supplying water for agriculture, hydropower, recreation, the environment, and tribal, municipal, industrial, and domestic uses. The watershed is divided by the Cascade and Siskiyou Mountains, which create two distinct climates: an arid climate in the upper basin, generally east of the mountains, and a maritime climate in the lower basin. The upper portion of the basin covers approximately 38 percent of the watershed but contributes only 12 percent of the entire watershed's annual flow (Congressional Research Service [CRS], 2005). The lower portion of the basin covers approximately 62 percent of the watershed, yet contributes 88 percent of the watershed's annual flow. The primary tributary inflows are located in the Lower Klamath Basin and include the Shasta, Scott, Salmon, and Trinity Rivers.

The Klamath River Basin has a history of complex water management challenges, dating back more than a century. In large part, these challenges relate to the competing needs of the various mainstem users, irrigation diversions on the Scott, Shasta, and Trinity Rivers (tributaries to the Klamath), and the construction of six mainstem dams (see Figure 1-1), which have altered the natural flow and nutrient and sediment regimes in the river and have inhibited upstream passage of migratory fish above Iron Gate Dam (river mile 190).

Managers of natural resources in the Klamath River Basin have long called for a comprehensive and integrated approach to water management. In 2008, the National Research Council reported that "the most important characteristics of research for complex river-basin management were missing for the Klamath River: the need for a 'big picture' perspective based on a conceptual model encompassing the entire basin and its many components" (Thorsteinson et al., 2011).

[1] Figure 1-1 produced by Michael Neuman, Klamath Basin Area Office of the Bureau of Reclamation.

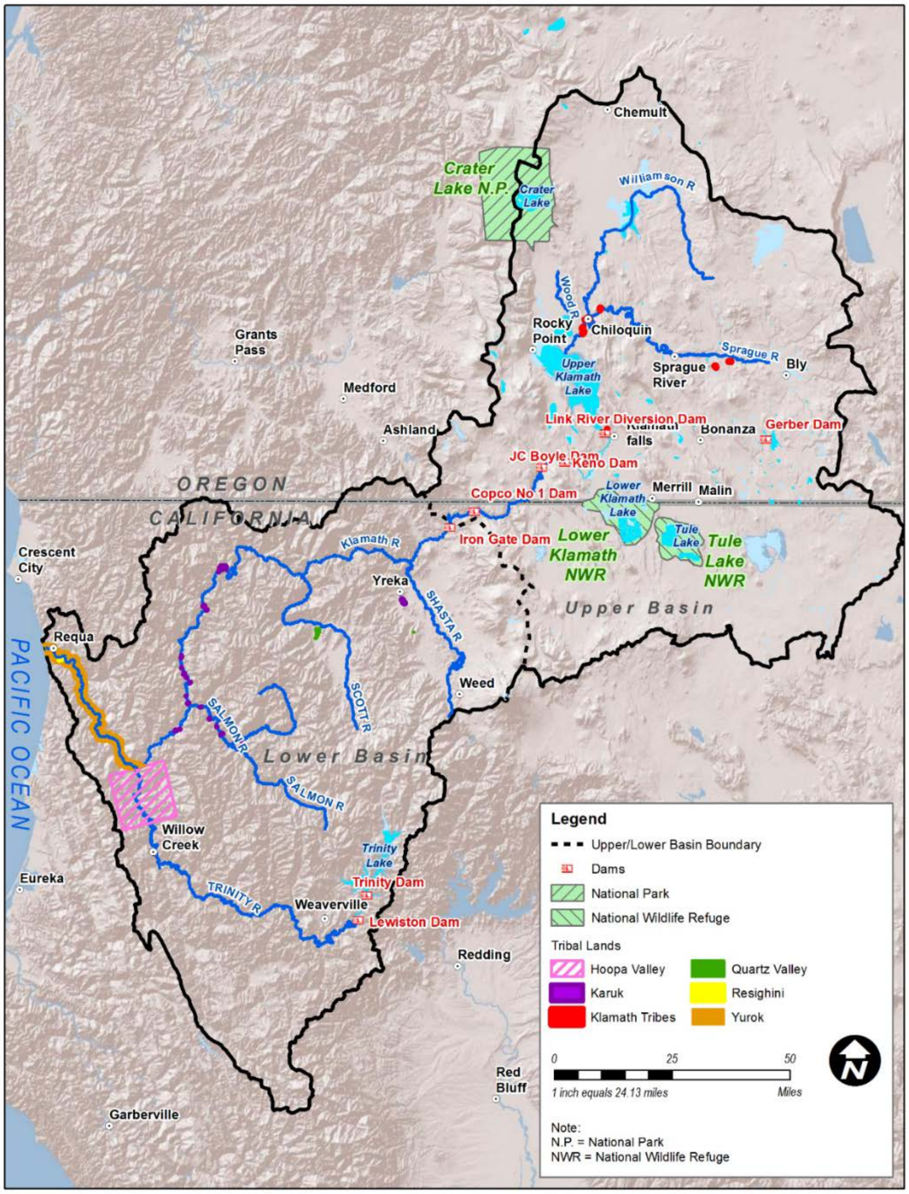

Figure 1-1.—Klamath River Basin overview map

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to achieve future water security. The Bureau of Reclamation (Reclamation) serves as the U.S. Department of the Interior's (Interior) primary water management agency. It developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (Public Law [P.L.] 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program, which was developed as a result. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management.

The Klamath River Basin Study commenced in September 2012. Non-federal cost share partners for the study include the California Department of Water Resources (CDWR) and the Oregon Water Resources Department (OWRD). It should be noted that the Klamath River Basin Study:

- Does not require federal or state environmental review
- Does not contain recommendations for action
- Is not a decisional document

This first chapter of the Klamath River Basin Study provides an overview of the basin, identifies the study purpose, scope, and objectives, and discusses the overall process of the basin study. This chapter also outlines the collaboration and outreach process, which is a significant component of the Klamath River Basin Study.

1.2 Purpose, Scope, and Objectives of the Study

The purpose of the Klamath River Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessment (WWCRA) but contain additional information, if available (refer to Reclamation [2011d] for water supply assessment; demand assessment is currently under development). The WWCRA is an ongoing complementary activity in the Basin Studies Program in which Reclamation is developing a comprehensive and consistent set of hydro-climate data resources west-wide by incorporating the best available science. These data resources provide a baseline for climate change adaptation planning.

More specifically, basin studies seek to build on existing knowledge through studies, reports, and stakeholder collaboration. The following objectives are key components of each basin study:

- Assess current and projected future water supply
- Assess current and projected future water demand
- Evaluate current and projected future system reliability with respect to chosen performance measures
- Identify and evaluate potential adaptation strategies that may reduce any imbalances

The Klamath River Basin has a long history of water management challenges. Numerous studies have been conducted that evaluate the projected impacts of climate change in the region (e.g., Reclamation, 2011; Risley et al., 2012; Oregon

Climate Change Research Institute, 2010; National Center for Conservation Science and Policy, 2010) and explore potential adaptation strategies (e.g., increase offstream storage) that may mitigate the impact. The Klamath River Basin Study seeks to add value to previous and ongoing work in the watershed by evaluating water supply and demand together in a modeling and decision support framework that allows for exploration of a range of management strategies.

The information presented in this report was developed in conjunction with basin stakeholders and is intended to inform and assist stakeholders by identifying potential future scenarios for long term planning. The analyses provided in this report reflect the use of best available datasets and data development methodologies at the time of the study. It is important to acknowledge the uncertainties inherent within projecting future planning conditions for water supply and demand. For example, projections of future climate, population, water demand, and land use contain uncertainties that vary geographically and temporally depending on the model and methodology used. Trying to identify an exact impact at a particular place and time remains difficult, despite advances in modeling efforts over the past half-century. Accounting for these uncertainties, Reclamation and its stakeholders used a scenario planning approach that encompasses the estimated range of future planning conditions. More detailed information about uncertainties related to each part of the study is available in the Klamath River Basin Study Full Report.

The study was prepared with acknowledgement of the four non-Federal dams on the Klamath River (Iron Gate, Copcos 1 and 2, and J.C. Boyle). The study acknowledges the Klamath Basin Restoration Agreement (KBRA) and companion Klamath Hydroelectric Settlement Agreement (KHSA), two documents which include plans to remove the four dams. While an amended KHSA and a 2016 Klamath Power and Facilities Agreement maintain a path for removal of the dams, the study takes no position on dam removal and does not rely on dam removal in order to sustain its conclusions about potential water supply and demand strategies. A dam removal strategy was not identified as part of the study.

1.3 Location and Description of the Study Area

1.3.1 Geographic and Geologic Setting

The Klamath River flows over 253 miles from its headwaters north of (and including part of) Crater Lake National Park in Oregon to its outflow at the Pacific Ocean in Requa, California (Figure 1-1). The Klamath River Basin includes all or parts of Klamath, Lake, Modoc, Siskiyou, Del Norte, Trinity, and Humboldt Counties. Five national forests intersect the Klamath River Basin: Six Rivers, Klamath, Shasta-Trinity, Modoc, and Winema. The Klamath River Basin also contains a substantial amount of land managed by the Bureau of Land Management. From a water management perspective, the basin is divided into two regions, the dividing line being approximately at the location of Iron Gate Dam: the upper portion (hereafter referred to as "Upper Klamath Basin"), and the lower portion (hereafter referred to as "Lower Klamath Basin"). The Upper Klamath and Lower Klamath Basins generally have differing climates and management challenges.

The Klamath River begins in Lake Ewauna, south of Upper Klamath Lake and the city of Klamath Falls, Oregon. The river reach between Upper Klamath Lake and Lake Ewauna is called the Link River. Contributing flows to Upper Klamath Lake originate from the slopes of the Cascade Range and Siskiyou Mountains. The primary tributaries to the Klamath River above Upper Klamath Lake include Wood River to the north, Williamson River to the north, Sprague River to the east, and inflows from the eastern flank of the Cascades. The Klamath River flows southwesterly into California and then west to the Pacific Ocean. The major tributaries entering the mainstem river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers all join the Klamath River downstream of Iron Gate Dam and provide 44 percent of the mean annual flow, which heavily influences the hydrology of the Klamath River Basin.[2] The mean annual flow of the Klamath River is about 17,900 cubic feet per second. Eleven miles of the Klamath River between the J.C. Boyle Powerhouse and the California-Oregon border were designated as "scenic" in 1994 under the National Wild and Scenic Rivers System (P. L. 90-452, October 2, 1968). The mainstem lower Klamath River from Iron Gate Dam to the Pacific Ocean, as well as reaches of the Scott River, Salmon River, Wooley Creek (tributary of the Salmon River), and Trinity River, are classified under the National and California Wild and Scenic River Systems (California classifications according to Public Resources Code Section 5093.50 et seq.). These classifications include "wild," "scenic," and "recreational."

The Klamath River contains six mainstem dams (Table 1-1). Link River Dam, at river mile 253 in Oregon, maintains Upper Klamath Lake levels and largely replaced a natural reef that historically formed the lake. Keno Dam, at river mile 232 in Oregon, replaced a natural reef which historically regulated water surface elevations of Lower Klamath Lake (Reclamation, 2005). The remaining mainstem dams were constructed where the Klamath River enters sections of the canyon through the coastal mountain range. These dams were primarily constructed for hydropower production and include: California Oregon Power Company (COPCO) 1 dam at river mile 197 (California); COPCO 2 dam at river mile 198 (California), which was constructed to reregulate flows out of COPCO 1; J.C. Boyle Dam at river mile 227 (Oregon), which was constructed primarily

[2] Major tributary flow as percentage of Klamath River flow (44%) was reported by BLM (1990) and verified by computing the percentage on a mean annual basis (water years 1951-2012) using the following streamflow gages: 1) USGS 11530500 Klamath R. nr Klamath, CA; 2) USGS 11522500 Salmon R. at Somes Bar, CA; 3) USGS 11519500 Scott R. nr Fort Jones, CA; 4) USGS 11517500 Shasta R. nr Yreka, CA; 5) USGS 11530000 Trinity R. at Hoopa, CA. This reported value is based on a simplified water balance which may not be an accurate accounting of the contribution of the four major tributaries to flow in the Klamath River at Klamath, CA.

for producing peaking power upstream of the COPCO dams; and, Iron Gate Dam at river mile 190 (California). PacifiCorp (owned by MidAmerican Energy Holdings Company) owns and operates the hydropower producing facilities on the Klamath River under Federal Energy Regulatory Commission license 2082 and provides most of the Klamath River Basin's power (CDWR, 1960).

The Upper Klamath Basin once held pluvial Lake Modoc at an elevation of about 4,200 feet above sea level with an estimated 400 miles of shoreline and 1,000 square miles of surface area. As temperatures warmed during the Late Pleistocene, only Tule Lake, Lower Klamath Lake, and Upper Klamath Lake remained. Parts of the bed of Lake Modoc became Langell Valley and Poe Valley (Beckham, 2006). Lower Klamath and Tule Lakes are discussed further in Section 1.4.2.1. Upper Klamath Basin.

The Klamath River Basin covers three geologic provinces from east to west: the Modoc-Oregon Lava Plateau, the Cascade Range, and the Klamath Mountains. The Modoc-Oregon Lava Plateau includes nearly all of the Klamath River Basin in California east of (and including) Butte Valley. Downstream from Iron Gate Dam and for most of the river's length to the Pacific Ocean, the river maintains a steep, coarse-grained, confined channel. From Iron Gate east to the Oregon-California state line, the river is predominantly nonalluvial and sediment-supply-limited. The Cascade Range forms a north-south belt through the basin, extending from beyond Crater Lake on the north to Mount Shasta on the south. It is bounded in part on the east by the western edge of Butte Valley and on the west by the western edge of Shasta Valley. The Klamath Mountains province includes the entire remainder of the basin lying west of the Cascade Range (CDWR, 1960).

1.3.2 Historical Climate and Hydrology

Mean annual precipitation in the basin ranges from as little as 10 inches at lower elevations to more than 70 inches in the mountains to the west (Reclamation, 2011a). About two-thirds of the precipitation falls as snow between October and March. The annual long-term average snowfall in Klamath Falls is about 41 inches per year. Crater Lake (62 miles northwest of Klamath Falls) averages about 521 inches of snow annually.

Table 1-1.—Summary of Klamath Basin dams

Dam Name	Location	Klamath River Mile	Year Completed	Reservoir Capacity (acre-feet)	Purpose
Upper Klamath Basin					
Clear Lake[1]	Lost River	NA	1910	527,000	Irrigation
COPCO 1	Klamath River	197	1918	6,235	Hydropower
Link River	Klamath/Link River	253	1921	873,000	Control UKL level
COPCO 2	Klamath River	198	1925	73	Hydropower
Gerber[1]	Miller Creek	NA	1925	94,300	Irrigation
JC Boyle	Klamath River	227	1958	3,377	Peaking power
Iron Gate	Klamath River	190	1962	58,000	Hydropower
Keno	Klamath River	232	1966	18,500	Hydropower, recreation
Lower Klamath Basin					
Dwinnell Dam[2]	Shasta River	NA	1928	50,000	Water supply
Lewiston[2]	Trinity River	NA	1967	14,660	CVP water supply
Trinity	Trinity River	NA	1962	2,400,000	CVP water supply

Notes: CVP = Central Valley Project. UKL = Upper Klamath Lake
[1] Clear Lake and Gerber Reservoirs are briefly discussed in Section 4.2.1, Upper Klamath Basin.
[2] Dwinnell and Lewiston Dams are briefly discussed in Section 4.2.2, Lower Klamath Basin.

Historical runoff in the Klamath River Basin is highly variable from year to year. Although precipitation predominantly occurs in the winter months, water percolates and moves through the volcanic soil such that monthly discharge is almost constant in the Upper Basin (CDWR, 1960). Under natural conditions the Upper Klamath Basin area lakes have a significant regulatory effect on the river (CDWR, 1960). A review of historical information in the Klamath River Basin suggests that, although there may be trends in historical runoff at some sites, they are relatively weak or insignificant (Reclamation, 2011c).

All precipitation and snowmelt in the Shasta River watershed (draining to the Klamath River) percolates into the volcanic soil and appears in springs or discharges directly from the ground water into the Shasta River. The only significant surface runoff from the Cascade Range along the eastern edge of Shasta Valley occurs in the Little Shasta River (CDWR, 1960). In the Scott, Salmon, Trinity, and other tributaries of the lower Klamath River, runoff is a function of precipitation and snow storage (CDWR, 1960).

Since 1900, temperatures in the Pacific Northwest have increased by 1.0 degree Celsius, which is 50 percent greater than the global average, as reported by other studies (Knowles et al., 2007; Regonda et al., 2005; Mote, 2008). Further, the Klamath River Basin, like the western United States overall, has experienced a general decline in spring snowpack, reduction in the amount of precipitation falling as snow in the winter, and earlier snowmelt runoff between the mid- and late-20th century. Although observed trends of temperature, precipitation, snowpack, and streamflow in the western United States might be partially explained by anthropogenic influences on climate (Barnett et al., 2008; Pierce et al., 2008; Bonfils et al., 2008; Hidalgo et al., 2009; and Das et al., 2009), these changes are difficult to distinguish from natural climate variability (Villarini et al., 2009), particularly in the case of precipitation (Hoerling et al., 2010). Similarly, future projections of climate over the next 30 to 50 years indicate that the Klamath River Basin will continue to experience warming, as well as increased winter precipitation and decreased summer precipitation. Natural modes of variability like the El Nino/Southern Oscillation and the Pacific Decadal Oscillation (PDO) will continue to influence these general trends (Thorsteinson et al., 2011).

1.3.3 Vegetation, Wildlife, and Fish

The Klamath Basin is home to a diverse range of plant species. Tree species include willows, pines, ash, oak, cedar, juniper, alder, and birch. Shrubs range from poison oak and sumac to dogwood, manzanita, honeysuckle, currant, mock orange, ninebark, plum, chokecherry, crabapple, snowberry, sagebrush (several varieties), and Oregon grape. Hundreds of indigenous herbaceous plants grow in this region including orchids, lilies, paintbrushes, grasses, ferns, horsetails, and lichens (Beckham 2006).

Wildlife includes numerous mammals, birds, fish, amphibians, and reptiles. Large animals include black bear, black-tailed deer, mule deer, elk, and mountain lion. Smaller mammals range from beaver, ermine, and fisher to bats, river otter, foxes, squirrels, chipmunks, rabbits, shrews, woodrats, and voles. Numerous reptiles live in the area and include the western rattlesnake, garter snake, and pond turtle. Raptors, game birds, woodpeckers, and other water and land birds are at home in this setting. The Upper Klamath Basin is a part of the Pacific Flyway where hundreds of thousands of migrating birds stop to rest. The U.S. Fish and Wildlife Service (USFWS) listed the northern spotted owl as threatened under the Endangered Species Act (ESA) in 1990, the shortnose and Lost River suckers as endangered in 1988, and the bull trout as threatened in 1999. The National Marine Fisheries Service (NMFS) listed the Southern Oregon/Northern California Coast Ecologically Significant Unit (SONCC ESU) of coho salmon as threatened in 1997 and reconfirmed the listing in 2005, and listed critical habitat for the threatened distinct population segment of the Pacific Eulachon in 2011, which includes the Klamath River estuary. In total three plant, eight fish, seven whale, four turtle, four bird species, and one sea lion in the vicinity of the Klamath River are ESA listed; however, the suckers, coho, and bull trout are most often affected by water management practices.

The Lower Klamath and Tule Lake National Wildlife Refuges (NWR), located in the upper Klamath Basin of Oregon and California, encompass approximately 46,700 and 39,100 acres, respectively (Risley and Gannett, 2006). According to the study by Risley and Gannett (2006), mean annual (2003–2005) water use for the Lower Klamath and Tule Lake NWRs was approximately 124,000 and 95,900 acre-feet, respectively, including precipitation and water deliveries.

The Klamath River is home to numerous resident and migrating fish species. Resident fish resources include redband trout and rainbow trout in the mainstem Klamath River (Beckham, 2006). The shortnose and Lost River sucker reside in the Upper Klamath Basin. Historically, the Klamath River was the third most productive river for salmon in the continental United States. Spring Chinook, fall Chinook, and coho salmon, as well as steelhead, spawn in reaches of the Klamath River and its tributaries.

The six mainstem Klamath River dams were all initially constructed without fish passage; therefore, anadromous fish were cut off from the Upper Klamath River reaches above the COPCO 1 dam site in 1918. They were cut off from an additional 7 miles of river, upstream of Iron Gate Dam (river mile 190) in 1962. Two primary hatcheries were established in the Klamath Basin for raising coho, Chinook, and steelhead: the Trinity River Hatchery, built in 1963, and the Iron Gate Hatchery, built in 1966 (CRS, 2005).

Although the COPCO expressed willingness to construct a single fish ladder at COPCO 1, they and the State of California agreed to close off all runs of anadromous fish and to compensate for the loss of natural runs by stocking the lakes and streams of the Klamath Basin with hatchery-raised fish. Most fishery biologists at the time did not believe fish migration over COPCO 1 via fish ladder was feasible (Beckham, 2006).

Because the SONCC ESU of coho salmon is listed as threatened under the federal ESA, the commercial harvest of these fish has been prohibited. In addition, the Chinook salmon harvest has been restricted in northern California and southern Oregon marine waters for several years to allow the Klamath River to attain the Pacific Fishery Management Council's spawning escapement goals (CRS, 2005). In 2006 the lack of returning adult salmon to the Klamath River resulted in the closure of several hundred miles of Pacific Coast salmon fisheries (USGS, 2007). Each summer large blooms of the blue-green algae Aphanizomenon flos-aquae in the Upper Klamath Lake lead to low dissolved oxygen and lethal conditions (in part because they produce harmful toxins) for endangered suckers. Major die-offs of suckers occurred in 1986, 1995, 1996, and 1997 (USGS, 2007).

1.4 Present Water and Related Resources Development

1.4.1 History of Settlement

Indigenous people have inhabited the Klamath River Basin since time immemorial (Beckham, 2006). Currently the basin is home to six federally recognized Indian Tribes: the Yurok Tribe; Hoopa Valley Tribe; Karuk Tribe; the Klamath Tribes, comprised of Klamath, Modoc, and Yashookin; Quartz Valley Indian Community; and Resighini Rancheria (77 FR 47868). Numerous additional native groups that are not federally recognized, such as the Shasta people, inhabit parts of Northern California and Southern Oregon. Although they are not federally recognized, some of them have been inducted into the Karuk Tribe (Beckham, 2006).

The Klamath River and canyon are considered sacred by the native tribes (Bureau of Land Management, 1990). The study area includes burial grounds of the Shasta people and their principal ceremonial areas, which are used for spiritual and educational purposes. Native tribes also value the canyon for other important cultural activities. The river area has long been used for fishing, gathering, and hunting; as a meeting place between the area's various tribes and bands; as shared fishing villages; and as a pathway for inter-tribal exchange and communication (Bureau of Land Management, 1990).

Initial Euro-American explorers in the Klamath Basin included fur traders from the Hudson Bay Company as well as surveyors from the United States Navy and Army and emigrant travelers. Settlement began in the mid-1800s, with the discovery of gold in the Lower Klamath Basin, below the Shasta River confluence (Beckham, 2006). Long-term settlement solidified with the passing of the Homestead Act in 1862, which allowed citizens (or those intending to be naturalized) over 21 years old to settle on 160 acres (or less) of land. Railroad development and logging came later due to the rugged terrain in the southern Cascades and Siskiyou Mountains (Beckham, 2006; CDWR, 1960). The Reclamation Act of 1902 initiated a number of federal irrigation projects across the western United States to manage already existing irrigation and to expand settlement in the arid west. Development of Reclamation's Klamath Project is described in Section 1.4.2. Water Resources Development.

At one time the Klamath watershed was one of the greatest timber-producing regions in the nation (CDWR, 1960). The Klamath River and tributaries were historically used to transport logs to mill sites. For example, in the late 1800s the Klamath River Improvement Company drove logs from the Spencer Creek area (west of Keno, Oregon) to the California-Oregon state line. Splash dams made of wood and rock were historically used to create surges of water that would facilitate transportation of logs downstream (Beckham, 2006). The timber industry continues to be a significant portion of the regional economy, despite declines since the late 1970s and early 1980s.

Recreational facilities like campgrounds and trails have drawn many tourists annually into the area including Crater Lake, the Modoc Lava Beds, the Trinity Alps, Marble Mountain Primitive Areas, and the coastal redwoods (CDWR, 1960). River reaches between JC Boyle Dam and Iron Gate Dam, as well as below Iron Gate Dam, are major destinations for commercial and private white-water rafting and kayaking (CRS, 2005).

1.4.2 Water Resources Development

1.4.2.1 Upper Klamath Basin

The passing of the Reclamation Act in 1902, in addition to legislation passed by Oregon and California to transfer ownership of land to the federal government, led to the development of the Klamath Irrigation Project (Figure 1-2). The initial project was completed in 1907. By 1924 portions of Lower Klamath and Tule Lakes were drained to uncover additional desirable farmland. In addition, dams were built to facilitate diversions and produce hydropower for the region (Reclamation, 2000).

Reclamation's Klamath Project is primarily fed by Upper Klamath Lake and the Lost River system, which includes Clear Lake Reservoir on the Lost River and Gerber Reservoir on tributary Miller Creek (refer to Table 1-1). Releases from Clear Lake and Gerber Reservoirs are delivered to the east side of the Klamath Project to irrigate lands in Langell Valley. The Lost River also receives water from Bonanza Springs located in Bonanza, Oregon. During the irrigation season, flows from the springs in the Lost River may be available for irrigation (Reclamation, 2012).

Prior to development of Reclamation's Klamath Project, the Klamath and Lost River Basins were linked by a flood channel, the Lost River Slough, which allowed water from the Klamath River to enter the Lost River and flow to Tule Lake during high runoff conditions. The two watersheds are now linked by the Lost River Diversion Channel, which facilitates water management and surface delivery of water to the Klamath Project, Tule Lake NWR, and Lower Klamath NWR. During the wet periods of the year water is diverted to the Klamath River; during the drier periods irrigation water is diverted to the Lost River from the Klamath River for irrigation needs (Reclamation, 2011a).

Reclamation's Klamath Project has historically included approximately 254,000 acres of land. It provides water to approximately 1,400 farms covering about 200,000 acres as well as about 27,000 irrigable acres of refuge lands. Principal crops raised on Reclamation's Klamath Project include alfalfa, irrigated pasture, small grains, and potatoes. Onions, horseradish, mint, and strawberry plants are also grown (Reclamation, 2011a; CRS, 2005). In 2011 the Klamath Project's gross crop values were estimated at $204 million (Reclamation, 2012). Water released from one of the project's storage reservoirs may be reused several times before it is returned to the Klamath River. Some of the return flows provide water to the Lower Klamath NWR and the Tule Lake NWR. Excess water and water released from NWR lands is returned to the Klamath River via the Klamath Straits Drain.

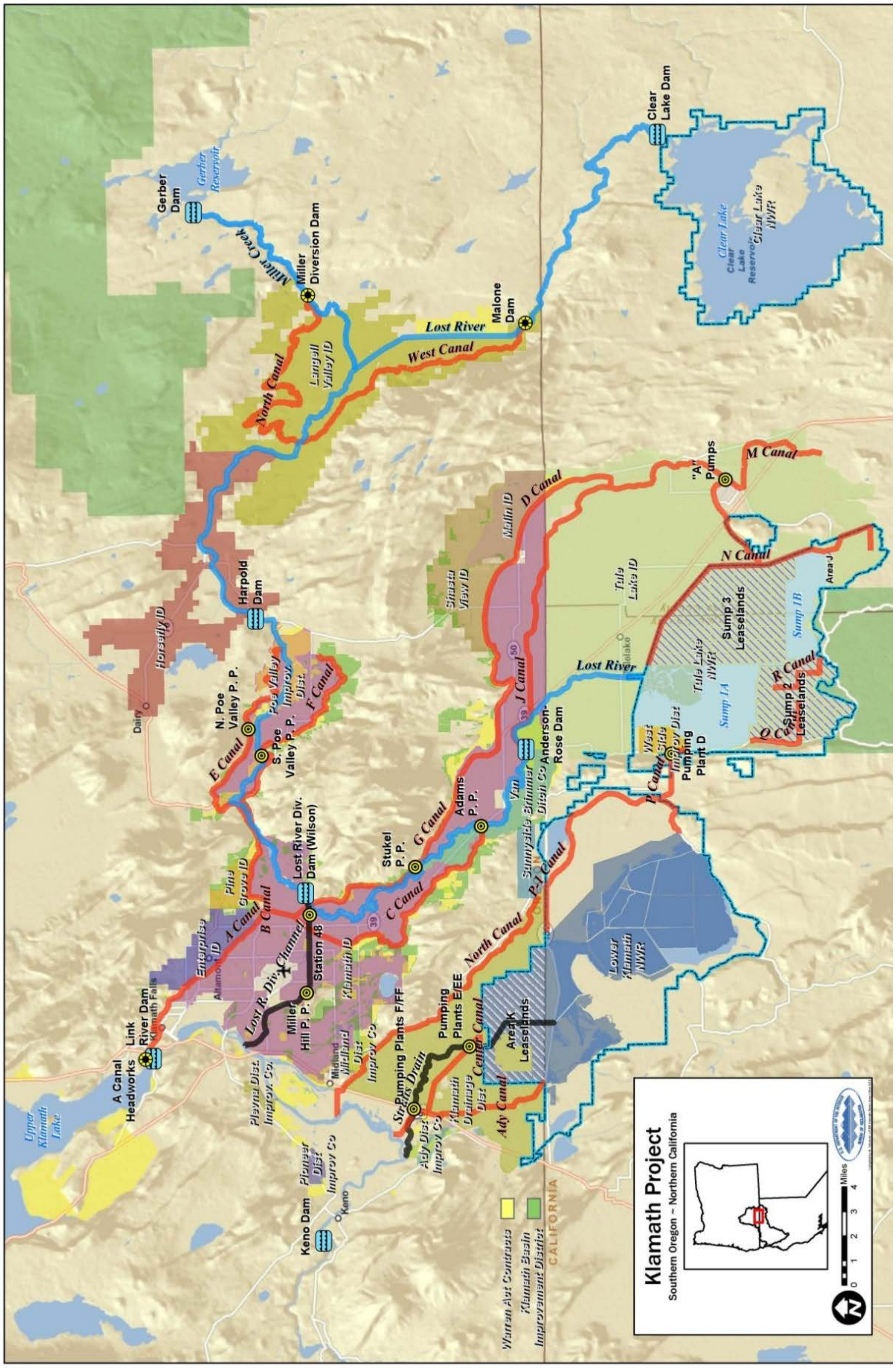

Figure 1-2.—Klamath Irrigation Project map.

Additional irrigation in the Upper Klamath Basin occurs in Butte Valley, California, where the Butte Valley Irrigation District supplies water for approximately 4,000 irrigated acres in the southern end of the valley (CDWR, 1960).

1.4.2.2 Lower Klamath Basin

The Lower Klamath Basin also supports agriculture, but to a lesser extent than the Upper Basin. As of 1997 the number of Lower Basin farms was about 40 percent of those found in the Upper Basin, and agricultural production was estimated to be less than half the value of Upper Basin agriculture ($114 million compared to $283 million) (CRS, 2005).

There are four organized irrigation districts in the Shasta Valley (approximately 10,000 irrigated acres). The Dwinnell Dam, forming Dwinnell Reservoir, or Lake Shastina (Table 1-1), is maintained by the Montague Water Conservation District, the largest of the Shasta watershed irrigation districts. About 24,000 acres within the Shasta Valley, but lying outside the irrigation districts, are served by individual diversions from various streams (CDWR, 1960). The only known trans-boundary diversion into the Klamath River Basin is from the Sacramento River Basin in California. About 4,000 acre-feet seasonally are diverted into the basin and used for irrigation purposes in the extreme southern end of Shasta Valley.

The Scott River Irrigation District is the single major organized water provider in Scott Valley, California. The district serves approximately 3,500 irrigated acres (CDWR, 1960). Surface water supplies for irrigation are supplemented by pumping of ground water. Most of the irrigated area in Scott Valley, however, lies to the west of the river and is supplied by individual development (CDWR, 1960).

There are additional small cultivated areas in the Lower Klamath Basin, including Hayfork Valley, a portion of the Hoopa Valley Indian Reservation on the Trinity River, and small areas in the vicinity of Lewiston and Seiad Valley (CDWR, 1960).

The Trinity River, the lowermost tributary of the Klamath River, provides water to the California Central Valley Project (CVP), another federal project (CRS, 2005). The Trinity River Division of the CVP was completed in 1964. The Trinity River is the largest tributary of the Klamath River. It enters the Klamath River about 20 miles upstream of its mouth at the Pacific Ocean. The Trinity River Diversion diverts and exports water from the Trinity River system by means of dams, reservoirs, tunnels, and power plants to the Sacramento River (CRS, 2005). At one time, nearly 90 percent of the water in the Trinity River was exported to the Central Valley (CRS, 2005). However, a 2000 Record of Decision reduced that percentage to restore fisheries (CRS, 2005). Lewiston and Trinity Dams (refer to Table 1-1) had cut off 109 miles of anadromous fish habitat on the Trinity River (CRS, 2005).

There are two additional trans-boundary diversions from the Klamath Basin, both in the western portion of the Upper Klamath Basin. One diversion is made from Keene Creek by way of Hyatt Prairie Reservoir, and the other diversion is made from Fourmile Creek by way of the Cascade Canal. This diverted water supplies irrigate lands adjacent to Ashland and Medford in the Rogue River Basin (CDWR, 1960).

1.4.3 History of Water Management Challenges

The Klamath River Basin, like many watersheds in the arid western United States, suffers from use beyond the sustainable capacity of the basin (i.e., over-appropriation). This may be due to a number of factors. First, there are physical constraints in the watershed that are unique to the Klamath Basin. Second, federal and state policies with respect to indigenous people and the environment have not been consistent over time, which has contributed to complex socioeconomic challenges. Finally, regulatory constraints exist in terms of conflicting state and federal policies. This section will briefly describe these constraints as a way of identifying historical and current water management challenges in the basin and to emphasize the need for a comprehensive Klamath River Basin Study to evaluate any identified current and/or projected future imbalances in water supply and demand.

The Klamath River Basin is unique in that the largest agricultural development in the basin occurs in the Upper Klamath, which receives disproportionately low precipitation compared with the rest of the basin. The Upper Klamath Basin has limited suitable sites for reservoir storage; therefore, water users are subject to the effects of climate variability. For example, Upper Klamath Lake, which is the primary source of water for Reclamation's Klamath Project, is relatively shallow and has little carryover storage from year to year, which makes the project highly dependent on current precipitation and snowmelt for water supply (CRS, 2005).

Implementation and enforcement of state and federal water allocation policies has been a challenge. The Klamath River Compact (ORS 542.620; CA Water Code § 5900 et seq.; P.L. 85-222) between California and Oregon was ratified by the states and consented to by the United States in 1957, giving domestic and irrigation users in the Klamath River Basin preference for applications for higher use of water supplies over applications for lower use supplies, defined as recreation, industrial, hydropower, and other uses. Water rights adjudication in California was completed for the Shasta River Basin in 1932 and for the Scott River Basin in 1980, but the mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court, demarking a significant milestone in determining the water rights of the Upper Klamath Basin.

The United States must provide sufficient water to sustain and protect Indian Trust Assets, which include sufficient water to meet treaty rights such as hunting, gathering, and fishery purposes. The Klamath Tribes were terminated in 1954 (Klamath Termination Act, P. L. 587) and then regained federal recognition in 1986. As a result, the Klamath Tribes lost designated reservation land. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the Klamath Treaty of 1864, which may significantly affect water management in the Upper Klamath Basin. Lower Klamath NWR and Tule Lake NWR rely on water from Reclamation’s Klamath Project. These refuges have received lower priority for water than irrigators. However, the Lower Klamath NWR (established in 1908) may have federal reserved rights which would advance their priority (CRS, 2005).

Endangered species issues have been an integral component of operating decisions for Reclamation’s Klamath Project since the USFWS listed the shortnose and Lost River suckers as endangered in 1988 and the NMFS listed the SONCC ESU coho salmon as threatened in 1997 (CRS, 2005). Management challenges associated with opposing water needs and policies are illustrated by the events that took place in the early 2000s (described briefly below), which resulted in the largest fish die-off ever recorded in the Klamath River and severe curtailment of irrigation deliveries to Klamath Project irrigators, resulting in economic hardship.

Reclamation is required to comply with the ESA by consulting on the ongoing operations of the Klamath Project with the USFWS and NMFS (the agencies with delegated authority to implement the ESA) to ensure that its operations do not jeopardize listed species or listed or proposed critical habitat. The USFWS has jurisdiction over inland fish and terrestrial species (shortnose sucker, Lost River sucker, and proposed critical habitat for both sucker species). The NMFS has jurisdiction over marine species and anadromous fish (e.g., SONCC ESU coho salmon). In early 2001 a federal district court faulted Reclamation for failing to formally consult with NMFS on the effects of water storage and diversion on downstream coho salmon under its 2000 operating plan, and prohibited Reclamation from making further diversions until it formally consulted on its next (2001) annual plan. Reclamation prepared an operation plan for 2001 which was forecast to be one of the driest years of record. Reclamation prepared a biological assessment (February 13, 2001) which covered operations until April 1, 2001. In April 2001, the USFWS and NMFS each issued final Biological Opinions concluding that Reclamation’s proposed operation of the Klamath Project for 2001 would jeopardize the two species of suckers and the population of coho salmon, and it would harm, but not jeopardize, the continued existence of bald eagles. NMFS recommended release of additional water from Upper Klamath Lake for coho salmon, while USFWS simultaneously recommended maintaining higher lake levels. Because of severe drought conditions, there was not enough water to implement both Biological Opinions simultaneously, even without providing irrigation water for farmers. A judge’s order prevented Reclamation from fulfilling water orders under contracts to the irrigators whenever flows dropped below the minimum flows recommended in the 2001 NMFS Biological Opinion (Reclamation, 2011e).

Reclamation announced its response on April 6, 2001, implementing proposed alternatives that severely limited the delivery of irrigation water. For the 2001 water year, Reclamation stated that the normal deliveries would be available for lands receiving water from Clear Lake and Gerber Reservoirs (70,000 to 75,000 acre-feet), but no water would be available from Upper Klamath Lake for deliveries to irrigators or to the Lower Klamath NWR (CRS, 2005). Water conservation measures and higher than expected lake levels later in the summer prompted the Secretary of the Interior to announce that up to 75,000 acre-feet would be released from Upper Klamath Lake to assist farmers. However, this came too late in the season to provide significant assistance.

The National Research Council reviewed the scientific decisions of the controversial 2001 Biological Opinions. The National Research Council Committee concluded that scientific data were insufficient to support the Upper Klamath Lake level management regimes proposed by the 2001 USFWS Biological Opinion. Although Reclamation's written response to the USFWS 2001 Biological Opinion expressed disagreement with the Biological Opinion's conclusions, Reclamation agreed to not deliver any water from Upper Klamath Lake to Klamath Project water users and NWRs from April through September 2001. Water from Gerber and Clear Lake Reservoirs was used for irrigation on and to meet evaporative losses on the NWR. Releases from Upper Klamath Lake were made to meet minimum stream flows; however, the project was operated to modified minimum elevations for Upper Klamath Lake, which deviated from the minimums prescribed in the USFWS Biological Opinion. An above average number of Chinook salmon entered the Klamath River that August and September, while river flows were unusually low due to drought conditions and unusually warm temperatures. These conditions contributed to the death of more than 33,000 adult salmon (primarily Chinook but also coho, steelhead, and others) due to epizootic disease in the first 40 miles of the river (California Department of Fish and Game, 2004; CRS, 2005).

Several ESA consultations since the early 2000s have affected Klamath Project operations. The most recent to date (and to which current operations adhere) is the 2012 Biological Assessment and 2013 Biological Opinion (BiOp) jointly prepared by the USFWS and NMFS on the Lost River and shortnose sucker, the SONCC coho salmon, the Southern distinct population segment (DPS) green sturgeon, and the Southern DPS eulachon, which directs the operations throughout the Upper Klamath Basin and influences river flows from Link River Dam to the Klamath Estuary. The Biological Assessment and Joint BiOp were completed following a multi-year consultation effort between Reclamation, the USFWS, and NMFS to develop a new long-term operations plan that would "allow Reclamation to continue to operate the Klamath Project to store, divert, and convey water to meet authorized Klamath Project purposes and contractual obligations in compliance with applicable state and federal law while meeting the conservation needs of affected listed species in a coordinated manner" (NMFS and USFWS, 2013).

1.5 Future Challenges and Considerations

The Klamath River Basin Study identifies and evaluates potential adaptation strategies to reduce any identified water supply/demand imbalances. Numerous studies have already identified and investigated potential adaptation strategies. To the extent possible, this study builds upon past or existing efforts and encompasses a wide range of options, perhaps even previously rejected strategies that may perform differently under a wider range of evaluation measures.

This study must also consider the regulations that are in place or in progress in the basin, including among other things total maximum daily load (TMDL) water quality criteria established in parts of the watershed, as well as past and existing restoration efforts. For example, this study considers, in a scenario context, the ongoing negotiations of the Klamath Basin Restoration Agreement (KBRA) and Klamath Hydropower Settlement Agreement and the related Secretarial Determination Process. The following section of this report touches on these considerations in more detail and concludes with recognition of future challenges.

1.5.1 Previously Identified Management Alternatives

Numerous studies have been initiated to investigate options for increased or new storage (including groundwater), demand reduction, and habitat restoration, even before the events of 2001 and 2002. The Klamath Basin Water Supply Enhancement Act of 2000 (P.L.106-489) authorized Reclamation to study the feasibility of increasing storage capacity in the Upper Klamath Basin and Reclamation's Klamath Project through surface or groundwater supplies (CRS, 2005). Potential options were identified and developed in the 1990s through the Klamath Basin Water Supply Initiative, a public input process involving potentially affected state, local, and tribal interests as well as concerned stakeholders (for example, potential new storage in the Long Lake Valley [Reclamation, 2010]). The Initial Alternatives Information Report, Upper Klamath Basin Offstream Storage Study (Reclamation, 2011a) further investigated options including an aquifer storage and recovery groundwater option at Gerber Reservoir and a hybrid option involving aquifer storage and recovery at Clear Lake and surface storage at a new dam (to be named Boundary Dam). However, these investigations have not identified viable options from a cost/benefit perspective.

Water banking has also been proposed as a management strategy. During the water shortage of 2001, Reclamation initiated the Groundwater Purchase Program, a water bank to buy water for fish and wildlife (CRS, 2005). As part of the NMFS 2002 Biological Opinion, Reclamation could avoid jeopardizing ESA threatened coho salmon by creating and implementing a water bank. Eligible farmers could bid to irrigate their lands with groundwater from their own wells in exchange for payment, thereby freeing water from Upper Klamath Lake (CRS, 2005). These pilot water bank programs were successful in meeting NMFS Biological Opinion requirements for the 2003 and 2004 water years. Reclamation employed a combination of land idling and groundwater substitution in an attempt to meet water banking targets for 2005–2011; however, in 2006 the court eliminated the water banking requirement that was part of the NMFS 2002 Biological Opinion (Reclamation, 2011). Groundwater pumping has also been identified as a potential long-term water management strategy. Pumping groundwater provides short-term benefits, but over-drafting of aquifers has long-term consequences that are less clear (CRS, 2005).

A number of entities are undertaking specific projects to improve water quality and restore habitat. For example, the U.S. Department of Agriculture's Natural Resources Conservation Service has a Work Plan for Adaptive Management for the Klamath Basin to mitigate the effects of drought on agriculture. The core objectives of this program are: (1) decreasing water demand, (2) increasing water storage, (3) improving water quality, and (4) developing fish and wildlife habitat.

1.5.2 Development of Water Quality Criteria

Criteria for TMDLs have been established for the Klamath River Basin (including Lost River) through collaboration between the California North Coast Regional Water Quality Control Board, Oregon Department of Environmental Quality, U.S. Environmental Protection Agency (EPA) Regions 9 and 10, and contractors. The TMDLs for the mainstem Klamath River (including an implementation plan for the already approved Lost River TMDL) were approved by the California State Water Resources Control Board and EPA Region 9 in December 2010. NMFS completed its ESA consultation on the Klamath River TMDLs in December 2010 (National Oceanic and Atmospheric Administration [NOAA], 2011). The Oregon Department of Environmental Quality issued a departmental order adopting TMDLs for the listed parameters for the Upper Klamath (Link River Dam to California state line) and the Upper Lost River. The Oregon TMDLs have been submitted to EPA Region 10 for final approval. TMDLs for the Klamath River's major tributaries (Lost, Scott, Shasta, and Trinity Rivers) were previously established. Klamath River Basin TMDLs are summarized in Table 1-2. When TMDLs are developed, water quality criteria are established for sustaining fish and wildlife species, then acceptable waste load allocations are identified. In many cases existing natural conditions exceed established water quality criteria.

Table 1-2.—Summary of Klamath Basin TMDLs

Sub-basin or Reach	TMDL
Sprague River, Williamson River, Upper Klamath Lake	Dissolved oxygen, chlorophyll a, pH (2002)
Lower Lost River (Oregon)	Dissolved oxygen, pH, ammonia toxicity, temperature in Lost River tributaries (2010)
Lower Lost River (California)	Nutrients, pH (2008) Temperature (2006)
Klamath River (Oregon)	Dissolved oxygen, pH, ammonia toxicity, temperature, chlorophyll a (2010)
Klamath River (California)	Nutrients, temperature, dissolved oxygen/organic enrichment (2010)
Shasta River	Temperature, dissolved oxygen (2007)
Scott River	Temperature, sediment (2006)
Salmon River	Temperature (2005)
Trinity River	Sediment (2001)

Source: EPA, 2008

1.5.3 Past or Existing Restoration Efforts

Numerous programs have been established in an effort to restore natural function of the Klamath River, to the extent possible, and to encourage recovery of the basin’s ESA listed species. This section highlights some of these activities; however, it does not attempt to identify all past and present planning activities.

The Klamath River Basin Fishery Resources Restoration Act of 1986 established the Klamath Fishery Management Council to monitor the fish population and recommend annual fish harvest limits, as well as the Klamath River Basin Fisheries Task Force to advise the Secretary of Interior regarding implementation of the Restoration Program (U.S. Government Accountability Office, 2005). A USFWS office was established in Yreka, CA in 1987 to facilitate implementation and management of the Restoration Program (U.S. Government Accountability Office, 2005). However, due to funding constraints the Restoration Program was left to expire in 2006.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 required the NMFS to develop a recovery plan for SONCC ESU coho salmon in 2007 (NOAA, 2011). Since the early 1990s, harvesting of the Klamath River fall-run Chinook salmon stock was restricted offshore from California and Oregon due to low returns. However, based on recent increases in naturally spawning adults, the Secretary of the Interior declared Klamath River fall Chinook salmon populations restored in 2011 (NOAA, 2011).

Additional restoration and recovery actions include construction and monitoring of off-channel ponds (initiated in 2010) to address limited winter rearing habitat for ESA-listed coho salmon. Monitoring efforts following construction showed more than 250 juvenile coho salmon moving into the new ponds in Terwer Creek, illustrating the importance of this habitat for overwintering coho salmon. In 2010 NOAA's Open Rivers Initiative provided funding to the Shasta River Fish Passage Project for removal of the Grenada Irrigation District diversion dam. The Nature Conservancy continues to work on the Shasta River Big Springs Creek to restore more than 11 miles of salmon and steelhead spawning and rearing habitat.

The Trinity River Flow Evaluation (USFWS and Hoopa Valley Tribe, 1999) recommended a restoration strategy for the Trinity River that integrates restoration of riverine processes with the instream flow-dependent needs of salmonids. As a result, the Trinity River Restoration Program strives to restore the natural physical processes in the river and create spawning and rearing conditions (including adequate water temperatures) downstream of the dams that best compensate for lost habitat upstream (Trinity River Restoration Program, 2009).

The federal Wetlands Reserve Program is one of several programs implemented by the U.S. Department of Agriculture. Since the program's inception in 1990, it has resulted in the restoration of approximately 30,400 acres of wetlands in Oregon's Upper Klamath River Basin (Duffy et al., 2011).

Some major Reclamation actions to conserve native fish include construction of a fish screen on the A-Canal, completed in 2003; completion of the Link River Dam fish ladder in 2005; numerous monitoring and research studies; and the removal of Chiloquin Dam on the Sprague River to allow suckers access to historic spawning areas in 2008. The USFWS maintains a habitat restoration program and activities on the NWRs, including walking wetlands. The Nature Conservancy restored 7,000 acres of wetlands at the Williams River Delta of Upper Klamath Lake.

1.5.3.1 Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement

A large coordinated Klamath Basin restoration planning effort involving 42 Klamath Basin stakeholders began in 2007 and was completed in 2010. The resulting agreement, the KBRA, takes a multi-dimensional approach that attempts to resolve complex problems by focusing on species recovery while recognizing the interdependence of environmental and economic problems in the Basin's rural communities (Klamath Settlement Group, 2009a). The goals of the KBRA include:

- Restoring and sustaining natural production and providing for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin

- Establishing reliable water and power supplies which sustain agricultural uses, communities, and NWRs
- Contributing to the public welfare and the sustainability of all Klamath Basin communities

The KBRA was intended to be implemented alongside the Klamath Hydroelectric Settlement Agreement (KHSA), which lays out the process for conducting necessary additional studies, environmental reviews, and a decision by the Secretary of the Interior (called Secretarial Determination) surrounding the possible removal of the lower four dams on the Klamath River owned by PacifiCorp beginning in 2020. These dams are Iron Gate, COPCO 1, COPCO 2, and J.C. Boyle. The KHSA includes provisions for the interim operation of the dams prior to dam removal, the process to transfer, decommission, and remove the dams, and the transfer of Keno Dam to the Department of the Interior (Klamath Settlement Group, 2009b). On December 31, 2015 the KBRA terminated because federal authorizing legislation was not enacted. The KHSA is still in effect but its interdependent connection to the KBRA requires its amendment to continue. On February 2, 2016 an agreement-in-principle to amend the KHSA was announced between the states of Oregon and California, PacifiCorp, and the US Departments of Interior and Commerce. The ultimate timing of its implementation is not currently known, but the KHSA describes the implementation of the dam removal action in 2020.

A joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis has been performed and a final Environmental Impact Statement/Environmental Impact Report containing 18 alternatives has been completed. Five of the alternatives, including the no project/no action alternative, were carried forward for detailed evaluation. Among the five alternatives carried forward is full implementation of the KHSA and KBRA (Interior and the California Department of Fish and Game, 2011; Thorsteinson et al., 2011).

1.5.4 Future Challenges

The primary challenge of the Klamath River Basin Study is determining how to address the uncertainties related to water management in the basin. For example, the fate of the KBRA and KHSA is unknown at this time. Quantification of potential imbalances in current and projected future supply and demand and subsequent evaluation of identified management strategies would yield vastly different outcomes, depending on whether the four lower Klamath River dams are removed and associated restoration efforts move forward. To address this future challenge, the Klamath River Basin Study takes a scenario approach in order to increase flexibility in evaluating climate change impacts on the baseline system.

1.6 Collaboration and Outreach

The Klamath River Basin Study is a collaborative effort involving Reclamation and two non-federal cost share partners, the CDWR and the OWRD. The study seeks additional tribal and stakeholder involvement through a process described in the Public Participation and Outreach Plan. The Public Participation and Outreach Plan describes the tribal, stakeholder, and public participation process; however, an overview is provided in this chapter. The process of involving tribes and stakeholders is likely to evolve: consequently, the plan will be adapted, as needed, as the study gets underway.

The Klamath River Basin Study was guided by a technical working group (TWG), with input from interested organizations and individuals. The non-federal cost share partners (CDWR, OWRD, and Reclamation) comprise the TWG, which was the primary decision-making body for the Basin Study and which conducted a peer review of technical deliverables. Interested organizations and individuals were asked to provide input on the study approach and findings throughout the process. These groups or individuals included federal, state, and local governments; tribes; water use organizations; and non-profit groups. The general public was kept apprised of the progress and findings of the Basin Study primarily through existing public meetings that took place across the region. Figure 1-3 illustrates the Basin Study organization.

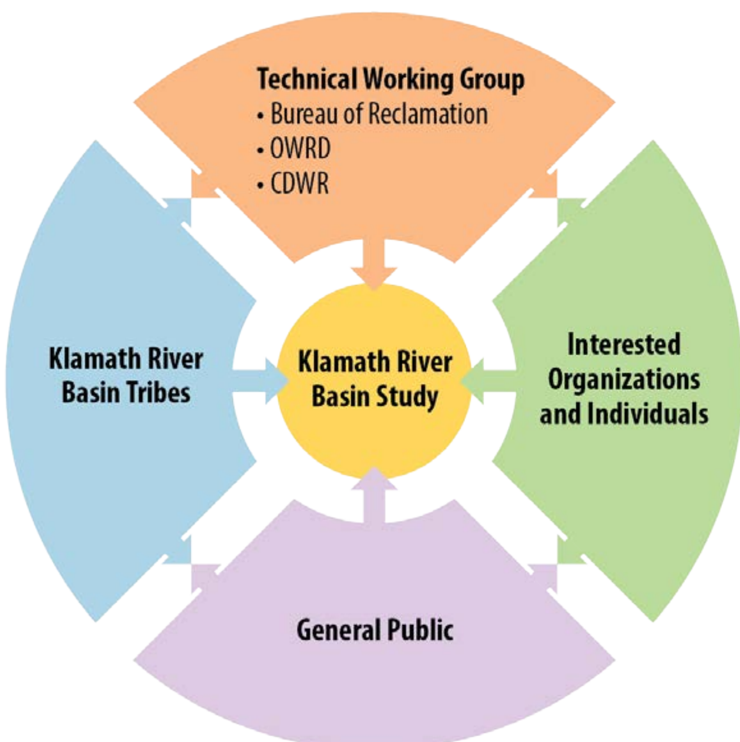

Figure 1-3.—Klamath River Basin Study organizational chart.

1.7 What to Expect in this Study

The Klamath River Basin Study, consistent with the Basin Study Framework (Reclamation, 2009), contains four primary components. These are listed in Section 1.2, Purpose, Scope, and Objectives of the Study. They are also illustrated in Figure 1-4, which provides an overview of the basin study approach, highlighting Chapter 1. The first component of the Klamath River Basin Study includes an assessment of current and projected future water supplies. Projected scenarios of future water supply are drawn from methods described by WWCRA (Reclamation, 2011d). However, this study also incorporates climate scenarios from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al., 2012). The Klamath River Basin Study also utilizes streamflow reconstructions from tree-rings to provide a greater variability context for historical climate and hydrologic conditions. This portion of the study evaluates past and projected future changes in precipitation and temperature, as well as changes in snowpack, evapotranspiration, and groundwater if possible.

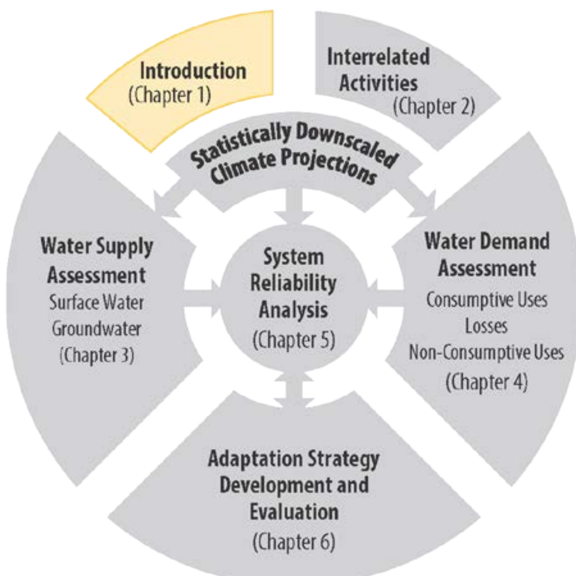

Figure 1-4.—Overall approach for Klamath River Basin Study, highlighting Chapter 1.

The second component of the Klamath River Basin Study includes an assessment of current and projected future water demands. The assessment includes quantification of historical and projected future agricultural demands and open water evaporation. This study takes advantage of newly available demand information through the WWCRA.

The third component of the Klamath River Basin Study includes evaluating the watershed's ability to meet or withstand any identified future water supply/demand imbalances (these may include infrastructure, fish and wildlife, etc.). System reliability is determined by testing the system against various defined performance measures. These measures were developed with input from the Klamath River Basin Study TWG and interested organizations and individuals. This component relies heavily on projections from the first two components of the study (assessment of current and projected future water supply and demand). The proposed approach includes evaluation of risk and reliability considering multiple scenarios of projected future climate/demand conditions. The fourth and final component of the Klamath River Basin Study includes identifying and quantifying potential adaptation strategies or opportunities to address potential supply/demand imbalances, considering a range of future scenarios. Adaptation strategies include a range of concepts including operational changes or habitat restoration, among others. In general, the study aimed to identify potential adaptation strategies that that have the potential for reducing water supply/demand imbalances that are likely as a result of climate change. Adaptation strategies are evaluated using a decision-making framework. Chosen strategies in the Klamath River Basin Study were general in nature in order to evaluate the sensitivity of the basin's water resources to different types of strategies.

The goal for the Klamath River Basin Study is to provide added value to past and ongoing studies to work toward meeting the needs of water users and fish and wildlife in the basin. Further, the Basin Study provides a holistic view of the entire Klamath watershed and does not discount any recommended adaptation strategies. All adaptation strategies identified through the stakeholder and public participation process are included as Appendix E to the Klamath River Basin Study final report.

1.8 Supporting Information

The literature synthesis, along with a list of corresponding references, is provided as Appendix A.

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Chapter 2
Klamath River Basin Study
Identification of Interrelated Activities

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Contents

Figures

Chapter 2
Identification of Interrelated Activities

The Klamath River Basin is unique in that its natural setting and inherent challenges require cooperation among all levels of government and organization. The Klamath River Basin is an interstate watershed with six federally recognized tribes. Three ESA listed fish species are directly affected by water use, and these are being managed by a combination of federal, state, and local efforts. The variety of groups with management responsibilities in the basin has resulted in numerous interrelated activities and coordinated efforts. Following is a brief description of interrelated activities in the Klamath River Basin that are relevant to the Klamath River Basin Study. Also, Figure 2-1 illustrates how Chapter 2 fits into the overall basin study approach.

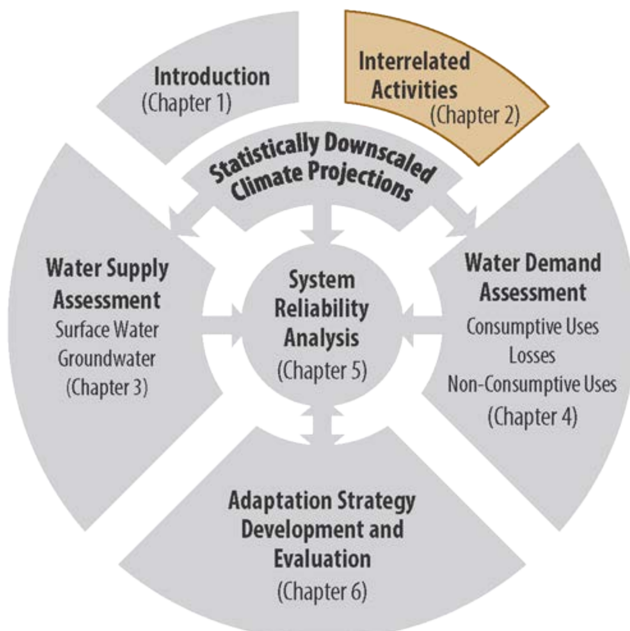

Figure 2-1.—Overall approach for Klamath River Basin Study, highlighting Chapter 2.

2.1 Federal

Because the Klamath River Basin contains two federal irrigation projects (Reclamation's Klamath Project and a part of the Trinity River Division), provides habitat for species listed as threatened or endangered under ESA, contains one national park (Crater Lake National Park) and thousands of acres of

National Forest and Bureau of Land Management Lands, plus is home to six federally recognized native tribes, numerous past and ongoing federal activities overlap and have common goals. The primary common thread that brings various agencies and activities together is the effort to recover three of the basin's seven ESA listed fish species: the SONCC ESU coho salmon (threatened) and Lost River and shortnose suckers (endangered).

Reclamation's Klamath Project first began providing water to irrigators in 1907, and since then the project has grown to about 254,000 acres of land. The Upper Klamath Basin hydrologic system was significantly altered as a result of:

- wetlands drained from Upper and Lower Klamath and Tule Lakes,
- construction of dams and conveyance structures by Reclamation,
- construction of seven hydroelectric facilities by PacifiCorp,
- a Bureau of Indian Affairs dam on the Sprague River, subsequently removed by Reclamation in 2008, and
- other water diversions and withdrawals above the Klamath Project.

Development in the Klamath River Basin over the last century, including construction of dams without fish passage facilities, has caused declines in anadromous and resident fish species. Their decline was recognized in the early 1980s with passage of the Klamath River Basin Fishery Resources Restoration Act (P.L 99-552), which established the Klamath Basin Restoration Fisheries Task Force and charged it with developing a 20-year Klamath River Basin Conservation Area Fishery Restoration Program. This program was allowed to expire in 2006 and no longer operates; however, numerous restoration projects were implemented over the 20-year period.

Since the listing of three Klamath River Basin fish species under ESA, Reclamation has worked with the NMFS (responsible for SONCC ESU coho salmon) and the USFWS (responsible for Lost River and shortnose sucker) on Klamath Project operations plans that reduce regulated flow impacts to these species (Reclamation, 2011f; Reclamation, 2012a). Due to low water availability in 2001, Reclamation was not able to meet irrigation needs or recommended Klamath River flows and Upper Klamath Lake levels for the ESA listed species. As a result, the National Research Council (charged with advising the federal government on science issues) was directed to review the science underlying recommendations by the NMFS and the USFWS (National Research Council, 2002; National Research Council, 2004; National Research Council, 2008).

In an interim report completed in 2002, the National Research Council concluded that the recommendations had substantial scientific support except for those regarding minimum lake levels of Upper Klamath Lake and increased minimum flows in the mainstem Klamath River. Also, it found Reclamation's Klamath Project operations would not affect tributary conditions, which were deemed the most critical for species survival. At the same time, the National Research Council found Reclamation's proposed minimum Klamath River flows would result in an unknown risk to the population.

In their final report in 2004, the National Research Council corroborated their interim findings and, in addition, provided a broad set of recommendations for the recovery of threatened and endangered species in the entire basin, including expanding the scope of ESA actions by the NMFS and USFWS, planning and organizing research activities and monitoring, identifying specific high priority recovery actions for endangered suckers (e.g., removal of Chiloquin Dam which occurred in 2008), identifying information needs related to SONNC ESU coho salmon, and identifying remediation measures that could be implemented based on current information.

Reclamation has conducted numerous studies with the overarching goal of reducing the Klamath Project impacts on the natural river system. These studies include efforts to evaluate potential new off-stream storage facilities, groundwater pumping and aquifer storage options, and water banking mechanisms. Examples of these studies include the Long Lake Valley appraisal report (Reclamation, 2011a), the Upper Klamath Basin Offstream Storage Investigations, Initial Alternatives Information Report (Reclamation, 2011e), the Klamath Project Yield and Water Quality Improvement Options Appraisal Study (Reclamation, 2012e), and the KBRA On-Project Plan (Klamath Water and Power Agency, 2011).

Other federal agencies have also undertaken numerous activities with the goal of managing natural resources for the livelihoods of Klamath River Basin residents while maintaining, as much as possible, the natural ecosystem critical for ESA listed species and others. The Bureau of Land Management (BLM) has conducted watershed analyses for the mainstem Trinity River (BLM, 1990), for which the goal was to compile existing knowledge about various physical processes important in the basin and work toward more holistic ecosystem management. The BLM was also involved in the process to classify reaches of the Klamath River and its tributaries in the National Wild and Scenic Rivers System (BLM, 1990).

The U.S. Forest Service (USFS) conducted a watershed analysis for the Six Rivers National Forest (Orleans Ranger District) in 2003 to support potential watershed restoration actions related to the recovery of ESA listed anadromous salmonid fish species, and to implement fuels reduction around local communities, municipal water sources, and private lands as outlined by USFS fire plans (USFS, 2003). The Six Rivers National Forest intersects part of the Lower Klamath Basin. The USFS also completed a land and resource management plan (USFS, 1995) for the Six Rivers National Forest, which takes into account impacts to the ESA listed species.

The USFWS and NMFS work cooperatively with private entities to produce habitat conservation plans for incidental take of fish and wildlife species. The USFWS has also been involved in Trinity River Restoration Program efforts to improve the natural function of the Trinity River below Lewiston Dam. For example, they completed the Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (USFWS et al., 2000) on the Trinity River Flow Evaluation Study, which resulted in the December 19, 2000 Record of Decision to establish the Trinity River Restoration Program (Interior, 2000).

The NMFS has been involved in a wide variety of interagency efforts, including the development of the SONCC ESU coho salmon recovery plan and working with the North Coast Regional Water Quality Control Board to develop TMDLs for the Klamath River in California. The NMFS has also been involved in a number of habitat restoration projects including construction of off-channel ponds by the Mid-Klamath Watershed Council and Karuk Tribe, and installation of a series of boulder step pools to replace gravel push-up dams in a partnership between Scott Valley Resource Conservation District and local landowners (NMFS, 2009; NMFS, 2011).

The KBRA and KHSA are companion agreements between federal agencies, Klamath Basin Tribes, irrigators, fishermen, conservation groups, counties, the states of Oregon and California, and dam owners, which aim to restore Klamath River Basin fisheries and sustain local economies. The agreements include:

- removal of four dams in the upper Klamath River
- increased flows for fish
- greater reliability of irrigation water deliveries
- reintroduction of salmon above the dams and into and above Upper Klamath Lake
- investment in comprehensive and coordinated habitat restoration
- a power program for Klamath River Basin farmers and ranchers
- mitigation to counties for the effects of dam removal
- investment in tribal economic revitalization

Current Federal Energy Regulatory Commission (FERC) licenses for the dams expired in 2006. These facilities are now operated on annual licenses using existing operating plans. FERC continues to participate in the ongoing process to determine the fate of the dams.

2.2 Tribal

Tribal activities in the watershed include the Klamath Basin Tribal Water Quality Work Group, which conducts coordinated surface water sampling activities and participates in the Klamath River Basin monitoring program. The Klamath Basin Monitoring Program is a multi-agency organization aiming to implement, coordinate, and collaborate on water quality monitoring and research throughout the Klamath Basin. As an example, Reclamation and the Klamath Tribes have together been collecting water quality data in Upper Klamath and Agency Lakes since 1988.

The Karuk Tribe and the USFS have coordinated on the land management of the Katimiin Cultural Management Area near Somes Bar, California. Management strategies outlined are consistent with both Karuk cultural environmental management practices and the Klamath National Forest Land and Resource Management Plan. The Katimiin Cultural Management Area is where the Tribe's Pikyawish, or World Renewal, ceremonies are concluded each year (CDWR, 2013).

Three of the six federally recognized tribes in the Klamath River Basin have supported the KBRA and KHSA agreements (Klamath Settlement Group Communications Committee, 2009a, b). Although the others also strive for ESA listed species recovery and return of the Klamath River to a more natural condition, some have expressed the position that dam removal would occur more immediately if left to the FERC relicensing process.

The Hoopa Valley Tribe worked alongside Interior to lead the Trinity River Restoration Agreement, which aims to mitigate the detrimental effects of decades of out of basin diversions of Trinity River water to Reclamation's Central Valley Project (USFWS et al., 2000). The Hoopa Valley Tribe worked with the USFWS to complete the Trinity River Flow Evaluation Study, which became the basis for the Trinity River Restoration Agreement (USFWS and Hoopa Valley Tribe, 1999). The Yurok Tribe is also a member of the council governing the Trinity Restoration Agreement.

The tribes in the Klamath River Basin have also conducted or commissioned their own studies to quantify the needs of environmental resources on which they depend. For example, Trihey and Associates, Inc. (1996) sought to quantify the monthly flow requirements of Tribal Trust fish species in the mainstem Klamath River between Iron Gate Dam and the river mouth.

2.3 Interstate (including regional)

California and Oregon have coordinated on several activities involving the Klamath River, which flows between the states. The Klamath River Basin Compact was ratified by the states of Oregon and California in April 1957. The compact was meant to facilitate and promote the orderly, integrated, and comprehensive development, use, conservation, and control of Klamath River water for various purposes. Uses include domestic, irrigation, protection, and enhancement of fish and wildlife, industrial, hydroelectric power production, navigation, and flood prevention.

In addition to water quantity and timing, California and Oregon have coordinated on water quality issues with respect to the development of TMDLs for the mainstem Klamath River and its tributaries. The California North Coast Water Quality Control Board and the Oregon Department of Environmental Quality coordinated on completion of draft TMDLs for respective parts of the mainstem river by 2010. These are both complete and await approval.

PacifiCorps's hydropower facilities in the Klamath River Basin reside in both California and Oregon. As such, California and Oregon have undertaken studies to evaluate effects of these facilities on the environment, as well as potential effects of removal of the dams. For example, the California Coastal Conservancy (2006) evaluated sediment supplies under potential dam decommissioning scenarios.

2.4 State

The Klamath River Basin spans parts of California and Oregon and both states have been involved in management and planning efforts in the basin. In California, the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) aims to act as a nexus between statewide planning efforts and local planning, helping to synchronize the large, complex planning processes, regulations, and priorities at the state level with the locally specific issues, data, concerns, planning, and implementation needs at the local level.

The OWRD and CDFW (which prior to January 2013 was the California Department of Fish and Game) have collaborated with federal agencies and tribes on a number of studies. For example, the Instream Flow Study Phase II (Hardy et al., 2006) for the Klamath River, which was developed to help determine flow needs of ESA listed fish species, was a collaborative effort involving Utah State University, the USFWS, the NMFS, the USGS, the Bureau of Indian Affairs, Reclamation, CDFG, OWRD, the Karuk Tribe, the Hoopa Tribe, and the Yurok Tribe. In another example, the USGS and OWRD collaborated in a study to characterize regional groundwater in the Upper Klamath Basin and develop a groundwater flow model to test management options (Gannett et al., 2007).

2.4.1 Relationship to State Law including State Water Plan

Water rights adjudications in California and Oregon are in different stages of completion. The Shasta Valley in California was adjudicated in 1932, the Scott Valley in California in 1980. The mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court demarking a significant milestone in determining the water rights of the Upper Klamath Basin. The adjudication covers all claims to the use of surface water that predate Oregon's 1909 Water Code. It also covers those referred to as "federal reserved water right" claims. The Circuit will now handle the remaining administrative process prior to issuance of a Court Decree. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the "time immemorial", which may significantly affect water management in the Upper Klamath Basin. The Klamath Tribes have currently agreed not to exercise their rights prior to August 9, 1908. Another significant finding of the Final Order of Determination granted co-ownership of Klamath Project water rights to both Reclamation and Klamath Project water users.

California's water plan update (CDWR, 2013) includes a discussion of activities through the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) as well as a discussion of overall planning activities in the Klamath River Basin. However, most planning activities are carried out by federal agencies and coordinated groups.

Oregon completed its water resources strategy in 2012 and the state legislature has directed that this plan be updated every 5 years (OWRD, 2012). The plan discusses general recommendations for additional groundwater investigations, improved water monitoring, and continued research on the implications of climate change. Like California, Oregon does not direct planning activities in the Klamath River Basin as these are primarily carried out by interagency consortia.

2.5 Local

There are numerous local landowner and water user groups within the Klamath River Basin and many of these interact with interagency planning efforts. One example is the KBRA/KHSA planning process, which involves 42 stakeholder groups including local water managers and land owners. Also, the Klamath Basin Rangeland Trust, a nonprofit organization with the mission of improving water availability in the Upper Klamath Basin, was formed in 2002. The Trust facilitates partnerships between private landowners and public agencies to conserve water resources and restore habitat and wetlands.

Local groups are also involved in the Trinity River Restoration Planning efforts, as many of the restoration projects take place using local resources and expertise. For example, the Coordinated Resource Management Plan Group for the South

Fork Trinity River is a consortium of local landowners and various agencies who are interested in water conservation, habitat improvement, and educational outreach in the South Fork Trinity River. The group is funded by the Trinity River Restoration Program. Also, in coordination with the NMFS, Scott Valley Resource Conservation District and local landowners installed a series of boulder step pools to replace gravel push-up dams in the basin.

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Chapter 3
Klamath River Basin Study
Assessment of Current and Future Water Supply

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Chapter 3
Assessment of Current and Future Water Supply

3.1 Introduction

The purpose of the Klamath River Basin Study is to identify current and projected imbalances in water supply and demand across the entire Klamath River Basin, and to develop and analyze adaptation strategies to help resolve any identified imbalances. A system diagram illustrating the primary components of the Klamath River Basin Study is provided in Figure 3-1.

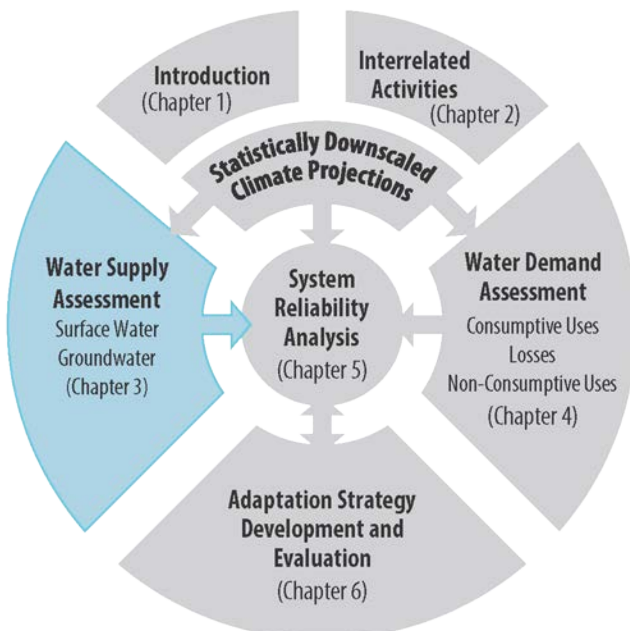


Figure 3-1.—Overall approach for Klamath River Basin Study, highlighting Chapter 3

The water supply assessment consists of analyses of both surface and groundwater resources, including quantification of historical trends and projections for two future planning horizons, the 2030s (represented as the mean from 2020–2049) and 2070s (represented as the mean from 2060–2089). The water demand assessment (Chapter 4 of the Klamath River Basin Study) consists of analysis of agricultural, tribal/cultural, environmental, evaporative demands, and domestic, municipal, and industrial demands. Statistically downscaled climate projections provide the basis for the assessments of projected water supply and demand. They are also used directly, along with supply and demand information, to evaluate the river system with respect to environmental demands such as water quality. Current and projected water supply and demand are brought together to evaluate how the river system has responded historically to changes in supply and demand, and may respond in the future as a result of climate change. Potential water supply/demand gaps are evaluated as part of a system reliability analysis. Performance measures are used to analyze system reliability; these are developed through an input process involving Klamath River Basin Study cost share partners, stakeholders, and tribes. The analysis of system risk and reliability is summarized in Chapter 5.

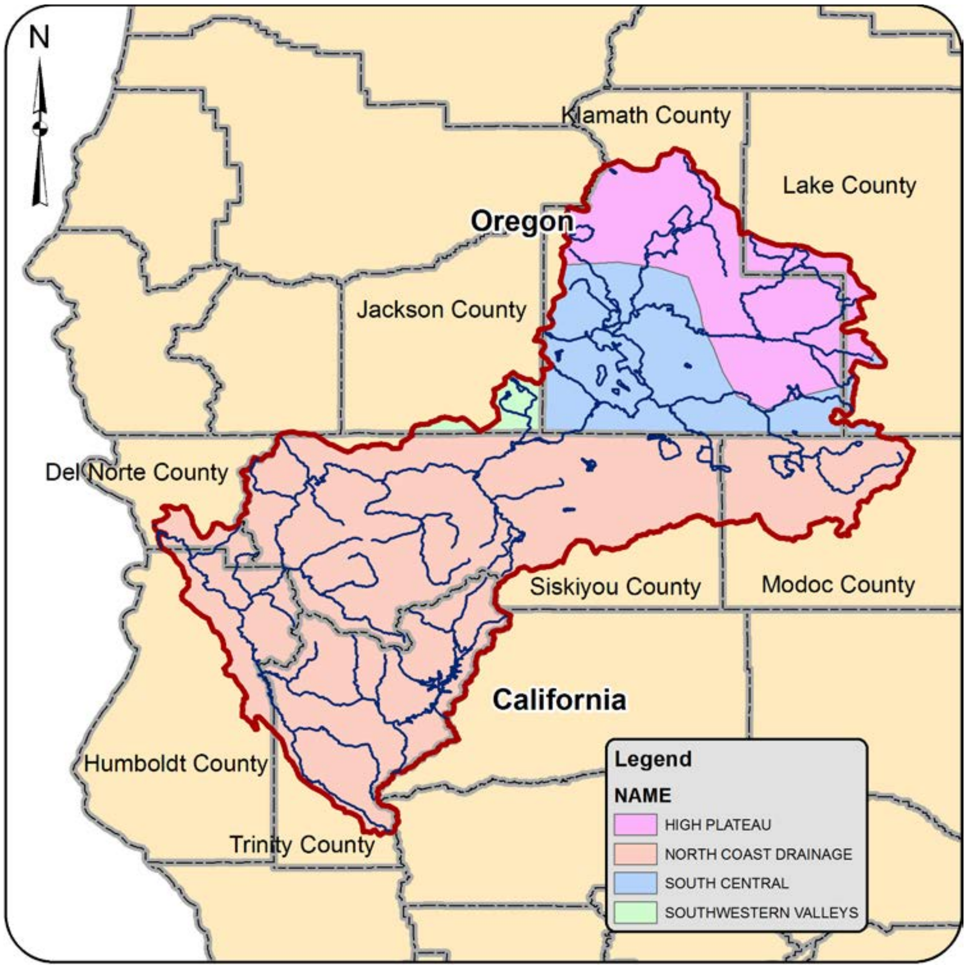
This chapter summarizes the findings of the current and future water supply assessment. The chapter begins with a general discussion of surface and groundwater resources in the watershed, followed by discussions of the technical approach for evaluation of historical water supply (surface and groundwater) and an assessment of historical water supply. The chapter then assesses projected water supply (surface and groundwater), including a detailed discussion of the approach for developing climate scenarios. The assessment of historical and projected surface water supply encompasses the entire Klamath River watershed, while the assessment of historical and projected groundwater supply is focused on three dominant groundwater basins in the watershed: the Upper Klamath Basin, Shasta Valley, and Scott Valley. The difference in approach is due to the extents of existing surface and groundwater modeling tools that may be applied in the study.

3.2 Description of Surface and Groundwater Supplies

This section briefly describes the general characteristics of surface and groundwater in the Klamath River Basin. These characteristics provide context for subsequent analysis of historical and projected water supply throughout the watershed. As previously mentioned, surface water supply is analyzed basin-wide, concentrated on three primary regions for analysis of groundwater supply: the Upper Klamath groundwater basin, the Scott Valley groundwater basin, and the Shasta Valley groundwater basin.

The Klamath River Basin is a complex watershed, due in part to its distinct climatic regions and distinct geologic zones which influence surface and groundwater interactions throughout the watershed. The Klamath River Basin spans four NOAA climate divisions, including High Plateau, North Coast Drainage, South Central, and Southwestern Valleys (Figure 3-2). Climate divisions are generally climatically distinct regions; however, they are also defined by political boundaries, as evidenced on Figure 3-2 where climate divisions are separated by the Oregon-California border and, in one case, by county boundaries (the boundary between Southwestern Valley and South Central).

The elevation ranges of Klamath River Basin climate divisions help to illustrate the complexity of the watershed. Basin-wide elevations range from sea level to about 13,600 feet. These two elevation extremes both fall within the North Coast Drainage climate division. The High Plateau ranges between 4,200 feet and 8,500 feet, while the South Central region ranges between 2,870 feet and 8,000 feet. Even the Southwestern Valley Climate Division, which covers only 15 percent of the watershed, ranges between 3,000 feet and 9,040 feet.



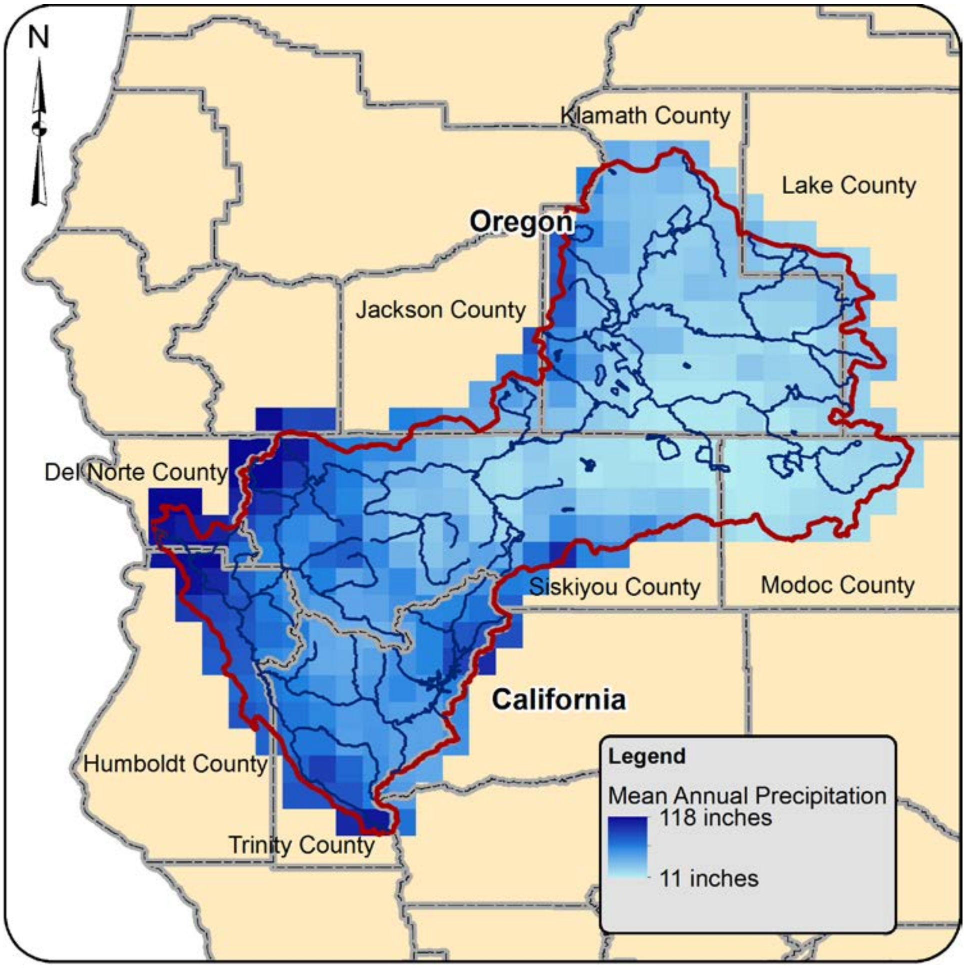
Source: NOAA, http://www.esrl.noaa.gov/psd/data/usclimdivs/boundaries.html.

Figure 3-2.—Map of climate divisions within the Klamath River Basin.

Mean annual precipitation and temperature were computed for the three dominant climate divisions within the watershed over calendar years 1950–1999, based on a widely used grid-based meteorological dataset developed by Maurer et al. (2002). This historical meteorological dataset is used as the basis for the historical and projected water supply assessments, as discussed later in this chapter.

Mean annual precipitation varies substantially across the three dominant climate divisions within the watershed (Figure 3-3), from about 24 inches per year in the South Central to about 44 inches per year in the North Coast Drainage and about

26 inches in the High Plateau. The historical basin-wide mean annual precipitation over the same period is approximately 37 inches per year. Mean annual average temperature varies from almost 41 degrees Fahrenheit (F) in the High Plateau to 43 degrees F in the South Central and about 46 degrees F in the North Coast Drainage climate division, with a basin-wide average of 45 degrees F (computed over the same 1950–1999 period as for precipitation).



Source: based on meteorological data from Maurier et al., 2002

Figure 3-3.—Mean annual precipitation (inches/year) over the period 1950–1999.

The seasonality of precipitation and temperature in the Klamath River Basin is typical of coastal watersheds, where the winter season (defined as December through February) experiences the greatest precipitation, about 18 inches per year for this watershed historically (1950–1999), ranging from about 10 inches per year in the South Central to about 11 inches in the High Plateau and 22 inches in the North Coast Drainage. The summer season (defined as June through August) experiences relatively dry conditions, receiving about 2 inches per year for the same period with less than 12 percent of that experienced in the winter, and ranging from slightly less precipitation in the North Coast Drainage to slightly more in the High Plateau.

Winter temperatures average about 31 degrees F over the historical period 1950–1999 across the basin and range from about 29 degrees F in the High Plateau and South Central to about 33 degrees F in the North Coast Drainage. Summer temperatures average about 60 degrees F basin-wide and range from about 58 degrees F in the High Plateau to about 60 degrees F in the South Central and about 61 degrees F in the North Coast Drainage. Note that diurnal fluctuations in temperature as well as temperatures at different elevations may vary substantially from these daily averages.

Table 3-1.—Summary of Klamath River Basin characteristics

	Basin Wide	North Coast Drainage	South Central	High Plateau
Mean annual precipitation	37 inches	44 inches	24 inches	26 inches
Mean winter precipitation	18 inches	22 inches	10 inches	11 inches
Mean summer precipitation	2.1 inches	1.9 inches	2.1 inches	2.4 inches
Mean annual daily average temperature	45 degrees F	46 degrees F	43 degrees F	41 degrees F
Mean winter daily average temperature	31 degrees F	33 degrees F	29 degrees F	29 degrees F
Mean summer daily average temperature	60 degrees F	61 degrees F	60 degrees F	58 degrees F
Runoff ratio	0.46	0.52	0.27	0.24
Elevation range	0–13,600 feet	0–13,600 feet	2,870–8,000 feet	4,200– 8,500 feet

3.2.1 Surface Water

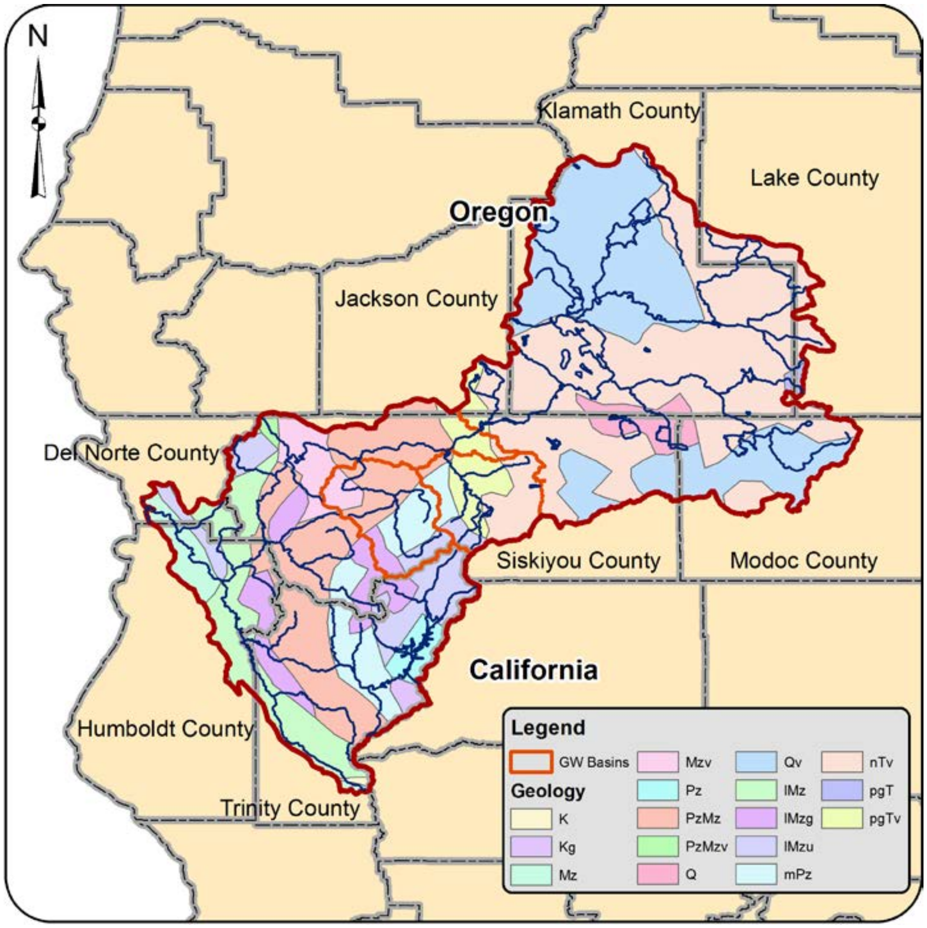
The Klamath River Basin may be considered a mixed rain and snow influenced watershed. March has historically had the greatest snowpack, averaging about 4.5 inches across the basin (statistics based on historical hydrologic model results are discussed below).

As previously mentioned, the relative magnitudes of key elements of the water balance in the Klamath River Basin vary due to its climatic diversity. Precipitation is one key element of the water balance described above. Other key elements include runoff and evapotranspiration. The ratio of mean annual runoff to mean annual precipitation is an indicator of how much precipitation results in streamflow as opposed to being lost through evapotranspiration or to groundwater recharge. On the whole, the basin has a historical runoff ratio of about 0.46, which translates to 46 percent or almost half of annual precipitation resulting in streamflow. This ratio varies substantially by climate division, from about 0.24 in the High Plateau climate division to about 0.27 in the South Central climate division and 0.52 in the North Coast climate division. In the High Plateau and South Central climate division areas evapotranspiration rates are higher, resulting in lower runoff ratios. In general, over snowmelt-dominated basins of the western U.S., runoff ratios are typically close to 0.5. Little is known regarding how runoff ratios may change in a changing climate; however, future research may shed light on this question.

3.2.2 Groundwater

Groundwater systems are dynamic, with rates of recharge and discharge and hydraulic head varying in response to external stresses. Climate is one primary external influence on groundwater systems, along with human-caused stresses such as pumping, artificial recharge from canal leakage, and other sources. This section offers an overview of three primary groundwater basins to provide context for analysis of historical and projected future conditions in these areas and to provide greater understanding of how climate and other stressors may influence them.

The Klamath River Basin spans numerous geologic formations including volcanic, sedimentary, and granitic (Figure 3-4 and Table 3-2). Each formation, with its various overlying soil types, causes unique surface and groundwater interactions. Groundwater is an important water source for fish, wildlife, irrigators, and residents throughout the watershed, and in particular the Upper Klamath Basin and Scott and Shasta Valleys. For example, it provides cool, late summer streamflows to sustain fish at a critical time for spawning and rearing. In another example, some irrigators depend on groundwater supply to supplement surface water supplies during low water years where surface water supplies may not fully meet water needs, while many more irrigators depend solely on groundwater supplies. Increasing reliance on groundwater makes this an important component of the water supply assessment.



Source: Generalized Geologic Map of the United States,
http://pubs.usgs.gov/atlas/geologic/

Figure 3-4.—Map of geologic units within the Klamath River Basin.

Table 3-2.—Descriptions of Klamath River Basin geologic types by ID as represented in Figure 3-4

ID	Geology	ID	Geology
nTv	Neogene volcanic rocks	IMzu	Lower Mesozoic ultramafic rocks
Qv	Quaternary volcanic rocks	mPz	Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks
Mz	Mesozoic sedimentary rocks	IMzg	Lower Mesozoic granitic rocks
pgTv	Paleogene volcanic rocks	mPz	Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks
pgT	Paleogene sedimentary rocks	Pz	Paleozoic sedimentary rocks
PzMzv	Paleozoic and Mesozoic volcanic rocks	IMzg	Lower Mesozoic granitic rocks
IMz	Lower Mesozoic (Triassic and Jurassic) sedimentary rocks	Kg	Cretaceous granitic rocks
PzMz	Paleozoic and Mesozoc sedimentary rocks	K	Cretaceous sedimentary rocks
Mzv	Mesozoic volcanic rocks	Q	Quaternary deposits

As noted previously, the Klamath River Basin Study water supply assessment focuses on three primary groundwater basins including the Upper Klamath Basin, the Scott River Valley (Scott Valley), and the Shasta River Valley (Shasta Valley). The Upper Klamath Basin includes agricultural areas upstream of Upper Klamath Lake and areas in and surrounding Reclamation's Klamath Project, as well as Butte Valley and the Lost River drainage. Each of the three dominant groundwater basins is described below and highlighted in Figure 3-4.

3.2.2.1 Upper Klamath Groundwater Basin

The Upper Klamath groundwater basin spans about 8,000 square miles upstream of Iron Gate Dam on the Klamath River. Gannett et al. (2012) estimated approximately 500,000 acres of irrigated land for agriculture in 2011. Descriptions of the Upper Klamath groundwater basin primarily come from studies by Gannett et al. (2007) and Gannett et al. (2012).

The Klamath River Basin spans the Cascade Range geologic province (roughly corresponding with the Lower Klamath Basin) and Basin and Range geologic province (roughly corresponding with the Upper Klamath Basin). The Western Cascades sub-province of the Cascade Range constitutes part of the western boundary of the regional groundwater flow system and has very low permeability. The High Cascade sub-province of the Cascade Range consists mostly of volcanic vents and lava flows. There are two main areas in the Upper Klamath Basin with these Quaternary volcanic deposits: near Crater Lake (forming part of the northwest Upper Klamath Basin boundary), and from Mount Shasta east to Medicine Lake Volcano (forming part of the southern Upper Klamath Basin boundary).

Groundwater recharge from precipitation accounts for about 20 percent of the total precipitation in the Upper Klamath Basin. The exact percentage varies spatially and temporally (Gannett et al., 2007). The primary recharge areas in the upper Klamath Basin are the Cascade Range and uplands within and on the eastern margin of the basin. In the northeast part of the Upper Klamath Basin, basalt formations are an important source of recharge due to their high permeability. According to multiple references, at least 60 percent of the inflow into Upper Klamath Lake can be attributed to ground-water discharge in the Wood River sub-basin and springs in the lower Sprague River drainage and the Williamson River drainage below Kirk (Gannett et al., 2007).

Basin and Range Province deposits in the study area include a region from Clear Lake Reservoir eastward to the Upper Klamath Basin boundary. This region generally has low permeability. The region around the Tule Lake sub-basin and to the south consists of major water-bearing volcanic rock from the Late Miocene to Pliocene eras. Rock from these periods consists of volcanic vent deposits and flow rocks. These are generally located throughout the area east of Upper Klamath Lake and Lower Klamath Lake, underlying most of the valley-fill and basin-fill deposits in the study area. The lake deposits near the original lakebeds have much lower groundwater yield due to low permeability and a tendency to have confining layers. About a mile below J.C. Boyle Dam, a large spring complex contributes significant flow to the Klamath River, on the order of 200 cubic feet per second.

The City of Klamath Falls, which is the primary population center in the Upper Klamath Basin at about 21,000 residents, is entirely supported by groundwater sources. Demand for groundwater has increased in recent decades in the Upper Klamath Basin as a replacement water source for both municipal and agricultural uses.

3.2.2.2 Scott Valley Groundwater Basin

The Scott River is a major tributary of the Klamath River. The Scott Valley sub-basin consists of 813 square miles, approximately 63 percent in private land and 37 percent in federally managed lands (Harter and Hines, 2008). It is fed by a number of tributaries, many of which become dry in the summer months. CDWR Bulletin 118 (2003), which describes California's primary groundwater basins, characterizes the Scott Valley Groundwater Basin as a narrow alluvial floodplain about 28 miles long and ½ mile to 4 miles wide. The basin boundary is generally defined as the contact between the valley alluvium and rocks from the surrounding mountains, dating from Pre-Silurian to Cretaceous. The CDWR Bulletin 118 groundwater basin within the Scott Valley defines the model domain for the assessment of groundwater supply for this region.

The largest water storage in the watershed occurs in the alluvial fill of the Scott Valley groundwater basin, which is recharged annually by the Scott River and tributary streams, and by infiltration of precipitation and snow melt. This flood plain aquifer area was calculated to represent more than half of the total groundwater stored in the Scott Valley (Mack, 1958). The recent alluvium ranges in thickness from less than one foot to greater than 400 feet in the center of the Scott Valley at its widest point. The thickness of the alluvium decreases both to the north and to the south (Harter and Hines, 2008).

The Scott Valley's largest municipalities, Etna and Fort Jones, use a combination of surface and groundwater sources. Most rural residences use wells, but a few are served by springs and surface diversions (Harter and Hines, 2008). Land use is dominated by agriculture and cattle-raising. Almost 90 percent of the agricultural area within Scott Valley is used for alfalfa and pasture (CDWR, 2000). CDWR (2003) estimates that groundwater use for agriculture and municipal/industrial demand is about 1,300 acre-feet (AF), based on the 1991 flow augmentation survey for Scott Valley (CDWR, 1991).

3.2.2.3 Shasta Valley Groundwater Basin

The Shasta River is near the size of the Scott Valley and encompasses almost 800 square miles. The agricultural area within the Shasta Valley is comprised primarily of pasture and alfalfa, which amounts to about 80 percent of the total agricultural area. Many sub-basins of the Shasta Valley have pasture/hay and cultivated crops, which together account for more than 10 percent of the land area.

CDWR Bulletin 118 describes the Shasta Valley as having Quaternary alluvium as the primary formation supporting groundwater. This formation appears continuous throughout the valley region. Mack (1960) also reported volcanic rock formations of the western Cascade Mountains and the ancestral Mount Shasta debris avalanche. The southeastern boundary of the watershed is formed by Mount Shasta, one of the few glacier peaks in California. Glacial melting on Mount Shasta and mountain precipitation are principal sources of groundwater recharge in the Shasta Valley. A portion of this recharge reaches the Shasta River through spring discharge in the vicinity of Big Springs (CDWR, 1991). The CDWR Bulletin 118 groundwater basin within the Shasta Valley defines the model domain for the assessment of groundwater supply for this region.

The hydrology of the Shasta River has been and continues to be affected by Dwinnell Dam (built in 1928 and raised in 1955), surface water diversions, and interconnected alluvial groundwater pumping. Domestic, municipal, and industrial water use information available for the Shasta Valley, which had a population of 18,225 based on the 2000 Census, primarily consists of urban water management plans for the cities of Yreka and Weed, California. Water supply for the City of Yreka, with a population of 7,765 according to the 2010 Census, is completely sourced from surface water. The water supply for Weed, with a 2010 population of 2,967, is comprised of springs and wells.

3.3 Historical Surface Water Availability

This section summarizes historical and current surface water availability in the Klamath River Basin. Specifically, it provides a brief discussion of previous studies, a discussion of data and models used, and an analysis of historical availability and trends. Although the literature synthesis (Appendix A of the Klamath River Basin Study Report) contains a detailed discussion of previous studies, this section touches on those related to historical water supply availability to provide context for the assessment of surface water supplies.

3.3.1 Previous Studies

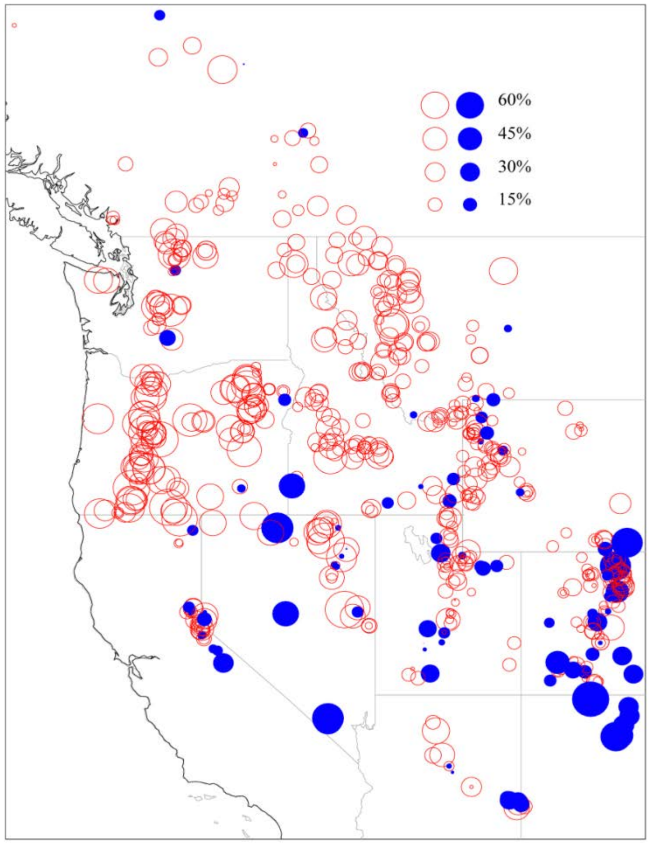
Numerous studies conducted over regions including northern California show increasing trends in historical temperatures, both annually and seasonally (Bonfils et al., 2007; Cayan et al., 2001; Dettinger and Cayan, 1995). Temperature increases over the 20th century have been estimated at 1.7 degrees F (1895–2011 over California by Moser et al., 2012) and 0.2–1.5 degrees F (difference between 1991–2007 and 1961–1990 over Shasta-Trinity National Forest by Furniss et al., 2012). Historical trends in precipitation have been inconsistent. Furniss et al.

(2012) found no apparent increase in precipitation variability, but found an increase in winter, defined as January and February (0.1 to 7.9 inches) and growing season precipitation (0.1 to 2.1 inches). Research has shown small increasing trends in the frequency of historical extreme events over the mid-Pacific region (Kunkel, 2003; Madsen and Figdor, 2007; Gutowski et al., 2008).

Historical trends in snowpack and runoff over Northern California include declines in spring snowpack and earlier snowmelt runoff (Knowles et al., 2007; Regonda et al., 2005; Peterson et al., 2008; Stewart, 2009; Furniss et al., 2012; Reclamation, 2011c). However, glaciers on Mount Shasta are among the few in the world that are increasing in size (Furniss et al., 2012). Note that any trends in climate and water balance (i.e., snowpack and runoff) are dependent on the time period of analysis and are a direct result of the combined influences of natural climate variability and climate change (Reclamation, 2011k).

In the Upper Klamath River Basin, dry season (April to September) and summer streamflow (July to September) declined 16 percent and 38 percent, respectively during the period between 1961 and 2009 (Mayer and Naman, 2011). This decline is closely associated with decline in April 1 snowpack, which decreased approximately 40 percent during the same study period for snowcourse sites located below 1820 meters (5,970 feet) in elevation.

In response to temperature increases in the Pacific Northwest (Cayan et al., 2001; Regonda et al., 2005), snowpack in western North America has declined over the past 50 years (Mote et al., 2008). Figure 3-5 illustrates declines in April 1 snow water equivalent (SWE) at 594 locations in the western U.S. and Canada between 1950 and 2000. Mote et al. (2008) noted that the Pacific Northwest (generally including Washington, Oregon, and Idaho) has experienced the largest decline in snowpack in the western U.S. Although many regions have experienced decreasing trends, some regions have experienced increasing trends in April 1 SWE, namely in parts of the southwestern U.S.



Source: Mote et al., 2008

Note: Negative trends are shown by open red circles, positive trends by solid blue circles.

Figure 3-5.—Relative trends in April 1 SWE at 594 locations in the western U.S. and Canada, 1950–2000.

Attribution studies have aimed to distinguish historical trends due to climate change versus trends due to natural climate variability (Bonfils et al., 2007 and Cayan et al., 2001 for the western United States; Gershunov et al., 2009 for California and Nevada). Bonfils et al. (2008) found that increases in daily minimum and maximum temperatures over 1950–1999 cannot be fully explained by natural climate variability. Pierce et al. (2008) found that climate change may be the cause of about half of reductions in the fraction of annual precipitation falling as snow observed in the western United States from 1950 to 1999. The strongest changes in winter runoff, and in the fraction of precipitation accumulated as snow, have occurred at medium elevations (750–2,500 meters or 2,460–8,200 feet and 500–3,000 meters or 1,640–9,840 feet, respectively) close to freezing level. These are not likely to be associated with natural variability (Hidalgo et al., 2009). Barnett et al. (2008) found that, over the western United States, up to 60 percent of the climate-related trends in streamflow are human induced. These as well as other attribution studies of streamflow timing (Hidalgo et al., 2009 and Das et al., 2009) and snow/rain days (Das et al., 2009) show that statistical significance of the anthropogenic signal is greatest at the scale of the western U.S. and weak or absent at the watershed scale, except in the Pacific Northwest (Hidalgo et al., 2009). However, attribution of any apparent trends in precipitation to climate change remains difficult (Hoerling et al., 2010).

3.3.2 Approach

The general approach for assessing historical surface water supply in the Klamath River Basin is to evaluate how historical climate has influenced the quantity, timing, and form of precipitation falling on the landscape. Assessment of historical water supply involves (1) evaluating trends in historical climate using a widely used spatially distributed meteorological dataset; (2) utilizing a hydrologic model to simulate the partitioning of precipitation into snow storage, evapotranspiration, runoff, and recharge to groundwater based on meteorological inputs and landscape characteristics; and (3) evaluating trends in historical water balance parameters based on hydrologic model simulations. This overall approach is illustrated by Figure 3-6.

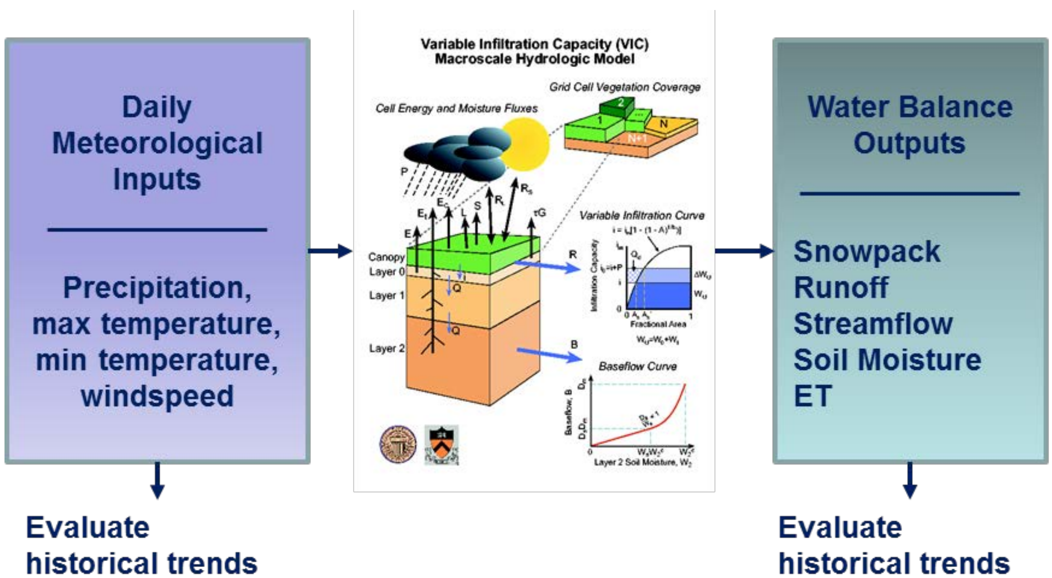


Figure 3-6.—Summary of approach for assessment of historical surface water availability.

For the Klamath River Basin Study, current and future water supply assessments rely on the variable infiltration capacity (VIC) model for simulation of surface water hydrology. The VIC model (Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) is a grid-based hydrologic model that solves the water balance at a spatial scale of 1/8th degree, or approximately 10 kilometers on a side. Details regarding the VIC model and the configuration used in the Klamath River Basin water supply assessment are provided in Appendix B, Supplemental Information for Assessment of Water Supply; however, details relevant to this study are provided below.

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind speed magnitude (at a minimum) as input to simulate water balance variables. The Klamath River Basin Study utilizes historical gridded observations developed by Maurer et al. (2002) for the period from January 1949 to July 2000. Additional model forcings that drive the water balance, such as solar (short-wave) and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficit, are calculated within the model.

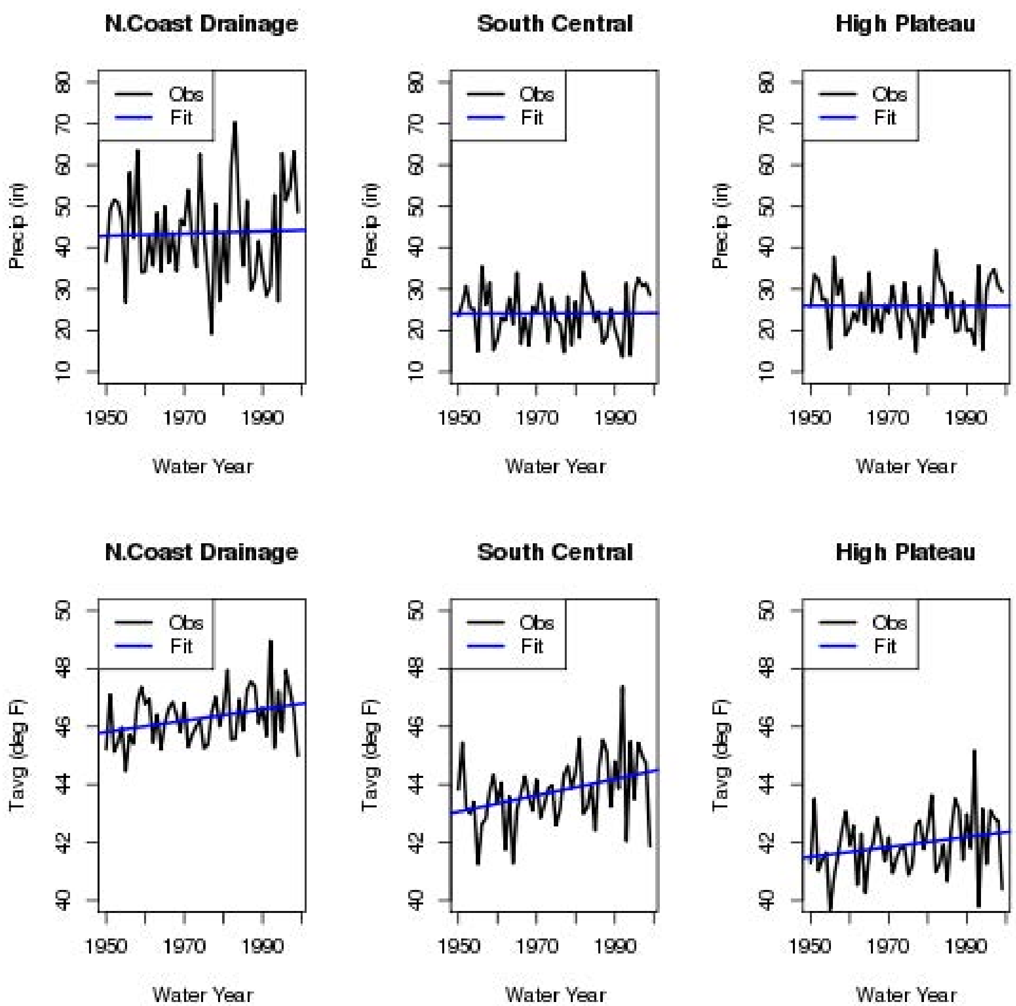
The VIC model outputs may be defined by the user, but typically include grid cell water balance terms such as evapotranspiration, baseflow, or runoff. Gridded surface runoff and baseflow are hydraulically routed to produce streamflow at a select group of locations, using the model presented by Lohmann et al. (1996). Routed streamflow using this approach represents natural streamflow – that is, streamflow that would occur in the absence of water management (i.e., diversions, return flows, and storage). For climate change impact studies, VIC is commonly run in water balance mode due to its higher computational efficiency compared to the alternative energy balance mode, which facilitates numerous projected climate simulations.

3.3.3 Present Availability and Historical Trends

This section summarizes present climate and surface water availability as well as historical trends. Historical simulated trends in climate and water balance variables are based on data used in the Klamath River Basin water supply assessment. The trends presented for climate (precipitation and temperature) likely have less uncertainty than those based on water balance parameters, primarily because climate trends were computed based on interpolated observations whereas water balance trends were computed based on hydrologic model output. Where appropriate, results are compared with findings from previous studies.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. For example, this dataset was used to develop climate and hydrologic projections developed and supported by Reclamation as part of its West-Wide Climate Risk Assessment (Reclamation, 2011d) and data portal (Archive Collaborators, 2000). The dataset has been extended beyond the original July 2000 date to December 2010 (Maurer et al., 2010). However, we utilized the original dataset as the basis for evaluating historical hydrology in the region to maintain consistency with previous efforts.

Historical trends in April 1 SWE, total annual runoff, total annual evapotranspiration, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model described briefly in the previous section. Because summer months typically receive low precipitation in the Klamath River Basin (see Table 3-1), soil moisture is an important water source for natural vegetation and perhaps some dryland agriculture. Hence, the Klamath River Basin Study Water Supply Assessment reports trends in June 1 soil moisture, which was found to be the month with maximum soil moisture in the greater watershed. Trends were computed over the entire Klamath River Basin, as well as over the three dominant climate divisions within the basin: North Coast Drainage, South Central, and High Plateau. The fourth climate division within the watershed, Southwestern Valleys, covers only a small portion of the watershed (spanning just five spatially distributed VIC model grid cells). Therefore, data for this region is not summarized.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

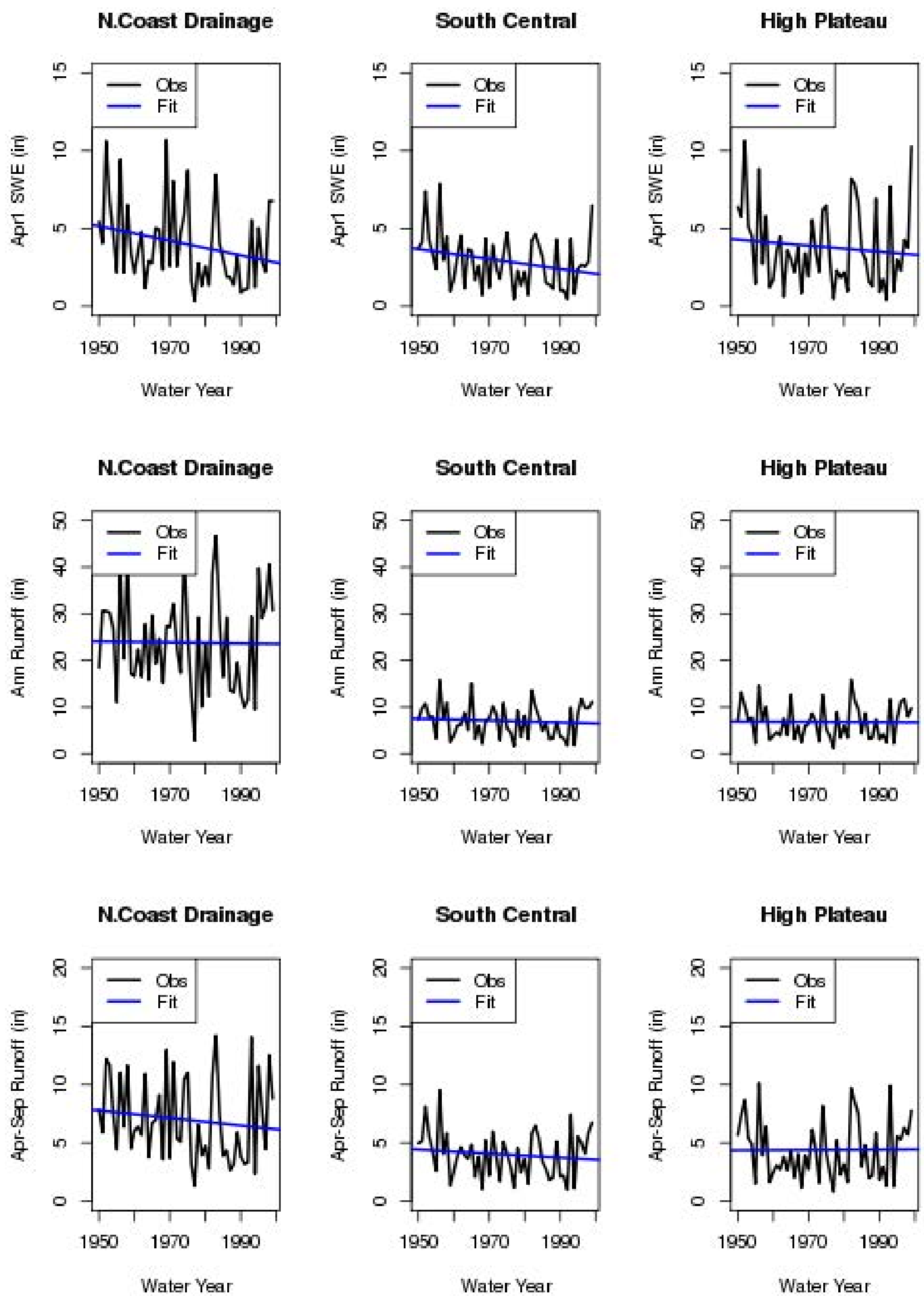
Figure 3-7.—Trends in mean annual water balance parameters (precipitation and temperature) over 1950–1999 water years.

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50-year period), small but increasing trends over the portions of the basin within the North Coast Drainage and South Central Climate Division (about 1.3 inches [+3 percent] and +0.1 inches [+0.5 percent] over the 50-year period, respectively), and a small decreasing trend over the portion of the basin within the High Plateau Climate Division (-0.03 inches [-0.1 percent]). None of these historical trends is statistically significant at the 95th percentile level (see Figure 3-7 and Table 3-3 for a summary of trends). The combination of both increasing and decreasing historical trends in precipitation over parts of the watershed is consistent with previous findings (Hoerling et al., 2010) showing a lack of clear historical change signal for annual precipitation.

All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999 (Figure 3-7 and Table 3-3). The trends in those portions of the basin within the North Coast and South Central climate divisions, as well as in the basin as a whole, are statistically significant at the 95th percentile level. Historical trends in mean annual temperature (+1 degree F basin-wide and +0.8 to +1.4 degrees F, depending on the climate division) are consistent with previous findings indicating positive change in temperature (Moser et al., 2012; Furniss et al., 2012).

Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide as well as for each of those portions of the basin within the North Coast, South Central, and High Plateau climate divisions (see Figure 3-8 and Table 3-3). Historical trends basin-wide indicate about a 41 percent decrease in April 1 SWE, with a range of about 22 percent to 45 percent over the portions of the basin within the three dominant climate divisions. The range of historical decreases in SWE computed by this study closely corresponds with the reported decrease in Upper Klamath Basin April 1 SWE by Mayer and Naman (2011) of 40 percent over the period 1961–2009, using snow course measurements below about 6,000 feet. Although the computed declines in April 1 SWE may be considered substantial, none are statistically significant at the 95th percentile level.

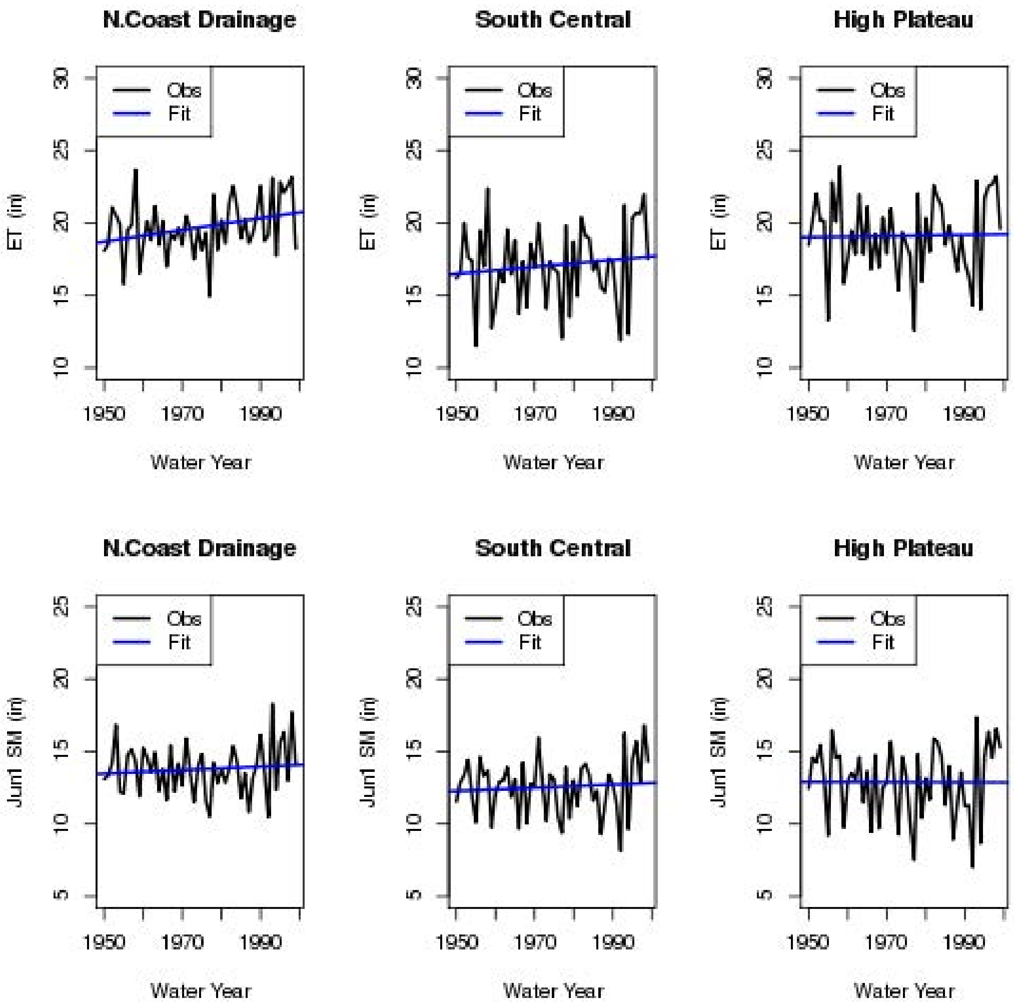
Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent, with a range of 4 to 22 percent depending on the climate division (see Figure 3-8 and Table 3-3). Mayer and Naman (2011) reported larger declines in streamflow over the 1961–2009 period (16 to 38 percent), albeit over spring and summer months only. None of the computed trends in runoff (regional or basin-wide) are statistically significant at the 95th percentile level.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

Figure 3-8.—Trends in mean annual water balance parameters (April 1 SWE, annual runoff, and irrigation season runoff) over 1950–1999 water years.

Evapotranspiration (ET), as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide (see Figure 3-9 and Table 3-3). Portions of the basin within the three dominant climate divisions indicate a range of increase from about 1 percent in the High Plateau region to 11 percent in the North Coast Drainage region. The increase in ET is statistically significant at the 95th percentile level for the North Coast Drainage climate division only.



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

Figure 3-9.—Trends in mean annual water balance parameters (annual evapotranspiration and June 1 soil moisture) over 1950–1999 water years.

Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole, yet the trends by climate division range from a decrease of about 0.3 percent in the High Plateau region to an increase of 5 percent in the South Central region and an increase of 4 percent in the North Coast Drainage region (Figure 3-9 and Table 3-3). These trends are not statistically significant at the 95th percentile level.

Table 3-3.—Mean change over 1950–1999 period (water years) by climate division within the Klamath River Basin and basin wide

	Basinwide		N Coast Drainage		South Central		High Plateau	
Precip	+0.8in	+2%	+1.3in	+3%	-0.1in	+0.5%	-0.03 in	-0.1%
Tavg	**+1°F**	**--**	**+1.0°F**	**--**	**+1.4°F**	**--**	**+0.8°F**	--
April 1 SWE	-2.0in	-41%	-2.3in	-45%	-1.6in	-42%	-1.0 in	-22%
Annual Runoff	-0.5in	-7%	-0.5in	-6%	-0.6in	-22%	-0.1 in	-4%
Apr-Sep Runoff	-1.2in	-18%	-1.6in	-20%	-0.9in	-19%	+0.1in	+2%
Annual ET	+1.5in	+8%	**+2.0in**	**+11%**	+1.2in	+7%	+0.2 in	+1%
June 1 Soil Moisture	0.4in	+3%	+0.6in	+4%	+0.6in	+5%	-0.03 in	-0.3%

Note: Numbers in bold indicate statistical significance of trends at the 95th percentile level.
Precip =mean annual precipitation/ Tavg = mean daily average temperature; SWE = snow water equivalent; ET = evapotranspiration

As previously mentioned, computed trends are highly dependent on the time period over which they are calculated. The primary reason for the dependence on duration is that, coincident with the low frequency trends resulting from human-induced climate change, there are various patterns of natural climate variability. Temporal patterns of climate variability in the Northwest are strongly influenced by variations over the Pacific Ocean, chiefly El Niño/Southern Oscillation (ENSO). ENSO involves linked variations in the tropical Pacific Ocean and overlying atmosphere. During the El Niño phase of ENSO the wintertime jet stream tends to split, with warmer air flowing into the Northwest and Alaska and a southern branch of the jet stream directing unusually frequent and heavy storms toward southern California. During the El Niño winter and spring, Oregon's climate is slightly more likely than usual to be warm and dry. The Pacific Decadal Oscillation (PDO) is another pattern of climate variability that acts similarly to

Historical Surface Water Availability

Of historical precipitation, temperature, snowpack, runoff, evapotranspiration, and soil moisture, the only statistically significant trends at 95th percentile level are:

Temperature (all regions) and evapotranspiration (North Coast Climate Division).

ENSO, but typically over longer time frames (on the order of multiple decades). Depending on the time period chosen for trend analysis, patterns of natural climate variability may mask or amplify the apparent trends due to human-induced climate change. Choosing longer time periods over which to compute historical trends can help to reduce the relative influence of natural climate patterns on the computed trends.

3.4 Historical Groundwater Availability

For analysis of groundwater impacts of climate change, outputs from surface water hydrology simulations, informed by climate projections, may be used as inputs to groundwater models. For the Klamath River Basin Study, groundwater hydrology is simulated using the USGS MODFLOW, or moderate finite-difference flow model, over the Upper Klamath Basin (upstream of Iron Gate Dam), developed through studies by Gannett et al. (2007, 2012). This model simulates evapotranspiration, groundwater head, and discharge to streams, among other things. Groundwater hydrology is also simulated in the Scott and Shasta Valleys using a multiple regression-based tool. This groundwater simulation tool performs an overall water balance to simulate relative groundwater levels. This modeling tool may be used to evaluate projected changes in the overall water balance of these river systems, as well as to evaluate the effects of projected changes in streamflow on the groundwater system.

3.4.1 Previous Studies

Groundwater modeling studies have been previously conducted for parts of the Klamath River Basin including the Upper Klamath Basin (Gannett et al., 2007, 2012) and the Scott River Valley (S.S. Papadopulos & Associates, Inc., 2012). Additional groundwater modeling efforts are currently underway, including research studies in the Scott and Shasta Valleys by faculty and graduate students at the University of California at Davis (Harter and Hynes, 2008). These studies are further described below.

3.4.1.1 Upper Klamath Basin

Gannett et al. (2007, updated in 2010) completed a groundwater investigation of the Upper Klamath Basin, upstream of Iron Gate Dam, to improve understanding of the groundwater dynamics in the region. The investigation was based on collected data, monitoring, and analysis. Since 2001 the basin has experienced increased groundwater pumping, particularly within and near Reclamation’s Klamath Project, in response to various biological opinions and court orders. A water bank program administered by Reclamation, as well as subsequent Klamath Water and Power Agency Water Use Management Plans, have purchased varying quantities of groundwater to supplement surface water in 8 of the past 11 years

(2003 through 2013). The water bank provided incentives for irrigators to increase groundwater pumping during years of low surface water availability as a pathway for retaining greater instream flows.

In a subsequent study by Gannet et al. (2012), in collaboration with the OWRD and Reclamation, a MODFLOW finite-difference groundwater model was developed to represent the system and to improve understanding of the long term effects of the above-described water banking program. In this investigation, the authors sought to identify the optimal strategy for meeting user needs while not exceeding defined impact constraints. This study found that some supplemental groundwater pumping could occur while not exceeding defined constraints, and that groundwater levels should recover from the observed declines if pumping was reduced to pre-2001 rates.

3.4.1.2 Scott Valley

A groundwater study for the Scott Valley (tributary region to the Klamath River, see Figure 3-13) was completed by S.S. Papadopulos & Associates, Inc. in 2012 for the Karuk Tribe. The study examined the impacts of groundwater pumping on the aquifer and on the Scott River by evaluating groundwater levels under three scenarios including recent use conditions, an alternative water use condition representing partial build-out of the existing groundwater capacity, and partial build-out with gradual increases in pumping levels.

Results from the study indicated that long-term declines in groundwater levels were minimal in winter and greater in late summer, corresponding with seasonal groundwater pumping. The declines can, and have, impacted streamflows. The model was used to develop a relationship between groundwater levels and stream depletions, showing that increases in groundwater pumping result in reductions in streamflow mostly within the first year or two (S.S. Papadopulos & Associates, Inc., 2012).

Researchers at the University of California, Davis completed the Scott Valley Community Groundwater Study Plan (Harter and Hynes, 2008, hereafter referred to as the UC Davis Groundwater Study Plan), which discusses the motivation for the approach of their ongoing groundwater modeling study for the Scott Valley. The study is being conducted in cooperation with Siskiyou County and Scott Valley stakeholders as a result of recommendations made in the TMDL Action Plan (State of California, 2005) and the Scott River Watershed Council Strategic Action Plan (Scott River Watershed Council, 2005). The State of California has determined that the water quality standards for the Scott River are exceeded due to excessive sediment and elevated water temperature. Studies on which the TMDL Action Plan is based state that groundwater inflows are a primary driver of stream temperatures in the Scott Valley, along with human-caused changes in riparian shading.

The UC Davis Groundwater Study Plan identifies a number of statements, hypotheses, and research questions that will be addressed during the study. A couple of noteworthy statements include: (1) there is a statistically significant correlation between SWE, total annual precipitation, and average Scott Valley groundwater table elevation in subsequent months/years, and (2) the magnitude and dynamics of seasonal and intra-annual groundwater level fluctuations have significantly changed since 1950.

The S.S. Papadopulos & Associates (2012) modeling study and the ongoing UC Davis groundwater study rely on a survey of geology and groundwater features of the Scott Valley conducted by the USGS in 1958 (Mack, 1958). The report describes in detail the geologic features in the basin and points out some interesting features of the groundwater system. Most of the wells in the area are shallow dug wells, averaging about 25 feet. Recharge to groundwater comes in the form of rainfall, seepage from tributary streams, and irrigation. Losses from groundwater come mainly in the form of evapotranspiration and hyporheic flow into the Scott River. Mack estimated the storage capacity in the flood-plain sediments to be about 220,000 acre-feet. As part of the Mack (1958) study, a number of groundwater level measurements were made either from existing or installed monitoring wells. A number of these wells continued to be used as monitoring wells. These data serve as a primary data source for subsequent Scott Valley groundwater modeling studies, including the current study presented in this chapter.

3.4.2 Approach – Upper Klamath Basin

Groundwater in the Upper Klamath Basin is being simulated using the USGS MODFLOW finite-difference model developed by Gannett et al. (2012). Details of the model configuration may be found in the mentioned study; however, a general discussion is included here. Emphasis in this discussion is placed on two elements of the model with direct linkages to the surface water hydrologic model developed over the region (VIC). The approach discussed below helps to provide context for the approach of evaluating the impacts of projected climate.

The MODFLOW model developed for the Upper Klamath Basin has 100,070 active cells and a historical simulation period of water years 1970 through 2004 (October 1969–September 2004). For the purposes of this study, and to maintain consistency with datasets used to evaluate surface water supply, the historical period was modified to water years 1970 to 1999. The model has quarterly stress periods (every 3 months) and each stress period is divided into five equal timesteps. Model input data are developed on a quarterly basis (i.e., disaggregation to individual timesteps occurs internally within the model).

The MODFLOW model utilizes a number of packages that help to improve its representation of physical processes. The packages implemented in this configuration include the recharge package, well package, stream package, general head boundary package, evapotranspiration package, drain package, and reservoir package, in addition to the basic package. There are two primary linkages with surface water inputs, such as outputs from the VIC surface water hydrologic model. First, VIC model precipitation inputs are used to develop seasonal relationships between precipitation and recharge, which are later used to develop scenarios of future recharge based on projected precipitation. Second, VIC simulated potential evapotranspiration (PET) and actual ET are used to compute the upper threshold for ET used by the MODFLOW model (computed as the difference between PET and actual ET). The modeling study conducted by Gannett et al. (2012) relied on surface water inputs from the USGS Precipitation Runoff Modeling System (PRMS), developed over the same region.

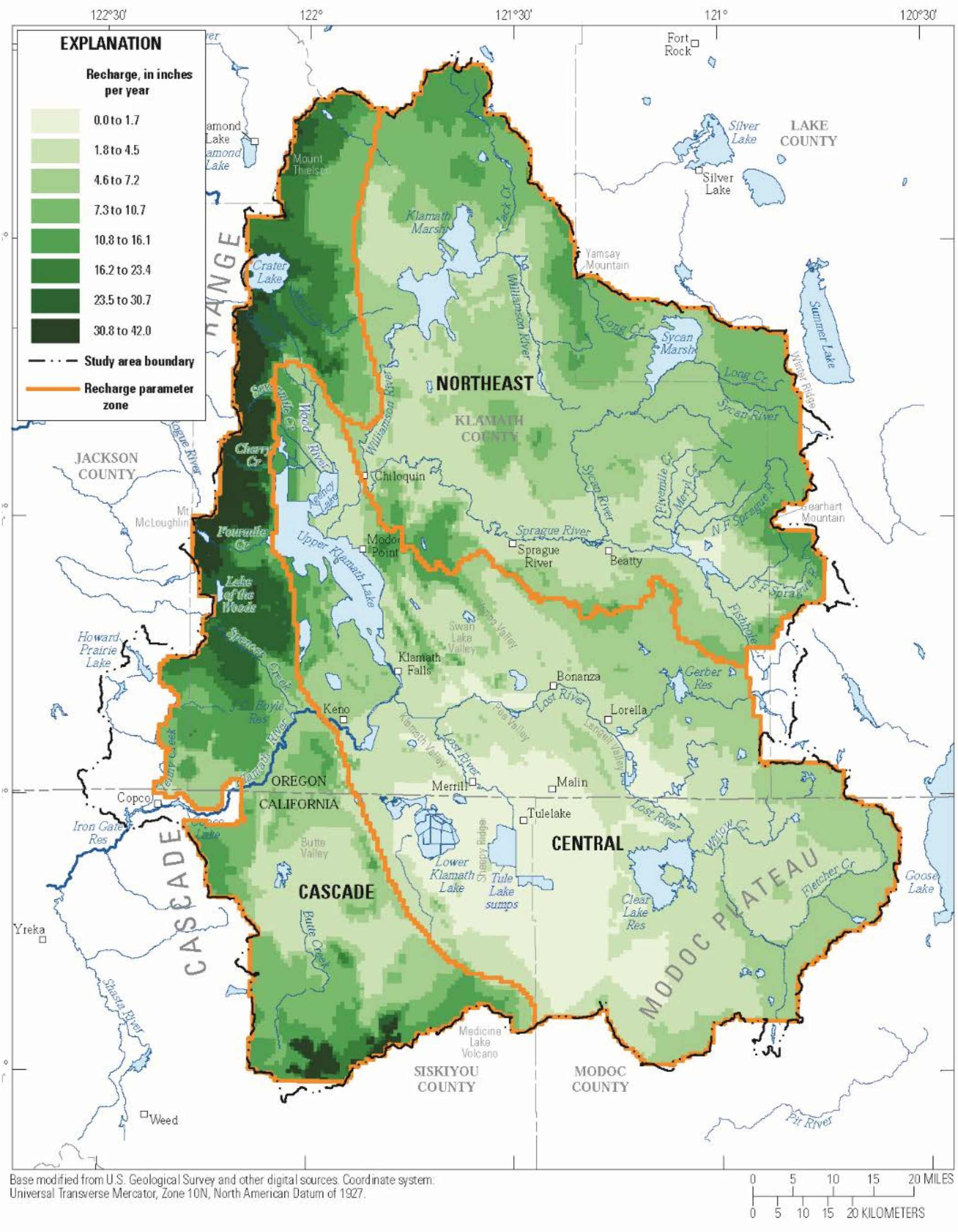
Assessment of historical groundwater levels in the Upper Klamath Basin primarily comes from the modeling efforts by Gannett et al. (2012). However, as part of the assessment of groundwater supplies, the MODFLOW model was rerun over the modified historical period and is the baseline for comparison of projected groundwater levels.

3.4.3 Present Availability and Historical Trends – Upper Klamath Basin

Present availability and historical trends in groundwater elevation and recharge are discussed in the context of previously completed work by Gannet et al. (2012). The historical MODFLOW simulation described by Gannett et al. (2012) was used as the historical baseline for the assessment of groundwater in the Upper Klamath Basin for this water supply assessment.

Historical availability of groundwater is presented in this section with respect to recharge and groundwater elevations. Historical recharge to the groundwater system was developed by Gannett et al. (2012) using summed subsurface flow (interflow) and groundwater flow terms from the PRMS model. Subsurface (interflow) generated by PRMS represents shallow rapid subsurface flow, which is not well simulated by MODFLOW. Therefore, adjustment factors were applied to the summed recharge values to more accurately simulate recharge in the basin. The resulting historical recharge used as input to the MODFLOW model is illustrated by Figure 3-10.

The highest recharge, according to Figure 3-10, is along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains. The lowest recharge amounts are in the central and southern parts of the basin. It should be noted that amount of recharge does not necessarily correspond to areas with highest ground permeability. Discussions from Section “Upper Klamath Groundwater Basin”, addressing groundwater characteristics of the basin, indicate that the western part of the basin is generally characterized by low permeability, while parts of the central basin are characterized as having high permeability and high groundwater yield. Greater recharge occurs along the western boundary primarily due to the fact that there is more water available for recharge, compared with the central portion of the basin.

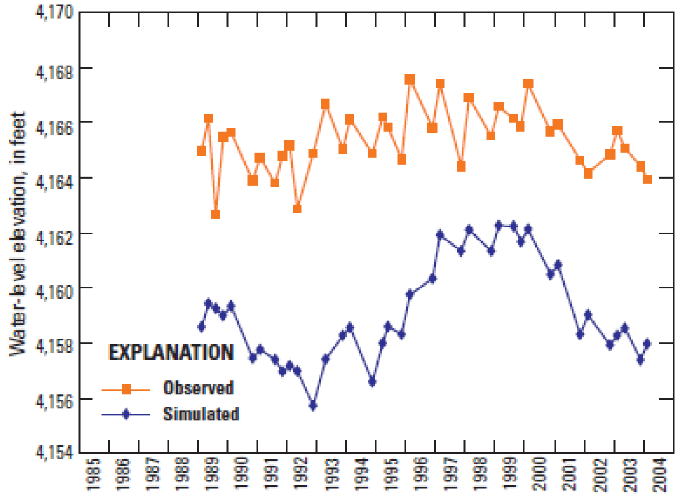


Source: Figure 7 from Gannet et al., 2012

Note: Recharge Zone 1 (Cascade) lies along the western boundary of the basin. Recharge Zone 2 (Northeast) covers the northeastern part of the basin. Recharge Zone 3 (Central) covers the central and southeastern part of the basin.

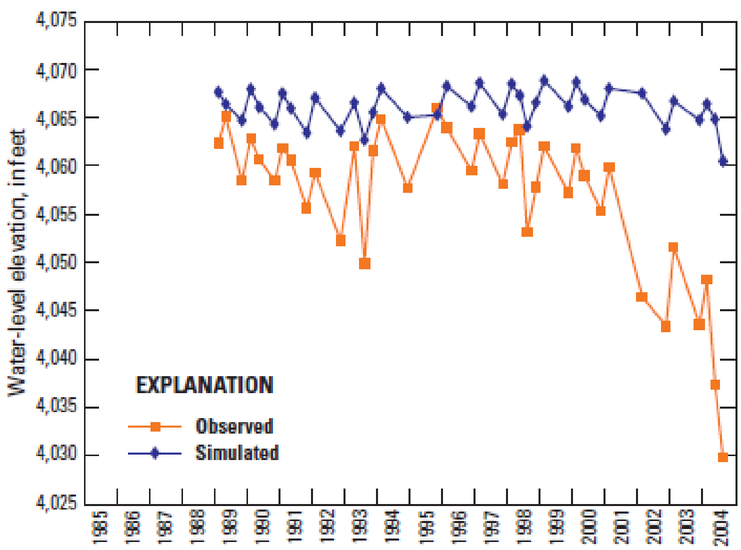
Figure 3-10.—Summary of mean annual recharge over the Upper Klamath River Basin.

Gannett et al. (2012) also summarizes historical simulated groundwater elevations, compared with observations, for a number of sites throughout the Upper Klamath Basin model domain. We provide a sample of figures for two sites, including the Wood River sub-basin, located upstream of Upper Klamath Lake (Figure 3-11) and the Lower Klamath Lake sub-basin, located in the southcentral portion of the model domain (Figure 3-12).



Source: Figure 18 from Gannett et al., 2012

Figure 3-11.—Observed and simulated water-level elevations in the Wood River sub-basin. (Source: Figure 18 from Gannett et al., 2012.)



Source: Figure 36 from Gannett et al., 2012

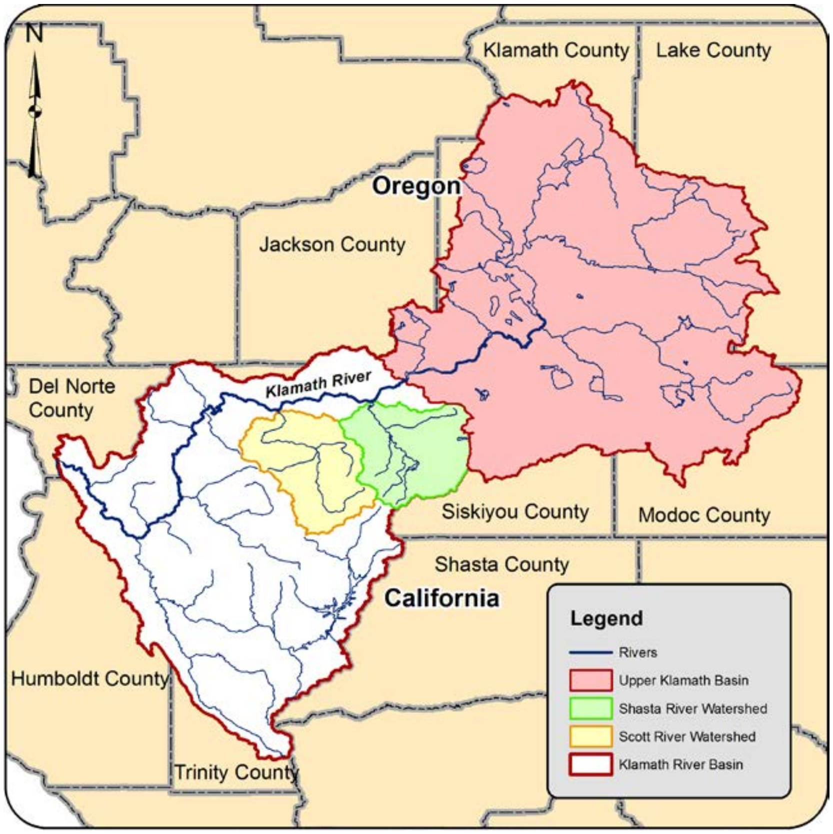
Figure 3-12.—Observed and simulated water-level elevations in the Lower Klamath Lake sub-basin.

Results for these two sites are representative of the types of calibration results for the MODFLOW model. In general, the model captures the low frequency variability in groundwater levels over the period from the late 1980s through 2004. The model is also able to capture much of the year-to-year variability in groundwater levels. The difference between simulated and observed groundwater elevations can vary from on the order of 5 feet to 30 feet, depending on the site and year. Gannett et al. (2012) suggest the larger differences (seen in parts of the Wood River sub-basin as shown on Figure 3-11, for example) may be due to the coarse vertical discretization of the model, relative to the gradients of groundwater flow. Also for the Lower Klamath sub-basin site (Figure 3-12), the model is not able to capture the decline in observed groundwater elevation that occurs after about 2000 (corresponding with drought and increases in pumping). Differences between observed and simulated groundwater elevations may be attributed, at least in part, to lack of accurate information on rates and locations of pumping in some parts of this sub-basin (Gannett et al., 2012).

> **Historical Groundwater Availability – Upper Klamath Basin**
>
> The highest recharge to groundwater occurs along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains, while the lowest recharge amounts are in the central and southern parts of the basin.

3.4.4 Approach – Scott and Shasta Valleys

The groundwater portion of the Klamath River Basin Study water supply assessment consists of analysis for three main regions within the Klamath River Basin: the Upper Klamath Basin, the Scott Valley, and the Shasta Valley (see Figure 3-13). These regions represent the majority of groundwater use in the Klamath River Basin, as inferred from defined groundwater regions from California’s Groundwater Bulletin 118 (CDWR, 2003). To the extent possible, these analyses rely on existing modeling tools and data.



Sources: Principal Aquifers, http://www.nationalatlas.gov/mld/aquifrp.html; Scott and Shasta Valley Well Data, http://wdl.water.ca.gov/waterdatalibrary/groundwater/index.cfm

Figure 3-13.—Map of modeled groundwater basins within the Klamath River Basin.

Existing groundwater modeling tools for the Scott and Shasta Valleys were explored in the preparation of this water supply assessment. No existing groundwater modeling tools were identified for the Shasta Valley, although there are ongoing studies at the University of California at Davis related to groundwater dynamics of the Shasta Valley.[3] There is also an existing draft groundwater data needs assessment developed by CDWR which has not been finalized (CDWR, 2011). The existing groundwater model for the Scott Valley, developed by S.S. Papadopulos & Associates, Inc. (2012) for the Karuk Tribe, was explored for possible use in the Klamath River Basin Study. However, use of this modeling tool was deemed infeasible due to the reasons outlined below:

1. The modeling tool was not readily available for use by Reclamation. In other words, additional funding would have been required to either contract with S.S. Papadopulos & Associates, Inc. to participate in the study or fund them to package the model for use by Reclamation staff.

[3] https://watershed.ucdavis.edu/project/shasta-river

2. The model was designed with a relatively narrow focus on the impact of groundwater pumping on streamflows.
3. Confidence in the results from a sophisticated MODFLOW finite-difference groundwater model for the Scott Valley, where input data are limited, was not high enough to justify the cost of its implementation in the study.
4. The spatial resolution of the surface water hydrologic model that provides surface water inputs to the groundwater model is coarse in comparison with the size of the Scott River Basin, which also limits confidence in the utility of applying a sophisticated MODFLOW model in the basin.

Conceptual regression-based groundwater screening tools were developed for both the Scott and Shasta Valleys based on the approach taken by Reclamation (2013) in the Santa Ana Watershed Basin Study. The added advantage of developing these tools is consistency in the approach for the two neighboring watersheds. This section briefly describes the groundwater screening tool as it was applied in this Klamath River Basin Study. Details regarding data used as input to the Scott and Shasta Valley tools are described in Appendix B, Supplemental Information for Assessment of Water Supply.

The regression-based groundwater model relies on historical inflows and outflows from the groundwater system, estimated from available data, including spatially distributed recharge from precipitation, focused recharge from stream and canal seepage losses or deep percolation of irrigation water, groundwater abstraction by pumping, and other inflows and outflows. The model is calibrated and verified with respect to available observations. The model may then be applied using projected future conditions, as well as applied management alternatives, to evaluate the effects of climate change and adaptation strategies on groundwater resources.

The groundwater screening tool estimates fluctuations in basin-scale groundwater levels in response to natural and anthropogenic drivers, including climate and hydrologic conditions, agricultural land use, municipal water demand, and trans-basin water imports, if applicable. The tool allows users to quickly estimate basin-scale groundwater conditions under a broad range of future scenarios and provides insight into the primary factors driving basin-scale groundwater fluctuations.

This screening tool is based on a conceptual model which considers fluctuations in basin-average groundwater elevations as a function of basin-scale drivers. These drivers are illustrated in Figure 3-14 and may be categorized by the following: water availability (precipitation, local streamflow, and trans-basin imports), water demand (municipal and industrial demand, agricultural land use, and evaporative demand), and an optional exogenous input that represents groundwater management objectives that affect basin-scale groundwater levels. As a result, use of the groundwater screening tool does not require detailed information regarding local hydrologic, geologic, climatic, and anthropogenic factors that may affect local groundwater fluctuations. However, it should be noted that as a result of this basin-scale approach, the groundwater screening tool is primarily applicable at the scale of individual groundwater basins or sub-basins, where the effects of local-scale conditions are largely averaged out and where subsurface inflows and outflows from surrounding areas are negligible.

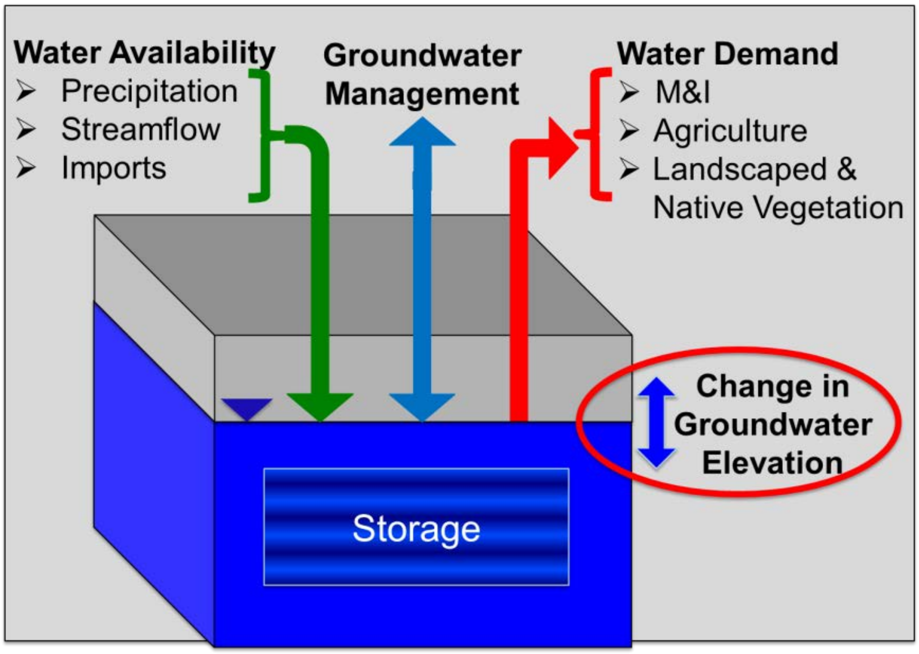
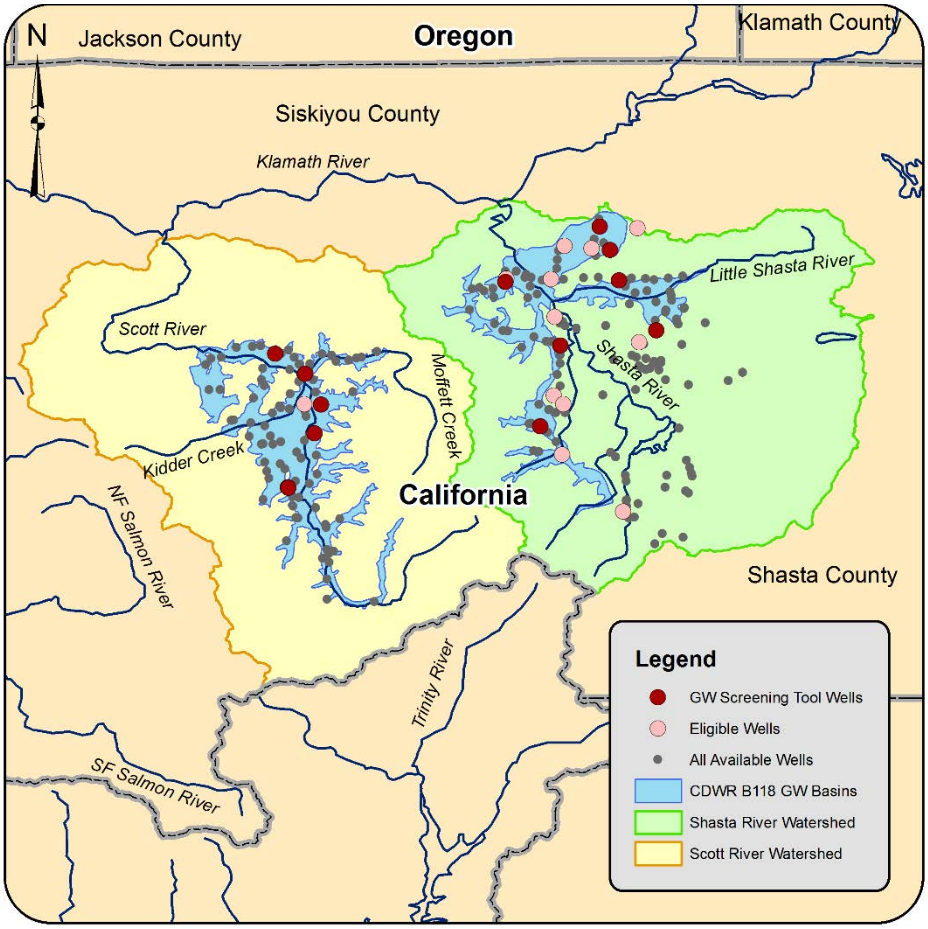


Figure 3-14.—Conceptual model of basin-scale groundwater fluctuations used in developing the groundwater screening tool.

The model domains for the Scott and Shasta Valleys correspond with groundwater basins defined by CDWR's Bulletin 118 (CDWR, 2003). CDWR Bulletin 118 was first created in the 1950s as a means for collection and evaluation of groundwater data throughout California. Bulletin 118 has been updated numerous times, with the latest update in 2003. Bulletin 118 has defined groundwater basins, including one each for the Scott and Shasta Valleys. Scott and Shasta Valley groundwater basins roughly correspond with the unconsolidated sand and gravel PNW Basin-fill aquifers from the USGS (2003) National Atlas of Principal Groundwater Aquifers[4] map. The Bulletin 118 groundwater basins define the model domain for the groundwater screening tools for the Scott and Shasta Valleys. These groundwater basins are illustrated in Figure 3-15.

[4] https://water.usgs.gov/ogw/aquifer/map.html



Note: The map shows all available wells (grey), eligible wells3 (pink), and wells[3] used in development of the groundwater screening tools for both watersheds (red).

Figure 3-15.—Map of CDWR Bulletin 118 groundwater basins for the Scott and Shasta River basins.

Historical data were used to determine regression coefficients and to evaluate model performance over the historical period (1980–1999). For this study, historical groundwater elevation data averaged over each groundwater basin were used to fit the regression models. These data came from CDWR and USGS data archives. Monthly mean groundwater elevations were calculated from the available instantaneous measurements. Note that for the Scott and Shasta Valleys, well measurements typically occurred once in the spring and once in the autumn, and interpolated monthly time series were computed from these measurements. Well data were screened for individual outliers and analyzed to determine whether the groundwater elevations at the well are representative of the average behavior of each groundwater basin (Scott and Shasta). Steps were taken to avoid potential biases due to variations in the period of record between wells, and outlier wells that are not representative of large-scale groundwater fluctuations within a basin. Additional details are provided in Appendix B, Supplemental Information for Assessment of Water Supply, regarding the sources of well data, methods for screening the data, and methods to account for potential biases in well records. Inputs of precipitation, evaporative demand, and streamflow were computed based on VIC model simulations, aggregated to a monthly timestep and averaged over each groundwater basin. Demands such as agricultural and municipal, domestic, and industrial demand were developed based on available data described in detail in Appendix B, Supplemental Information for Assessment of Water Supply. Note that aquifers outside of CDWR Bulletin 118 and well data not archived by CDWR or USGS were not considered as part of this modeling study, which may present limitations in the applicability of the modeling tools to simulate basin-wide behavior.

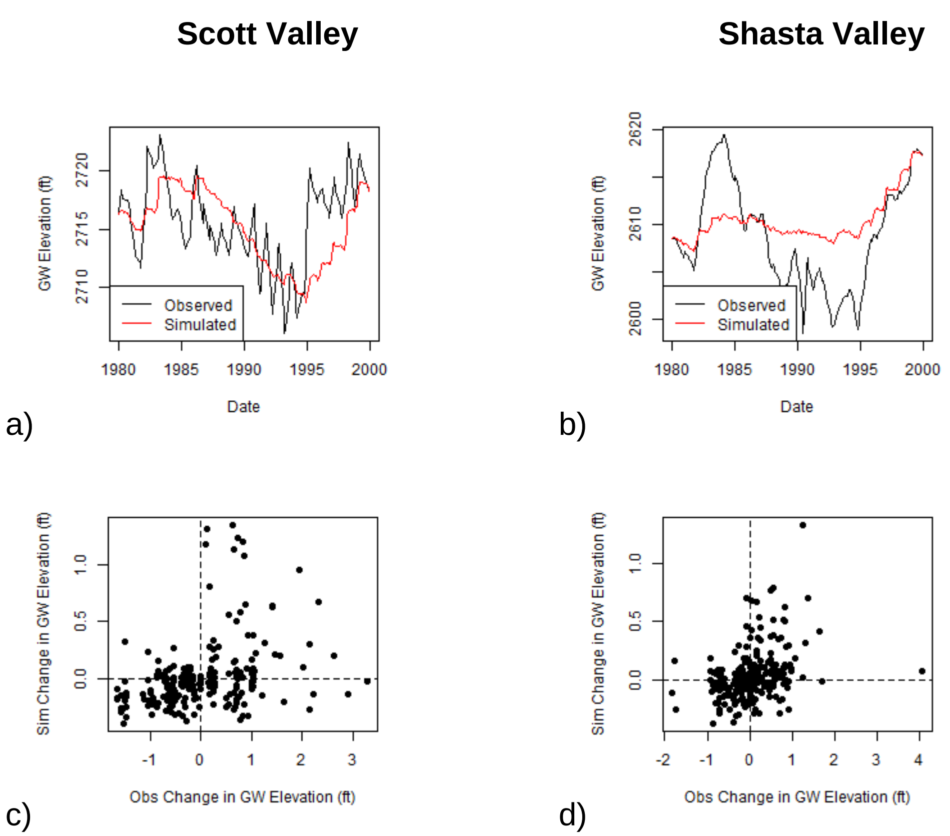
3.4.5 Present Availability and Historical Trends – Scott and Shasta Valleys

The groundwater screening tool was applied to the groundwater basins in the Scott and Shasta watersheds that were defined by CDWR Bulletin 118 (CDWR, 2003) and are shown on Figure 3-15. There is one defined groundwater basin for each of the watersheds. The screening tools were fit using a linear regression model to the collected observed data (see Equation 1 in Appendix B, Supplemental Information for Assessment of Water Supply). The models were then verified by exploring variations of the groundwater elevation input data. The regressions were tested to ensure that well data used most closely represented basin-wide behavior. Correlations of observed groundwater elevation with individual model inputs were explored and statistically significant correlations (at the 95th percentile confidence level) were found between observed groundwater elevation, precipitation, and runoff for some wells (but not all), indicating that groundwater levels in the Scott and Shasta Valley CDWR Bulletin 118 aquifers are related to climatic fluctuations.

> **Historical Groundwater Availability – Scott and Shasta Valleys**
>
> The statistical groundwater screening tools may be applicable for evaluating the relative impacts of climate change amounts in the central and southern parts of the basin.

Figures 3-16 (a) and (b) illustrate observed and simulated basin-averaged groundwater elevation for the Scott and Shasta groundwater basins, respectively, for the period 1980–1999. The figures show that the groundwater screening tools capture the larger frequency fluctuations (i.e., multi-year trends) in groundwater elevation, but are not able to resolve finer interannual fluctuations. Both groundwater basins experienced declines in groundwater elevation during the late 1980s and early 1990s on the order of about 20 feet, corresponding with lower precipitation and streamflow during that period. Observed groundwater elevations in the Scott Valley have ranged between about 2,705 feet and 2,725 feet, while observed groundwater elevations in the Shasta Valley have ranged between about 2,600 feet and 2,620 feet. Interannual fluctuations may be driven by local-scale non-linear processes that are not represented in the basin-scale screening tool, or by management activities (for example, pumping) that are not included in this analysis.

Figures 3-16 (c) and (d) illustrate observed change in groundwater elevation versus simulated change in groundwater elevation. They graphically show the data points on which the linear regressions for the groundwater screening tools are based. Model fit statistics summarized in Table 3-4 show that for both the Scott and Shasta Valleys, the screening tools are able to explain a little more than 10 percent of the variance in the data (coefficient of determination, or R^2, of 0.11 and 0.12, respectively, for Scott and Shasta groundwater basins). A more robust model would have higher R^2 values. The degree of model fit indicates that the tool may be applicable for evaluating the relative impacts of climate change, but is not applicable for evaluation of short-term management decisions. In the future, additional and improved data sources may help to improve model fit and thereby the applicability of the tool for a range of purposes.

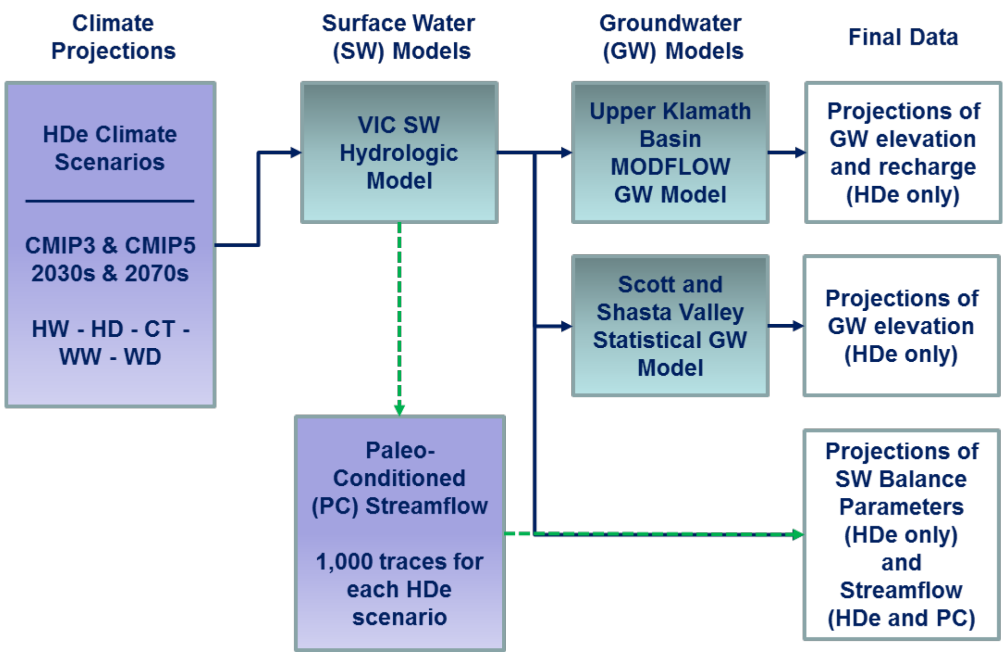


Note: (a) groundwater elevation for the Scott groundwater basin; (b) groundwater elevation for the Shasta groundwater basin; (c) groundwater elevation change for the Scott groundwater basin; (d) groundwater elevation change for the Shasta groundwater basin

Figure 3-16.—Simulated and observed Scott and Shasta basin groundwater elevations, as well as simulated and observed changes in groundwater elevations.

3.5 Effects of Climate Variability and Change on Supply

This section builds upon tools developed for assessment of historical supplies and provides a detailed discussion of the approach for developing and utilizing future climate scenarios to evaluate projected changes in surface and groundwater. A diagram illustrating the overall approach for evaluating the effects of climate change on water supply is provided in Figure 3-17. Details regarding data linkages between steps are provided in the next section.



Note: HDe refers to ensemble hybrid delta climate scenarios; PC refers to paleo-condition streamflow projections.

Figure 3-17.—Summary of approach for evaluating the effects of climate change on surface water and groundwater supplies.

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020 through 2049) and 2070s (represented by the mean from 2060 through 2089). In evaluating the effects of climate change on water supply, projections of future supply are commonly compared with that of a historical reference period. The historical reference period for the Klamath River Basin Study is 1970–1999. It should be noted that historical climate has not changed steadily through the 20th century. Basin average temperature has increased from the 1970s through the rest of the century, following an approximate 40-year period of relatively steady temperatures. Basin annual precipitation has fluctuated considerably during the past century, but was relatively steady from the 1940s through the rest of the century (Reclamation, 2011c). Figure 3-7 illustrates historical trends from 1950 through 1999.

3.5.1 Approach

As a step toward greater understanding of the implications of climate change on the Klamath River Basin, this section first describes the approach for development of climate scenarios for the Klamath River Basin Study water supply assessment, followed by discussions of approaches for evaluation of climate change impacts on surface and groundwater supplies. With respect to surface water, the assessment focuses on projected changes in snowpack, timing and quantity of runoff, ET and soil moisture, and low streamflow periods that have major implications for fish and wildlife and the livelihoods of basin residents. With respect to groundwater, the assessment focuses on projected changes in groundwater recharge and discharge, as well as overall changes in groundwater elevations.

3.5.1.1 Climate Projections

> **Climate Projections**
>
> The Klamath River Basin Study utilizes climate projections from World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5).

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades as opposed to days or weeks. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings, both natural (such as volcanic eruptions, solar variations) and anthropogenic (such as changing atmospheric composition and land-use change). Climate variability describes deviations from mean climate that may be due to natural internal processes or to variations in natural or anthropogenic forcings. Natural variability includes multi-year cycles in climate such as El Niño and La Niña, as well as cycles that can occur on even longer time scales (for example, the PDO). Changes in climate due to natural variability will continue to occur in the future, along with changes due to increased greenhouse gas concentrations from human activities. Climate change may be differentiated from climate variability as the persistence of anomalous conditions.

The state of practice for evaluation of the long-term availability of water supply is to incorporate a range of approaches to characterize past and projected climate. The approaches may include use of paleo-conditioned climate data and use of projections from general circulation models (GCMs). Paleo-conditioned climate data are developed from long-term climatic records (such as tree rings, pollen, etc.) that have been used to capture the natural variability of climate over thousands of years.

Another approach involves downscaling information (in space and time) from native scale GCM resolution to a finer resolution suitable for watershed-scale climate change impact studies. This can be done using dynamical downscaling, which uses GCM output to define boundary conditions for a finer scale regional climate model, or statistical downscaling, which uses historical data as a way of statistically mapping GCM scale information to a finer resolution. Statistical downscaling may involve delta method experiments, which compute period change values based on GCMs and apply them as perturbation factors to historical data. Numerous variations exist within these three categories and there are also approaches that are hybrids of these categories.

The Klamath River Basin Study relies on data and modeling from Reclamation’s West-Wide Climate Risk Assessment (Reclamation, 2011d). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 western states that fall within Reclamation’s management domain. These projections are based on simulations from the World Climate Research Programme’s Coupled Model Intercomparison Project Phase 3 (CMIP3; Meehl et al., 2007), which are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). Projections based on Phase 5 of the same model intercomparison project (CMIP5) reflect improvements in modeling of the Earth system since the CMIP3 effort and revised scenarios of global growth and greenhouse gas emissions. These simulations, which were made available in 2011, are summarized in IPCC’s Fifth Assessment Report (Taylor et al., 2012). Both sets of projections, CMIP3 and CMIP5, are utilized as part of the Klamath River Basin Study water supply assessment.

Details regarding the approach for use of climate projections and development of climate scenarios for the Klamath River Basin Study are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, Figure 3-18 illustrates the overall approach for downscaling GCM projections to a finer spatial scale. The figure shows that a similar approach is taken regardless of the choice of CMIP3 or CMIP5 simulations: namely, emissions scenarios are incorporated into GCM simulations. These simulations are bias corrected at the resolution of the GCM and then statistically downscaled to the resolution of the Klamath River Basin Study hydrology models. Bias correction allows for the removal of systematic biases from GCM simulations, based on historical regional climate datasets derived from observations.

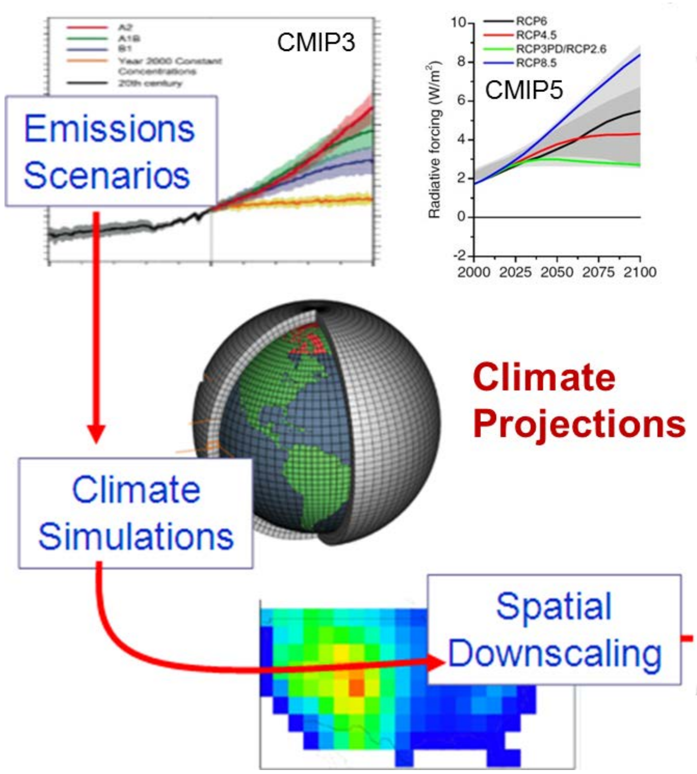


Figure 3-18.—Downscaling elements.

3.5.1.2 Deriving Climate Change Scenarios from Climate Projections

The high number of climate projections from CMIP3 and CMIP5 (on the order of hundreds of realizations) make their direct use in long term planning studies cost prohibitive in many cases. The Klamath River Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes the available suite of climate projections to derive a smaller number of climate change scenarios to inform long term planning.

The Klamath River Basin Study primarily utilizes climate scenarios that are derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d). The scenarios are developed based on both CMIP3 and CMIP5 statistically downscaled GCM projections, as these are considered equally likely potential climate futures at this time. Details regarding the approach for deriving climate scenarios from CMIP3 and CMIP5 climate projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, a brief overview is provided below.

The hybrid delta method approach for developing climate scenarios involves perturbing historical climate (precipitation and temperature) by change factors computed as the change in precipitation and temperature by month between a chosen future planning horizon and a baseline historical period (Reclamation, 2010). Change factors may be developed for each available downscaled climate projection (CMIP3 or CMIP5) or may be developed based on ensembles of climate projections. The Klamath River Basin Study utilizes an ensemble of climate projections based on both CMIP3 and CMIP5.

HDe Climate Scenarios

Ensemble hybrid delta climate scenarios representing five quadrants of precipitation and temperature change (warm wet, warm dry, central tendency, hot dry, hot wet) are used to encompass a range of possible climate futures for two future time horizons, the 2030s and the 2070s.

The HDe method involves defining a climate change scenario based on pooled information from a collection of climate projections. Use of a sufficiently large number of projections (commonly called an ensemble) pooled together reduces the signal of internal climate variability (which is inherent in each single projection), which may be misinterpreted as climate change. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios. These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT).

Historical precipitation and temperature are mapped, using a quantile mapping technique, onto the bias corrected GCM data to produce a set of transformed observations reflecting future conditions. The entire observed time series of temperature and precipitation at each hydrologic model grid cell is perturbed in this manner, resulting in a new time series that has the statistics of the bias corrected GCM data for the future period, but preserves the time series and spatial characteristics of the gridded temperature and precipitation observations.
The HDe scenarios for the Klamath River Basin Study culminate in a total of 20 scenarios, including two future time horizons (2030s and 2070s), five quadrants of projected change (HW, HD, CT, WW, and WD), and two sets of projections (CMIP3 and CMIP5). Each of these scenarios resemble the historical inputs of daily precipitation and temperature (minimum and maximum) to the VIC surface water hydrologic model in format and period of record because they are all perturbations of historical time series. Windspeed, the remaining required input to the VIC model, was assumed not to change between historical and future time periods. This assumption is in part due to the coarse resolution of historical windspeed data used in the Maurer et al. (2002) historical meteorological dataset

and the associated high level of uncertainty in the data. However, to provide some context, Pryor et al. (2012) found some evidence of lower intense windspeeds in the western U.S. for the 2041–2062 period compared with 1979–2000 from regional climate model simulations.

Figure 3-19 summarizes projected changes in precipitation (a) and temperature (b) by month according to the five HDe climate scenarios for each time period in relation to the full suite of CMIP3 and CMIP5 projections by month. This figure illustrates that the derived climate scenarios generally span the range of projected future precipitation and temperature by the greater number of climate projections. However, with respect to precipitation change, it appears the HDe scenarios project a greater tendency toward increased precipitation during summer months (August, in particular) than the raw climate projections indicate. This is likely due to the fact that the HDe projections are based on projected annual changes in precipitation, not seasonal or monthly changes. Projected annual changes in precipitation appear to be influenced more by increases in winter precipitation.

HDe scenarios have a number of distinguishing features, with associated strengths and weaknesses. One weakness of this approach is that analysis of climate change impacts is limited to the future time horizons chosen when developing precipitation and temperature change factors. Another weakness is that the scenarios do not incorporate projected changes in drought variability or sequencing of storm events. One key strength of the HDe approach is that the time sequence of projected future storm events matches historical climate data, facilitating direct comparison between the observations and future scenarios. The HDe approach is suitable for water resources planning at both daily and longer time scales, supports analysis of daily hydrologic extremes such as flood and drought intensity, and provides consistency across a range of spatial scales (Hamlet et al., 2010).

3.5.1.3 Deriving Paleo-Conditioned Streamflow Projections

Understanding drought variability is critical to managing water resources across the western U.S. The HDe scenarios described in the previous section may be used as input to surface and groundwater hydrologic models to evaluate changes in the water balance. As mentioned, HDe scenarios are perturbations of the historical record that reflect the statistics of future climate over some chosen time period. As a result, they do not explore the possibility of changes in drought variability (i.e., length or severity of drought periods and wet periods).

Paleo-climate information derived from tree rings or other proxies provides a greater context for sequencing and duration of wet and dry periods than the historical record can provide, often going back hundreds of years. The paleo-conditioned streamflow projections described in this section achieve a blend of projected climate information derived from GCMs and paleo-climate information.

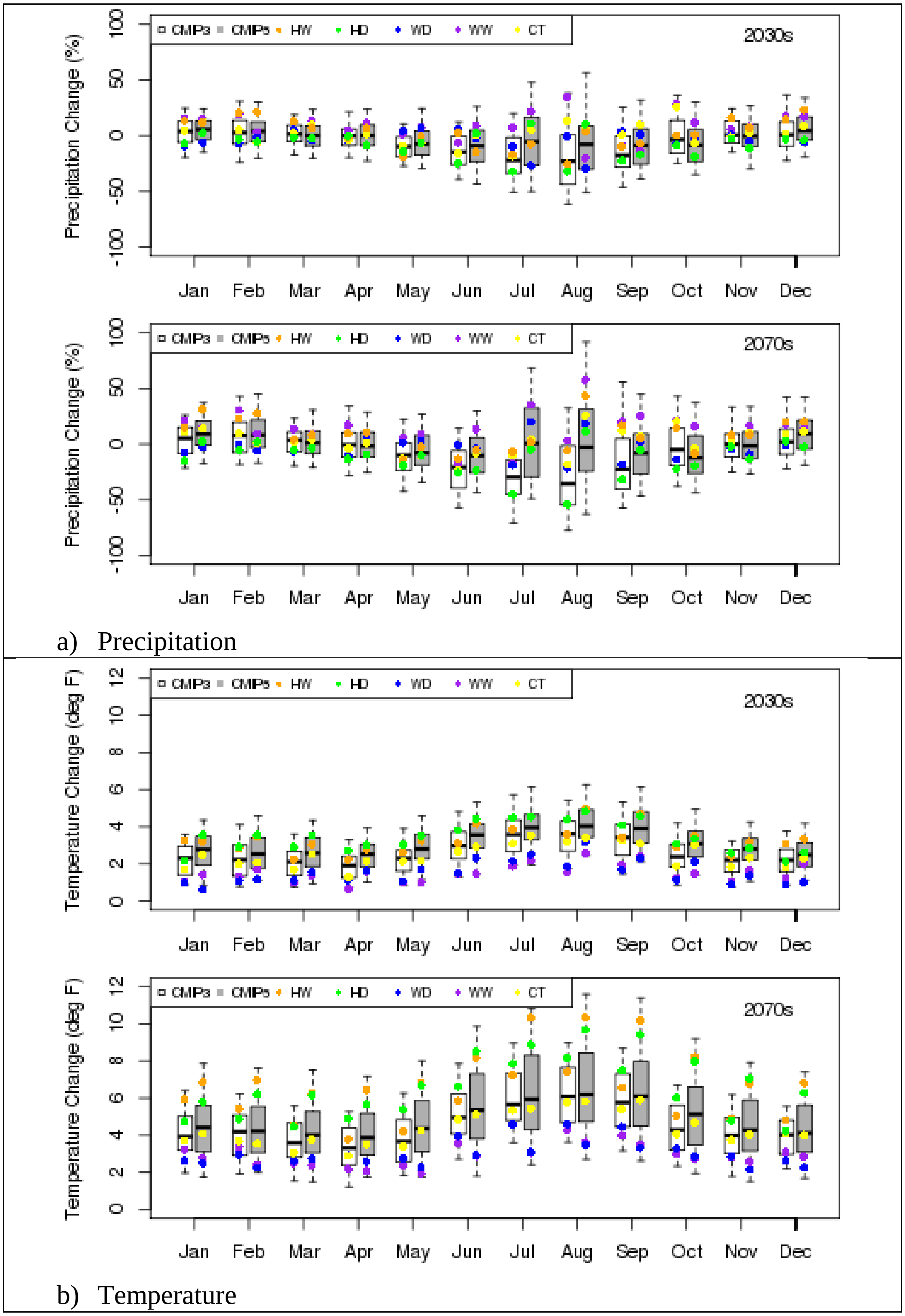


Figure 3-19.—Changes in mean monthly precipitation and temperature.

To develop a long-term understanding of drought variability across North America, Cook et al. (2004) developed an extended record of summer time PDSI (Palmer Drought Severity Index) using tree-ring chronologies. This extended PDSI record for North America is available as a gridded (2.5 degrees latitude by 2.5 degrees longitude) timeseries, nearly 200 miles on a side, that dates back nearly 2000 years in some locations. Availability of this extended gridded PDSI record provides an opportunity to analyze regional drought and wet spell characteristics.

For the Klamath River Basin Study water supply assessment, a representative grid location (see Figure 3-20) from the extended gridded PDSI archive was used to analyze long-term wet and dry spells in the Klamath River Basin. Adjacent grid locations provided similar results. The specific location of the PDSI grid used has a center with latitude 42.5 degrees N and longitude 120.0 degrees W., shown by a green triangle in Figure 3-20. The PDSI time-series used from this grid extended from 1400 through 1999.

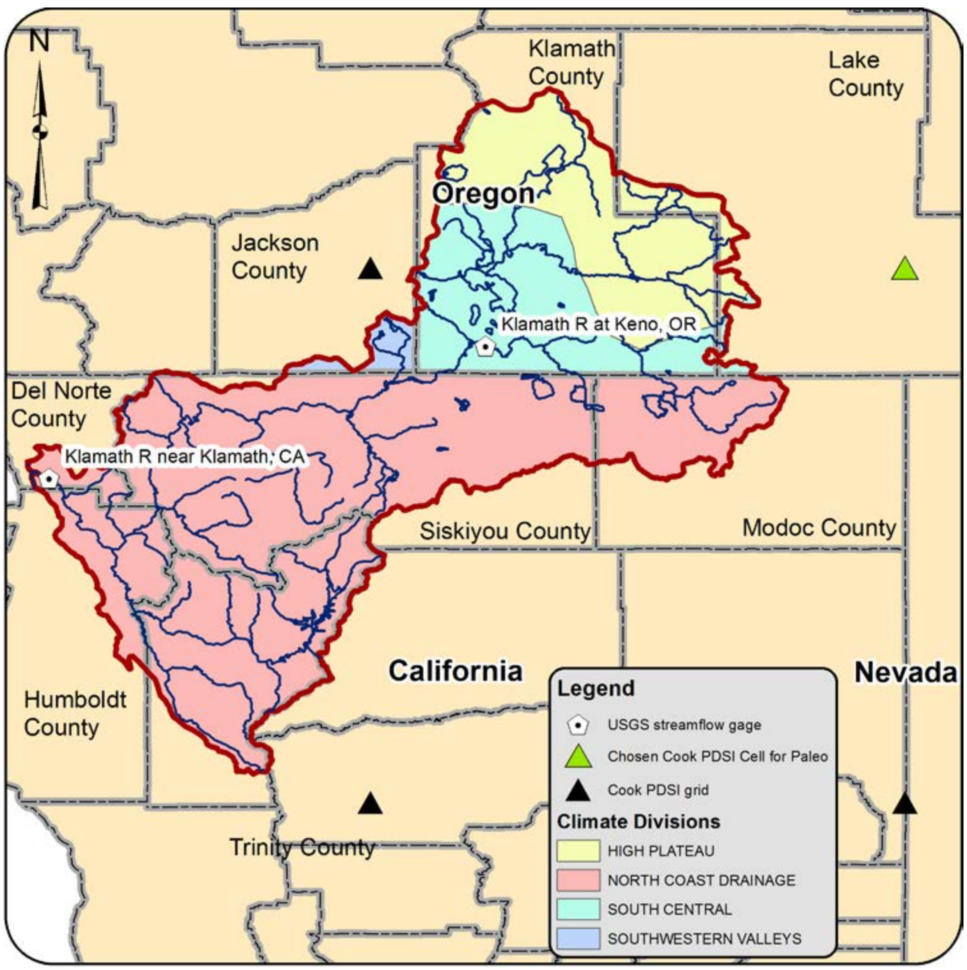


Figure 3-20.—Overview map of the Klamath River Basin with Cook PDSI grid and two USGS streamflow gages used in the analysis of paleo-hydrology: Klamath River near Klamath, CA and at Keno, OR.

To understand the time-varying nature of wet and dry spells, the PDSI index can be used to determine the probability of regional hydrology shifting from one state to another. In this study, the Klamath River Basin was defined to be either in dry state when the summer time PDSI value in a given year was less than 0 (negative PDSI corresponds to dry conditions), or in a wet state when PDSI was greater than 0 (positive PDSI values correspond to wet conditions). Based on the defined states, probabilities may be derived for the likelihood of transitioning from one state to another. Flow magnitudes can be assigned based on the probabilities, which allows for evaluation of historical streamflow over the instrumental record and projected streamflow compared with the paleo period.

The results for the Klamath River indicate that paleo-conditioned historical simulations show reduced lengths and volumes of wet periods. Results also show droughts of reduced length and deficit, demonstrating that just changing the ordering of flows over the historical period results in periods of both reduced droughts and surpluses. Furthermore, the wet period volumes could be quite a bit lower than what has been historically available, according to the instrumental record. Similarly, droughts were also less severe over the last 600 years than is shown in the recent instrumental record.

> **Paleo-Conditioned Streamflow Projections**
>
> Wet period volumes could be quite a bit lower than what has been historically available according to the instrumental record. Similarly, droughts were also less severe over the last 600 years than what is shown in the recent instrumental record.

Paleo-conditioned streamflow projections are not carried throughout the Klamath River Basin Study water supply assessment and subsequent phases of the Basin Study for two primary reasons. First, analysis of paleo-conditioned streamflow, including historical and HDe scenarios, suggests that periods of drought and surplus over the paleo record are within the range of variability experienced for the historical 1950–1999 period. Thus, including paleo-conditioned projections of streamflow, and potentially other variables, would be computationally time-intensive yet would not yield additional information. Second, because the Klamath River Basin lacks an integrated surface water – groundwater model, there would be inconsistencies in data linkages between models that make use of paleo-conditioned projections infeasible. For example, the groundwater models rely on inputs of climate, recharge, and streamflow, yet paleo-conditioned projections of climate and water balance variables do not exist to correspond with the paleo-conditioned streamflow projections. Paleo-conditioned streamflow projections may provide a greater context for future water supply projections, but are not directly used in further analysis.

3.5.1.4 Surface Water Hydrology

Assessment of climate change impacts on surface water supply was conducted using HDe (ensemble informed hybrid delta) scenarios and was informed by paleo-conditioned streamflow projections. The overall approach is described below and is illustrated in an overview diagram in Figure 3-21.

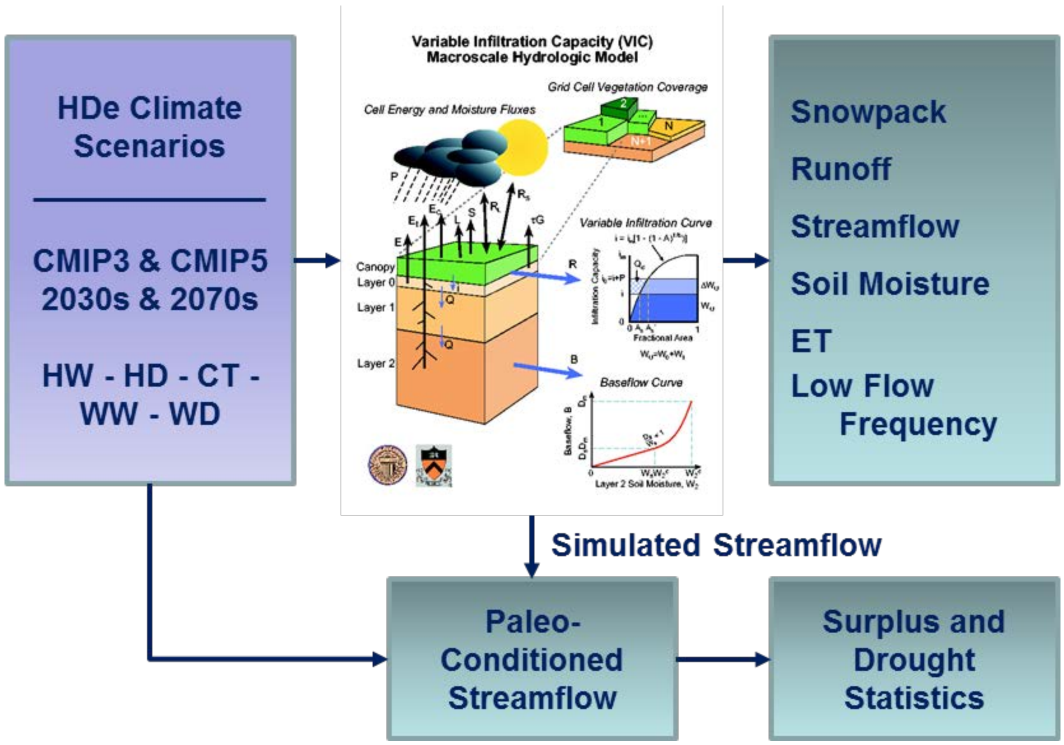


Figure 3-21.—Approach for assessment of projected surface water supplies.

HDe scenarios may be directly used by the VIC model to generate associated projections of snowpack, runoff, and other elements of the water balance. In evaluating the implications of climate change, the water supply assessment first provides comparisons of results based on CMIP3 and CMIP5 projections with respect to mean annual precipitation and temperature, April 1 SWE, and mean annual runoff.

Following the comparison of CMIP3 and CMIP5 results, the assessment discusses projected changes in seasonal precipitation and temperature, snowpack on April 1, mean annual runoff, spring runoff, June 1 soil moisture, mean annual ET, mean monthly streamflow at select sites, annual runoff timing, and changes in the 7-day low flow with 10 year recurrence interval (also called 7Q10). This part of the assessment focuses on results using CMIP5 projections (unless otherwise noted) for the two future time horizons (2030s and 2070s); however, figures based on CMIP3 projections, corresponding to those presented in the water supply assessment, are presented and briefly discussed in Appendix B, Supplemental Information for Assessment of Water Supply.

Drought and surplus statistics are evaluated based on the developed paleo-conditioned streamflow traces. Paleo-conditioned streamflow relies on projected natural streamflow output from the VIC model as well as statistics developed from the analysis of the paleo-record. Projected natural streamflows from the VIC model are resampled 1,000 times for each of the five HDe climate change scenarios, future time horizons, and projection types (CMIP3 and CMIP5) to develop statistics of projected surplus and drought volumes and lengths.

3.5.1.5 Groundwater Hydrology

This section describes the approaches for utilizing climate change scenarios to evaluate projected changes in groundwater recharge, discharge, and elevations in three groundwater basins of the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys.

3.5.1.5.1 Upper Klamath Basin

The effects of projected climate on groundwater in the Upper Klamath Basin were analyzed using the existing MODFLOW finite-difference groundwater model developed by Gannett et al. (2012). For this study, the model was driven by HDe climate scenarios and surface water hydrologic projections, and results were compared with the historical simulation (presented and summarized in Section 3.4.3, Present Availability and Historical Trends – Upper Klamath Basin) to evaluate results due to changes in climate alone, excluding any impact due to changes in groundwater demand (i.e., pumping). Paleo-conditioned streamflow projections were not taken through the Upper Klamath Basin groundwater impacts analysis because stream stages are held constant in the MODFLOW simulations and Gannett et al. (2012) determined that streams generally have very little net exchange with the groundwater system. The avenues for incorporation of projected surface water inputs into the MODFLOW model are listed below, and they do not have associated paleo-conditioned projections.

1. Projected maximum ET for each of the five HDe climate change scenarios, where maximum ET is represented as PET less actual ET as computed from VIC surface water hydrology model output.

2. Projected groundwater recharge for each of three recharge zones for each of the five HDe climate change scenarios.

The methodology for developing each type of projected MODFLOW input is described briefly below and illustrated in an overview diagram in Figure 3-22.

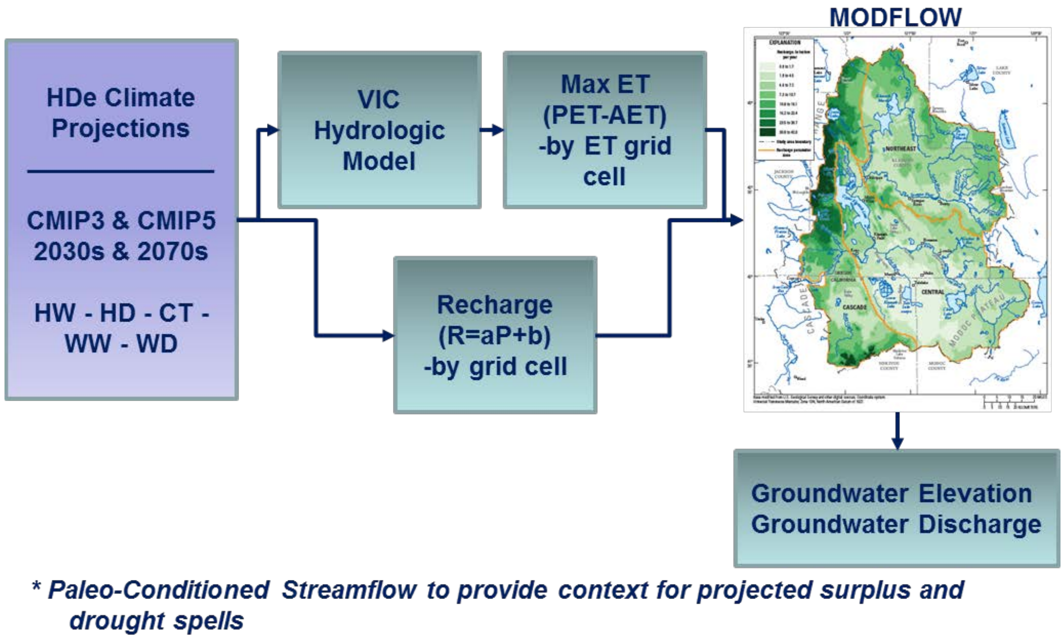


Figure 3-22.—Approach for assessment of projected groundwater supplies in the Upper Klamath Basin.

Maximum Evapotranspiration Rate

Evapotranspiration is modeled in the Upper Klamath Basin MODFLOW model (Gannett et al., 2012) using the EVT, or evapotranspiration package. One of the principal input parameters is the maximum ET rate associated with groundwater. Gannett et al. (2012) computed this parameter based on output from the PRMS surface water hydrology model. Specifically, this parameter is computed as the difference between PET and actual ET. This difference represents the amount of potential demand that could be supplied by groundwater and is not supplied by precipitation.

In this study, the VIC model was used to generate meteorological inputs for future MODFLOW simulations. The VIC model was chosen, as opposed to PRMS, because it is available for the entire Klamath River Basin, is widely used for studies of climate change impacts, and was used in the hydrologic modeling and development of hydrologic projections as part of Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). Maximum ET was computed on a quarterly (seasonal) basis from VIC simulations for the five HDe climate change scenarios. Quarterly maximum ET computed from VIC simulations (at 1/8th degree spatial resolution) was compared with historical maximum ET used in the historical MODFLOW simulation, aggregated to VIC's spatial resolution. Quarterly (stress period) change factors were developed at the VIC model spatial resolution and factors were applied to historical maximum ET from MODFLOW for each MODFLOW cell within a VIC grid cell. The reason for using change factors and not directly applying projected maximum ET from the VIC model is to avoid introducing bias due to the differing model constructs (i.e., PRMS generated historical maximum ET while VIC generated projected maximum ET).

Groundwater Recharge

The Gannett et al. (2012) historical groundwater simulation uses as input historical groundwater recharge computed by the PRMS model. Because the VIC model was used to generate inputs for future projection simulations, and because historical simulated recharge from VIC may be quite different from recharge used in the historical MODFLOW simulation (derived from the PRMS hydrologic model), a relationship was developed between historical annual precipitation (gridded dataset developed by Maurer et al. [2002] was used in development of surface water hydrology for this study as well as future climate scenarios) and historical annual recharge.

Although alternate relationships were explored in this study, a linear relationship between precipitation and recharge appeared to best represent the data. Such a relationship was developed using annual recharge and precipitation (at the spatial resolution of the VIC model), aggregated by recharge zone. Using the developed relationships between annual recharge and precipitation (by recharge zone) based on historical data, the same relationship was applied to each of the five HDe climate change scenarios of precipitation for two future time periods (2030s and 2070s) and for CMIP3 and CMIP5 projections. As a result, corresponding projections of recharge were developed at the VIC model resolution. These projections were used to generate annual change factors (based on ratios between projected recharge and MODFLOW historical), which were then applied to historical recharge uniformly over all MODFLOW grid cells within a corresponding VIC model grid cell.

Caveats

It should be noted that the described approach for developing projected surface water inputs to the Upper Klamath Basin MODFLOW model may introduce errors in the groundwater balance due to inconsistently developed inputs. For example, recharge and maximum ET projections were developed using established relationships between projections based on HDe scenarios and historical values used in MODFLOW historical simulations. Hence, they were not developed via an integrated surface water model. Despite the use of potentially inconsistent methodologies, this approach provides the best available estimates of projected surface inputs to the groundwater system.

3.5.1.5.2 Scott and Shasta Valleys

Projections of future groundwater elevation may be computed for the Scott and Shasta Valleys using the groundwater screening tools developed and described in Section 3.4, Historical Groundwater Availability. Similar to the Upper Klamath Basin, perturbed historical inputs representing projected conditions were used by the models to generate projections of groundwater elevation. Future projections were incorporated for climate and water balance input terms, as well as municipal, domestic, and industrial demand with respect to projected population. Agricultural demand was left unchanged for the water supply assessment in order to focus on the impacts of climate change on groundwater elevation, and not changes in agricultural demand. Variations in historical agricultural demand are incorporated into historical groundwater elevations used to develop relationships in the computation of groundwater response. However, projected changes in temperature and precipitation will affect agricultural demand, which may markedly affect groundwater levels beyond what was experienced historically. In the discussions of climate change impacts on water demand in the watershed and associated risks and system reliability (Chapters 4 and 5 of this Klamath River Basin Study report, respectively), we address projected changes in agricultural demand and how the watershed may be impacted by the compounded stresses associated with climate change (with and without management adaptations).

Specific projected inputs to the groundwater screening tools for the Scott and Shasta Valleys are further described below. An overview diagram illustrating how projected inputs are incorporated into the groundwater screening tools is provided in Figure 3-23.

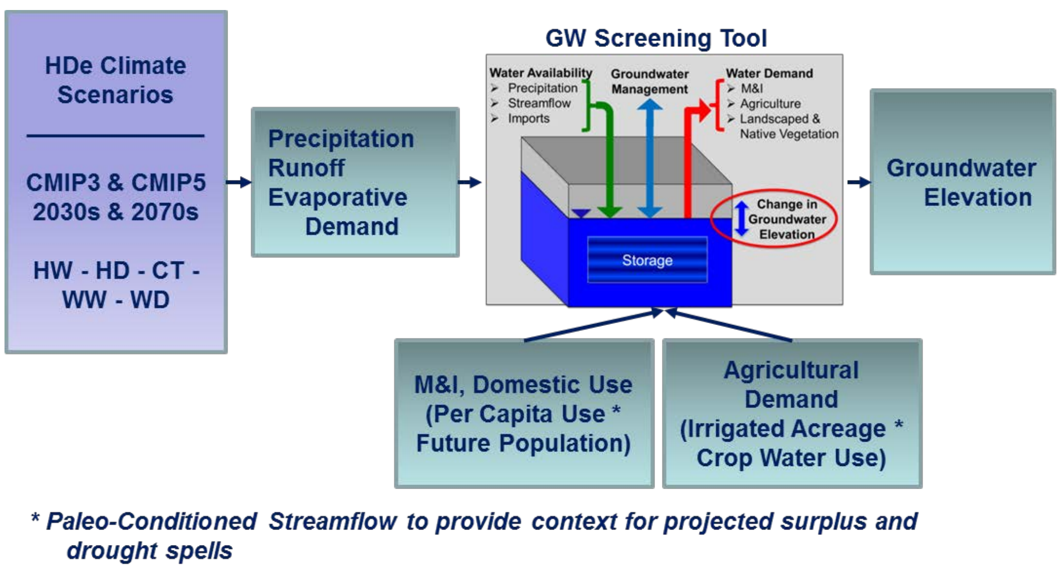


Figure 3-23.—Approach for assessment of projected groundwater supplies in the Scott and Shasta Valleys.

Future projections of monthly mean precipitation and daily mean temperature (surrogate for evaporative demand) computed over the groundwater basins were input to the groundwater screening tools for each basin. These climate scenarios were based on the five HDe climate change scenarios for two future time horizons (2030s and 2070s) as well as for projections based on both CMIP3 and CMIP5. Similar projections of mean monthly runoff over each of the groundwater basins were also input to the models.

It should be noted that the approaches described above for developing projected surface water inputs to the Scott and Shasta Valley groundwater screening tools (including precipitation, temperature, and runoff) are compatible. These inputs rely on HDe climate scenarios themselves (in the case of precipitation and temperature) or outputs generated by the VIC model (runoff) whose simulations rely on HDe climate scenarios.

Municipal, industrial, and domestic water demand, which was computed based on the product of per capita water use and population, was perturbed according to projected population growth. Per capita use was assumed to remain constant. Projected population for each of the two future time horizons (2030s and 2070s) was computed by assuming a percent increase in population equal to the percent change between 1990 and 2000, which was documented by the 2000 Census.[5] For the Scott Valley this was +1.93 percent, while for the Shasta Valley it was +2.01 percent over ten years. The mean of projected population 2020–2050 was used to represent 2030s population, while the mean of projected population 2060–2080 was used to represent 2070s population. Additional scenarios of population growth were not considered as part of the water supply assessment; however, additional scenarios may be considered in subsequent stages of the Klamath River Basin Study as part of the analysis of management alternatives and/or adaptation strategies.

As previously mentioned, agricultural water demands were not modified as part of the evaluation of climate change impacts on groundwater elevations in the Scott and Shasta Valleys. The primary reason changes in agricultural demand were not considered here is that detailed analysis of the implications of projected agricultural demand is part of the assessment of current and future water demands in Chapter 4.

3.6 Comparison between CMIP3 and CMIP5

Projections of climate as well as surface water and groundwater hydrologic variables were summarized using both CMIP3- and CMIP5-based projections to understand whether these projections provide a similar view of future conditions. Few studies exist to provide guidance on whether the more recent CMIP5 projections ought to supersede those from CMIP3, whether they are similar enough that one or the other may be used, or whether they ought to be used collectively in impacts assessments. The intent of the Klamath River Basin Study water supply assessment is not to provide such guidance, but instead to evaluate the impacts of climate change using both sources of projections to provide the most comprehensive understanding possible of projected changes in water supply in the watershed.

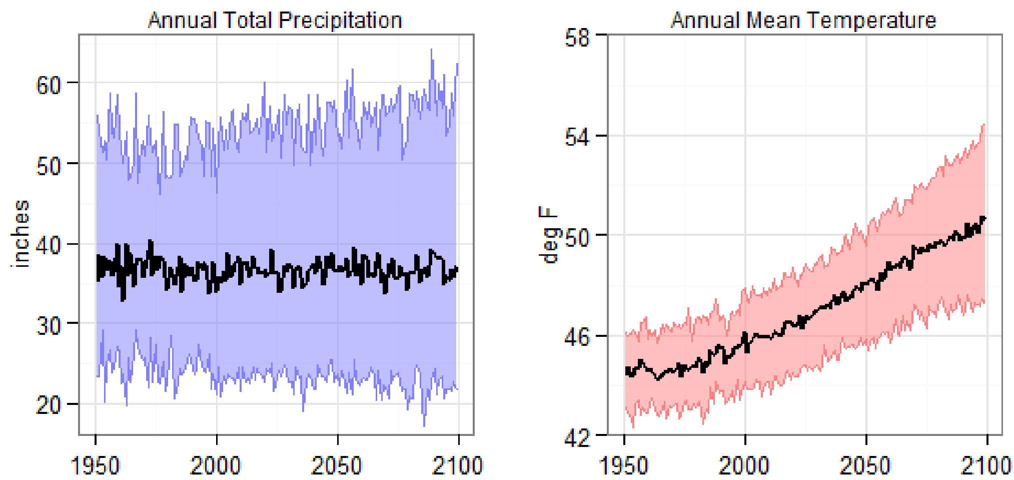
[5] https://www.census.gov/programs-surveys/decennial-census/data/datasets.html

3.6.1 Climate

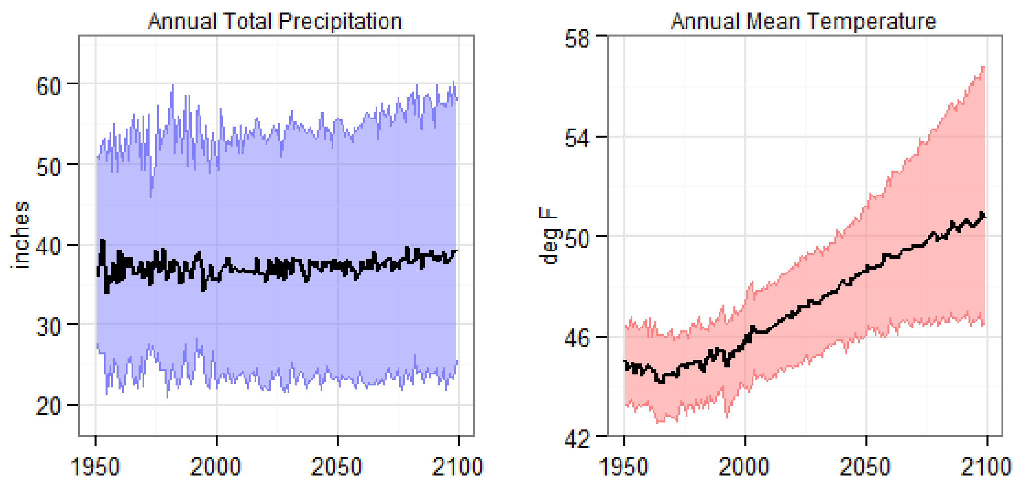
The basis for the five HDe climate change scenarios of precipitation and temperature (minimum and maximum) used throughout the Klamath River Basin water supply assessment is a suite of monthly statistically downscaled GCM simulations, based on CMIP3 and CMIP5 projections. As described in detail in Section 3.5.1.1, Climate Projections, HDe scenarios are generated by computing change factors between designated future time horizons (in this case the 2030s and 2070s) and a designated historical period (in this case 1970–1999).

Figure 3-24 illustrates the envelopes of projected mean annual precipitation and temperature as they evolve through time (i.e., light red on the top panel for temperature and light blue on the bottom panel for precipitation). All projections show that the region will become warmer during the 21st century, with greater uncertainty in annual temperature farther into the future as shown by the widening swath of projections. Annual precipitation in the Klamath River Basin is projected to increase slightly through time. However, it should be noted that this slight projected increase (both for CMIP3 and CMIP5 projections) is within the range of historical variability in precipitation from year to year. In contrast, for temperature, the median projection shows that temperatures will exceed the range of historical year to year variability by about 2050.

A comparison of CMIP3 and CMIP5 projections shows that trajectories through time appear similar; however, the range of projected precipitation is similar between the two types of projections, while projected temperature appears greater with CMIP5 projections. The larger projected range in projected temperature is likely due to the consideration of the full range of emissions scenarios for both CMIP3- and CMIP5-based projections. As shown in Figure 3-24, the range of projected global warming is greater for CMIP5 scenarios than for CMIP3.



a) **CMIP3**



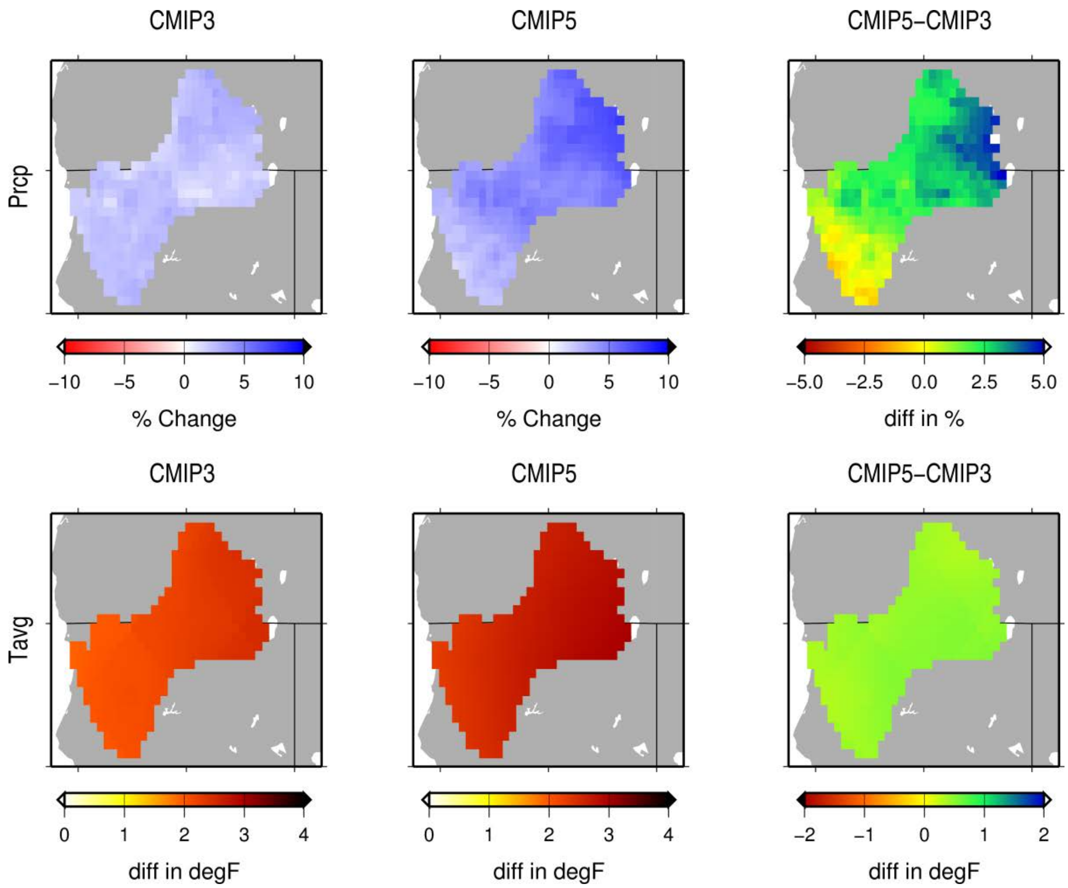
b) CMIP5

Note: The top row (a) and bottom row (b) illustrate the range of CMIP3 projections and CMIP5 projections, respectively. The black line in each panel shows the median of annual projections, while the colored band represents the range of all GCM projections (112 for CMIP3 and 234 for CMIP5).

Figure 3-24.—Summary of statistically downscaled GCM projections of mean annual precipitation and temperature from 1950 to 2100.

Figure 3-25 shows projected changes in mean annual precipitation (in percent) and average temperature (in degrees F) for the 2030s, compared with the historical baseline (1950–1999), using both CMIP3- and CMIP5-based HDe scenarios, while Figure 3-26 shows similar projections for the 2070s. It should be noted that these projections do not reflect information from the paleo record, as paleo-conditioned projections only correspond with streamflow. The projections shown in the figures represent the central tendency derived using the HDe approach. Each figure shows projections based on CMIP3 in the left panel, projections based on CMIP5 in the middle panel, and the difference between CMIP5 and CMIP3 in the right panel.

Projected changes in precipitation and temperature are positive for both CMIP3 and CMIP5 for the 2030s and 2070s. As can be seen in Table 3-5, which summarizes spatially averaged projected changes for both time horizons and over three dominant Klamath River Basin climate divisions as well as the basin as a whole, there are notable differences in the magnitude of projected change.



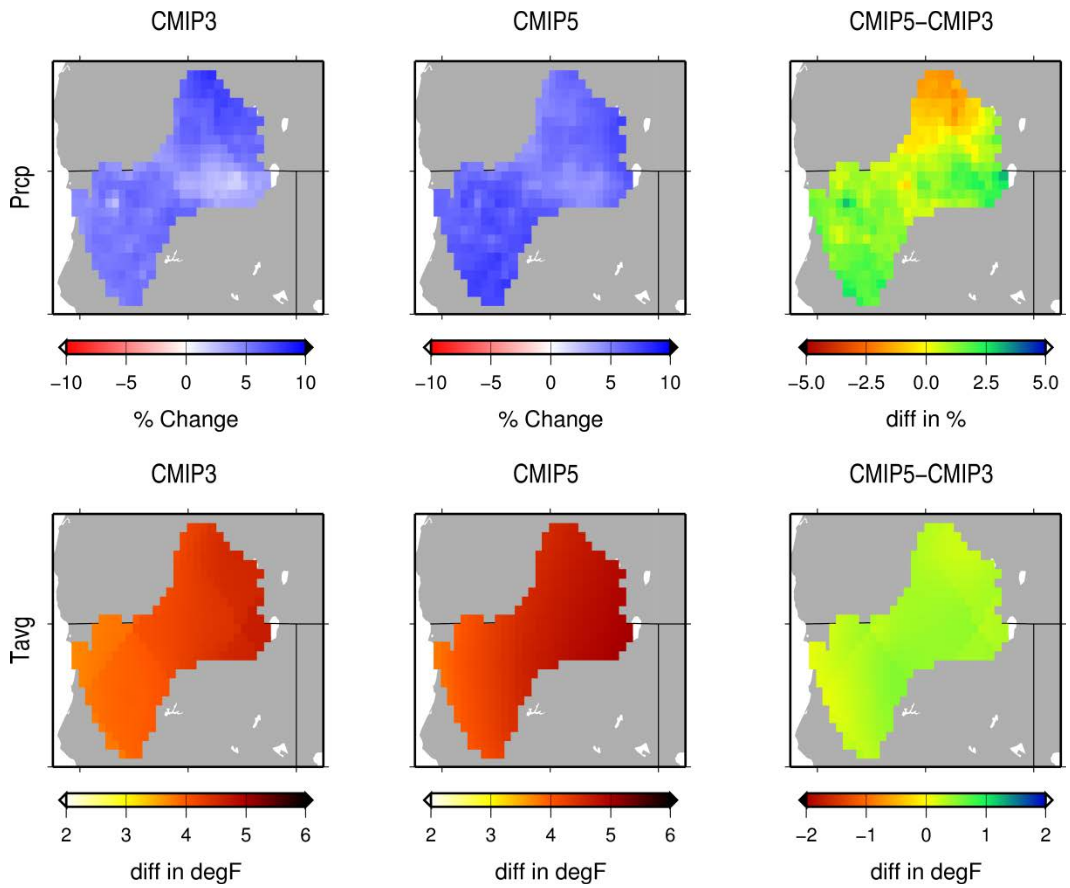
Notes:

1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

Figure 3-25.—Comparison of percent change (2030s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5.

For the 2030s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the North Coast Drainage, which is located at the California portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 4.1 percent increase in mean annual precipitation, while CMIP3-based scenarios indicate a 2.4 percent increase by the 2030s. CMIP5-based scenarios are noticeably wetter than CMIP3 in the eastern portions of the High Plateau and South Central climate divisions. However, CMIP5-based scenarios are noticeably drier in the southernmost portion of the watershed, as previously mentioned.

With respect to mean annual average temperature for the 2030s, CMIP5 projections indicate a greater increase in temperature than CMIP3 for all spatial domains considered (see Figure 3-2), although the projections are not substantially different. Projected temperatures basin-wide for the 2030s central tendency show an increase of 2.2 degrees F for CMIP3 and 2.7 degrees F for CMIP5.



Notes:

1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

Figure 3-26.—Comparison of percent change (2070s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5.

For the 2070s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the High Plateau, which is located at the northernmost portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 6.1 percent increase in mean annual precipitation, while CMIP3 projections indicate a 5.2 percent increase by the 2070s. With respect to mean annual average temperature for the 2070s, CMIP5 projections indicate a greater increase in temperature than CMIP3 projections for all spatial domains, which is similar to results for the 2030s. Projected temperatures basin-wide for the 2070s central tendency indicate an increase of 4.2 degrees F for CMIP3 and 4.5 degrees F for CMIP5.

CMIP3 and CMIP5 Comparison – Precipitation and Temperature

Ranges of projected precipitation appear similar while ranges of temperature appear greater with CMIP5 than with CMIP3 scenarios. Spatial differences between CMIP3 and CMIP5 scenarios may be due to internal variability in the model simulations and HDe scenario development. By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

Although the magnitude differences are quite similar between CMIP3 and CMIP5 for precipitation and temperature for each future time horizon (central tendency), the spatial differences between CMIP3 and CMIP5 are interesting (see the right panels of Figures 3-25 and 3-26). For the 2030s, CMIP3 projections show less increase in precipitation that CMIP5 in the lowermost portion of the Klamath River Basin, while also showing a larger increase in the easternmost portion of the basin. For the 2070s, CMIP3 projections show less increase in precipitation in the Oregon portion of the basin than CMIP5 projections, while in most other parts of the basin CMIP5 projections show greater increase. The spatial differences between CMIP3- and CMIP5-based scenarios may be due to internal variability in the model simulations, and therefore the spatial patterns should be viewed collectively as potential future conditions.

Table 3-5.—Summary of projected changes in mean annual precipitation and average temperature for the 2070s, compared with the historical baseline (1950–1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions

Climate Division	Basinwide	North Coast Drainage	South Central	High Plateau
2030s				
Prcp, CMIP3	+2.4 %	+2.3 %	+2.4 %	+2.7 %
Prcp, CMIP5	+4.1 %	+3.6 %	+5.4 %	+5.8 %
Tavg, CMIP3	+2.2 degF	+2.2 degF	+2.3 degF	+2.4 degF
Tavg, CMIP5	+2.7 degF	+2.6 degF	+2.8 degF	+2.8 degF
2070s				
Prcp, CMIP3	+5.2 %	+5.0 %	+5.1 %	+6.4 %
Prcp, CMIP5	+6.1 %	+6.3 %	+5.3 %	+5.7 %
Tavg, CMIP3	+4.2 degF	+4.1 degF	+4.3 degF	+4.4 degF
Tavg, CMIP5	+4.5 degF	+4.4 degF	+4.7 degF	+4.7 degF

3.6.2 Water Balance

Comparisons of CMIP3 and CMIP5 projections of April 1 SWE and mean annual runoff, both calculated using the VIC model, are illustrated in Figure 3-27 for the 2030s and Figure 3-28 for the 2070s and summarized in Table 3-6. Projections of snowpack on April 1 are presented, in part, because this is a common measure often used in climate change impact studies across the western U.S., but also because historical snowpack is at, or just past, its peak in early April and this measure is often used by water managers as a measure of spring and summer water supply. For the 2070s, CMIP3- and CMIP5-based projections of April 1 SWE show a similar magnitude of change and slight spatial differences (refer to Figure 3-28, upper left and upper central panels). The water balance terms are influenced by changes in precipitation and temperature across the landscape. Although both CMIP3 and CMIP5 projections indicate declines in April 1 SWE by roughly 30 to 40 percent by the 2030s and 60 percent by the 2070s for the central tendency, despite projected increases in annual runoff (see Table 3-5 for computed percent change over the basin and three dominant climate divisions).

For both future time horizons, greater decreases in snowpack are projected for lower elevation regions while mountainous parts of the basin, namely the Cascades and Trinity Alps, show smaller projected decreases in April 1 SWE. Further, for the VIC model pixel that contains Mount Shasta (refer to the white square in the central area of the upper left and upper central panels of Figure 3-27 and Figure 3-28), snowpack is not projected to change substantially, likely due to the combined effects of its relatively high elevation, projected increases in precipitation, and projected increases in temperature.

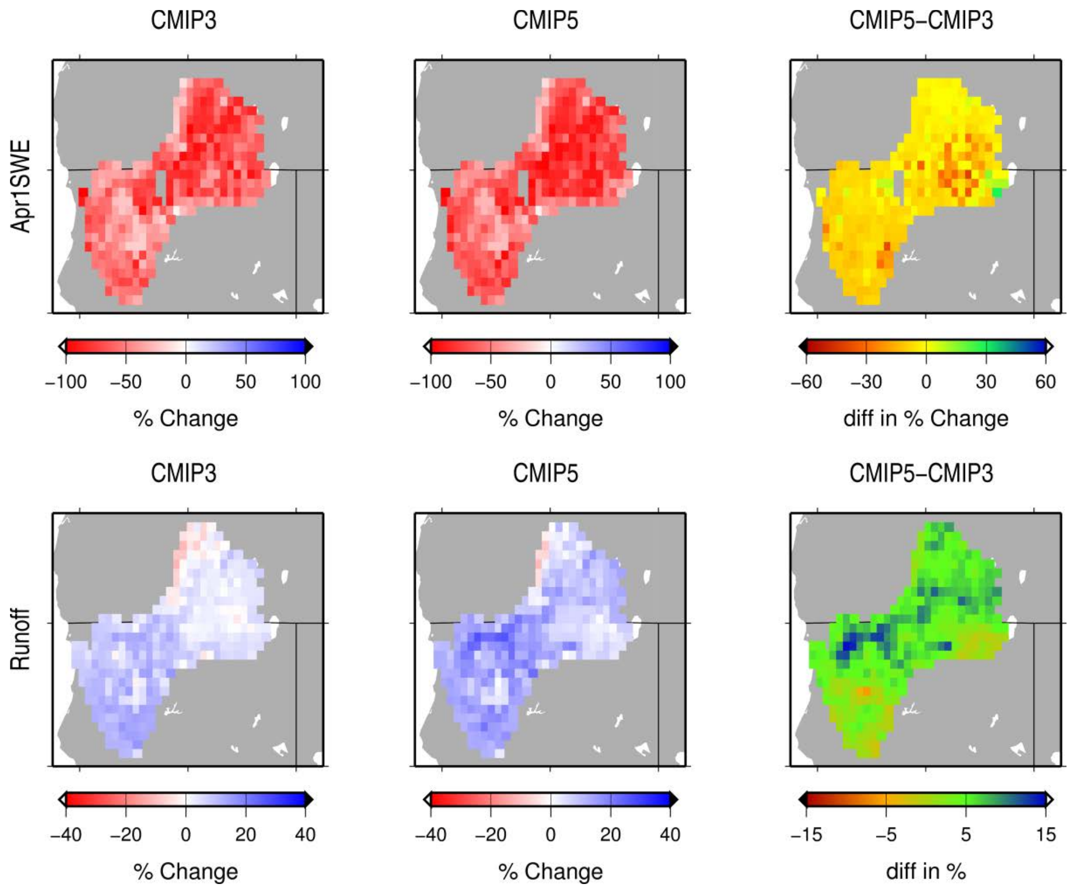
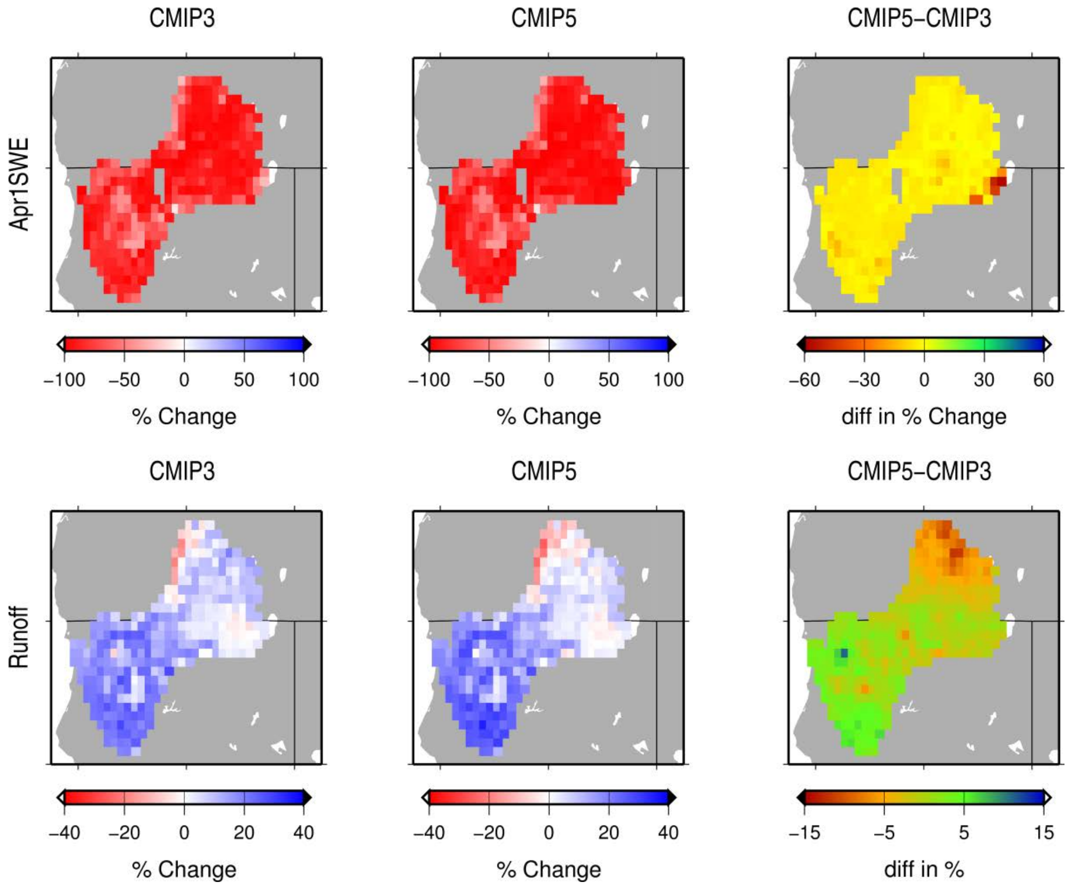


Figure 3-27.—Comparison of percent change (2030s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios based on CMIP3 and CMIP5. Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

The upper right panels of Figure 3-27 and Figure 3-28 show the differences in April 1 SWE between CMIP3 and CMIP5 projections. Although differences for the 2030s and 2070s central tendency are small, the CMIP3 projection indicates a larger decrease in snowpack than CMIP5 in parts of the Upper Klamath Basin for the 2030s and the easternmost portion of the basin in California for the 2070s. Smaller differences in April 1 SWE are projected for the 2070s. Mean percent change in April 1 SWE across the Klamath River Basin is -33.8 percent for the 2030s and -58.2 percent for the 2070s.



Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

Figure 3-28.—Comparison of percent change (2070s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios, based on CMIP3 and CMIP5.

Table 3-6.—Summary of projected changes in April 1 SWE and annual runoff for the 2030s compared with the historical baseline (1950-1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions

Climate Division	Basinwide	High Plateau	South Central	North Coast Drainage
2030s				
Apr1 SWE, CMIP3	-33.8 %	-38.9 %	-31.0 %	-32.5 %
Apr1 SWE, CMIP5	-39.8 %	-41.4 %	-35.4 %	-39.8 %
Ann Runoff, CMIP3	+7.3 %	+1.4 %	-0.6 %	+8.8%
Ann Runoff, CMIP5	+11.6%	+3.4 %	+4.6 %	+12.9 %
2070s				
Apr1 SWE, CMIP3	-58.2 %	-61.9 %	-54.7 %	-57.3 %
Apr1 SWE, CMIP5	-62.0 %	-65.6 %	-58.8 %	-61.1 %
Ann Runoff, CMIP3	+13.9 %	+0.1 %	-0.5 %	+16.4 %
Ann Runoff, CMIP5	+15.3 %	-5.1 %	-2.5 %	+18.7 %

According to projections based on both CMIP3 and CMIP5 for the 2030s and 2070s, mean annual runoff is projected to increase in the Lower Klamath Basin while changes in the Upper Klamath Basin vary both in magnitude and direction and between CMIP3 and CMIP5 (refer to lower panels of Figure 3-27 and Figure 3-28). Projected changes in runoff based on climate division show increases in the North Coast Drainage on the order of 16 or 19 percent (for CMIP3 and CMIP5, respectively) for the 2070s central tendency and decreases across the South Central climate division on the order of 1 to 3 percent (for CMIP3 and CMIP5, respectively). Across the High Plateau (the region upstream and to the east of Upper Klamath Lake; refer to Figure 3-2), projections are mixed, with CMIP3-based projections indicating a slight increase in mean annual runoff and CMIP5-based projections indicating a decrease in mean annual runoff for the 2070s. The lower right panels of Figure 3-27 and Figure 3-28 illustrate the spatial difference between CMIP3 and CMIP5 for the 2030s and 2070s, respectively. For the 2030s, CMIP5 projections indicate greater changes in runoff over the mainstem Klamath River area than CMIP3, yet smaller changes in runoff over the higher elevation regions of the Trinity River basin and Tule Lake area. For the 2070s, CMIP5 projects lower runoff change than CMIP3 in the Upper Klamath Basin and lower runoff change than CMIP3 in the Lower Klamath Basin.

> **CMIP3 and CMIP5 Comparison – Water Balance**
>
> CMIP3 and CMIP5 water balance projections are largely consistent, indicating decreases in April 1 SWE on the order of 34-40 percent for the 2030s and close to 60 percent for the 2070s, and increases in annual runoff of 7-12 percent for the 2030s and 14-15 percent for the 2070s.

The differences between CMIP3 and CMIP5 projections for the 2070s central tendency in projected precipitation, temperature, snowpack, and runoff show great similarities in the central tendency scenario for the Klamath River Basin as a whole. However, there are notable differences in that CMIP5 projections tend to be wetter and warmer over the Klamath River Basin than those from CMIP3. Also, there are notable spatial differences that are important to consider when relying on projections from either CMIP3 or CMIP5 (but not both) for water management decision-making.

3.7 Future Availability

Projected availability of surface water and groundwater in the Klamath River Basin was assessed by evaluating changes in seasonal precipitation and temperature, snowpack, timing and quantity of runoff, soil moisture and ET, low flow frequency, and groundwater recharge and discharge. For the most part, this assessment focuses on projections based on CMIP5; however, corresponding results based on CMIP3 projections were also developed and are included in Appendix B, Supplemental Information for Assessment of Water Supply.

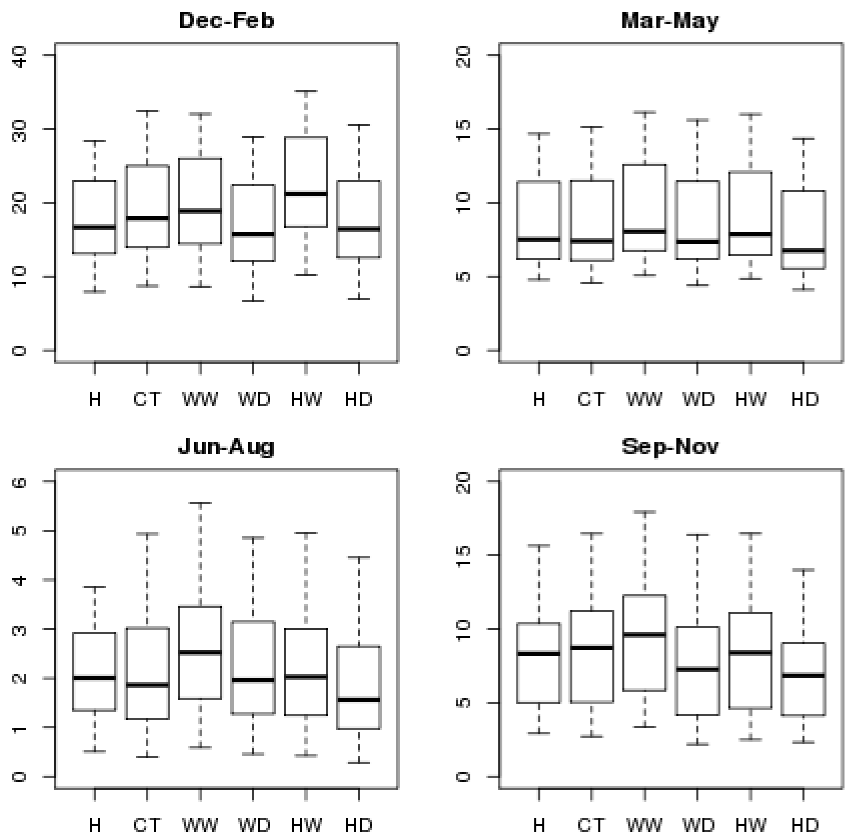
Figure 3-29 illustrates projections of seasonal basin mean precipitation for the 2070s compared with the historical period, based on CMIP5. Each panel includes box plots of historical and projected precipitation, where the boxes represent the 25th, 50th, and 75th percentile values for seasonal precipitation averaged across the Klamath River Basin, and the whiskers represent the 5th and 95th percentile values.

Future Availability – Precipitation and Temperature

Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

In general, the box plots show that the majority of precipitation falls between December and February, an order of magnitude greater than between June and August. In winter (December through February; refer to upper left panel of Figure 3-33), central tendency, WW, and HW scenarios indicate an increase in precipitation, while the WD and HD scenarios indicate decreases in precipitation over this time period. The range between 5th and 95th percentile values across each of the five HDe climate change scenarios appears similar. Projections for the spring period between March and May (upper right panel) and the autumn period between September and November (lower right panel) appear similar to historical conditions, with slight increases for the wetter scenarios (WW and HW) and slight decreases for the drier scenarios (WD and HD). Projections for the summer period (June through August; refer to lower left panel) show a slight decrease in the median of the central tendency scenarios compared with historical, and decreases in general for the drier scenarios and increases for the wetter scenarios. However, it is notable that the WW scenario indicates a larger increase in summer precipitation than the HW scenario.

It is important to mention that HDe climate change scenarios were developed based on projected changes from multiple GCMs in annual precipitation and temperature across the basin, potentially dampening the signal toward drier summers and wetter winters (as shown in Figure 3-19). Also, the Klamath River Basin water supply assessment does not evaluate projected changes in extreme precipitation events, which are also likely to change as a result of climate change. The focus of this water supply assessment is on the watershed's overall monthly to seasonal water balance, rather than the effects of individual storm events.

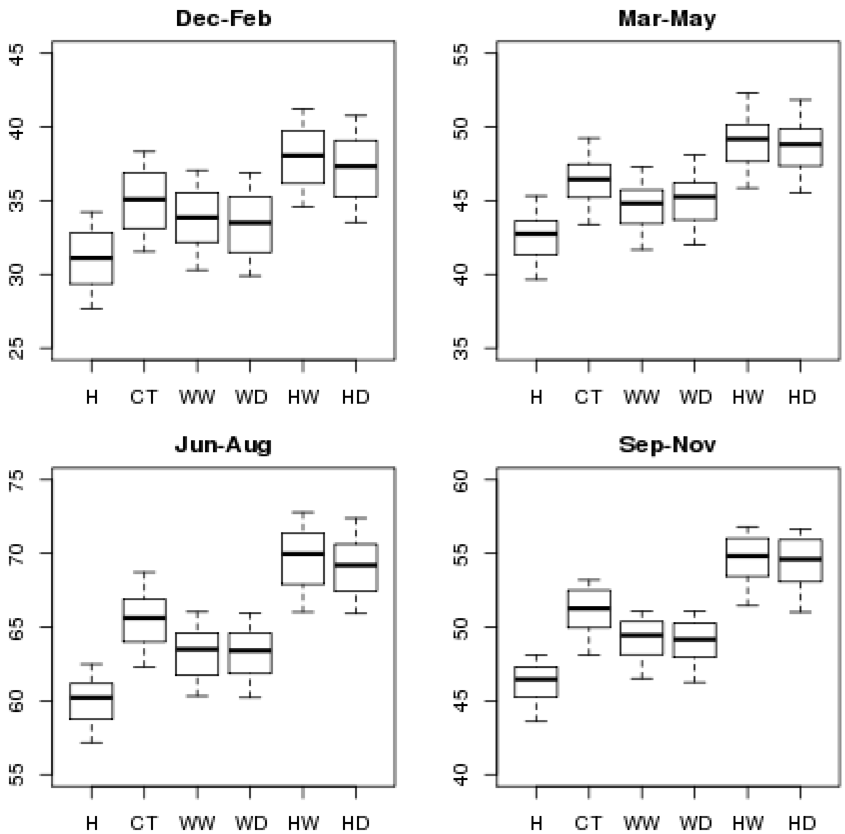


Notes:

1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

Figure 3-29.—Seasonal basin mean precipitation (in inches), CMIP5 2070s and historical (1950–1999).

Projections of seasonal temperatures for the 2070s, compared with the historical period (1950–1999) show similar patterns in HDe climate change scenarios across seasons (refer to Figure 3-30). The hotter HDe scenarios (HW and HD) indicate warmer temperatures relative to the warmer HDe scenarios (WW and WD), compared with historical temperatures. Central tendency scenarios tend to fall in between the warmer and hotter scenarios. What is notable about the seasonal temperature projections is that, for all seasons, the hotter HDe scenarios are mostly outside the range of corresponding historical seasonal temperatures. In summer and fall, even the central tendency HDe scenarios are mostly outside the range of historical temperatures.



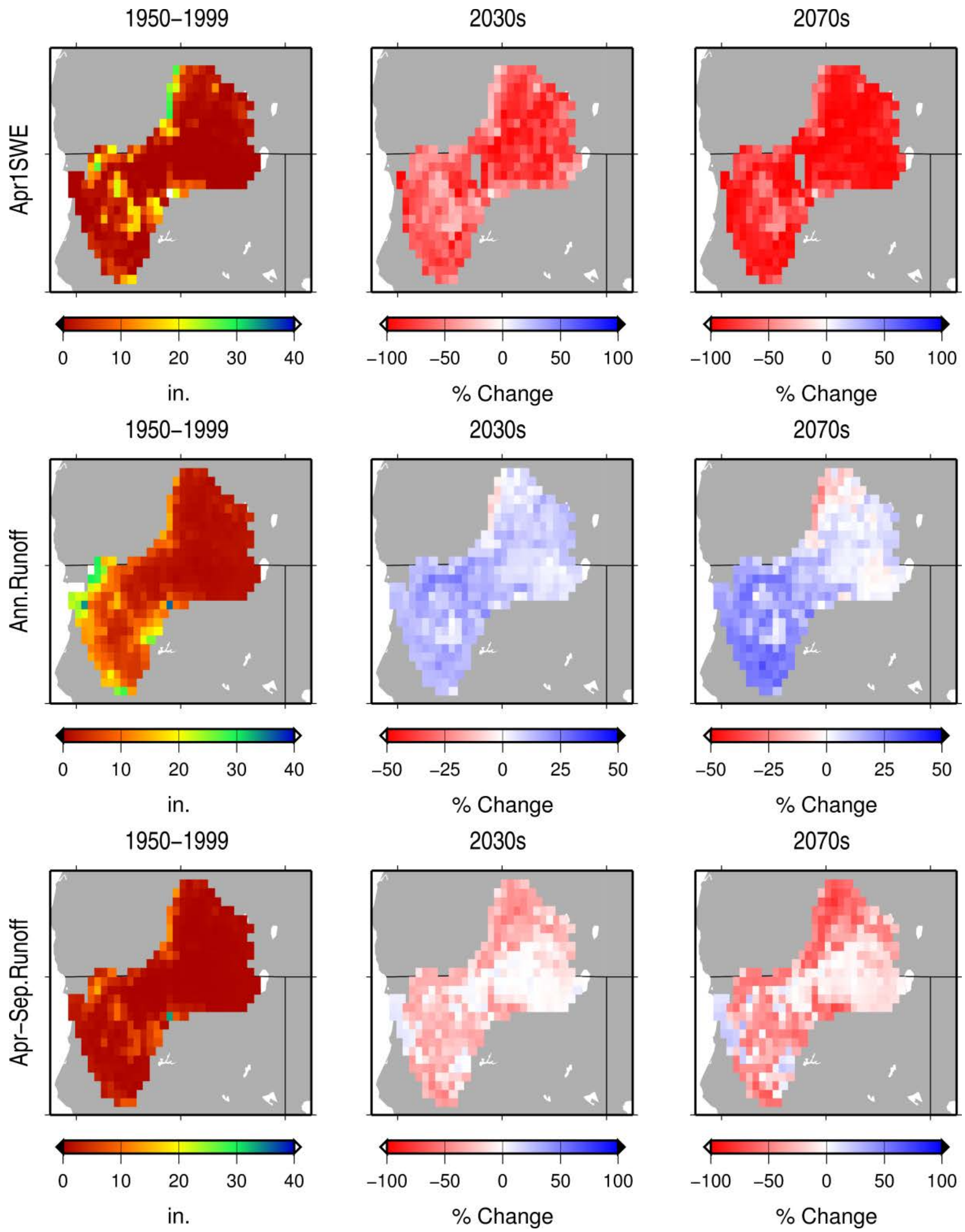
Notes:

1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

Figure 3-30.—Seasonal basin mean daily average temperature (in degrees F), CMIP5 2070s and historical (1950–1999).

3.7.1 Changes in Water Balance Terms

This section summarizes projected spatial and basin mean changes in snowpack, annual and spring runoff, soil moisture, and actual ET for the two future time horizons (2030s and 2070s), based on central tendency CMIP5 projections. Figures corresponding to those shown in this section based on CMIP3 projections are included in Appendix B, Supplemental Information for Assessment of Water Supply. It should be noted that paleo-conditioned streamflow projections were not incorporated into the analysis of climate change impacts on surface water balance variables. Figures 3-31 and 3-32 are similar in format in that the left column illustrates mean historical conditions over the period 1950–1999. The middle column illustrates projected percent change for the 2030s future time horizon compared with historical, while the right column illustrates projected percent change for the 2070s future time horizon compared with historical.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from historical values to the 2030s and 2070s, respectively.

Figure 3-31. Comparison of percent change in mean April 1 SWE, mean annual runoff, and mean April-September runoff for the central tendency HDe scenarios based on CMIP5.

Mean historical SWE on April 1 (Figure 3-31, top row) falls within the range of little or no snow in the coastal region to almost 40 inches of SWE in the Cascade Mountains (and even greater snowpack at Mount Shasta). Based on CMIP5 projections, mean percent change in April 1 SWE across the Klamath River Basin is -40 percent for the 2030s and -62percent for the 2070s. Greater decreases are projected for middle to lower elevation parts of the basin. Snowpack at Mount Shasta is expected to exhibit little change (on a percent basis) by the 2030s or 2070s.

Historical mean annual runoff over the 1950–1999 period ranges from a little less than 1 inch in the northeastern part of the basin to more than 40 inches in parts of the coastal region and near Mount Shasta. Basin-wide mean percent change in annual runoff is +12 percent for the 2030s and +15 percent for the 2070s. Most of the Lower Klamath Basin is projected to experience increases in mean annual runoff, while the Cascades region is projected to experience decreases. What is notable with respect to projected changes in mean annual runoff in the Upper Klamath Basin is that projected increases in runoff appear greater for the 2030s than the 2070s. This is likely due to the combined effects of projected increases in precipitation along with projected increases in temperature. For the 2030s, increased precipitation dominates the water balance, resulting in larger increases in annual runoff, while for the 2070s corresponding increases in temperature may cause actual ET to be great enough to show an overall smaller increase in mean annual runoff than for the 2030s.

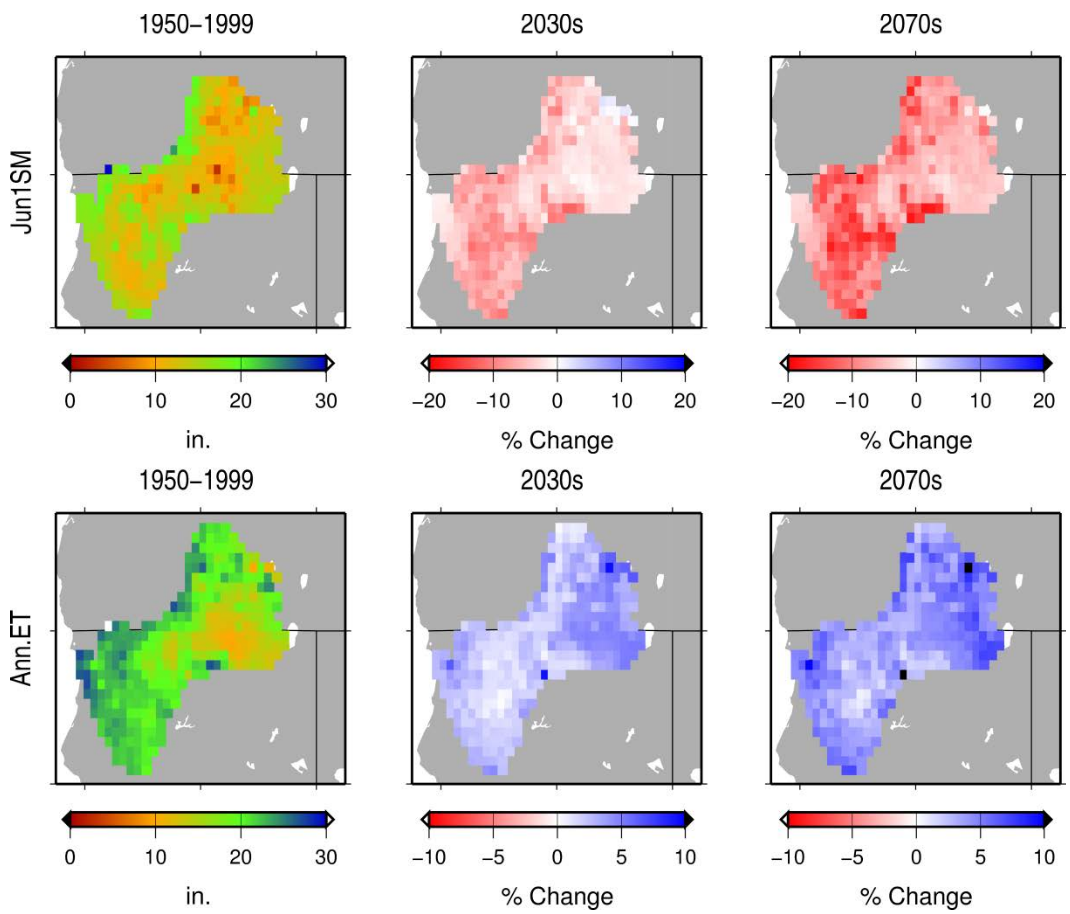
Future Availability – Water Balance

Mean percent change based on CMIP5 central tendency projections includes:

- April 1 SWE: -40 percent (2030s) and -62 percent (2070s)
- Spring (April–September) runoff: -25 percent (2030s) and -40 percent (2070s)
- June 1 soil moisture: -4.9 percent (2030s) and -8.7 percent (2070s)
- Annual ET: +2.6 percent (2030s) and +4.1 percent (2070s)

Historical irrigation season (April through September) runoff over the 1950–1999 period ranges from less than 1 inch to about 30 inches, with higher spring runoff occurring in the mountainous parts of the Klamath River Basin. Mean percent change in spring (April through September) runoff is -25 percent for the 2030s and -40 percent for the 2070s.

Similar to evaluating snowpack at its general peak, projections of soil moisture on June 1 are presented because, in the absence of irrigation or other water management, June is the month of greatest soil moisture throughout the Klamath River Basin. Changes in maximum soil moisture may be of interest to water managers in terms of understanding projected changes in groundwater and soil water availability. Mean historical soil moisture on June 1 over the period 1950–1999 ranges from less than 1 inch to almost 30 inches, with the greatest soil moisture occurring in mountainous regions with melting snowpack and generally higher precipitation (Figure 3-32). Mean percent change in June 1 soil moisture across the Klamath River Basin is a reduction by 4.9 percent for the 2030s and a reduction by 8.7 percent for the 2070s, compared with the historical period. The pattern of projected change in June 1 soil moisture is similar to that of spring runoff, indicating that projected reductions in soil moisture correspond with reductions in spring runoff. Interestingly, these reductions also correspond with projected increases in mean annual runoff, indicating that there may be a seasonal shift in runoff (discussed in the next section), and therefore June 1 soil moisture.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from 1990s values to the 2030s and 2070s, respectively.

Figure 3-32.—Comparison of percent change in mean June 1 soil moisture and mean annual evapotranspiration for the central tendency climate scenario, using groupings of GCMs from CMIP5

Mean historical annual ET over the period 1950–1999 ranges from less than 10 inches to about 33 inches (Figure 3-32). Higher ET values tend to occur in regions with greater water availability (i.e., greater precipitation), like in the Lower Klamath Basin and other mountainous regions. Mean percent change in annual ET basin wide is +2.6 percent for the 2030s and +4.1 percent for the 2070s. Larger percentage increases in ET appear to be projected for parts of the

Upper Klamath Basin. However, these results may not reflect relative increases in the amount of water lost to ET, due to the fact that the Upper Klamath Basin generally has lower annual ET.

Figure B-12 in Appendix B, Supplemental Information for Assessment of Water Supply, illustrates projected changes in June 1 soil moisture and mean annual ET for the 2030s and 2070s central tendency, based on the CMIP3 HDe scenarios. Results are similar in spatial patterns of projected change; however, CMIP3-based projections generally indicate smaller projected changes in June 1 soil moisture and annual ET than CMIP5.

3.7.2 Changes in Timing and Quantity of Runoff

This section evaluates projected changes in mean monthly streamflow at selected locations within the Klamath River Basin, the projected shift in timing of mean monthly hydrographs for one example location within the basin, and low flow frequency statistics for select locations. Analyses focus on projected changes for the two future time horizons (2030s and 2070s) based on CMIP5 projections. Figures similar to those presented in this section, but based on CMIP3 projections, are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, the presentation of projected streamflow results at Keno, Oregon (Figure 3-33) includes projections based on both CMIP3 and CMIP5 to allow for direct comparison of mean monthly hydrographs under various types of projections.

Simulated historical and projected mean monthly hydrographs for the Klamath River at Keno, Oregon are presented in Figure 3-33 to illustrate an example of projected changes in overall flow volume and seasonal peak timing of streamflow in the watershed. The top two panels summarize projections based on CMIP3 projections, while the bottom two panels summarize projections based on CMIP5 projections. The mean monthly historical hydrograph is identical in each panel and was computed over water years 1950–1999 (i.e., September 1949–October 1999).

Both CMIP3- and CMIP5-based projections indicate a decrease in spring and summer streamflow for the 2030s and a greater decrease by the 2070s. The wetter of the five HDe climate change scenarios (HW and WW) indicate greater streamflow volume overall, along with higher seasonal peaks. Drier scenarios (HD and WD) indicate reduced streamflow volumes and reduced peaks. Projections for the 2030s (based both on CMIP3 and CMIP5) indicate a shift in seasonal peak timing from approximately zero to one month earlier (a shift from April to March). For the 2070s, projected shifts in seasonal peak timing are zero to two months earlier (a shift from April to as early as February).

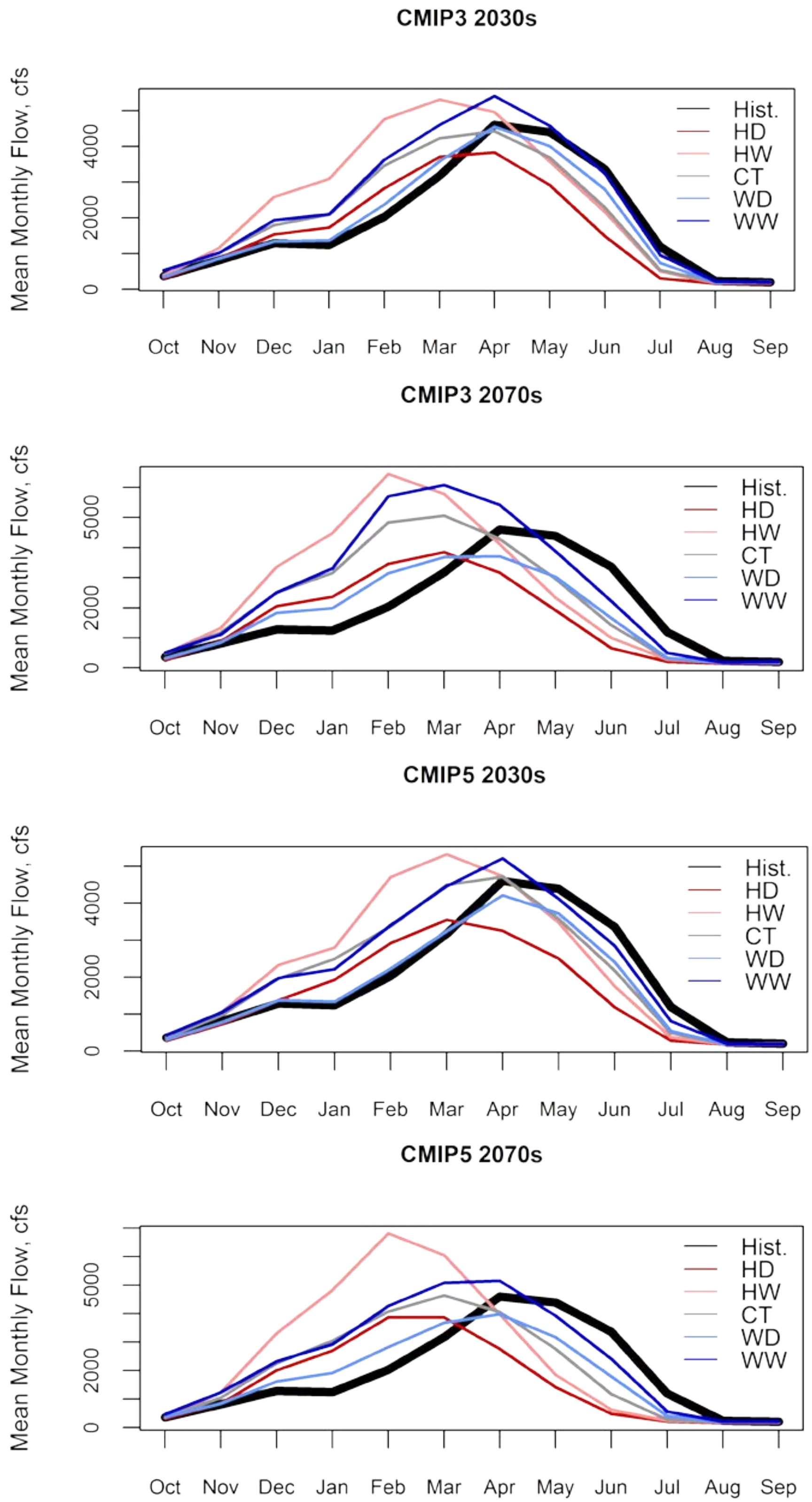


Figure 3-33.—Historical and projected mean monthly hydrographs for Klamath River at Keno, OR (USGS ID 11509500).

The projected shifts in streamflow volume and timing for Keno, Oregon are typical of those sub-basins within the Klamath River Basin that are influenced in part by snowmelt. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume. Wetter scenarios indicate greater increases, while drier scenarios indicate anywhere from a slight decrease in flow volume to a slight increase in flow volume (figures not shown).

The seasonality of streamflow, in particular low flow periods, is of interest to water managers since there is often limited supply for numerous competing resources during low flow periods. At the same time, natural streamflow variability, including low flows, serves an important function for a river ecosystem. Richter et al. (1997) discuss an approach for setting streamflow-based targets for ecosystem management. The approach is based on the notion that streamflow characteristics are useful indicators for assessing ecosystem integrity over time. One of the identified indicators is the annual 7 day minimum of flow. As part of the assessment of future water supply, we evaluated projected changes in the 7Q10 low flow frequency statistic. This statistic is defined as the lowest 7 day mean flow at a location, occurring at a 10 year recurrence interval. As one example of its application, this statistic is used to define the "critical condition" for adverse impact on aquatic biota in Washington state (Chapter 173-201A of the Washington Administrative Code). As part of this assessment, the 7Q10 low flow frequency statistic is evaluated for a number of sites throughout the Klamath River Basin.

Projected changes in the 7Q10 low flow frequency statistic were evaluated as part of the Klamath River Basin water supply assessment as a way of focusing on changes in streamflow during their seasonal low periods. Low flow periods typically occur in late summer when precipitation is low, stored water supplies have largely been consumed, and anadromous fish species begin their upstream migration to spawning grounds.

Table 3-7 summarizes projected changes in 7Q10 low flow frequency for eight selected sites throughout the Klamath River Basin. Primary projected values in the table represent the central tendency, while the values in parenthesis represent the range of the five HDe climate change scenarios for CMIP3 and CMIP5 for each future time horizon. Projected changes were computed as a ratio between the projected value and the historical value. Values greater than one indicate an increase in the 7Q10 low flow, while values less than one indicate a decrease in the 7Q10 low flow (these are shown in bold in the table).

Table 3-7.—Summary of ratios between projected and historical 7Q10 low flow frequency statistics for various sites within the Klamath River Basin

Site ID	Site Name	Hist. 7Q10 (cfs)	2030s CMIP3	2030s CMIP5	2070s CMIP3	2070s CMIP5
00020	Sprague R near Chiloquin	68.6	1.03 (**0.943**-1.06)	1.00 (**0.955**-1.05)	1.01 (**0.917**-1.07)	1.01 (**0.927**-1.07)
00026	Klamath R blw Iron Gate Dam	167	**0.989** (**0.965**-1.01)	**0.989** (**0.970**-1.01)	**0.994** (**0.949**-1.01)	**0.995** (**0.952**-1.01)
00004	Klamath R at Orleans	313	**0.998** (**0.980**-1.01)	**0.995** (**0.982**-1.01)	**0.996** (**0.969**-1.01)	**0.994** (**0.977**-1.01)
00029	Klamath R near Klamath	443	1.00 (**0.983**-1.00)	**0.997** (**0.989**-1.00)	**0.998** (**0.977**-1.00)	**0.996** (**0.981**-1.00)
00022	Salmon R at Somes Bar	23.4	**0.966** (**0.932**-1.01)	**0.979** (**0.957-0.966**)	**0.949** (**0.940-0.996**)	**0.983** (**0.953-0.987**)
00031	Shasta R near Yreka	29.2	1.01 (**0.990**-1.01)	1.01 (**0.979**-1.01)	1.02 (**0.990**-1.02)	1.02 (**0.979**-1.02)
00032	Scott R near Ft Jones	25.9	1.02 (1.01-1.04)	1.04 (1.01-1.05)	**0.996** (**0.996**-1.03)	1.07 (**0.981**-1.07)
00034	Trinity R at Hoopa	99.4	1.01 (1.00-1.01)	1.01 (1.00-1.02)	1.02 (1.00-1.02)	1.01 (1.01-1.02)

Note: Primary values represent the central tendency HDe scenario. Values in parenthesis represent the range of the five HDe climate change scenarios. Values above 1 indicate an increase. Values less than 1 indicate a decrease (shown in bold).

Select sites on the Sprague, Shasta, Scott, and Trinity Rivers are projected to experience increases in 7Q10 low flows for the 2030s and 2070s central tendency, compared with the historical period; however, projections range from slight decreases to slight increases. Projected increases are largely due to projected increases in precipitation. The Trinity River site (00034) is the only site evaluated where the entire range of projections indicate an increase in the 7Q10 low flow statistic. Select sites including three on the mainstem Klamath River (below Iron Gate Dam, at Orleans, and near Klamath) and one on the Salmon River are projected to experience decreases in the 7Q10 low flow central tendency, compared with the historical baseline; however, projections range from slight decreases to slight increases. The Salmon River site (00022) is the only one evaluated where the entire range (except for the 2030s CMIP3) indicates a decrease in the 7Q10 low flow statistic. Projected decreases are likely due to the combined effects of

Future Availability – Runoff Quantity and Timing

For those basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

increased precipitation, increased temperature, and increased ET. It should be noted that projections based on CMIP3 and CMIP5 show similar results in their central tendency.

Projections shown in Table 3-7 are based on streamflow generated by the VIC hydrologic model which represents natural flow, absent of management effects such as withdrawals and groundwater pumping. Combined effects of changes due to climate change and changes in management practices may alleviate or exacerbate projected changes in low flows in the Klamath River Basin. It should be stressed that the historical values presented in Table 3-7 are lower than those typically experienced in the watershed. These values are based on the lowest 7-day running mean that has a 1:10 chance of occurrence. Such an occurrence would likely occur in a prolonged drought condition where groundwater levels (which would typically provide supplemental baseflow) are also negatively impacted. In addition, it should be noted that the VIC model does not represent complex surface and groundwater interactions and therefore may not generate realistic baseflow in a heavily groundwater influenced watershed such as the Klamath River Basin. Additional discussion related to VIC model limitations is provided in Appendix B, Supplemental Information for Assessment of Water Supply.

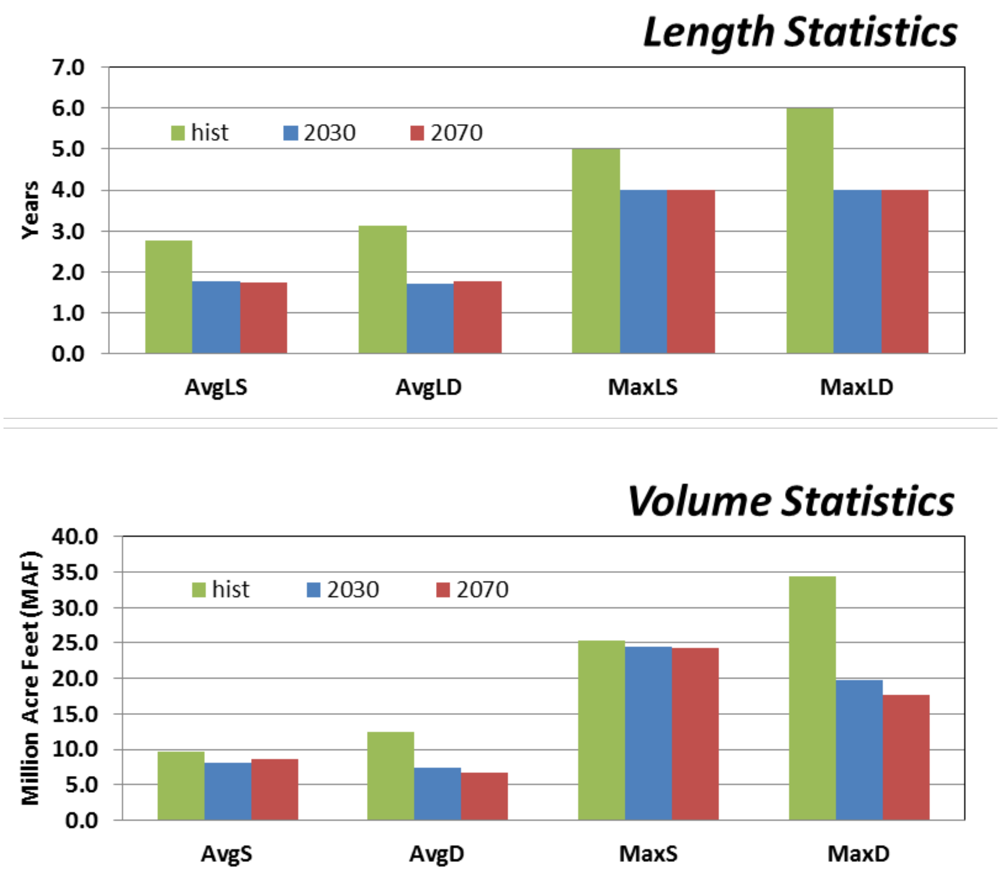
3.7.3 Changes in Drought and Surplus based on Paleo Conditioned Streamflow Projections

Using the approach described in Section 3.5.1.3, Deriving Paleo-Conditioned Streamflow Projections, drought and surplus statistics were analyzed for all HDe scenarios to characterize projected changes in droughts and surpluses. Drought and surplus statistics may be generated at any streamflow location in the Klamath River Basin using this approach. For the Klamath River Basin water supply assessment, we focus on results at the Klamath River near Klamath, California, which represents the integrated response to drought and surplus throughout the basin since it is close to the mouth of the river. Results are summarized graphically for the 2030s and 2070s for CMIP5-based central tendency scenarios in Figure 3-34. The data behind the figure, in addition to other HDe climate change scenarios, is summarized by Tables B-1 and B-2 in Appendix B, Supplemental Information for Assessment of Water Supply.

Future Availability – Droughts and Wet Periods

Analyses of surplus and drought statistics based on the paleo record are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes.

Overall, the surplus and drought statistics are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes. The projections correspond with projections of increased precipitation overall in the Klamath River Basin for both future time horizons (2030s and 2070s). In spite of these statistics pointing to wetter conditions, the maximum surplus volumes are estimated to be nearly equal to the historical maximum surplus. The paleo-hydrologic analysis provides a way to superimpose variability by altering sequences, and for water systems the sequence in which wet and dry spells occur is critical.



Note: AvgLS and AvgLD: average length of surplus and drought, respectively. MaxLS and MaxLD: maximum length of surplus and drought, respectively. AvgS and AvgD: average surplus and drought, respectively MaxS and MaxD: maximum length of surplus and drought, respectively.

Figure 3-34.—Surplus and drought statistics for the paleo-conditioned CMIP-5 central tendency climate scenario.

3.7.4 Changes in Groundwater Supply

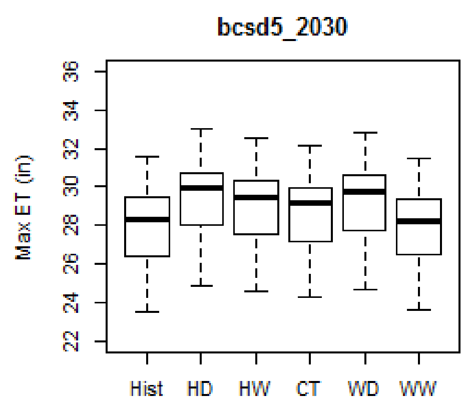
The impacts of climate change on groundwater supplies were evaluated for three primary groundwater basins within the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys. Similar to the assessment of surface water supplies, this assessment focuses on results based on CMIP5 projections. Figures similar to those presented below but based on CMIP3 projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. This assessment also focuses on groundwater impacts as a result of projected changes in climate and surface water hydrology (as well as population for the Scott and Shasta Valleys) and does not consider changes in pumping or other changes in water management.

3.7.4.1 Upper Klamath Basin

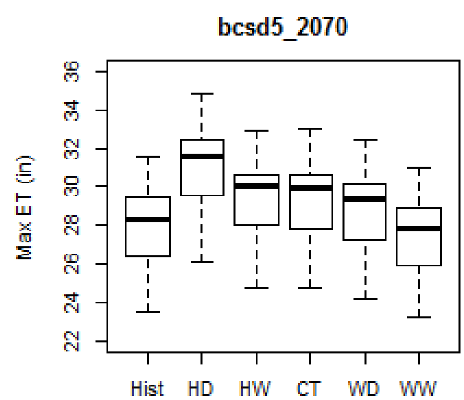
The following analysis of climate change impacts focuses first on the perturbed inputs of maximum ET and mean annual recharge for the projected MODFLOW simulations, and then on MODFLOW simulation results including projected changes in groundwater elevations and discharge to surface water.

3.7.4.1.1 Inputs

Projections for the three perturbed MODFLOW input terms are first discussed to provide context for the discussion of projected changes in groundwater elevations and discharge. Figure 3-35 shows historical and projected mean maximum ET (as defined in the approach) for the five HDe climate change scenarios on an annual basis. As described in the approach, projected maximum ET values were computed based on annual change factors applied to historical maximum ET. The figure shows that mean annual maximum ET is projected to increase for the 2030s and 2070s, compared with the historical period, when looking at corresponding percentile levels. For the 2030s, the drier scenarios (HD and WD) appear to have slightly larger increases than the wetter scenarios. For the 2070s, the HD scenario indicates a larger increase in maximum ET than all other scenarios.



a)



b)

Notes:

1. The heavy black line represents median of values across the 47 VIC cells within the Upper Klamath Basin MODFLOW model domain that contains evapotranspiration cells (defined by Gannett et al. [2012] Figure 4), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

Figure 3-35.—Summary of projected mean annual maximum ET for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years.

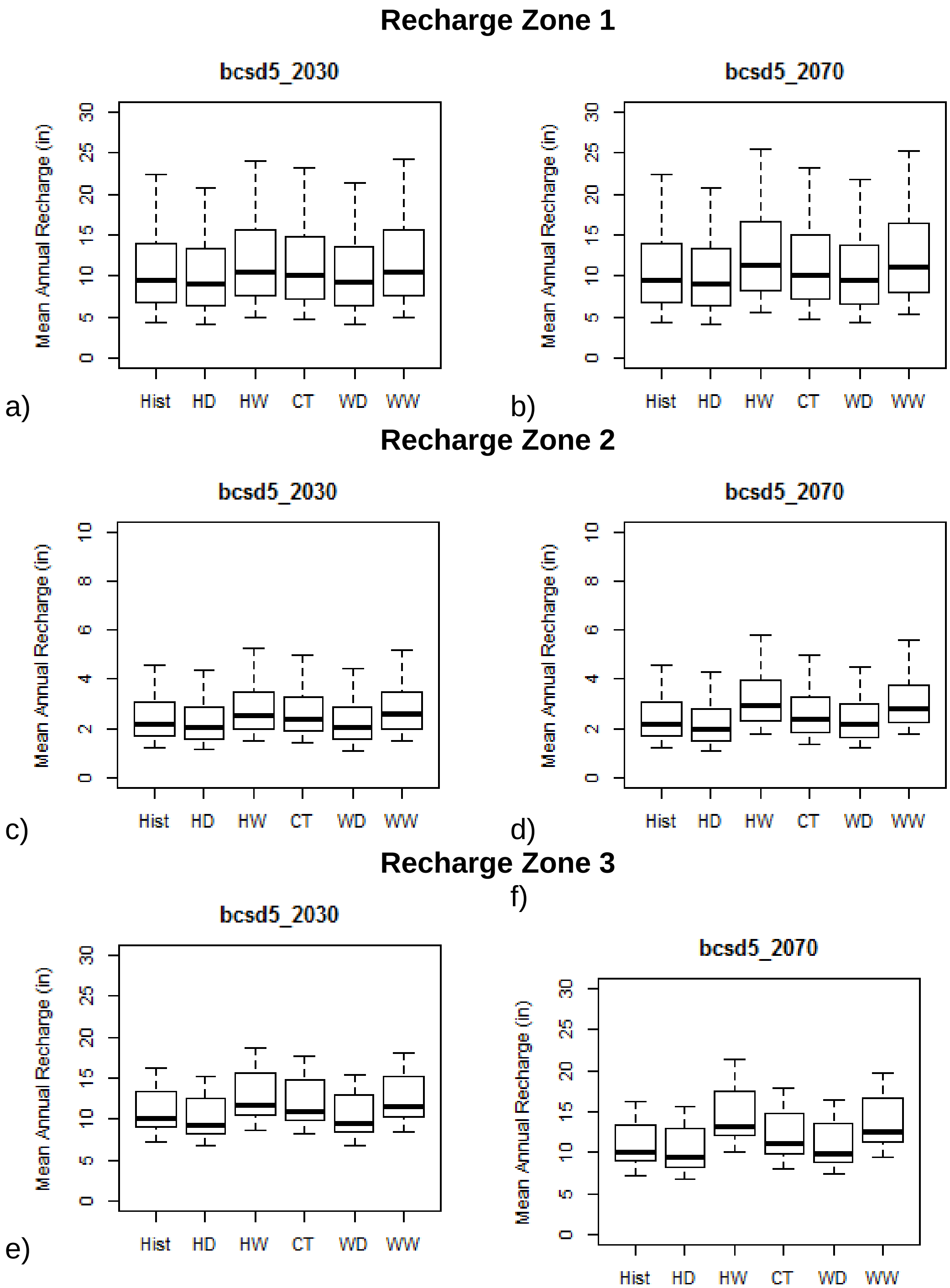
Table 3-8 summarizes the projected increases in the central tendency of mean annual maximum ET for the 2030s and 2070s, for projections based both on CMIP3 and CMIP5. Results show greater increases in maximum ET for projections based on CMIP3 than those based on CMIP5.

Table 3-8.—Summary of central tendency projections of maximum ET for the 2030s and 2070s, compared with the historical baseline (1970–1999).

Central Tendency Projections	2030s	2070s
CMIP3	+4.5%	+7.1%
CMIP5	+3.3%	+5.7%

Projected recharge was input into future simulations of the Upper Klamath Basin MODFLOW model for five HDe climate change scenarios (for two future time periods and both CMIP3 and CMIP5), based on unique historical precipitation-recharge relationships by recharge zone. Figure 3-36 illustrates box plots of projected mean annual recharge by zone based on CMIP5 projections (refer to Figure 3-10 for identification of recharge zones). In general, projections of recharge are similar between future time horizons, both in magnitude and when considering the relative change across different climate change scenarios. Recharge zone 1 has a greater range of recharge (as evidenced by the difference between 5th and 95th percentile values) than zones 2 or 3. Also, recharge zone 2 has substantially lower recharge than the other zones, including the historical values. Lower recharge in zone 2 likely corresponds with less precipitation and snowpack to help drive recharge. Projected changes in mean annual recharge for zone 1 range from increases to small decreases. Wetter scenarios generally indicate increases in recharge, while drier scenarios generally indicate decreases, particularly looking at the median (50^{th} percentile) change.

Table 3-8 summarizes mean annual recharge by zone, and basin-wide, for the central tendency (2030s and 2070s, CMIP3 and CMIP5). For the 2030s, projected changes in recharge differ substantially between CMIP3- and CMIP5-based scenarios. However, by the 2070s CMIP3- and CMIP5-based scenarios are more similar. In fact, the difference in projected recharge change for zone 1 is almost as great between CMIP3 and CMIP5 for the 2030s as the difference between the 2030s and 2070s based on CMIP3. These results were verified; however, it illustrates how closely recharge projections correspond with projections of future precipitation. Basin-wide precipitation changes for the central tendency are projected to be about +2.4 percent (based on CMIP3) and +4.1 percent (based on CMIP5) for the 2030s and about +5.2 percent (based on CMIP3) and +6.1 percent (based on CMIP5) for the 2070s. Projections of recharge for other HDe climate change scenarios show similar correspondence with precipitation projections.



Notes:

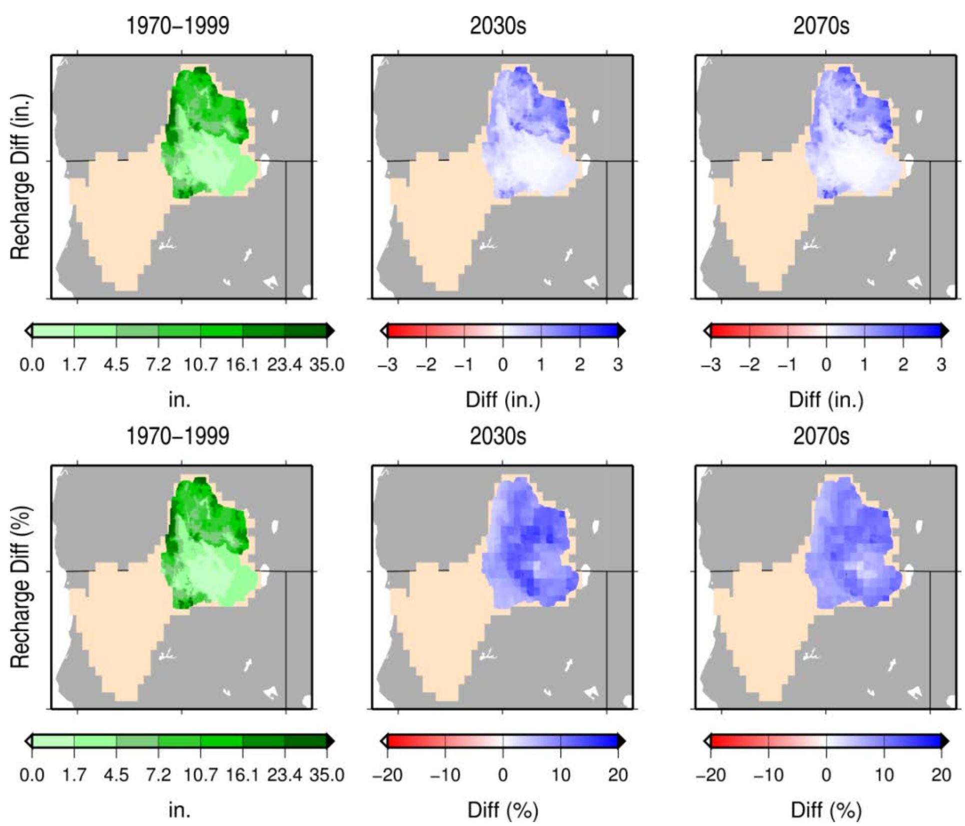
1. Heavy black line represents median of values across the 62 VIC cells within the MODFLOW model domain that are within recharge zone 1, while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

Figure 3-36.—Summary of projected mean annual recharge for MODFLOW model recharge zone 1 for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years.

Table 3-9.—Summary of central tendency projected change in mean annual recharge by zone for the 2030s and 2070s, compared with the historical baseline (1970–1999 water years)

Central Tendency Projections	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Recharge Zone 1	+3.0%	+6.1%	+7.9%	+6.5%
Recharge Zone 2	+4.3%	+8.9%	+8.0%	+9.4%
Recharge Zone 3	+4.6%	+8.8%	+10.5%	+10.0%
Basin Wide	+3.4%	+8.4%	+8.8%	+8.2%

Figure 3-37 spatially illustrates historical and projected change in mean recharge for CMIP5-based central tendency scenarios (2030s and 2070s) based on data used as input by the MODFLOW model for the Upper Klamath Basin. The left column contains identical panels (top row and bottom row) showing the historical seasonal mean recharge (in inches) used in the calibrated model (similar to Figure 3-10). The middle and right columns contain projected change for the 2030s and 2070s, respectively (top row in inches, bottom row in percent change).



Note: The left-hand column illustrates the historical values (top row and bottom row are identical), while the middle and right-hand columns illustrate change (top row in inches, bottom row in percent change) from 1970-1999 values to the 2030s and 2070s, respectively.

Figure 3-37.—Comparison of change in mean annual recharge to groundwater for the central tendency climate scenarios, using groupings of GCMs from CMIP5.

3.7.4.1.2 Outputs

The Upper Klamath Basin MODFLOW model was implemented using projected inputs as previously described. For the purpose of the Klamath River Basin water supply assessment, historical pumping was used to explore the effects of climate change alone on the groundwater balance.

The MODFLOW model computes an overall groundwater budget on a seasonal timestep. Table 3-10 summarizes projected mean changes in the primary output components of the budget for the central tendency HDe scenario. These components consist of groundwater discharge to drains, evapotranspiration, and groundwater discharge to streams. Drains include surface water conveyances such as constructed canals and ditches and natural springs. Units for discharge to drains may be described as cubic feet per second (cfs) per grid cell, where discharge (in cfs) is the mean computed over the simulation period (water years 1970–1999) and across all MODFLOW grid cells designated as drains. Basin-wide changes in groundwater discharge to drains are projected to increase by less than two percent for both the 2030s and 2070s. Considering four central tendency scenarios (CMIP3 2030s and 2070s as well as CMIP5 2030s and 2070s), the greatest increase in discharge to drains is projected for the CMIP5-based 2030s scenario. The integration of projected changes in temperature and precipitation in the modeled domain (i.e., the Upper Klamath Basin) indicate greater increases for the 2030s than for the 2070s based on CMIP5.

Units for ET are inches, where ET is the mean computed over the simulation period and across all MODFLOW grid cells designated as having ET. Projected changes in mean ET indicate increases according to all central tendency projections (Table 3-10), with greater increases projected for the 2070s than for the 2030s. ET corresponds more closely with temperature than with precipitation. Projections of annual temperature (Table 3-5) indicate similar projected increases in the central tendency for the 2030s (CMIP3 and CMIP5) and similar yet greater increases for the 2070s.

Discharge to streams is presented in units similar to discharge to drains, namely mean discharge (cfs) per MODFLOW grid cell designated as stream. Seasonal mean discharge to streams is projected to increase, with the greatest increases projected for the CMIP5 2030s and the CMIP3 2070s scenarios (Table 3-10).

Table 3-10.—Average percent change in mean groundwater balance variables

Central Tendency Projections	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
GW Losses to Drains	+0.4%	+1.8%	+1.2%	+1.3%
GW Losses to ET	+4.1%	+5.2%	+7.3%	+6.4%
GW Losses to Streams	+2.0%	+5.2%	+5.3%	+4.8%

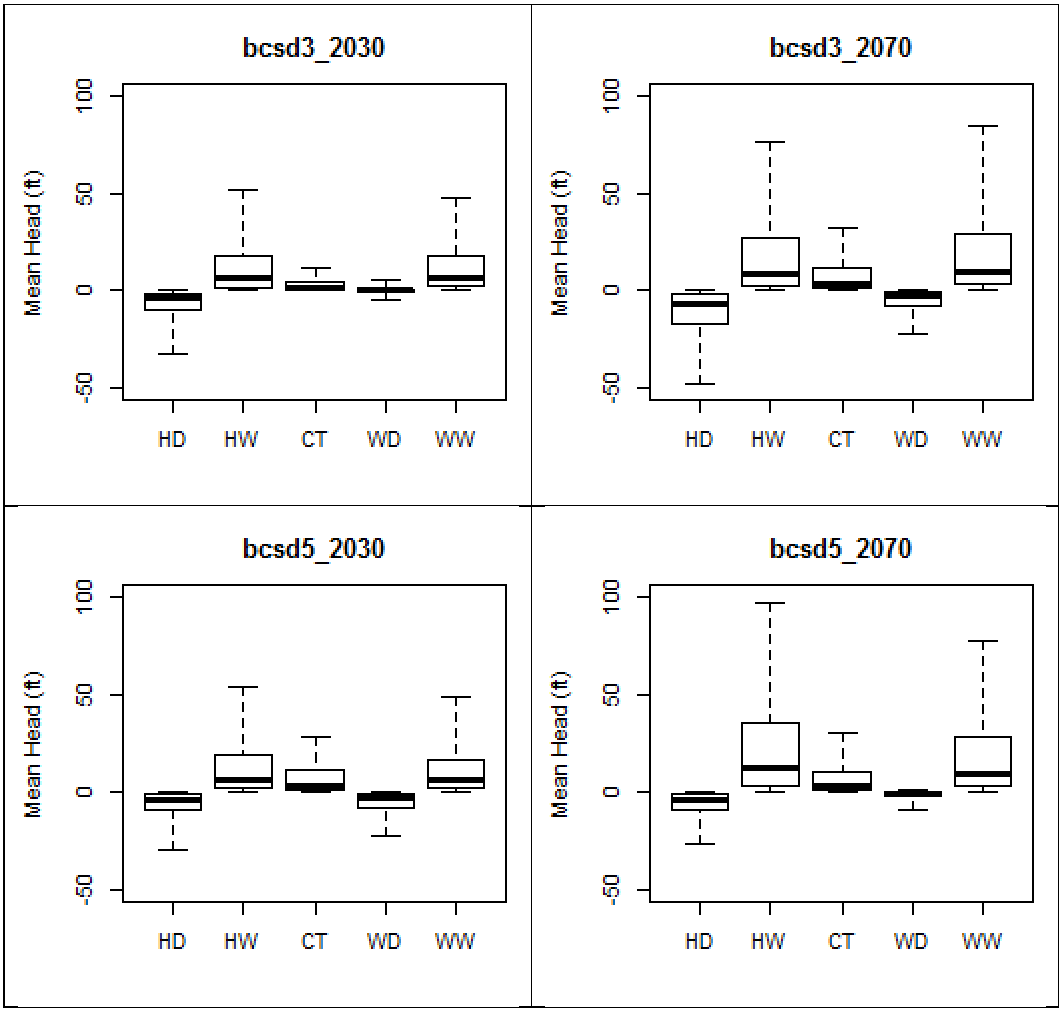
In addition to projected changes in the overall groundwater budget, projected changes in groundwater head for the three vertical layers represented in the MODFLOW model were evaluated as part of the water supply assessment. Groundwater head corresponds with the elevation of the water table. Projected changes in mean groundwater head for the central tendency scenario (2030s CMIP3 and CMIP5 as well as 2070s CMIP3 and CMIP5) are summarized in Table 3-11. Groundwater head is projected to increase by between 1.8 and 7.8 feet for the 2030s (central tendency) and between 4.4 and 8.2 feet for the 2070s.

Table 3-11.—Average change in groundwater head due to MODFLOW simulations based on projected changes in all variables for the central tendency projection

Central Tendency Projected Change (in feet)	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Change in Head, All, Layer 1	3.1	7.8	8.2	7.7
Change in Head, All, Layer 2	2.0	5.0	4.9	4.8
Change in Head, All, Layer 3	1.8	4.6	4.4	4.3

Note: “All” variables include recharge and max ET

Figure 3-38 focuses on layer 1 and shows how projected changes in groundwater head (in feet) for the central tendency compare with other HDe scenarios. Layer 1 is presented because it has the greatest sensitivity to projected climate changes. The wetter scenarios (HW and WW) generally indicate larger increases in groundwater head than the central tendency, while the drier scenarios (HD and WD) indicate smaller increases or even decreases in groundwater head, depending on the type of projection (CMIP3 or CMIP5) and time horizon (2030s or 2070s).

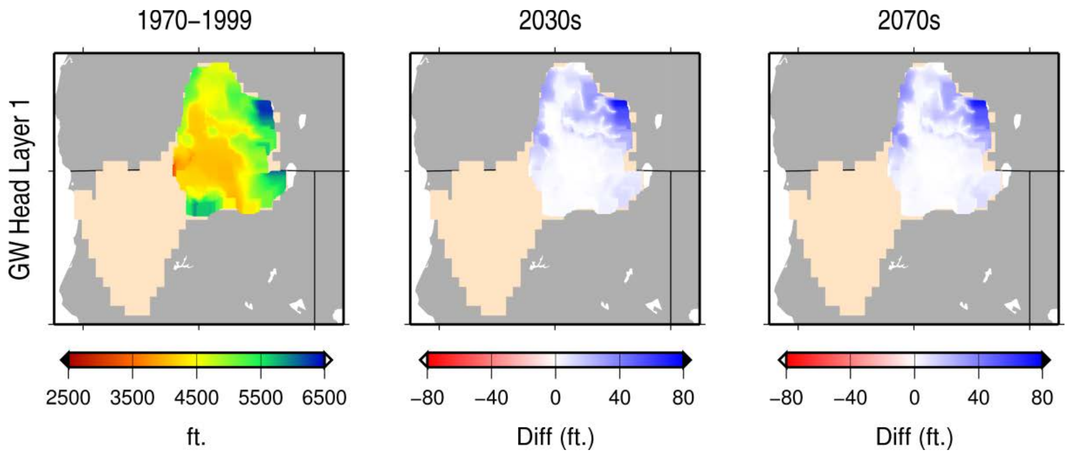


Notes:

1. The heavy black line represents median of values across the roughly 32,000 cells within the MODFLOW model domain (MODFLOW spatial resolution), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW=– hot wet, HD = hot dry.

Figure 3-38.—Summary of difference in projected mean groundwater head for MODFLOW model layer 1 for 2030s and 2070s time horizons compared with the historical baseline period of 1970–1999 water years.

Projected changes in groundwater head for layer 1 for the CMIP5-based central tendency scenario are presented spatially in Figure 3-39. The left column illustrates historical mean seasonal groundwater head over the simulation period 1970–1999 (water years), while the middle and right columns illustrate projected changes in feet for the 2030s and 2070s, respectively. The figure shows that projected changes may result in a substantial depth of water, up to about 50 feet in the northeast portion of the basin. As a point of reference, land surface elevations in the Upper Klamath Basin modeled domain range from 2,500 feet to 8,500 feet.



Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate change (in feet) from 1970–1999 values to the 2030s and 2070s, respectively.

Figure 3-39.—Comparison of change in mean groundwater head in the uppermost layer of the MODFLOW model for the central tendency climate scenario, using groupings of GCMs from CMIP5.

The following analysis summarizes projected discharge to individual stream reaches across the Upper Klamath Basin, as defined in Figure 3-40. Projections summarized in Table 3-12 indicate increases in groundwater discharge for all designated stream reaches. Similar to projections of precipitation and recharge, CMIP5 projections for the 2030s show larger increases than CMIP3 projections, while for the 2070s CMIP3 projections show larger increases than CMIP5. Also, CMIP3 2030s projections show the greatest change overall (even greater than for the 2070s). As previously discussed, the relative differences between scenarios are a result of the process of grouping GCM projections as part of the HDe approach. The smallest projected increases are for Lost River and Wood River reaches, while the largest projected increases are for Sycan and Sprague River reaches.

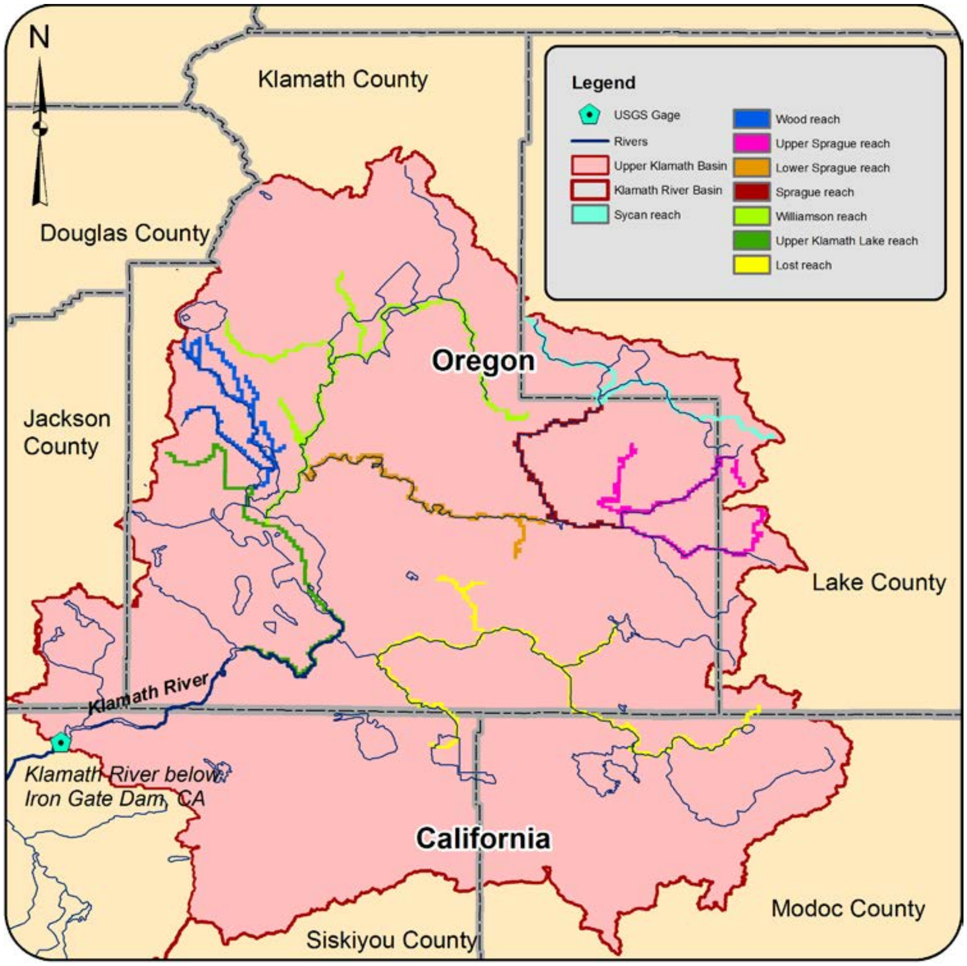


Figure 3-40.—Overview map of MODFLOW stream reaches analyzed as part of the Klamath River Basin Study water supply assessment.

Table 3-12.—Average percent change in groundwater losses to streams over the simulation period for central tendency projections

Central Tendency Projections (Percent Change)	CMIP3 2030s	CMIP5 2030s	CMIP3 2070s	CMIP5 2070s
Lost River	+0.7%	+2.6%	+1.9%	+1.7%
Lower Sprague	+2.8%	+6.5%	+6.8%	+5.3%
Sprague	+3.5%	+9.1%	+8.7%	+8.0%
Sycan	+5.2%	+13%	+13%	+12%
Upper Klamath Lake	+1.2%	+3.5%	+4.0%	+3.6%
Upper Sprague	+2.6%	+7.4%	+6.8%	+6.7%
Williamson	+2.7%	+6.9%	+7.6%	+6.2%
Wood River	+1.0%	+3.0%	+3.6%	+3.1%

3.7.4. Scott Valley

The groundwater screening tools developed for the Scott and Shasta Valleys allow for the evaluation of projected changes in mean groundwater elevation. Figure 3-41 illustrates projected changes in monthly groundwater elevations for the two future time periods based on CMIP5 (panels a and b). Individual boxes in each panel represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. The historical simulation period is calendar years 1980–1999, while the future simulation period is effectively a 50-year period that represents the characteristics of the chosen future time horizon (2030s or 2070s, in this case). Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period in the absence of any changes in groundwater use beyond that associated with population growth. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases.

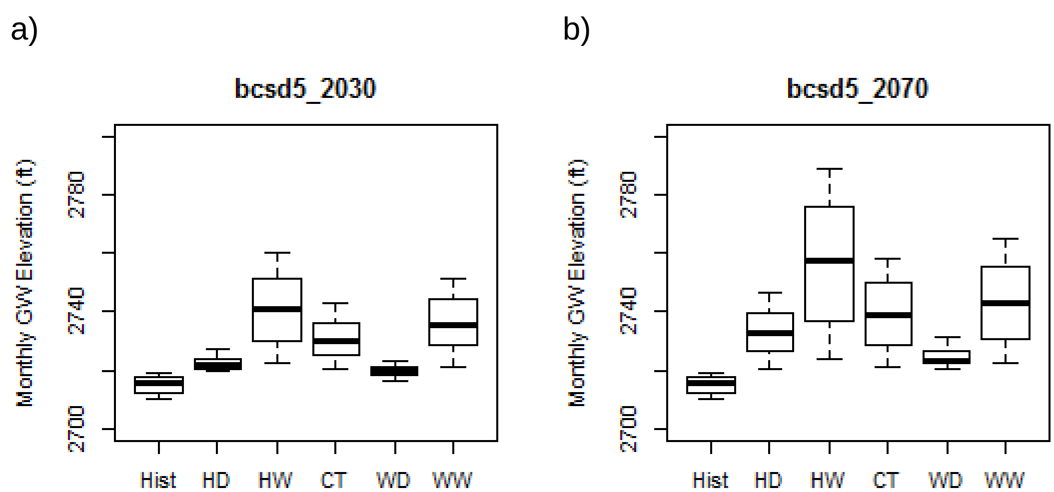


Figure 3-41.—Summary of projected groundwater elevation for Scott Valley.

The central tendency projections fall in between, with a median projection of a 15-foot increase in groundwater elevation by the 2030s and a 23 foot increase by the 2070s. To provide some context, the Scott and Shasta Valleys experienced fluctuations in annual groundwater elevation of about 20 feet over the period 1980–1999. Projected increases in groundwater elevation in the Scott Valley correspond with projected increases in precipitation in the watershed. Projected increases in actual ET computed by the VIC surface water hydrologic model (based on an assumption of natural vegetation) are not great enough to offset the projected increases in precipitation, resulting in greater potential for groundwater recharge.

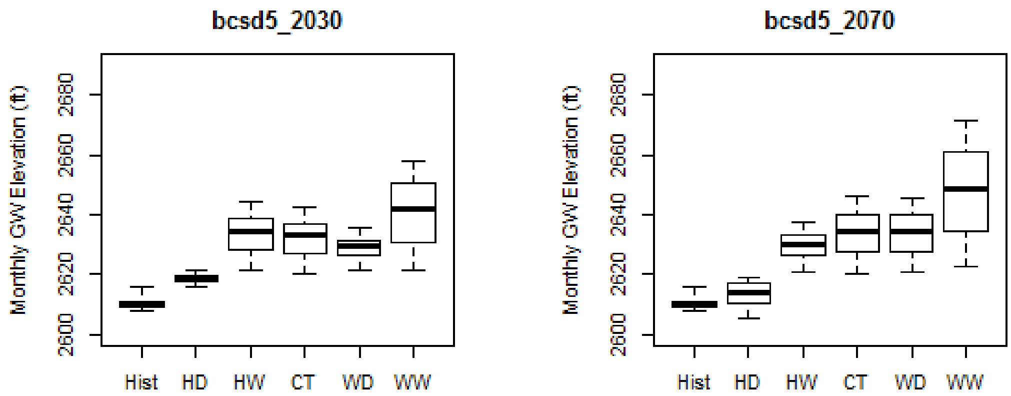
It is notable that the HW scenario based on CMIP5 indicates a greater increase in groundwater elevation than the cooler (WW) scenario. One would expect the HW scenario to have a smaller increase in groundwater elevation due to greater ET losses. However, the HW scenario may actually be wetter than the WW scenario, which may compensate for any additional ET losses due to higher temperatures.

CMIP3- and CMIP5-based projections are similar for the two future time horizons; however CMIP5-based projections generally result in greater increases in groundwater elevation, corresponding with greater increases in precipitation compared with CMIP3. Individual scenarios may also differ to due to the automated selection process for individual GCM projections within a quadrant (refer to Section 3.5.1.1, Climate Projections for additional explanation of the projection selection procedure).

3.7.4.3 Shasta Valley

Projected changes in monthly groundwater elevation for the Shasta Valley are summarized in Figure 3-42 (panels a and b) for the two future time periods based on CMIP5. Box plots are similar to those in Figures 3-41 and represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations in the Shasta Valley.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. The central tendency scenarios based on CMIP5 indicate about a 24-foot increase in groundwater elevation for the 2030s and a 25-foot increase for the 2070s, compared with the historical baseline. To provide context, historical Shasta Valley groundwater elevations fluctuated approximately 20 feet over the historical simulation period. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases. The WW scenario indicates the greatest projected change, likely because ET rates are probably lower than in the hotter scenarios and more water may be available for groundwater recharge.



a) b)

Figure 3-42.—Summary of projected groundwater elevation for Shasta Valley.

A majority of the projections for the 2070s show greater increases in groundwater elevation than for the 2030s, with the exception of the hotter scenarios (for example, CMIP3-based HD and CMIP5-based HD and HW). A smaller increase in groundwater elevation in the 2070s compared with the 2030s, despite greater projected increases in precipitation, may be due to the combined effects of increased ET corresponding with higher temperatures.

When comparing CMIP3-based projections with CMIP5-based projections, the differences in median projections of monthly groundwater elevation are more dissimilar than would be expected. For example, the median monthly change in groundwater for the 2070s compared with the historical baseline is almost 5 feet for CMIP5 and 12 feet (more than double) for CMIP3. This example illustrates the importance of considering a wide range of climate scenarios (including both CMIP3 and CMIP5) in the analysis of water supply impacts.

Future Availability – Scott and Shasta Valley Groundwater

Projected monthly groundwater elevations in the Scott and Shasta Valley alluvial aquifers (as defined by CDWR Bulletin 118) for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. However, the projected changes are within or close to the historical fluctuations in groundwater elevation in the two basins (on the order of 20 feet for both basins).

3.8 External Factors Affecting Water Supply

In addition to detailed analysis of historical and projected surface and groundwater supplies, this chapter also discusses existing knowledge and research regarding historical and projected sea level rise and wildfire risk. We acknowledge that these phenomena have and may continue to change due to projected changes in climate, and they are important considerations when analyzing water supplies in the Klamath River Basin. Sea level rise poses many risks to the coastal landscape and population. Projected increase in wildfires also poses risks to water supply through increased sediment loads to lakes, reservoirs, and streams, potential damage to water supply infrastructure, and changes to landscape characteristics that affect water temperatures, infiltration dynamics, and runoff timing, among other things.

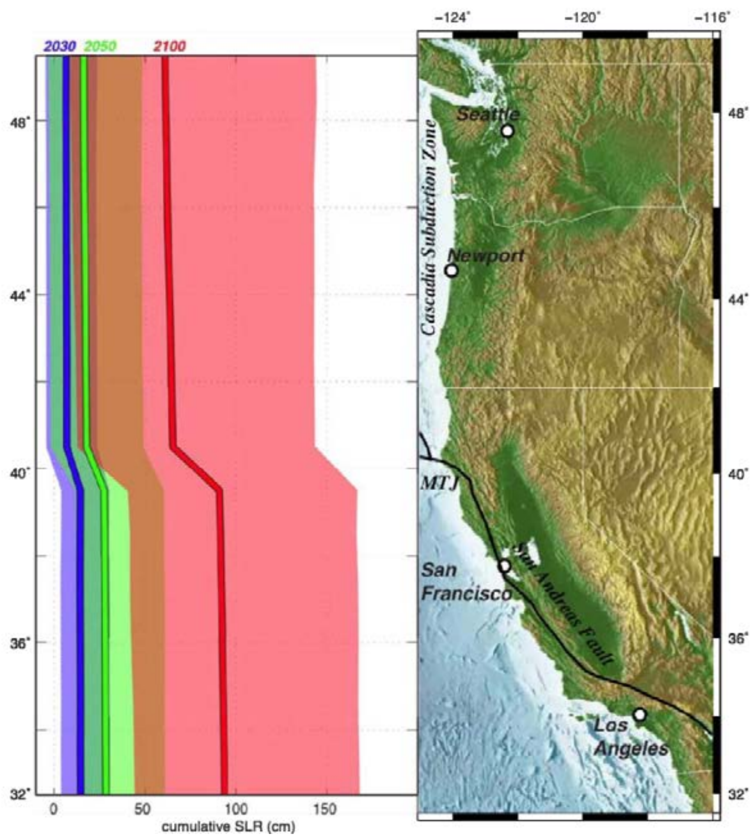
3.8.1 Projected Sea Level Rise

A warming climate causes global sea level to rise by two primary mechanisms: increasing ocean volume due to expanding sea water associated with warming, and the melting of land ice. Other, more regional phenomena impact the extent of sea level rise off the coast of Oregon and California. For instance, climate patterns such as El Niño and the PDO affect winds and ocean circulation, raising local sea level during warm phases (e.g., El Niño) and lowering sea level during cool phases (e.g., La Niña). Large El Niño events can raise coastal sea levels by 4 to 12 inches for several winter months (NRC, 2012). Tectonics may also affect regional sea levels. In some regions, tectonics may cause the land surface to rise in some regions and fall in others, indicating rising and falling sea levels, respectively. For example, records from 12 west coast tide gages indicate local variability in sea-level change along the coast, although most of the gages north of Cape Mendocino, California, show that relative sea level has been falling over the past 6–10 decades (NRC, 2012). Sea level projections due to climate change are confounded by changes due to naturally occurring phenomena described above.

This section summarizes the findings from three primary documents describing the impacts of climate change on sea level rise in the coastal region of the Klamath River Basin. The first is a 2012 assessment by the National Research Council of best available science with respect to sea level rise in California, Oregon, and Washington. The second document is the Public Draft Report of the most recent National Climate Assessment, which was published in 2013. At the completion of the Klamath River Basin Study water supply assessment, the final National Climate Assessment Report was yet not complete. The third document is the State of California Sea Level Rise Guidance Document, which was published in 2013 by the Coastal and Ocean Working Group of the California Climate Action Team. This document provides guidance for incorporating sea-level rise projections in planning and decision-making for projects in California, but also summarizes existing knowledge on projected sea level rise.

National Research Council (2012) summarized past and projected sea-level rise for the coasts of California, Oregon, and Washington. The assessment states that vertical land motion from geological processes and human activities, estimated by global positioning system (GPS) measurements, show that much of the western coast north of Cape Mendocino (including the coastal region of the Klamath River Basin) is rising about 0.06–0.1 inches per year (NRC, 2012). Flooding and erosion in coastal areas is already occurring and is damaging some areas of the California coast during storms and extreme high tides (Garfin et al., 2014). Rising land masses may exacerbate the issue of coastal flooding and erosion.

Projections for the Washington, Oregon, and California coasts north of Cape Mendocino indicate that sea level is projected to change between -2 inches (sea-level fall) and +9 inches by 2030, between -1 inch and +19 inches by 2050, and 4–56 inches by 2100 (NRC, 2012). Sea level is likely to rise at a greater rate during the 21st century than it has in the 20th century. Figure 3-43 illustrates projected sea level rise (in centimeters) along the entire west coast of the U. S.



Source: NRC, 2012, Figure S.1

Figure 3-43.—Projected sea level rise along the west coast of the United States.

Risks associated with projected sea level rise include the increased risk of coastal flooding, storm surge inundation, coastal erosion and shoreline retreat, and wetland loss. NRC (2012) highlights the significant risk posed to the region north of Cape Mendocino from a large earthquake (magnitude greater than 8) along the Cascadia Subduction Zone, which could cause significant land subsidence resulting in instantaneous sea-level rise as well as a tsunami. In addition, many coastal wetlands, tidal flats, and beaches will likely decline in quality and extent as a result of sea level rise.

3.8.2 Projected Wildfire Risk

The sections of the Public Draft of the most recent National Climate Assessment most relevant to the area of this study (Garfin et al., 2013 for the southwest U.S.; Mote et al., 2014 for the northwest U.S.) summarize past and projected trends in wildfire risk along the west coast, including the greater region surrounding the Klamath River Basin. Increased warming, due to climate change, and drought have increased wildfires and impacts to people and ecosystems in the Southwest, including California. A number of studies have documented increases in wildfire fire season duration and fire frequency and project increases in the probability of large wildfires. Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s (Mote et al., 2013). Between 1970 and 2003, warmer and drier conditions increased the burned area in western U.S. mid-elevation conifer forests by 650 percent (Westerling et al., 2006). Models project up to 74 percent more fires in California in the future (Westerling et al., 2012).

Some of the causes of increased wildfire risk include projected decreases in late summer stream flows in some parts of the Klamath River Basin, changes in the timing and amount of recharge, increases in evapotranspiration, and declines in the groundwater table due in part to increases in pumping demand. Potential increases in water deficits may increase tree stress and mortality, tree vulnerability to insects, and fuel flammability (Mote et al., 2013). Also, an increased risk of watershed vegetation disturbance is anticipated due to increased wildfire potential (Interior and CDFG, 2011).

3.9 Uncertainties Associated with Impacts Assessment Approach

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study water supply assessment, including the use of climate change scenarios as well as surface and groundwater hydrologic models to evaluate climate change impacts. Additional discussion regarding the use of

GCM climate projections and applied downscaling techniques is provided by Reclamation (2011d). The nature of these uncertainties is only briefly described below.

3.9.1 Global Climate Projections, Modeling, and Downscaling

The climate projections considered in this report represent a range of future greenhouse emission pathways (Reclamation, 2011d); however, uncertainties associated with estimating these pathways, including those introduced by assumptions of global growth and land use, are not explored in this analysis. Additional uncertainty is associated with feedbacks such as the influence of human-produced aerosols in the atmosphere.

GCMs themselves have associated uncertainty with respect to their initial conditions and representation of physical processes. Model simulations may have quite different realizations of longer timescale climate patterns. Regarding representation of physical processes, the most recent generation of GCM simulations (based on CMIP5) incorporate, in many cases, improved understanding of the climate system. By using both CMIP3- and CMIP5-based projections as part of the Klamath River Basin Study water supply assessment, we may evaluate the differences in results based on a wider range of model constructs. GCMs may have biases toward being too wet, too dry, too warm, or too cool, and these should be identified and accounted for in climate change impacts studies (Reclamation, 2011d). For example, Bindoff et al. (2013) acknowledge that the observed global mean surface temperature has shown a much smaller increasing linear trend over 1998-2012 than the suite of CMIP5 models. However, there is very high confidence that the CMIP5 models show long-term trends consistent with observations, despite the disagreement over this period. Due to internal climate variability, in any given 15-year period the observed trend in the global mean surface temperature sometimes lies near one end of a model ensemble.

Generally, to account for potential inconsistencies between simulated climate and observed conditions, projections are bias corrected. The term bias correction refers to the use of a statistical procedure to adjust global climate model projections to remove differences between simulated and observed climate conditions computed over a common historical time period. This method assumes that biases are systematic and their distributions over the historical time period would be similar to a future time period. The IPCC identifies primary causes of bias in global climate model simulations to be related to the coarse resolution of global climate models and the corresponding inability to resolve important stationary features such as land surface topography and land-water interfaces along coastlines and the use of simplified parameterizations to represent physical processes that occur at too small a scale or are too complex to be represented physically. Model biases can significantly affect impact studies that use climate projections to evaluate hydrologic and ecosystem response to potential changes in climate. As a result, bias correction is often required before global climate model outputs can be used as inputs to other types of models.

Uncertainties are also associated with the methodology used to downscale information at the scale of GCMs to the regional, or watershed, scale. The Klamath River Basin Study utilizes statistically downscaled climate projections to derive HDe climate scenarios. Although these types of scenarios have been used to support numerous water resources impacts studies, uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies, such as statistical downscaling, require historical reference information use on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which presumably would change somewhat with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have statistical stationarity. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

3.9.2 Watershed Vegetation Changes under Climate Change

In Reclamation (2011d) and related literature sources cited, the chosen approach for assessing hydrologic effects under projected climate changes is to use a surface water hydrologic model that computes hydrologic conditions, given changes in weather, while holding other watershed features constant. Vegetation features might be expected to change as climate changes, and that, in turn, would affect runoff through changes to evapotranspiration and infiltration processes.

3.9.3 Quality of Hydrologic Model Used to Assess Hydrologic Effects

In Reclamation (2011d) and most of the cited literature sources, the chosen approach for assessing surface water hydrologic effects has typically involved using surface water hydrologic models, which may not represent key hydrologic processes related to groundwater and/or large water bodies. Reclamation (2011d) discusses these limitations, and they are illustrated in Section 3.3.2, Historical Surface Water Availability – Approach, which shows how the VIC model imperfectly reproduces historical runoff conditions. Some of these imperfections could be reduced through refined redevelopment, or calibration, of the model.

Another approach for exploring the uncertainty associated with the VIC hydrologic model, which was not taken in this study, would be to apply additional surface water hydrology models and compare results across simulations.

In the case the Klamath River Basin, refinement of VIC model calibration is challenging due to the lack of available naturalized flow datasets. Reclamation (2005) showed the difficulty in developing naturalized flows in such a complex watershed. Additional efforts may be invested in this area; however, focusing on a change of projected future conditions relative to historical conditions is a scientifically defensible approach taken in numerous climate change impacts studies, and is the approach taken for the Klamath River Basin Study water supply assessment.

3.9.4 Quality of Groundwater Models Used to Assess Groundwater Effects

Groundwater modeling in general is extremely challenging due to the complexity of most groundwater systems (the Klamath River Basin included) coupled with a general lack of sufficient data to characterize groundwater basins in great detail. The USGS has made great efforts in collecting data and developing a fine scale finite-difference MODFLOW model for the Upper Klamath Basin (Gannett et al., 2012). Despite the high level of effort taken in this study, significant uncertainties still remain about the adequacy of the model to characterize detailed groundwater dynamics in the basin. Gannett et al. (2012) discuss possible reasons for differences between observed and simulated groundwater elevations in parts of the basin, including lack of accurate information on rates and locations of pumping, and coarse vertical discretization of the model relative to the gradients of groundwater flow. Nonetheless, we may assume that historical biases in the MODFLOW model may carry through to the future. As such, we may evaluate the relative change of projected groundwater elevations and discharge compared with the historical simulation.

The Scott and Shasta Valleys have greater issues of data availability for characterizing the groundwater systems than the Upper Klamath Basin, where more resources have been invested in monitoring and evaluating the groundwater system. Monitoring wells are few and the monitoring data available for those wells is sparse, generally consisting of two or so measurements per year. In addition, CDWR Bulletin 118 was used to define groundwater basins in these regions, and these likely do not represent the complexity of groundwater aquifers that exist there. Development of groundwater models for these basins using this information poses a challenge. Furthermore, the size of these groundwater basins is much smaller than the Upper Klamath Basin, making the coarse spatial resolution of groundwater model inputs (such as precipitation, temperature, and gridded runoff) less relevant at the scale of these sub-basins. Due to these high levels of uncertainty, a statistical modeling approach was taken to simulate groundwater elevations in the Scott and Shasta Valleys. A simpler approach may be justified when uncertainty associated with input data is high. Still, the statistical models may be used to evaluate the relative change of projected groundwater elevations compared with estimated historical conditions.

3.9.5 Climate Projections from CMIP3 and CMIP5

The above discussions of uncertainty related to climate forcings and downscaling techniques are based on analysis of projections from CMIP3. The models and scenarios of emissions used in CMIP5 differ in several ways from those used in CMIP3. First, model resolution has generally increased by a factor of 2 (i.e., CMIP5 models have, on average, twice the number of grid cells representing the atmosphere than CMIP3 models). Second, although many of the models used in CMIP5 are similar in structure to those used in CMIP3, many incorporate updated physics and added, or improved, individual process representation. Some of the models used in CMIP5 reflect a fundamental advancement in model structure by incorporating biogeochemical cycling; this new class of models is referred to as Earth System Models. Third, there are notable differences in precipitation for some regions (e.g., greater warming over the Upper Columbia Basin, less precipitation over the northern Great Plains, and more precipitation over California and the Upper Colorado Basin). Projections showing wetter portions of California and the Upper Colorado are notable because they challenge the prevailing perspective of climate change impacts to the region that has been held since 2007 (informed by CMIP3 projections): namely, that these regions will become drier, resulting in reduced runoff. It is important to recognize that while CMIP5 offers new information, more work is required to better understand CMIP5 and its differences compared to CMIP3. In some regions, model resolution is likely the leading factor in these differences. In the North American Monsoon region, for example, the higher resolution of CMIP5 models allows these models to better capture the landward moisture transport and overland convection that results in monsoon precipitation events. These processes were not resolved in the lower resolution CMIP3 models.

The CMIP5 projections represent a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. While CMIP5 projections may inform future analyses, many completed and ongoing studies are informed by CMIP3 projections that were selected as the best information available at the time of the study. Even though CMIP5 provides the latest available suite of climate projections, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 projections. Current state of practice relies on one or both suites of climate projections for use in impacts studies.

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Chapter 4

Klamath River Basin Study

Assessment of Current and Future Water Demands

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Chapter 4
Assessment of Current and Future Water Demands

4.1 Introduction

Changes in water demands in the Klamath River Basin over the next 50 years are uncertain, and will depend on a number of socioeconomic and other factors. The Klamath River Basin Study aims to assess the impacts of climate change on water supply and demand in the watershed from its headwaters to the mouth, and to identify current and projected water supply shortages. This chapter of the Klamath River Basin Study report quantifies current water demand and projected future water demand in a changing climate. Future demand projections are meant to be sufficiently broad to capture the plausible ranges of uncertainty. Projected water demands are evaluated along with the projected supply conditions in Chapter 3 as part of a system reliability analysis to identify potential water supply shortages in the Klamath River Basin, which is presented in Chapter 5. The system reliability analysis, presented in Chapter 6, identifies any potential shortfalls between demand and supply, as well as potential strategies to plan for and reduce gaps.

Statistically downscaled climate projections from general circulation models (GCMs) inform both the demand and supply analyses. As discussed in Chapter 3, two sets of downscaled GCM output were used in the analyses: Coupled Model Intercomparison Project Phase 3 (CMIP3) and Coupled Model Intercomparison Project Phase 5 (CMIP5). The main components of the Klamath River Basin Study and their interaction with developed climate change scenarios are shown in Figure 4-1. The ensemble hybrid delta (HDe) period change method (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d) described in Chapter 3 was used to assess the impacts of climate change on demands. The future periods used for the Klamath River Basin Study are the 2030s and 2070s (represented as the mean over 2020–2049 and 2060–2089, respectively) and the historical baseline period used for the analyses is 1950–1999.

Some of the analyses described in this chapter are based on previous work done as part of Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). WWCRA is a component of the Department of the Interior WaterSMART Program that was implemented to meet requirements of the Secure Water Act (Public Law 111-11, Sections 9501-9510).[6]

[6] https://www.usbr.gov/watersmart/baseline/index.html

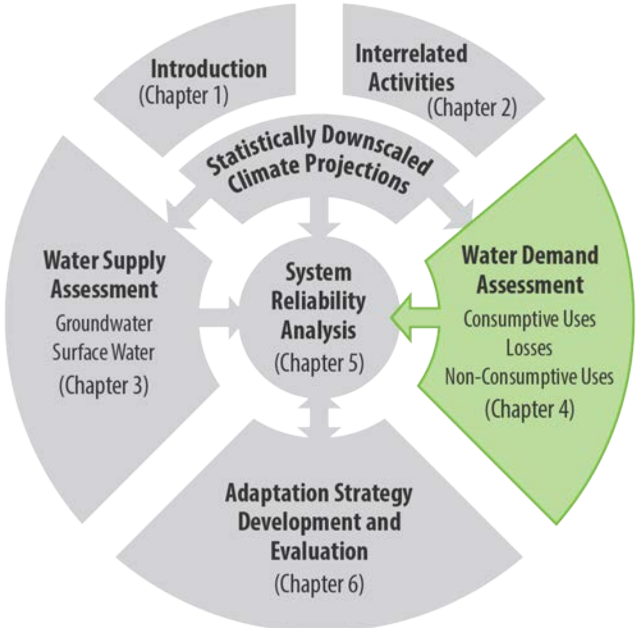

Figure 4-1.—Overall approach of Klamath River Basin Study, highlighting Chapter 4

4.1.1 Description of Water Demands

Water demands are typically associated with one or more water uses that can be consumptive or non-consumptive. Consumptive water use results in a loss of water from the supply system, often associated with human activities. Examples of consumptive uses include manufacturing, agriculture, and food preparation where water is not returned to the supply system. Evaporation from water bodies such as reservoirs is another type of consumptive use that is more typically considered a loss. Non-consumptive uses are those which do not deplete the water supply. There are many types of non-consumptive uses; significant examples relevant to this study include hydropower generation, environmental resources, recreation, and aquaculture. Municipal and industrial (M&I) and rural domestic demands are typically comprised of both non-consumptive and consumptive uses. Another significant demand category relevant to the study is tribal demands, which are also comprised of both consumptive and non-consumptive uses.

Definition of Terms

Demand – Water needed to meet identified uses.

Consumptive Use – Water use resulting in a loss of available water supply, often associated with human activities.

Loss – Reduction of available water supply due to evaporation and operation inefficiencies.

Non-Consumptive Use – Water use not resulting in reduction of available water supply.

The focus of the Klamath River Basin Study is the assessment of current and future demands with respect to consumptive uses (both human-influenced and natural) and losses. Non-consumptive demands are either discussed qualitatively in this chapter or are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6.

4.1.2 Previous Studies

Many previous studies have quantified various types of water demand in all or part of the Klamath River Basin. Table 4-1 identifies the references that were reviewed in development of the water demands assessment. In the case of agricultural irrigation and reservoir evaporation, we utilized methods described by Reclamation (2014) in order to maintain consistency with approaches used in other western U.S. watersheds.

The following sections discuss current and future water demands, and detail how previous studies were used and whether the analysis was quantitative or qualitative.

Table 4-1.—Summary of demand categories and related previous studies

Demand Categories	Primary Information Source(s)	Domain
Human Influenced Consumptive Uses		
Agricultural irrigation	Reclamation WWCRA (2014)	Western U.S.
		U.S. Counties
	HDR (2008)	Oregon
	CDWR (2009)	California
	Cuenca (1992)	Upper Klamath Basin (Oregon)
	Gannett et al. (2007)	Upper Klamath Basin
	Reclamation (2005b)	Klamath Project area
Municipal & Industrial	CDM (2010)	Klamath Falls, OR
	SHN (2004)	Hayfork, CA
	Pace (2011)	Weaverville, CA
	Pace (2004)	Weed, CA
	Tully and Young (2010) and Pace (2006)	Yreka, CA
	The USGS Water Use Program (http://water.usgs.gov/watuse/; Kenny et al., 2009)	U.S. Counties
	HDR (2008)	Oregon
	CDWR (2009)	California
Rural Domestic	USGS Water Use Program	U.S. Counties
Tribal	Interior and CDFG (2012)	

Table 4-1.—Summary of demand categories and related previous studies

Demand Categories	Primary Information Source(s)	Domain
Other Consumptive Uses and Losses		
Wetlands	Stannard et al. (2013)	Upper Klamath Basin
	Mayer and Thomasson (2004)	Lower Klamath NWR
	Bidlake (2002)	Tule Lake NWR
Evaporation from lakes and reservoirs	Reclamation WWCRA (2014)	Western U.S.
	Bidlake (2000), Bidlake and Payne (1998), Janssen and Cummings (2007), and Stannard et al. (2013)	
Non-Consumptive Uses		
Environmental Resources	See Section 4.2.3.2, Environmental	
Hydropower	See Section 4.2.3.3, Hydropower	
Recreation	See Section 4.2.3.1, Recreation	
Aquaculture	See 4.2.3.4, Aquaculture	

4.2 Current Demands

Historical and current consumptive water uses and losses were quantified through findings from previous studies and model simulations and evaluated in order to compare with potential future changes due to climate change. Non-consumptive uses are briefly discussed; however, these uses are quantified in the modeling supporting the system reliability analysis in Chapter 5. Identified non-consumptive needs are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6. The current demands considered in this chapter are listed in Table 4-2 along with the sources or models used to provide an estimate for the Klamath River Basin Study. Each of the demands evaluated in this chapter, and the associated estimates used, are discussed in the sections that follow.

Current Human Influenced Consumptive Uses

Based on analyses supporting the Klamath River Basin Study, total consumptive water demand for human uses in the basin is about 800,000 acre-feet/year and about 98 percent of the total human influenced demand is for agricultural irrigation.

4.2.1 Human Influenced Consumptive Uses

Consumptive uses for human needs in the Klamath River Basin Study demands assessment have been quantified using a variety of existing sources as well as model simulations. Table 4-2 summarizes the categories for which demands have been quantified, showing primary sources of data and models used.

> **Current Human Influenced Consumptive Use Estimate Sources**
>
> Human influenced consumptive use estimates are based in part on USGS data, but this study uses WWCRA based model simulations for agricultural demands

One existing source of consumptive use information, which was used in conjunction with other sources described later, is the countywide USGS Water Use Program data. This is arguably the most comprehensive source of existing water use information for the study area (including both consumptive and non-consumptive uses). The most current data available are typically for 2005 and 2010, but more recent data were available in a few cases.

Table 4-2.—Summary of demand categories evaluated by the Klamath River Basin Study Assessment of Current and Future Water Demands and data and methods used

Demand Categories	Data Sources Used	Methods Used
Human Influenced Consumptive Uses		
Agricultural irrigation	Reclamation WWCRA (2014)	ET Demands Model (further described in corresponding section)
Municipal & industrial	Municipal water plans and USGS Water Use Program (see references in Table 4-1)	Statistical models and historical information
Rural domestic	USGS Water Use Program	Statistical models and historical information
Tribal	Addressed as part of agricultural, M&I, and Rural Domestic demand categories	
Other Consumptive Uses and Losses		
Wetlands	Stannard et al. (2013)	ET Demands Model and empirical relationships
Evaporation from lakes and reservoirs	Reclamation WWCRA (2014)	Complementary Relationship Lake Evaporation (CRLE) model

Included in Table 4-3 are 2005 USGS usage estimates for Siskiyou and Trinity Counties in California, Klamath County, Oregon, and the portion of Modoc County, California within the Klamath River Basin.[7] The total basin demand is approximately 1.2 million acre-feet per year (AFY). Note that Table 4-3 values are not all-inclusive since Del Norte and Humboldt Counties in the California portion of the basin are not included. Estimates for these counties are not included since only a very small portion of their water demands (estimated between 1 and 2 percent) occur within the basin. The in-basin demands for these counties are discussed later under the specific demand category discussions. Also note that the USGS data do not include reservoir evaporation. Additionally, the uses reported in Table 4-3 include both consumptive and non-consumptive components of these uses. For example, municipal and industrial (M&I) use includes water that eventually returns to the river system via a wastewater treatment plant.

Table 4-3.—Summary of USGS 2005 Water Use Program estimates for the Klamath River Basin

Water Use Category (note: includes both consumptive and non-consumptive uses)	2005 Use (AFY)
Surface water irrigation	717,154
Groundwater irrigation	433,164
Municipal and industrial	18,204
Rural domestic	11,255
Livestock	2,903
Mining and industrial/commercial	2,868
Total (human influenced uses)	**1,185,548**

Source: USGS Water Use Program

The Klamath River Basin Study estimates of current human influenced consumptive uses in the watershed are based in part on the USGS Water Use Program data summarized above. However, in the case of agricultural irrigation demand (surface and groundwater), this study utilizes model simulations of agricultural water requirements following the approach of Reclamation's West Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). In the case of M&I and rural domestic water uses, more current (2010) estimates were made based on historical population trends. Also, the study focuses only on the consumptive portion of these demands, which is assumed to be 40 percent for both M&I and rural domestic demands and comprised of landscape irrigation (refer to Section 4.2.1.2, Municipal and Industrial).

[7] https://www.usgs.gov/mission-areas/water-resources/science/water-use-united-states?qt-science_center_objects=0#qt-science_center_objects

Estimated current consumptive uses (including human influenced uses, wetland ET, and reservoir evaporation losses) by the Klamath River Basin Study are summarized in Table 4-4. These are estimated basin-wide uses that are the basis for assessment of projected changes in consumptive uses and losses for the two future time periods considered in this study, the 2030s and 2070s. Respective sections of this chapter provide details behind these estimates and the associated assumptions made. Note that the estimated reported M&I and rural domestic consumptive uses (see Table 4-4) are approximately 40 percent of the values reported by the USGS Water Use Program (see Table 4-3), which supports the assumption by the Klamath River Basin Study regarding the consumptive portion of total M&I and rural domestic demand.

Table 4-4.—Estimated current basin-wide consumptive uses and losses as computed by the Klamath River Basin Study

Basin Wide Consumptive Uses and Losses	Estimated Mean Annual Quantity (AFY)
Agricultural irrigation (NIWR)	755,734
Municipal and industrial	8,801
Rural domestic	4,537
Subtotal for Human Influenced Consumptive Use	**769,072**
Wetland ET	1,089,061
Reservoir and lake evaporation	181,297
Total Consumptive Uses and Losses	**2,039,430**

4.2.1.1 Agricultural Irrigation

Irrigation of croplands is by far the largest human influenced consumptive use in the Klamath River Basin, 97 percent[8] according to the USGS Water Use Program estimates (which include conveyance and on-farm losses) and approximately 98 percent[9] according to the Klamath River Basin Study estimates (which do not include conveyance and on-farm losses). Agricultural irrigation use typically includes crop demands, conveyance losses, and on-farm losses. Conveyance and on-farm losses are a function of methods employed to convey water to the croplands (open channels, pipe, etc.) and to apply irrigation water (flood, sprinklers, etc.). Given the numerous variables associated with conveyance and on-farm losses, these losses were not calculated in this study.

Crop demands are consumptive. Conveyance and on-farm losses can be consumptive or non-consumptive. Examples of non-consumptive conveyance and on-farm losses include field runoff and deep percolation, since associated

[8] Computed as sum of 717,154AFY and 433,164AFY, divided by 1,185,548AFY (refer to Table 4-3).
[9] Computed as subtotal for human influenced consumptive uses 755,734AFY, divided by 769,072AFY (refer to Table 4-4).

water generally returns to the supply system. An example of a conveyance or on-farm loss that is consumptive is evapotranspiration by natural vegetation on farm lands or in and around canals.

ET Demands Model Methodology

The model calculates historical and future daily net irrigation water requirements using the FAO-56 dual crop coefficient method with crops, temperature, precipitation, wind, and soil inputs. Solar radiation and humidity are estimated from daily minimum and maximum temperature inputs.

This study focuses on the crop demands, or crop net irrigation water requirement (NIWR). NIWR is equal to the total crop demand minus that amount of the crop demand that is met by precipitation, i.e., effective precipitation (P_e). NIWR does not include conveyance or on-farm losses. Crop water demand is a function of evapotranspiration (ET), which is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Allen et al., 1990). Crop water demand also does not include conveyance or on-farm losses.

Current NIWR estimates have been developed for this study. A discussion of recent irrigation demand estimates is presented first, followed by a discussion of the developed NIWR estimates.

4.2.1.1.1 Recent Irrigation Estimates by Others

Estimates by others are presented as background information and for comparison to those developed in the Klamath River Basin Study. As discussed previously, the USGS estimates that total irrigation water use for the basin in 2005 was 1,150,318 AF, including 717,154 AF from surface water sources and 433,164 AF from groundwater sources (Kenny et al., 2009). These estimates include irrigation of golf courses, parks, nurseries, cemeteries, and other self-supplied landscape-watering uses. The USGS estimates also include conveyance and on-farm water losses. Detailed information on how the USGS developed the 2005 irrigation estimates is provided in Dickens et al. (2011).

Current Agricultural Irrigation Demand

Agricultural irrigation demands, in the form of net irrigation water requirement (NIWR), were simulated by the ET Demands model using current cropping data and average climate conditions for the period 1950–1999.

The CDWR estimates crop irrigation demands annually for the California portion of the Klamath River Basin (the Klamath

Upper and Lower Planning Sub-area).[10] The CDWR estimates include NIWR and total water applied, which includes on-farm losses but not conveyance losses. The reported 2010 estimates for the California portion of the basin are 347,672 AF of NIWR and 482,504 AF total water applied (Coombe, 2013). It is estimated that approximately 62 percent of the total demand is met with surface water and 38 percent is met with groundwater sources.

The OWRD's recent Statewide Water Needs Assessment (HDR, 2008) includes a 2010 agricultural irrigation water use estimate for Klamath County, Oregon, which represents the approximate Oregon portion of the basin. The estimate is 730,000 AF and includes both on-farm and conveyance losses.
The sum of CDWR and OWRD estimates (1,212,504 AF) is greater than, though comparable to, the USGS estimate for total irrigation (1,150,318 AF). It is assumed the discrepancies are associated with which loss estimates were included and how they were estimated.

4.2.1.1.2 Estimation of Net Irrigation Water Requirements

Current and future NIWR estimates were developed for this study following the methods established by Reclamation's WWCRA. Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2014).

The current or baseline irrigation water demand estimates developed for this study are based on the most recent available crop data and climate conditions during the historical baseline period 1950 through 1999. Crop types and quantities reported for 2009 were provided by the Klamath Basin Area Office for Reclamation's Klamath Project lands, and crop data for the remainder of the basin were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service as reported for 2010.[11] The 1950 through1999 climate data used are from the same published data set by Maurer et al. (2002) discussed in Chapter 3. The values used from this data set were adjusted based on historical observations from 13 weather stations located near the irrigated crop areas to remove any biases that may exist between the gridded meteorological dataset (Maurer et al., 2002) and these point observations.

NIWR estimates were calculated for each of the basin's twelve Hydrologic Unit Code eight-digit level drainage areas (HUC8 sub-basin). The HUC8 sub-basins are shown in Figure 4-2. The map also includes the estimated number of irrigated acres by HUC8 sub-basin. Point locations in the figure represent corresponding weather stations used to support the modeling effort, including those used for removing biases in the gridded meteorological dataset and those used for estimating dewpoint and windspeed across the HUC8 sub-basins. Table 4-5 provides additional details for some of these features. A full summary of weather

[10] https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates
[11] http://www.nass.usda.gov/research/Cropland/SARS1a.htm

station information is provided in Appendix C, Section 2.0. Appendix C, Section 3.0 summarizes the estimated percentage of crop acreage within each HUC8 sub-basin according to crop type.

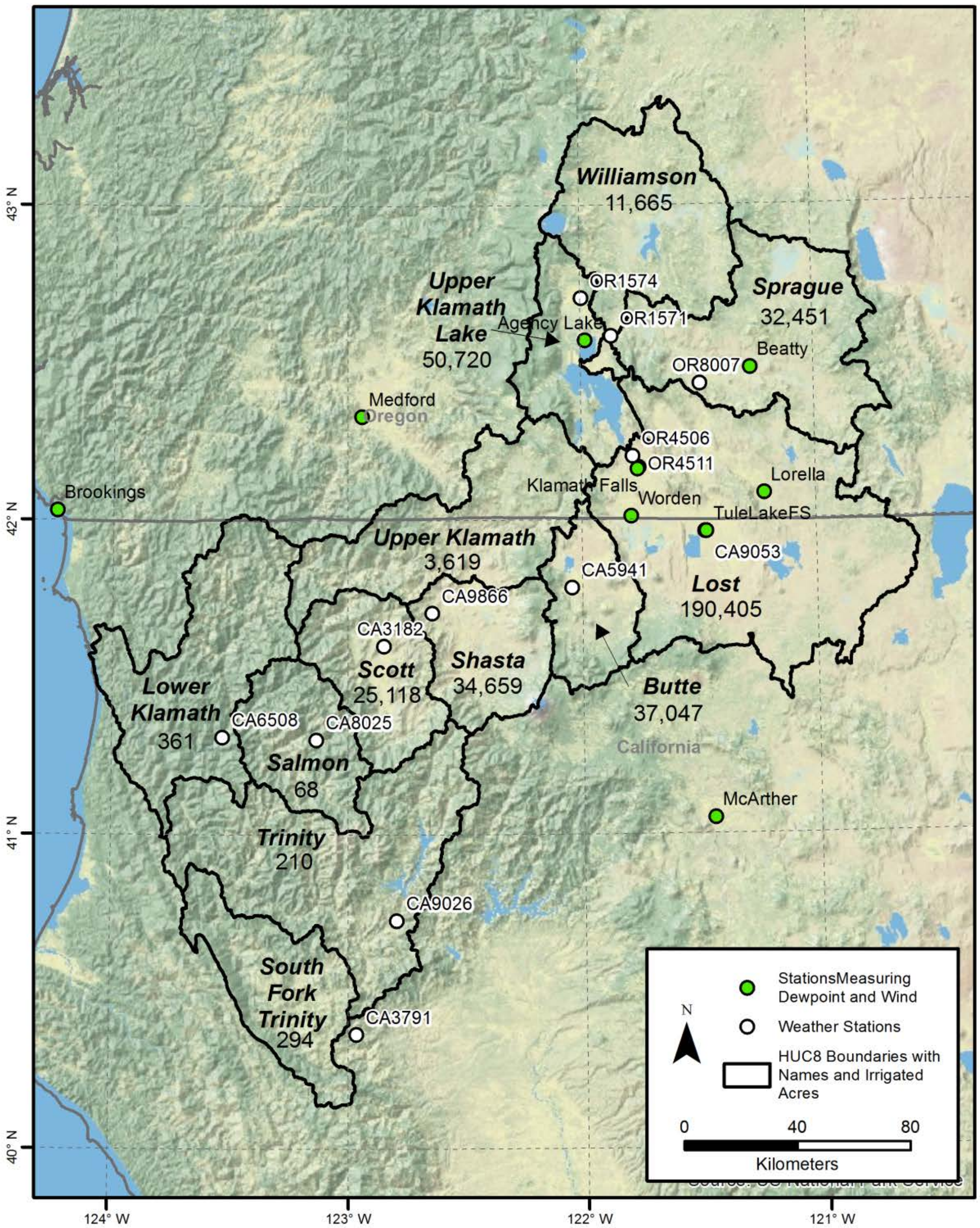

Figure 4-2.—Klamath River Basin – HUC8 Sub-basins, irrigated acres, and weather stations used to simulate baseline and projected irrigation demands.

Table 4-5.—Irrigated land totals and weather stations associated with HUC8 sub-basins

HUC8 Name / Number	Weather Station Name(s)	Irrigated Acres
Williamson / 18010201	Chiloquin	11,665
Sprague / 18010202	Sprague River 2 SE	32,451
Upper Klamath Lake / 18010203	Chiloquin NW	50,720
Lost River / 18010204	Tule Lake and Klamath Falls	190,405
Butte /18010205	Mount Hebron	37,047
Upper Klamath / 18010206	Klamath Falls 2 SSW	3,619
Shasta /18010207	Yreka	34,659
Scott / 18010208	Fort Jones	25,118
Lower Klamath / 18010209	Orleans	361
Salmon / 18010210	Sawyers Bar	68
Trinity / 18010211	Trinity River Hatchery	210
South Fork Trinity / 18010212	Harrison Gulch	294
Total Irrigated Acres		**386,616**

Estimates of NIWR were developed using the ET Demands model, originally developed by the University of Idaho, Nevada Division of Water Resources, and the Desert Research Institute (DRI). Recent modifications to the model for WWCRA applications were made through a collaborative effort by Reclamation, DRI, and the University of Idaho (Reclamation, 2014).

The ET Demands model is based on the Penman Monteith (PM) dual crop coefficient method (Allen et. al, 1998). The American Society of Civil Engineers (ASCE) has adopted the FAO-56 PM equation as the standardized equation for calculating reference ET (ET_o) (ASCE, 2005). The short grass reference crop version of the PM equation was used to be consistent with previous Reclamation work.

By using the PM dual crop coefficient method rather than a single crop coefficient approach, transpiration and evaporation are accounted for separately to better quantify evaporation from variable precipitation and simulated irrigation events. This also allows accounting of winter soil moisture conditions, which can be a significant factor when estimating early irrigation season NIWR. The dual crop coefficient method provides a robust means for estimating NIWR based on continuous accounting of soil moisture balance.

The ET Demands model first calculates daily ET_o for each HUC8 sub-basin as a function of maximum and minimum daily air temperature (T_{max} and T_{min}) from the 1950–1999 climate data set mentioned above. The PM equation variables of vapor pressure, solar radiation, and wind speed are empirically estimated as described in Reclamation (2014) per the methods recommended by ASCE (2005). Figure 4-3 shows the spatial distribution of mean daily historical baseline temperature, precipitation, dewpoint depression,[12] and wind speed (lower right) values used in the model. The historical baseline precipitation and temperature values for each HUC8 sub-basin are included in the model results summary tables provided in Appendix C, Section 1.0. The Figure 4-3 windspeed and dewpoint depression panels include the point locations of weather stations used as the basis for estimating these values for HUC8 sub-basins (see also Figure 4-2 and Appendix C, section 2.0).

Figure 4-3 illustrates warm to cool mean annual temperatures from west-southwest to northeast, respectively, while precipitation varies from moderately high to low amounts from southwest-central to northeast, respectively. The spatial distribution of mean annual dewpoint depression clearly shows northeast areas are more arid while southwest-central areas are more humid. The spatial distribution of mean annual wind speed generally exhibits lower wind speed in west and southwest areas, with higher wind speed in the northeast portion of the basin.

Weighted average soil conditions (including allowable water content and percent clay, silt, and sand) for the irrigated lands in each HUC8 sub-basin were input to the ET Demands model. The soils information is based on data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USDA-SCS, 1991). The soil parameters affect the estimation of irrigation scheduling, evaporation losses from soil, deep percolation from root zones, antecedent soil moisture condition, and runoff from precipitation.

The daily net or actual ET (ET_c) is then calculated as a function of the two primary crop coefficients and a crop stress coefficient. ET_c for all crop types within a given HUC8 was estimated as follows:

$$ET_c = (K_s K_{cb} + K_e) ET_o$$

where ET_o is the ASCE-PM grass reference ET, K_{cb} is the basal crop coefficient, K_e is the soil water evaporation coefficient, and K_s is the stress coefficient. K_{cb} and K_e are dimensionless and range from 0 to 1.4. Daily K_{cb} values over a season, commonly referred to as the crop coefficient curve, represent impacts on crop ET from changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on temperature. K_e is a function of the soil water balance in the upper 0.1 meter of the soil column, since this zone is assumed to be the only layer supplying water for direct evaporation from the soil surface. K_s ranges from 0 to 1, where 1 equates to no water stress, and is also dimensionless. A daily soil water balance for the simulated effective root zone is required and computed in ET Demands to calculate K_s. In the case of computing the ET_c and NIWR, K_s

[12] Dewpoint depression is equal to T_{min} minus dewpoint temperature and is used to estimate vapor pressure or humidity values. [13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

is generally 1 but cq2 1an be less than 1 in the winter if precipitation is low and winter surface cover is specified to be anything other than bare soil, such as mulch or grass.

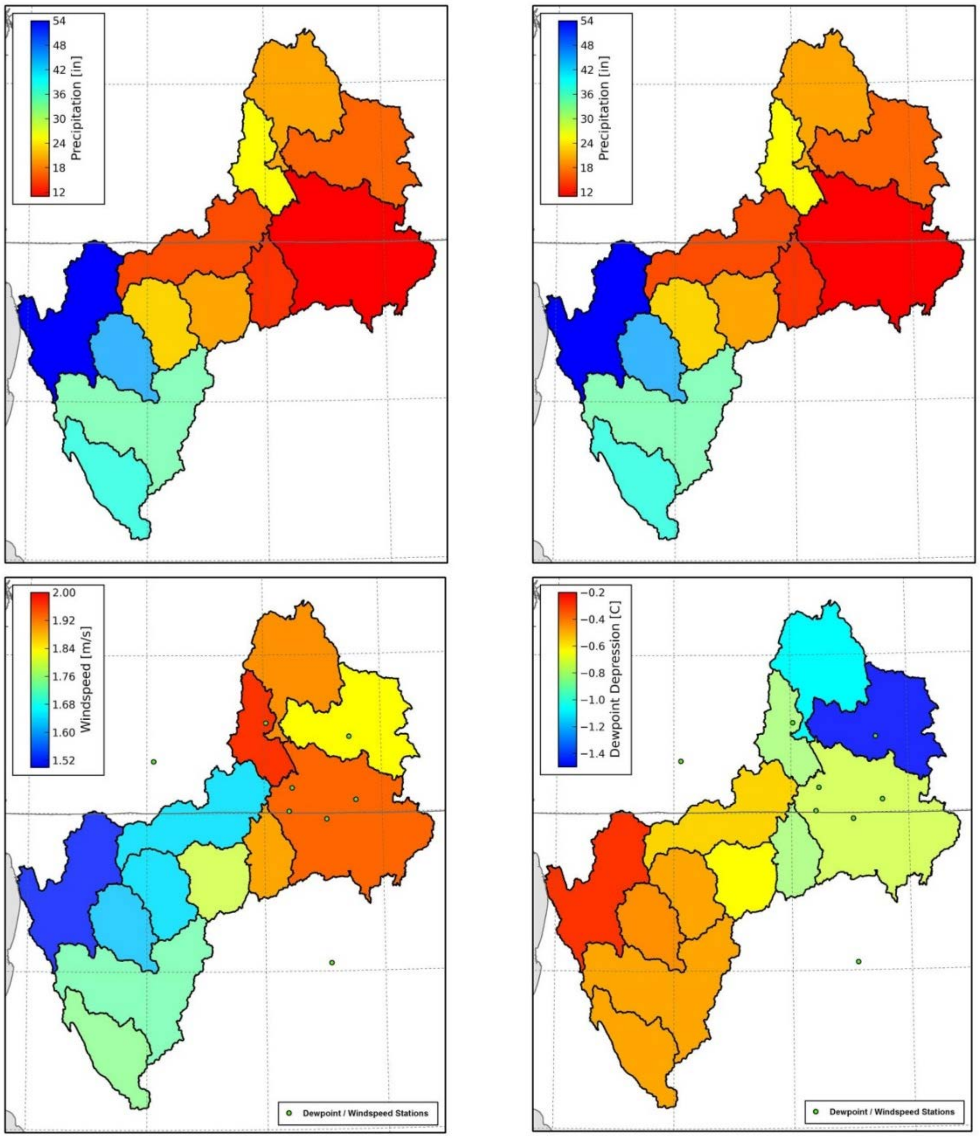

Figure 4-3.—Spatial distribution of historical baseline (1950–1999) mean annual temperature, precipitation, windspeed, and dewpoint depression.

Values of K_{cb} for a given crop vary seasonally and annually to simulate plant phenology as impacted by solar radiation, temperature, precipitation, and agricultural practice. Seasonal changes in vegetation cover and maturation are simulated in the ET Demands model by each crop specific K_{cb} as a function of air temperature. This is expressed in terms of cumulative growing degree days (GDD). After planting of annuals or the emergence of perennials, the value of K_{cb} gradually increases with increasing temperatures until the crop reaches full cover. Once this happens, and throughout the middle stage of the growing season, the K_{cb} value is generally constant or is reduced due to simulated cuttings and harvest. From the middle stage to the end of the growing season the K_{cb} value reduces to simulate senescence. GDD is calculated in the ET Demands model by three different methods as described in Reclamation (2014). The GDD equations' constants were calibrated based on historical data (green-up or planting, timing of full cover, harvest, and termination dates).

Having the ability to simulate year to year variations in the timing of green-up or planting, timing of effective full cover, harvest, and termination, is necessary for integrating the effects of temperature on growing season length and crop growth and development, especially under changing climate scenarios.

The NIWR rate or depth is calculated in the ET Demands model by factoring in P_e ($NIWR = ET_c - P_e$). P_e is calculated as a function of daily precipitation (from the climate data set), antecedent soil moisture, and precipitation runoff. Soil moisture is a function of the moisture holding capacity of the weighted average soil type input to the model for each HUC8 sub-basin. Precipitation runoff is calculated based on daily precipitation using the NRCS curve number method (USDA-SCS, 1972).

Simulation of irrigation events by the ET Demands model occurs when the crop root zone moisture content drops to the crop specific maximum allowable depletion threshold. Irrigations are specified to fill the root zone by the difference between field capacity[13] and the cumulative soil moisture depletion depth amount.

The NIWR and ET_c rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR and ET_c rates, as shown in the equation below.

$$HUC8\ subbasin\ rate\ =\ \sum_{i=1}^{i=n} crop\ ratio\ i * crop\ rate\ i$$

The product of the weighted average NIWR and the total irrigated acreage yields the NIWR volume for each HUC8 sub-basin in acre-feet. A similar approach is used to calculate the ET_o, ET_c, and NIWR estimates for the entire Klamath River basin where the ratios of sub-basin to basin irrigated acres are applied to the sub-basin values and the average of the weighted values is calculated. Crop types and corresponding percentages of total crop acreage by HUC8 sub-basin are provided in Appendix C, Section 3.0.

The ET Demands model results for baseline conditions include ET_o, ET_c, NIWR rate, and NIWR volume for each HUC8 sub-basin. The annual average values for 1950–1999, which represent the historical baseline or current conditions for the purpose of this study, are summarized in Table 4-6. Graphical representations of these values are provided in Figure 4-4. Spatial distributions of ET_o, ET_c, and

[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

NIWR depth ranges from 41 to 51, 29 to 52, and 18 to 37 inches per year, respectively, with higher rates occurring in the northeast portion of the basin where growing season air temperature, solar radiation, and dewpoint depression are significantly larger relative to the southwest-central portion of the basin. NIWR volumes range from 197 AFY in the Salmon HUC8 sub-basin, where there is very little irrigated land, to 329,469 AFY in the Lost River HUC8 sub-basin where the majority of Reclamation's Klamath Project irrigated lands are located.

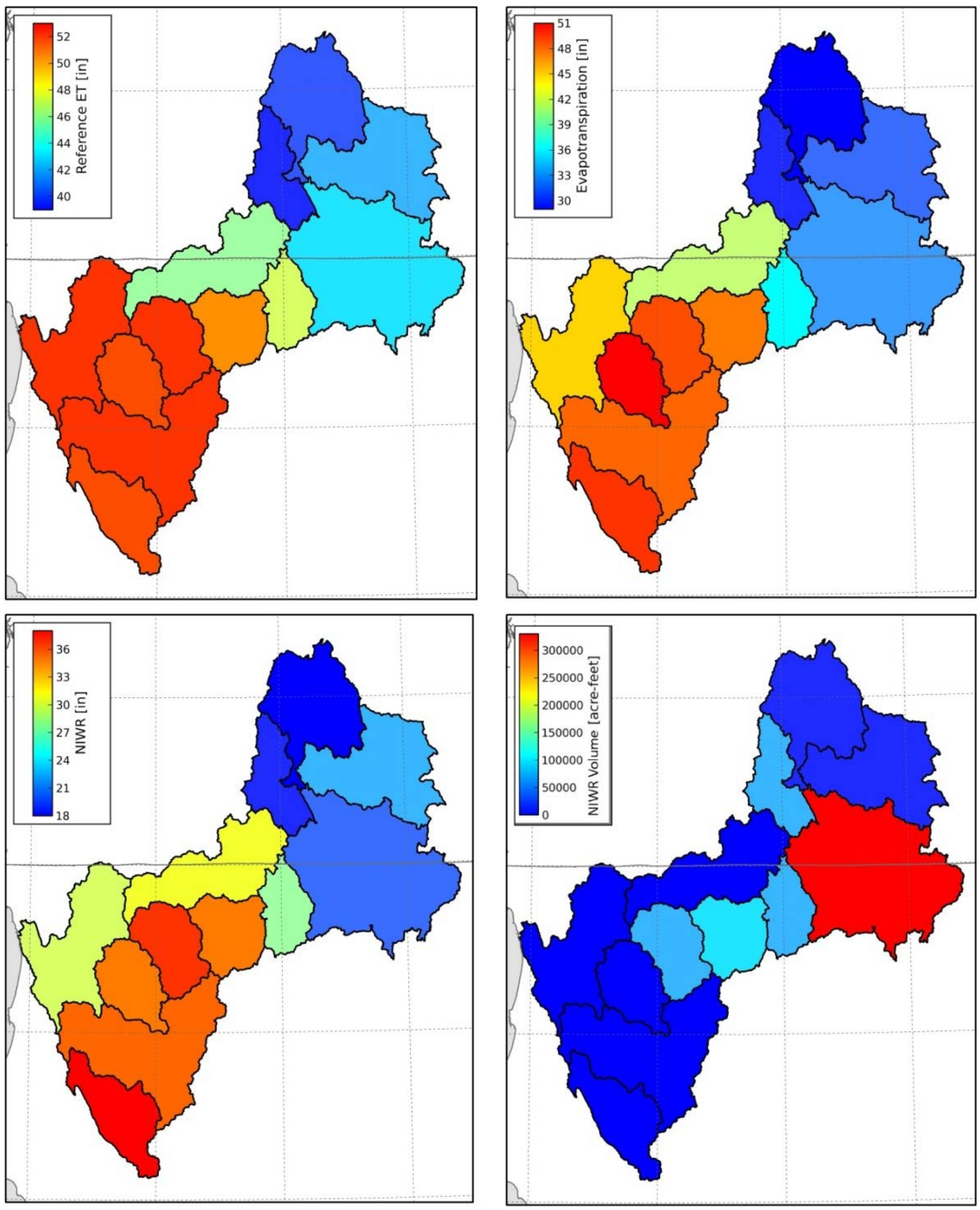

Figure 4-4.—Spatial distribution of baseline reference evapotranspiration, crop evapotranspiration, net irrigation water requirement depth, and NIWR volume.

Table 4-6.—Summary of baseline reference evapotranspiration, crop evapotranspiration, and net irrigation water requirement rates and volumes

HUC Sub-basin	ET_o (in/year)	ET_c (in/year)	NIWR Rate (in/year)	NIWR Volume (AFY)
Williamson	40.8	29.4	18.0	17,513
Sprague	42.3	29.5	20.4	55,216
Upper Klamath Lake	39.9	30.4	18.7	79,101
Lost River	43.3	34.1	20.2	329,469
Butte	46.9	36.5	27.2	83,976
Upper Klamath	45.4	40.9	30.7	9,255
Shasta	50.5	47.9	35.1	101,460
Scott	52.3	49.0	36.8	77,114
Lower Klamath	52.2	44.6	29.5	887
Salmon	52.0	50.6	35.0	197
Trinity	52.3	48.6	35.9	628
South Fork Trinity	51.8	49.6	37.4	917
Averages & Total NIWR Vol.	**47.5**	**40.9**	**28.7**	**755,734**

Notes: ETo = reference evapotranspiration; ETc = crop evapotranspiration; NIWR = net irrigation water requirement

Table 4-7 provides a summary of the basin total NIWR from Table 4-6 and the previous irrigation estimates by USGS, CDWR, and OWRD. As discussed previously, the USGS and OWRD estimates include conveyance and application losses; the CDWR estimate includes application losses; and the USGS estimate includes irrigation demands for other uses in addition to agricultural irrigation (e.g., golf courses, parks, etc.). Depending on local conditions, significant conveyance and application losses are considered consumptive uses when providing water sources for riparian and wetland plants and sources of evaporation.

The ratio of the basin study estimate (755,734) to the USGS estimate (1,150,318) implies the overall average efficiency of the irrigation systems is approximately 66 percent, which is reasonable. The USGS estimate (1,150,318) is within 5.1 percent of the sum of the QWRD and CDWR estimates (730,000 + 482,504 = 1,212,504).

Table 4-7.—Summary of irrigation demand estimate developed for this study and previous estimates by others

Description	Annual Volume (AFY)
Basin total crop net irrigation water demand estimated in Klamath River Basin Study	755,734
Basin total irrigation demand from 2005 USGS Water Use Program	1,150,318
OWRD 2010 estimate of crop irrigation demand for the Oregon portion of the basin	730,000
CDWR 2010 estimate of crop irrigation demand for the California portion of the basin	482,504

4.2.1.2 Municipal and Industrial

This category includes water demands that are met by public water supply systems that range in size from 15 connections[14] to many thousands of connections. The estimates are typically based on the supplier's production quantities, which include water delivered to customers plus leakage and other unaccounted for water. M&I customers include domestic households, industrial facilities, and commercial businesses.

Basin-wide total M&I use, shown in Table 4-3, is 18,204 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, which are entirely within the Klamath River Basin. Modoc, Humboldt, and Del Norte Counties each have small fractions within the Klamath River Basin. Most of the Humboldt and Del Norte County systems serve tribal communities. Note that within the California portion of the basin there is one small M&I system in Modoc County; there are four small systems in Humboldt County, and seven small systems in Del Norte County. Information on these California county systems is discussed later in this section.

Per capita total use estimates for the three counties entirely within the Klamath River Basin were calculated from the USGS data by dividing annual use by the reported population served. These estimates are summarized in Table 4-8.

Table 4-8.—Per capita total M&I water use estimates from USGS 2005 data (including consumptive and non-consumptive portions)

County, State	Per Capita Rates (gpcd)
Siskiyou , California	468
Trinity , California	146
Klamath , Oregon	188

Source: USGS

[14] The Safe Drinking Water Act, Section 1401(4) defines a public water system as that delivering water for human consumption to not less than 15 service connections or 25 regularly served persons.

The Siskiyou County per capita total M&I water use reported in 2005 by the USGS is much higher than for Klamath County and Trinity County. Further, review of near current total M&I use from recent planning studies for Weed and Yreka suggest this value to be outside the estimated range for the two largest municipalities in Siskiyou County.

Water plans were reviewed for the four largest municipalities in the Klamath River Basin which include Weed and Yreka in Siskiyou County, California, Weaverville in Trinity County, California, and Klamath Falls in Klamath County, Oregon. Most of the entities that provide M&I service to the smaller municipalities in Del Norte, Humboldt, and Modoc Counties were contacted for recent water use data, as they do not have municipal water plans. These include Willow Creek, Orleans, and Hoopa in Humboldt County, California, Newell in Modoc County, California, and Klamath in Del Norte County, California. Current annual water use for these municipalities is summarized in Table 4-9. Similar to uses identified by municipal water plans, these uses include both consumptive and non-consumptive components.

It should be noted that reported M&I uses typically include both consumptive and non-consumptive components. In the Klamath River Basin Study, those reported M&I uses that include both components are described as total M&I use. This study focuses only on the consumptive portion of M&I use and assumes that 40 percent of total M&I use is consumptive and is used for landscape irrigation, with the remaining 60 percent becoming wastewater effluent. In this section we distinguish between total M&I use and consumptive M&I use, where practicable.

Based on Mayer et al. (1999) and given that the majority of the basin's population is located in warmer-drier areas, it appears 40 percent is a reasonable average value for the basin. Mayer et al. (1999) reports the findings of a residential water use study that included 1,188 households in 12 North American cities. The reported range of outdoor use as the percentage of total use is 22 to 67 percent, with a range of 22 to 38 percent for wetter climates. Also, the U.S. Environmental Protection Agency WaterSense Program website[15] reports that one-third of U.S. residential water use is for landscape irrigation.

M&I and Rural Domestic Consumptive Use

Approximately 75 percent of the M&I demand within the Klamath River Basin is from the four largest municipalities (Klamath Falls, OR; Weed, CA; Yreka, CA; Weaverville, CA). Annual rural domestic uses represent approximately 0.4 percent of total basin demand.

[15] https://www.epa.gov/watersense

Table 4-9.—Summary of total M&I use for significant municipalities

Location	Annual Use (AFY)	Per Capita Demand (gpcd)	Reference
Klamath Falls, OR (Klamath County)	9,428 (2010 est)	167 (1998-2007est)	CDM (2010)
Yreka, CA (Siskiyou County)	2,243 (2010 est)	280-325 (2011 est)	Pace (2006), Tully and Young (2011)
Weed, CA (Siskiyou County)	994 (2010 est)	NA	Pace (2004)
Weaverville, CA (Trinity County)	841 (2010 est)	NA	Pace (2011)
Total of Above Annual Demands	**13,506**[16]		
Newell, CA (Modoc County)	188	194	2003 CDWR funding application (Hammond Engineering, 2001)[17]
Willow Creek, CA (Humboldt County)	767	401	Personal communication[18]
Hoopa, CA (Humboldt County)	565	168	Personal communication[19]
Orleans, CA (Humboldt County)	153 (OCSD) 50 (OMWC)	319 (OCSD) 529 (OMWC)	Personal communication[20]
Klamath, CA (Del Norte County)	166 (est)	150 (est)	Personal communication[21]
Total of Above Annual Demands	**1,889**		

Comparison of the total for the four large municipalities (13,506 AF) to the USGS reported 2005 M&I total (18,204 AF) indicates approximately 75 percent of the M&I demand within the majority of the basin (Klamath County, Oregon and Trinity and Siskiyou Counties in California) is from these municipalities and the other approximately 25 percent is made up by the smaller M&I systems. The

[16] Compare with USGS total demand for Klamath, Siskiyou, and Trinity Counties of 18,204 AFY. The comparison shows that demands from the four major municipalities comprise about 75 percent of the total demand in these three counties.

[17] CDWR funding application reports an annual use of 188 AFY and a 1999 service population of 866. This yields a per capita demand rate of 194 gpcd.

[18] Mr. Lonnie Danel, Administrator (personal communication, November 8, 2013). The 2012 approximate annual use for the Willow Creek Community Service District is 767 AF. Based on the 2010 census population for Willow Creek (1,710) this use yields a per capita demand of 401 gpcd.

[19] According to Mr. Murphy Lott, Operator for Hoopa Public Utilities District, Humboldt County, California (personal communication, November 12, 2013), the 2012 total use for the District's service area was approximately 565 AFY. Based on the reported service area population of approximately 3,000, the per capita average demand is 168 gpcd.

[20] Orleans, California in Humboldt County is served by two public water systems. Debbie Mace of the Orleans Community Service District (OCSD) reports (personal communication, December 5, 2013) approximate annual total M&I usage is 153 AFY serving a population of 430. This equates to a per capita demand of 319 gpcd. Jim Slusser of the Orleans Mutual Water Company (OMWC) reports (personal communication, December 5, 2013) approximate annual total usage is 50 AFY serving a population of 85. This equates to a per capita demand of 529 gpcd.

[21] Ms. Jan Chinook (personal communication, November 12, 2013) with the Klamath, California Chamber of Commerce reports there are seven public water systems serving this community in Del Norte County. The approximate population served by these systems is reported to be 985. Three of seven operators that were successfully contacted reported their systems are not metered. Given the lack of data and the generally transient service population, per capita demand was assumed (150 gpcd) to estimate an annual total M&I use of 166 AFY.

Klamath River Basin Study estimates 2010 total M&I use as the sum of use in Klamath, Siskiyou, and Trinity Counties, plus uses identified in the small municipalities of Modoc, Humboldt, and Del Norte Counties.

As stated above, an estimated 40 percent of total M&I use is for landscape irrigation. This fraction is considered 100 percent consumptive. The remaining 60 percent of the total M&I use is considered non-consumptive and is assumed to return to receiving waters as wastewater effluent. The computed basin-wide M&I consumptive use of 8,801 AFY is the baseline M&I consumptive use for the Klamath River Basin Study (see Table 4-4). The M&I uses that comprise the Klamath River Basin Study estimate of basin-wide current annual consumptive use are provided in Table 4-10.

Table 4-10.—Summary of total and consumptive M&I uses for the Klamath River Basin Study

Location	Annual M&I Use (AFY)
Klamath County	9,736
Siskiyou County	7,286
Trinity County	3,093
Small municipalities of Modoc, Humboldt, and Del Norte Counties	1,889
Basin Wide Total M&I Use	22,004
Basin Wide Consumptive M&I Use	8,801

4.2.1.3 Rural Domestic

The estimate of basin-wide rural domestic use shown in Table 4-3 is 11,255 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, plus a portion of the reported demand for Modoc County. The Modoc County estimate was calculated as the product of the reported use for the county and the ratio of the estimated population within the basin to the total county population. It is assumed the limited number of rural domestic water users in the portions of the basin in the counties of Del Norte and Humboldt in California and Lake and Jackson in Oregon are negligible. Based on these data and excluding hydropower and lake and reservoir evaporation, annual rural domestic uses represent approximately 0.4 percent of total basin demand. Note that, similar to M&I use, the rural domestic use reported by the USGS includes both consumptive and non-consumptive components. The Klamath River Basin Study assumes that 40 percent of total rural domestic use goes to landscape irrigation and is entirely consumed. (See discussion and references to Mayer et al. (1999) and the WaterSense program[22]

[22] https://www.epa.gov/watersense

above under Section 4.2.1.2, Municipal and Industrial.) The remaining 60 percent of the total rural domestic use is assumed to return to receiving waters via wastewater effluent (i.e., septic systems). This study differentiates between total rural domestic use, which includes both consumptive and non-consumptive components, and consumptive rural domestic use.

The total rural domestic per capita demands reported by USGS for 2005 range from 106 to 190 gpcd. The 2005 county rates and average for all but Humboldt and Del Norte counties are summarized in Table 4-11. Total rural domestic uses summarized here may be compared with total M&I demands provided in Tables 4-8 and 4-9 in terms of both per capita demands and mean annual total use volumes. Mean annual total rural domestic demands were computed based on the product of per capita demand and estimated population. Generally rural domestic demands are less than M&I demands, except for Trinity County where estimated rural domestic demand rates are higher than M&I. Table 4-9 also provides the estimated baseline consumptive rural domestic use for the Klamath River Basin Study.

Table 4-11.—Summary of 2005 county rural domestic use

County	Annual Rural Domestic Use (AFY)	Per Capita Demand (gpcd)
Siskiyou County, California	6,621	190
Trinity County, California	1,040	158
Klamath County, Oregon	3,481	150
Modoc County, California	201	180
Total Rural Domestic Use	11,343	
Consumptive Rural Domestic Use	**4,537**	

4.2.1.4 Tribal

This discussion addresses the consumption portion of water demands associated with the six federally recognized tribes that inhabit the Klamath River Basin: The Klamath Tribes, Quartz Valley Indian Community, Karuk Tribe, Hoopa Valley Tribe, Yurok Tribe, and Resighini Rancheria. Members of these tribes live along different reaches of the Klamath River and in different areas of the basin. Table 4-12 provides a summary of the Klamath basin Native Americans by culture, recognized representative tribal government, and the general location of each tribe in the Klamath basin (taken from Table 1-1, North State Resources, Inc., 2012). The Klamath Tribes live in the Upper Klamath Basin and the other five tribes are in the Lower Klamath Basin.

Tribal water uses are unique because the associated water rights are considered trust resources.[23] Tribal domestic and industrial water uses are included in the quantification of municipal and industrial demands as well as rural domestic uses summarized above. There are also inter-relationships between tribal water demands and other non-consumptive water use categories (e.g., environmental and ceremonial uses). Critical water-related trust resources associated with instream flow needs and lake levels to support hunting, trapping, gathering, and other cultural practices are briefly described in Section 4.2.3.2, Environmental Resources. However, instream flow uses are incorporated in the Klamath River Basin Study through development of measures which are used to evaluate the impacts of climate change and implementation of adaptation strategies (refer to Chapters 5 and 6).

The federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. The tribes have reserved rights to water according to the Winters Doctrine of 1908. Additionally, the Interior Solicitor's Office stated that "Reclamation is obliged to ensure that project operations not interfere with the Tribes' senior water rights" (Interior, Office of the Solicitor, Pacific Southwest Region, 1995). And, absent a "completed adjudication or other determination of the senior water rights," projects must be "operated on the best available information" (Interior, Office of the Solicitor, Pacific Southwest and Northwest Regions, 1997). The same recognition is extended to other resources such as vegetation and wildlife.

With the exception of the Klamath Tribes, tribal water rights are not officially recognized (adjudicated) by California and Oregon. Oregon's Klamath Basin Adjudication process reached the end of its "administrative" phase in March 2013, and the OWRD reached its Final Order of Determination generally confirming the senior water rights of the Klamath Tribes. In general, tribes' water rights claims seek to assure adequate quantities of good quality water to maintain tribal trust resources including fish, instream flows, groundwater, minerals, and land as well as cultural values, which may be described as traditional religious practices, traditional food preparation, trade and barter of goods, and other practices that reinforce personal and tribal identity (North State Resources, Inc., 2012).

Tribal Water Demands

Tribal trust resources and associated adjudicated and non-adjudicated water rights are described in this section. The needs of fish and wildlife for water are further described in Section 4.2.3.2, Environmental Resources.

[23] Indian trust resources consist of certain real property, natural resources, and related rights, held in trust by the federal government for federally recognized Indian Tribes or individual Indians.

Table 4-12.—Klamath Basin Native American peoples

Klamath Basin Native American Cultures	Recognized Representative Tribal Government	General Location of Tribe in the Klamath Basin
Yurok	Yurok Tribe Resighini Rancheria	Lower Klamath River Lower Klamath River
Hupa	Hoopa Valley Tribe	Lower Trinity River
Karuk	Karuk Tribe Quartz Valley Indian Community	Middle Klamath River Salmon River Scott River
Shasta (Wairuhikwaiiruka/Kammatwa)	Quartz Valley Indian Community	Scott River Shasta River Upper Middle Klamath River
Modoc	Klamath Tribes	Upper Klamath Basin
Klamath	Klamath Tribes	Upper Klamath Basin
Snake (Yahooskin)	Klamath Tribes	Upper Klamath Basin

Source: North State Resources, 2012

A portion of the adjudicated and non-adjudicated water rights of the tribes are for agricultural purposes. This consumptive use is addressed by Section 4.2.1.1, Agricultural Irrigation, which identifies the NIWR for existing crops within the basin. These demands are not differentiated between tribal and non-tribal uses. Primary references for this and additional information related to tribal trust resources include the Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report (Interior and CDFG, 2012), the Trinity Mainstem Fishery Restoration Environmental Impact Statement/Environmental Impact Report (Interior et al., 2000) and the North State Resources, Inc. (2012) report, supporting the Secretarial Determination Overview Report.

4.2.1.5 Livestock

Livestock water use is included in the USGS Water Use Program estimates. However, because water use by livestock comprises only 0.2 percent of total estimated basin water use and is not likely to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

4.2.1.6 Mining and Commercial/Industrial

Mining and self-supplied commercial/industrial use is included in the USGS Water Use Program estimates. However, because this consumptive use comprises only 0.2 percent of total estimated basin water use and is not expected to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

4.2.2 Other Consumptive Uses and Losses

This section quantifies current losses associated with evaporation at the Klamath River Basin's primary lakes and reservoirs and evapotranspiration by emergent wetlands. Losses result in a reduction of water supply and are therefore included in the assessment of water supply and demand with the intent to quantify current water supply shortages.

4.2.2.1 Wetlands

This section briefly summarizes the estimation of current wetland ET used for the Klamath River Basin Study, using findings from Stannard et al. (2013). Additional work by Mayer and Thomasson (2004) was used for verification of estimated current wetland ET. Additional work by Bidlake (2002) over the more focused region of Tule Lake NWR was also reviewed in support of estimated wetland.

The Klamath River Basin Study estimates mean annual wetland ET over 341,154 acres of wetlands estimated by the National Wetland Inventory for emergent wetlands.[24] Wetland ET volume is based on work by Stannard et al. (2013), who found that during the average 190-day alfalfa-growing season wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. Estimates of average daily alfalfa and pasture ET were computed by the ET Demands model. For ET Demands model simulations, daily ET for multiple crops was computed for HUC8 sub-basins within the Klamath River Basin, similar to the approach taken by Reclamation (2014) in the West-Wide Climate Risk Assessment. Alfalfa and pasture ET computed by HUC8 sub-basin were used to estimate wetland ET. Use of the ET Demands model for these values, as opposed to alfalfa ET and pasture ET reported by Stannard et al. (2013), allows for direct comparison of the consumptive uses quantified by this study and also allows for evaluation of projected changes in wetland ET in a changing climate. Current mean annual wetland ET, based on estimates of alfalfa and pasture ET using the ET Demands modeling approach described above, is approximately 1,089,061 AFY (averaging wetland ET based on each of alfalfa ET and pasture ET). Estimates of current wetland ET by this study corroborates with the findings of both Stannard et al. (2013) and Mayer and Thomasson (2004), as shown in Table 4-13 in which current wetland ET in units of AFY were computed based on reported ET rates and the same estimated wetland area. This study's estimate of mean annual wetland ET is included in the overall estimate of current water demands provided in Table 4-4. It should be noted that the ET Demands model was not configured to include wetlands ET. However, future research involving the ET Demands model may involve determining model coefficients for wetland vegetation.

[24] http://www.fws.gov/wetlands/

Table 4-13.—Comparison of average annual current wetland ET from available sources

Source of Wetland ET Estimate	Average Annual Current Wetland ET (AFY)	ET Rate (ft/yr)
Mayer and Thomasson (2004)	1,040,910	3.05
Stannard et al. (2013)	1,049,862	3.08
Klamath River Basin Study	1,089,061[25]	3.31

Mayer and Thomasson (2004) measured and modeled estimates of fall water requirements for the seasonally flooded and permanently flooded wetlands at the Lower Klamath NWR, located in the Lost River HUC8 sub-basin. They found that 60 percent of the total volume of inflow to the wetlands goes to saturate the underlying soils, adding to the water needs of seasonally flooded wetlands. Once the soils are saturated, little loss to infiltration or groundwater seepage in the wetlands would occur. Annual water requirements for both types of wetlands were comparable. Wetlands with 50 percent emergent vegetation and 50 percent open water had an estimated annual ET of 3.05 feet per year over the period 1999–2001. Using the current estimated wetland area of 341,154 acres from the National Wetlands Inventory (USFWS, 2014) for emergent wetlands in the Klamath River Basin along with the above ET rate, the estimated mean annual wetlands ET would be 1,040,910 AFY.

Stannard et al. (2013) sought to improve understanding of ET losses from wetlands by taking ET measurements using the eddy-covariance method from May 2008 through September 2010 at two sites near Upper Klamath Lake. As noted above, they estimated the area of wetlands near Upper Klamath Lake as approximately 70 square kilometers (17,300 acres). From their ET measurements, they found that during the average 190-day alfalfa-growing season, wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. In this study, Stannard et al. estimated a wetland ET rate of approximately 3.08 feet per year. If we extrapolate their computed rate for wetland ET to include the area identified in the National Wetlands Inventory (341,154 acres), their resulting estimate of mean annual wetland ET is 1,049,862 AFY.

[25] Note that the mean ET rate was computed as the mean rate across HUC8 sub-basins, while average annual current wetland ET was calculated as the ET rate multiplied by area, each unique by HUC8 sub-basin, then summed over the entire basin. The average annual current wetland ET is not mathematically equivalent to the mean ET rate multiplied by the basin's 341,154 acres of emergent wetlands. Conversely, the average annual current wetland ET computed using methods by Mayer and Thomasson (2004) and Stannard et al. (2013) was computed as the ET rate multiplied by the total basin area.

4.2.2.2 Lake and Reservoir Evaporation

The reservoirs evaluated by the study are listed in Table 4-14 along with their capacity and ownership information. Historical evaporation rates (in inches per year) and volumes (in AFY) for these reservoirs have been estimated using an energy balance model, as described below. The historical rates provide the baseline against which future estimates are compared in later sections of this chapter.

Table 4-14.—Klamath River Basin primary reservoirs

Reservoir	Storage Capacity (AF)	Maximum Surface Area (acres)	Owner
Clair Engle Lake	2,448,000	17,851	Reclamation
Upper Klamath Lake	629,780	90,000	Reclamation
Clear Lake	513,330	25,760	Reclamation
Gerber Reservoir	104,460	4,000	Reclamation
Tule Lake	60,592	13,074	Reclamation
COPCO 1 Reservoir	46,867	1,000	PacifiCorp
Iron Gate Reservoir	58,794	944	PacifiCorp
John C. Boyle Reservoir	3,495	420	PacifiCorp

Source: PacifiCorp (2004c)

The estimated evaporation rates for the Reclamation reservoirs in the basin were calculated using the complementary relationship lake evaporation (CRLE) model (Morton et al., 1985). CRLE is an open water evaporation model that accounts for water temperature, albedo, emissivity, and heat storage effects to estimates of monthly evaporation. Reclamation collaborated with the DRI (Reno, Nevada) in the development and application of the model for this study.

The collaborative reservoir evaporation modeling effort with DRI was initiated as part of the WWCRA. Under the WWCRA work, Upper Klamath Lake evaporation was modeled along with 11 other reservoirs in the western U.S.

The WWCRA Water Demands Report (Reclamation, 2015) provides a detailed description of the CRLE model and its application for Upper Klamath Lake. The model parameters for Upper Klamath Lake developed under the WWCRA were directly applied for simulation of open water evaporation in Upper Klamath Lake in this study. The other reservoirs listed in Table 4-14 were also modeled using the same approach.

The CRLE model calculates estimated evaporation for historical average reservoir conditions. Average monthly historical reservoir conditions (storage volume and surface area) were calculated using historical data and assumed constant for the analysis period (1950–1999). The same air temperature-based relationship used for estimating solar radiation for Upper Klamath Lake, based on Klamath Falls Agrimet weather station data, was applied for modeling evaporation at the other reservoirs. Relationships for estimation of dewpoint depression (humidity) were developed based on historical data from the weather stations, discussed above in Section 4.2.1.1, Agricultural Irrigation, and as shown in Figure 4-2.

Table 4-15 includes a summary of the CRLE model results for the historical baseline period (1950–1999), including average annual evaporation rates and net evaporation (evaporation minus precipitation) rates for each reservoir. Table 4-15 also includes evaporation and net evaporation volume estimates based on the model results and historical average reservoir conditions. Note that historical average reservoir conditions differ from the maximum conditions reported in Table 4-14.

Table 4-15.—Klamath River Basin reservoirs evaporation model results summary for 1950 to 1999 historical baseline period

Reservoir	Evaporation (inches/year)	Evaporation (AFY)[26]	Net Evaporation (inches/year)	Net Evaporation (AFY)[11]
Clair Engle Lake	45.0	49,152	-26.0	-28,412
Upper Klamath Lake	44.0	263,483	21.1	125,977
Clear Lake	45.6	81,711	32.0	57,300
Gerber Reservoir	44.4	8,947	24.1	4,862
Tule Lake	45.2	23,723	33.3	17,484
COPCO 1 Reservoir	43.9	3,427	20.8	1,626
Iron Gate Reservoir	44.8	3,446	27.2	2,089
J.C. Boyle Reservoir	44.2	729	22.5	371

Stannard et al. (2013) conducted an open water and wetland evaporation study for Upper Klamath Lake, Oregon. Bowen ratio energy balance was utilized to estimate open water evaporation during the summer and fall of 2008 and the growing seasons of 2009 and 2010. To evaluate the skill of CRLE application in the Klamath River Basin, the CRLE model was forced with measured solar radiation, air temperature, and dewpoint temperature obtained from the Klamath Falls Agrimet station for the 2008–2010 study period of Stannard et al. (2013). Results of the seasonal comparison are favorable, with daily average evaporation rates for this study of 0.20 inches per day compared to 0.21 inches per day by Stannard et al. (2013).

[26] Reservoir evaporation and net evaporation volumes were computed using mean monthly surface area over the simulation period.

4.2.2.3 Operational Inefficiencies

Operational inefficiencies such as canal seepage and on-farm losses associated with irrigation methods are not explicitly quantified in the Klamath River Basin Study. The largest irrigated region in the watershed is Reclamation's Klamath Project. Within the Project area, on-farm runoff and canal spills are captured in drains and reused such that the overall efficiency of the Project is considered to be relatively high. This is based on water budgets developed as part of previous studies (Davids, 1998; Freeman and Burt, undated; Reclamation, 2007b). For other irrigated regions, such as the Shasta and Scott Valleys, this study assumes that non-beneficial consumptive use of conveyance and on-farm losses is not a significant portion of the overall losses in the watershed. The USGS Water Use Program estimates for agricultural irrigation use include crop demands, conveyance losses, and on-farm losses.

4.2.2.4 Phreatophyte Vegetation

Phreatophytes are defined as deep-rooted plants that obtain water from the water table or in the vadose zone just above the water table. Phreatophyte losses are included in the water budget through the natural flow computations (refer to Chapter 3) and therefore are not shown separately as losses. Needs of other vegetation for water are also included in the water budget. For example, BLM and USFS conservation initiatives associated with the 1994 Northwest Forest Plan preserve old growth vegetation and riparian buffers throughout the Southern Oregon / Northern California Coast Evolutionary Significant Unit and range of the Northern Spotted Owl (BLM and USFS, 2005).

4.2.3 Non-Consumptive Uses

Non-consumptive uses are those which do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.), water needs to support fish and wildlife, and hydropower production, among others. In one sense, these uses may be considered demands in that certain water levels or flows are required to support them. However, because these uses do not result in a loss of water in a planning context, the Klamath River Basin Study addresses them in terms of measures of system reliability. The measures are used to evaluate how well the available water supply is able to meet various needs in the watershed.

> **Non-Consumptive Uses**
>
> Non-consumptive uses include recreation, environmental resources, hydropower, and aquaculture. Because non-consumptive uses do not result in a reduction of available water supply, they are addressed in Chapter 5, System Reliability as measures for evaluating the impacts of climate change and implementation of adaptation strategies.

This section briefly describes the identified non-consumptive uses in the Klamath River Basin. However, details of water requirements and/or needs to sustain these uses are further quantified in Chapter 5, System Risk and Reliability Analysis.

4.2.3.1 Recreation

The expansive rural landscape of the Klamath River Basin offers a myriad of outdoor recreational opportunities, many of which are either directly or indirectly associated with the basin's water resources. Rivers, streams, and lakes are common throughout the basin's mountainous landscape, and reservoirs and wetlands exist in the valleys and high plateau areas of the central and eastern portions of the basin. The basin's rivers, streams, lakes, reservoirs, and wetlands provide a variety of recreational opportunities including camping, sightseeing, hunting, fishing, boating, hiking, and wildlife viewing.

There are five national forests within the basin (Klamath, Fremont, Winema, Six Rivers, and Modoc), a joint national and State park (Redwood), a national park (Crater Lake), two national monuments (Lava Beds and Cascade-Siskiyou) and five national wildlife refuges that make up the Klamath Basin NWR Complex (Klamath Marsh, Tule Lake, Clear Lake, Upper Klamath, and Lower Klamath). Recreation opportunities in these forests, parks, and refuges include camping, hiking, snowmobiling, sightseeing, wildlife viewing, hunting, and fishing. Large sections of the Klamath River and its tributaries are designated as national wild and scenic rivers (WSR) under the Wild and Scenic Rivers Act, including segments of the Klamath, Scott, and Salmon Rivers and Wooley Creek totaling 297 miles. Extensive public and private recreational opportunities exist along the Klamath River and its tributaries.

The Klamath River Basin Study focuses on flow-related recreational uses, as they are more directly associated with water supply than other recreational demands such as camping and sightseeing, for example. The recreational uses considered in this study are fishing and boating in the Klamath and Trinity Rivers. Chapter 5, System Reliability quantifies optimal flow ranges for these activities, as reported by the Klamath Facilities Removal EIS/EIR (Interior and CDFG, 2012).

The modeling framework of the Klamath River Basin Study does not allow for evaluation of impacts of climate change on natural unmanaged lakes within the watershed; however, evaluation of reservoir levels is part of the system reliability analysis in Chapter 5.

4.2.3.2 Environmental Resources

Numerous fish species use the Klamath Basin during all or some portion of their lives. Native species include salmonids, lamprey, sturgeon, suckers, minnows, and sculpin. Many other species are present in the Klamath River estuary. Salmonids in the Klamath River include fall and spring Chinook salmon; coho salmon; fall-, winter-, and summer-run steelhead; and coastal cutthroat trout. The salmonids share many similar life-history traits, but the timing of their upstream migrations, habitat preferences, and distributions differ (Interior and CDFG, 2012). A number of non-native species have also been introduced into the watershed including yellow perch, largemouth bass, spotted bass, sunfish, and catfish. These species all have unique needs for Klamath River water which must be considered in conjunction with management practices for human uses.

4.2.3.2.1 Water Quality

Water quality in the Klamath River Basin is affected by both natural and human influences. The volcanic terrain supports soils that are naturally high in phosphorus. Human influences including development, wetland draining, agriculture, ranching, logging, and water management have altered streamflows and water temperatures and increased nutrient and sediment loading in the river system. In addition, mining activities, dam construction, and management for hydropower in the Lower Klamath Basin have further affected river conditions (Interior and CDFG, 2012). As a result of natural and human activities, water quality standards in the Upper Klamath Basin have not been met for many years (Stillwater Sciences, 2013). Table 4-16 summarizes the water quality impaired water bodies in the Klamath River Basin as identified by the Klamath Facilities Removal EIS/EIR (Table 3.2-8 in Interior and CDFG, 2012). The identified water quality impairments impact the beneficial uses of the Klamath River designated by the Klamath Facilities Removal EIS/EIR, which are categorized as Aesthetic and Cultural, Agricultural Water Supply, Commercial, Fish and Wildlife, Potable Water Supply, Industrial Water Supply, and Navigation.[27] For example, known and/or perceived concerns over health risks associated with seasonal algal toxins have resulted in the alteration of traditional cultural tribal practices such as gathering and preparation of basket materials and plants, fishing, ceremonial bathing, and ingestion of river water.

Effects on regional water quality have resulted in multiple federal, state, and tribal programs and planning documents to regulate and protect water quality in the area of the Klamath River Basin. For example, the states of Oregon and California have established and obtained EPA approval of water quality standards (referred to as "water quality objectives" in California) for waters in the Klamath River Basin, including designated beneficial uses (PacifiCorp, 2004b; Interior and CDFG, 2012). Also, several of the Klamath River Basin native tribes have adopted their own water quality objectives for portions of the Klamath and Trinity Rivers. Water quality objectives adopted by the Hoopa Valley Tribe establish water quality objectives for those portions of the Trinity and Klamath Rivers

[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

under the jurisdiction of the tribe. The Yurok and Karuk Tribes have also adopted water quality objectives, as has the Resighini Rancheria; however, the associated water quality plans have not yet been approved by USEPA (NCRWQCB, 2010b).

For water bodies included on the Clean Water Act Section 303(d) list of impaired water bodies, the state with jurisdiction over the water body must develop TMDLs to protect and restore beneficial uses of water. TMDLs set limits on the amount of pollutants that can be added to a water body while still protecting identified beneficial uses. TMDLs have been established for various parts of the Klamath River Basin since about 2001. The status and pollutants regulated under Klamath River Basin TMDLs are summarized in Table 3.2-9 of the Klamath Facilities Removal Final EIS/EIR (Interior and CDFG, 2012).

Water levels and flow rates are inherently related to water quality in the Klamath River Basin. The need for improved water quality by environmental resources may be considered a demand, in one sense, because threshold flows are needed to sustain a healthy river system. However, because these needs are non-consumptive, the Klamath River Basin Study incorporates water quality criteria and associated TMDLs in the analysis of system reliability. Specifically, environmental health of the watershed is assessed through analysis of water temperature as a surrogate for overall watershed ecological health. Water quality criteria and TMDLs for stream temperature are incorporated as measures for evaluation of system reliability in Chapter 5.

Table 4-16.—Water quality impaired water bodies within the area of analysis[1]

Water Body Name	Water Temperature	Sedimentation	pH	Organic Enrichment/Low Dissolved Oxygen	Nutrients	Ammonia	Chlorophyll-a	Microcystin
Oregon[2]								
Sprague River and tributaries	X^{S}		X^{S}	X^{S}				
Williamson River and tributaries	X							
Upper Klamath Lake and Agency Lake			X	X			X	
Upper Klamath River (Keno Dam to Link River Dam, including Keno Impoundment/Lake Ewauna)			X^{S}	X$^{SP,S,F,W\ (3)}$		X^{SP,S,F,W}	X^{S}	
Upper Klamath River Oregon-California state line to Keno Dam (including J.C. Boyle Reservoir) (4)	X$^{SP,S,F,S\ (5)}$			X$^{SP,S,F,W\ (3)}$				
California								
Lower Lost River (Tule Lake, Lower Klamath Lake National Wildlife Refuge, and Mt. Dome)			X		X			
Middle Klamath River Oregon-California state line to Iron Gate Dam (including	X			X				X

Table 4-16.—Water quality impaired water bodies within the area of analysis[1]

Water Body Name	Water Temperature	Sedimentation	pH	Organic Enrichment/Low Dissolved Oxygen	Nutrients	Ammonia	Chlorophyll-a	Microcystin
COPCO Lake Reservoir [1 and 2] and Iron Gate Reservoir)								
Middle Klamath River Iron Gate Dam to Scott River Reach 6	X			X	X			X
Shasta River	X			X				
Scott River	X	X						
Salmon River	X							
Middle and Lower Klamath River Scott River to Trinity River Reach 7	X			X	X			X
Lower Klamath River-Trinity River to Mouth	X	X		X	X			

Source: Table 3.2-8 in Interior and CDFG, 2012

Notes:

1 While there are additional water quality impaired waterbodies in the area of analysis, the waterbodies listed in this table are the ones that are directly relevant to the water quality analysis for this Klamath Facilities Removal EIS/EIR.

2 Oregon lists specific reaches of the Klamath River by river mile and includes specific seasons, in some cases (Kirk et al., 2010).

3 Listed for dissolved oxygen only (non-spawning) (Kirk et al., 2010).

4 Oregon defines particular river miles for their listings.

5 Non-spawning (Kirk et al., 2010).

6 Selected minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include Beaver Creek, Cow Creek, Deer Creek, Hungry Creek, and West Fork Beaver Creek (USEPA, 2010a).

7 Minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include China Creek, Fort Goff Creek, Grider Creek, Portuguese Creek, Thompson Creek, and Walker Creek (USEPA, 2010a).

Key:

Sp = Listed for spring season
S = Listed for summer season
F = Listed for fall season
W = Listed for winter season

4.2.3.2.2 Instream Flow Targets

Instream flow targets have been established for parts of the Klamath River Basin both through state codes, state and federal regulatory requirements, and cooperative agreements such as Reclamation's 2013 Biological Assessment for Proposed Klamath Project Operations and the associated 2013 non-jeopardy [28] Biological Opinion issued by the NMFS and USFWS. Instream flow targets are one means of working toward the maintenance and even recovery of threatened and endangered species in the basin. However, recommended instream flows are highly uncertain due to limited data availability and our limited understanding of

[28] An ESA Section 7 non-jeopardy Biological Opinion is one where USFWS or NMRS determines that a federal action is not likely to jeopardize the existence of a listed species or result in the destruction or adverse modification of critical habitat.

all of the direct and indirect effects of the environment on the species it supports. As we learn more about species recovery in responses to instream flow actions, these recommendations are likely to evolve through time.

Instream flow recommendations exist for reaches of the Klamath River (Reclamation, 2012d; NMFS and USFWS, 2013; Interior and CDFG, 2012; Hardy et al., 2006) as well as the tributaries of the Shasta River (McBain and Trush, 2014) and Trinity River (Interior, 2000). In addition, the federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. Interior supports Winters Doctrine rights which entitle tribes in the Klamath River Basin to sufficient water to support fishing and harvesting and cultural practices. Also, recognition of tribal reserved fishing rights is consistent with the federal precedent set in United States v. Adair (Interior and CDFG, 2012). Although the Klamath River Basin tribes have reserved rights to support their livelihoods, for the most part instream flow needs to support those activities have not been quantified, with the exception of the Klamath Tribes as part of Oregon's Klamath Basin adjudication process.

Similar to other non-consumptive water uses, recommended instream flow targets may be considered a demand in that certain flows are required to sustain fish species and support other uses. However, since these uses do not result in a reduction of water supply, they are incorporated in the analysis of system reliability in Chapter 5. Namely, instream flow targets may be used as measures in the evaluation of impacts of climate change on the watershed with and without implemented adaptation strategies. Details of recommended instream flow targets are included in Chapter 5.

4.2.3.2.3 Wildlife Refuge Water Targets

Klamath Basin National Wildlife Refuges is a complex of six refuges: Lower Klamath, Tule Lake, and Clear Lake in northern California and Bear Valley, Upper Klamath, and Klamath Forest Refuges in southern Oregon. All of the complex refuges are adjacent to or within Reclamation's Klamath Project with the exception of Bear Valley, which was established in 1978 and consists of old growth pine forest to protect a major night roost site for wintering bald eagles in Southern Oregon. The USFWS manages the refuges under the Migratory Bird Treaty Act (codified as 16 U.S.C. §§ 703-712), National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. §§ 668dd-668ee), National Wildlife Refuge System Improvement Act (Pub. L. 105-57, 111 Stat. 1252-1260), and other laws pertaining to the NWR System (Reclamation, 2012d). They were established by various executive orders starting in 1908, and support many fish and wildlife species and provide suitable habitat and resources for migratory birds of the Pacific Flyway. Each year these refuges serve as an annual stopover for approximately three-quarters of the flyway waterfowl with peak concentrations of over one million birds. Reclamation manages leases on refuge lands for agricultural purposes through a cooperative agreement with the USFWS (Reclamation, 2012d).

The refuges (with the exception of Bear Valley and Clear Lake) have federally-reserved water right claims for the water necessary to satisfy the refuges' primary purposes subject to more senior water rights in the basin, including the Klamath Tribes and Reclamation's Klamath Project. The 2013 BA for Klamath Project operations outlines the availability of water to the Lower Klamath and Tule Lake NWRs (Reclamation, 2012d). In addition, Risley and Gannett (2006) estimated water needs of the Lower Klamath and Tule Lake NWRs using evapotranspiration estimates, with different rates for each of four land-use categories. With the exception of open water evaporation and wetland ET, water used by refuges is generally non-consumptive. Recommended targets, like those summarized by the above sources, are provided in Chapter 5, System Reliability and incorporated as measures for evaluation of system reliability.

4.2.3.3 Hydropower

The Klamath River Basin has nine major hydropower generating facilities, seven in the Upper Klamath Basin and two in the Trinity River sub-basin. Other small hydropower generating facilities in the basin include the C Drop Plant on Reclamation's Klamath Project and two small hydropower facilities in Siskiyou County. The seven major hydropower plants in the Upper Klamath Basin are owned and operated by PacifiCorp of Portland, Oregon. The PacifiCorp facilities are regulated by the Federal Energy Regulatory Commission (FERC) as Project No. 2082 and are operating under annual licenses since the expiration of the original license in March 2006. Future operations are dependent on the resolution of the relicensing proceedings for these facilities, which may be addressed through either issuance of a new project license by FERC or the passage of federal legislation enacting the Klamath Hydroelectric Settlement Agreement (KHSA) and related Klamath settlements, which provide for the potential removal of these facilities.

Since 1992, operations of PacifiCorp's facilities have been adjusted to protect ESA-listed threatened species. These adjustments were made to address then-current minimum levels in Upper Klamath Lake and minimum instream flows in the Link River and in the Klamath River below Iron Gate dam described in biological opinions for Reclamation's Klamath Project (PacifiCorp, 2004b). The current river flow and Upper Klamath Lake level requirements are described in the 2013 Joint Biological Opinion for Klamath Project Operations by the USFWS and NMFS (NMFS and USFWS, 2013). If PacifiCorp's hydroelectric dams are removed as part of the KBRA/KHSA, the hydroelectric water rights at all of PacifiCorp's Klamath facilities (except Fall Creek) in Oregon will be dedicated or assigned to instream water rights and administered by the ODFW, while those in California will be abandoned, according to Section 7.6.5 of the KHSA.

The other two major hydropower generating facilities are located in the Trinity River sub-basin. The Lewiston powerplant provides power to the adjacent Trinity River Fish Hatchery and additional energy is sold. Trinity Power plant is a peaking plant associated with the Trinity River Diversion for Reclamation's Central Valley Project. Flow rates and associated power production at both facilities are subject to the Trinity River Restoration Program Record of Decision (Interior, 2000).

The Klamath River Basin Study provides the basis for evaluations of changes in future hydrologic conditions and resulting changes in power generation capacity and timing. The analysis of system reliability (refer to Chapter 5) allows for quantification of projected turbine releases and hydropower production as a result of climate change and implemented adaptation strategies. This study does not evaluate projected changes in the demand for hydropower in a changing climate. Water rights and instream flow requirements associated with hydropower production are utilized in the system reliability analysis as measures for evaluation of changes in power production associated with various managed flow conditions in a changing climate.

4.2.3.4 Aquaculture

Another non-consumptive use of water within the Klamath River Basin includes aquaculture, which is defined as the rearing of aquatic animals. This use is quantified by the USGS Water Use Program; however, the percentage of total basin water use is only 3 percent. Due to the small percentage of overall water use, the fact that this use is largely non-consumptive, and the lack of information as to the impacts of climate change on aquaculture, this use is not further considered in the Klamath River Basin Study.

4.3 Effects of Climate Variability and Change on Demand

4.3.1 Climate Change Scenarios

The Klamath River Basin Study primarily utilizes climate change scenarios that are derived using an ensemble informed hybrid delta (HDe) method approach (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d). The scenarios are derived from both CMIP3 and CMIP5 bias corrected and spatially downscaled (BCSD) GCM climate projections, as these are considered equally likely potential climate futures at this time. The approach allows a high number of CMIP3 and CMIP5 climate projections to be distilled into a small number of representative climate change scenarios. The same scenarios used for evaluation of future water supply are used in this chapter's estimation of demands to meet consumptive uses, namely M&I and rural domestic as well as losses due to reservoir evaporation. Development of future agricultural scenarios involved using similar climate change scenarios, but with prior adjustments made to the underlying BCSD climate projections to account for biases in projected versus observed weather over irrigated areas (for more information, refer to WWCRA Demands Assessment, Reclamation, 2015).

Development of climate change scenarios is described in Section 3.5.1.2, Deriving Climate Change Scenarios from Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). Five scenario types are derived from the large number of CMIP3 and CMIP5 BCSD climate projections: warm-wet (WW), warm-dry (WD), central-tendency (CT), hot-wet (HW), and hot-dry (HD). Discussions of how the temperature and precipitation projections for the five HDe scenarios are used to estimate the various future demands are provided in the following sections.

4.3.2 Growth Scenarios

Future water demand with respect to consumptive uses and evaporation losses may have a number of driving forces aside from those directly related to climate, including demographics, land use, technological development, and socioeconomics. Because it is highly uncertain how these driving forces may unfold in the future, we employ a scenario-based approach to projected growth.

To evaluate the impacts of climate change on system performance of existing and anticipated water infrastructure and operations in the Klamath River Basin, a baseline condition is established. In typical long term planning studies, this baseline condition may be called the Future No Action alternative. A Future No Action alternative incorporates climate change scenarios and requires that assumptions be made regarding future growth in the watershed. The Future No Action alternative in the Klamath River Basin Study corresponds with one future growth scenario and ten climate change scenarios (five CMIP3-based scenarios and five CMIP5-based scenarios), each for the 2030s and 2070s, for a total of twenty future scenarios.

In general, the growth scenario encompasses projected population growth, where reported by the states and municipalities, and current agricultural practices. A brief description of the growth scenario is provided in this section. Assumptions regarding the future growth scenario are summarized below and in Table 4-17. Additional details regarding the growth scenario are provided in Section 4.3.3 which quantify the impacts of climate change on water demands.

As shown in Table 4-17, this study assumes that cropping patterns and number of irrigated acres are static in quantifying future agricultural irrigation demands. Altered cropping patterns may be considered in this study as implemented adaptation strategies in the analysis of system reliability. For M&I and rural domestic uses, a defined percentage of the water use is landscape irrigation and this is also considered static. Population estimates that define the total M&I and rural domestic future water usage are based on two primary sources. If population projections are provided by individual municipal water plans, those projections are incorporated into the demand scenario. For regions where municipal water plans may not exist, and for rural domestic water use, historical population trends are extrapolated into the future and incorporated in the demand scenario. For losses due to reservoir or lake evaporation, it is assumed that historical average reservoir levels exist in the future. Alternative future reservoir levels are considered as implemented adaptation strategies in the analysis of system reliability. Finally, for future wetland ET estimates, it is assumed that the current number of wetland acres (based on the current National Wetland Inventory) is static.

Table 4-17.—Summary of assumptions for Klamath River Basin Study future growth scenario

Consumptive Use or Loss	Element	Assumptions for Future Scenarios
Agricultural irrigation		
	Cropping patterns	Static, based on historical
	Irrigated acres	Static, based on historical
M&I and rural domestic	Landscape irrigation = 40 percent of total use	Static, based on historical
	Population growth	Based on water plans or extrapolations of historical trends (if projections not available)
Lake and reservoir evaporation	Average lake and reservoir levels	Static, based on historical
Wetlands ET	Wetland acres	Static, based on historical

4.3.3 Projected Future Water Demands

Numerous factors were considered in the estimation of the basin's future water demands. The primary factors include population growth, agricultural practices, and climate change. Population growth, agricultural practices, and other socioeconomic conditions are incorporated in the demand scenario described above. Projections of climate change are incorporated separately, such that there are five HDe climate scenarios for each of the CMIP3- and CMIP5-based projections and for each future time horizon (2030s and 2070s). Each of these climate change scenarios is paired with the single demand scenario considered in this study.

As discussed previously, rigorous quantitative analyses were performed to estimate the demands to meet predominant consumptive uses in the watershed: agricultural irrigation, M&I, rural domestic, wetlands, and losses due to reservoir evaporation. The implications of climate change on non-consumptive uses are evaluated as part of Chapter 5, System Reliability Analysis.

Table 4-18 summarizes the projected changes in basin-wide consumptive use (both human influenced and natural) for the predominant use categories: agricultural irrigation, M&I, rural domestic, and losses due to reservoir evaporation and wetland ET. Projected changes are presented for all five HDe climate change scenarios for each of the CMIP3- and CMIP5-based projections, as well as for two future time horizons, the 2030s and 2070s.

Table 4-18.—Summary of basin-wide projected changes in consumptive water use and losses

Scenario	Period	BCSD Projection	Total (AFY)	Total Percent Change
Historical	Historical	-	2,039,430	-
Warm Dry	2030	CMIP-3	2,233,781	10%
Warm Dry	2030	CMIP-5	2,277,042	12%
Warm Wet	2030	CMIP-3	2,190,454	7%
Warm Wet	2030	CMIP-5	2,225,238	9%
Hot Dry	2030	CMIP-3	2,387,983	17%
Hot Dry	2030	CMIP-5	2,405,865	18%
Hot Wet	2030	CMIP-3	2,313,274	13%
Hot Wet	2030	CMIP-5	2,349,212	15%
Central Tendency	2030	CMIP-3	2,284,936	12%
Central Tendency	2030	CMIP-5	2,304,374	13%
Warm Dry	2070	CMIP-3	2,380,969	17%
Warm Dry	2070	CMIP-5	2,324,159	14%
Warm Wet	2070	CMIP-3	2,308,778	13%
Warm Wet	2070	CMIP-5	2,266,970	11%
Hot Dry	2070	CMIP-3	2,528,603	24%
Hot Dry	2070	CMIP-5	2,568,869	26%
Hot Wet	2070	CMIP-3	2,428,364	19%
Hot Wet	2070	CMIP-5	2,501,320	23%
Central Tendency	2070	CMIP-3	2,393,777	17%
Central Tendency	2070	CMIP-5	2,406,350	18%

Similarly, for all future climate scenarios Figure 4-5 summarizes projected changes for each type of consumptive use or loss considered in the Klamath River Basin Study for the 2030s and 2070s.

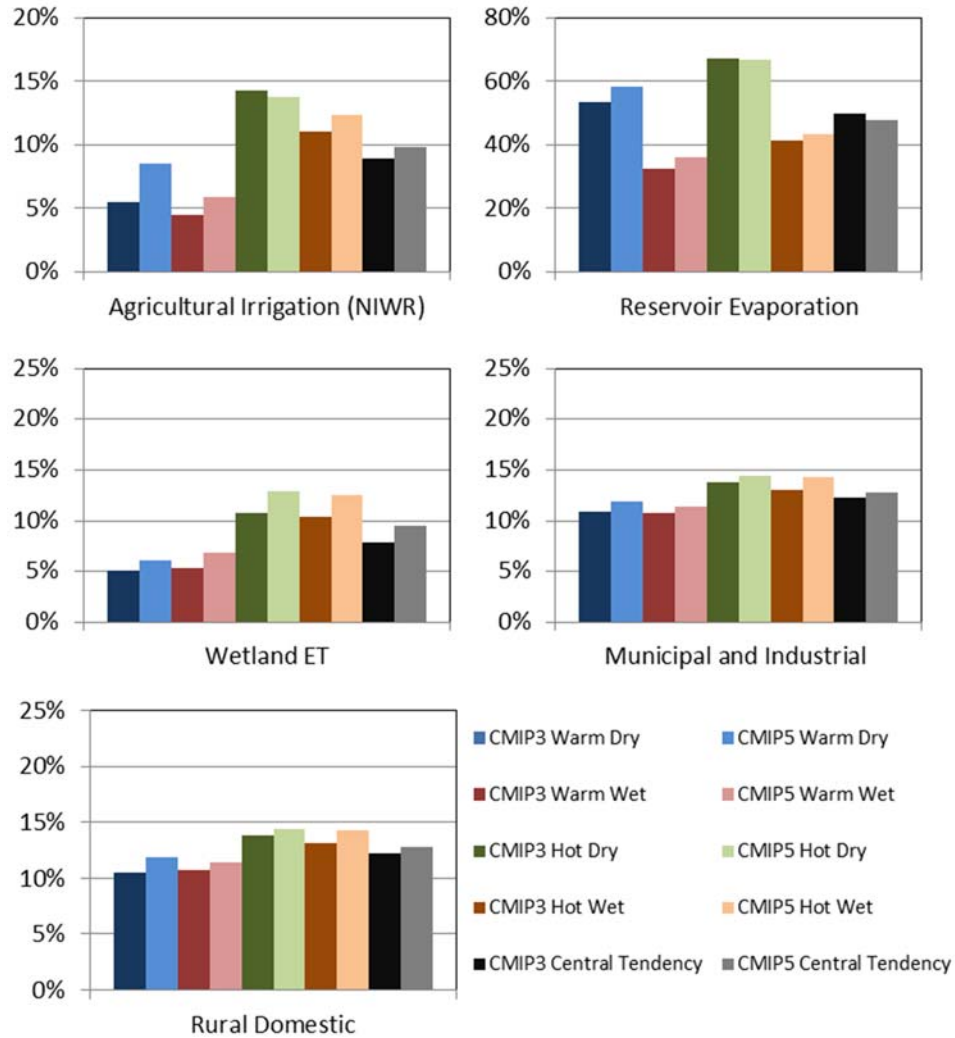

Figure 4-5.—Summary of basin-wide projected changes in consumptive water use and losses for the 2030s by use type.

4.3.3.1 Human Influenced Consumptive Uses

Projected consumptive uses to meet future demands are summarized in this section, incorporating projected HDe climate scenarios for two future time horizons, the 2030s and the 2070s, and a single future growth scenario. Descriptions of the approaches used to incorporate climate change scenarios and growth scenarios are provided in the respective subsections below on various consumptive uses and losses.

4.3.3.1.1 Agricultural Irrigation

To evaluate the impacts of climate change on agricultural irrigation demands, the ET Demands model described in Section 4.2, Current Demand was implemented using the approach described in Reclamation (2015). Any differences in the approach details are discussed below.

For example, the Klamath River Basin Study utilizes two future time periods for analysis of climate change impacts (2030s and 2070s), compared with three future time periods (2020s, 2050s, 2080s) used in the WWCRA. Also, there are slight differences in the projection ensemble selection process for development of HDe scenarios. This study utilizes a subset of 10 climate projections to inform each of the five climate scenarios, while the WWCRA utilizes the full set of climate projections. Further discussion of the approach for climate change scenario development for this study is provided in Chapter 3. Another difference in approach for assessing agricultural irrigation demands is the use of both CMIP3 and CMIP5 projections in this study; the WWCRA uses solely CMIP3 projections. At the time the WWCRA work began, CMIP5 projections were not readily available.

As mentioned above, a single growth scenario was used in conjunction with multiple future climate scenarios to encompass a range of potential future consumptive water demands. Collectively these scenarios comprise the Future No Action scenario. This alternative generally includes historical cropping patterns and irrigated acreage. Additional approach details for assessment of future agricultural irrigation demands are provided in this section. In the discussion of Current Water Demands, the ET Demands model is described as using basal crop coefficient (K_{cb}) curves, which are developed as a function of GDD. For this study, the K_{cb} curves for annual crops are developed using baseline (historical) temperatures, while perennial K_{cb} curves are developed using future projected temperatures.

Changes in future farming practice of annual crops, such as potential earlier planting, development, and harvest, are uncertain under warming climatic conditions. These potential changes will depend on future crop cultivars, water availability, and economics. For these reasons, static phenology K_{cb} curves were simulated for future periods where historical baseline temperatures were used for simulating planting, crop development, and harvest dates using the GDD approach previously described. In effect, all scenarios and time periods have identical seasonal K_{cb} curve shapes for each annual crop, and only exhibit differences in daily ET_c magnitudes due to daily ET_o and precipitation differences. A detailed discussion on this static phenology approach is included in Reclamation (2015).

The future irrigation demands results cover mean annual precipitation, temperature, reference evapotranspiration (ET_o), crop evapotranspiration (ET_c), and net irrigation water requirement (NIWR, both depth and volume). Mean monthly values of perennial crop ET_c for future time periods and scenarios are also presented to highlight potential changes in seasonal ET_c.

The future ET_o, ET_c and NIWR subbasin and basin total estimates were calculated using the same methods as the historical baseline values. Specifically, the NIWR and ET_c rates for each crop within a given HUC8 subbasin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 subbasin, and all crop values are summed to calculate weighted average HUC8 subbasin NIWR and ET_c rates. ET_o, ET_c and NIWR estimates for the entire basin were calculated using the ratios of subbasin to basin irrigated acres.

The results are summarized in a series of figures and tables (similar in format to the WWCRA [Reclamation, 2015]), with appended detailed results and additional figures. The figures below show projected changes in temperature, precipitation, ET_o, ET_c, and NIWR for the CMIP5-based climate scenarios and both future time periods (2030s and 2070s). CMIP3-based figures are shown in Appendix C. Projected changes are presented as the difference from historical baseline averages for temperature, and percent change from baseline averages for all other variables. Projected absolute values of ET_o, ET_c, and NIWR for the different scenarios and time periods are also included in Appendix C.

Figure 4-6 illustrates the spatial distribution of projected precipitation percent change for the different scenarios and time periods. Depending on the scenario, basin average precipitation percent changes range from -7.4 percent to +20.8 percent for the 2070 time period (considering CMIP5-based scenarios), with the central tendency scenario showing a general increase throughout the basin.

Figure 4-7 shows the spatial distribution of projected mean temperature change for the different climate scenarios and time periods. Increased temperatures are shown for all scenarios and periods. with slightly larger projected mean temperature changes in the northeast portion of the basin for all scenarios. Depending on the scenario, basin average temperature changes range from 1.6 to 8.4 degrees F for the 2070s time period (considering CMIP5-based scenarios).

Figure 4-8 shows the spatial distribution of projected ET_o percent change for different climate scenarios and time periods, and Table 4-19 provides a comparison of projected changes in annual ET_o for the central tendency climate scenario. Similar to temperature, the projected percent change in ET_o is larger in the northeast portions of the basin.

Figure 4-9 illustrates the spatial distribution of projected ET_c percent change for different climate scenarios and future periods, and Table 4-20 provides a comparison of projected changes in annual ET_c for the central tendency climate scenario. Spatial differences in the distribution of projected percent change in ET_c are largely due to differences in crop type and historical baseline ET_c. The northeast portion of the basin is projected to experience the largest percent change increase for all projected time periods, largely due to the fact that the difference between the projected and historical baseline ET_c is fairly large relative to the baseline estimate of ET_c (see Figure 4-4). The predominant crops in the Upper Klamath Basin include alfalfa, pasture grass, other hay, and winter wheat. In the Lower Klamath Basin, where alfalfa, other hay, and spring wheat are the dominant crops, projected increases in ET_c are lower. The Lower Klamath HUC8 subbasin has a projected decrease in ET_c, despite projected climate warming in all HUC8 subbasins. The increase may be due to projected changes in the harvesting of grass hay, which is projected to occur earlier in the year.

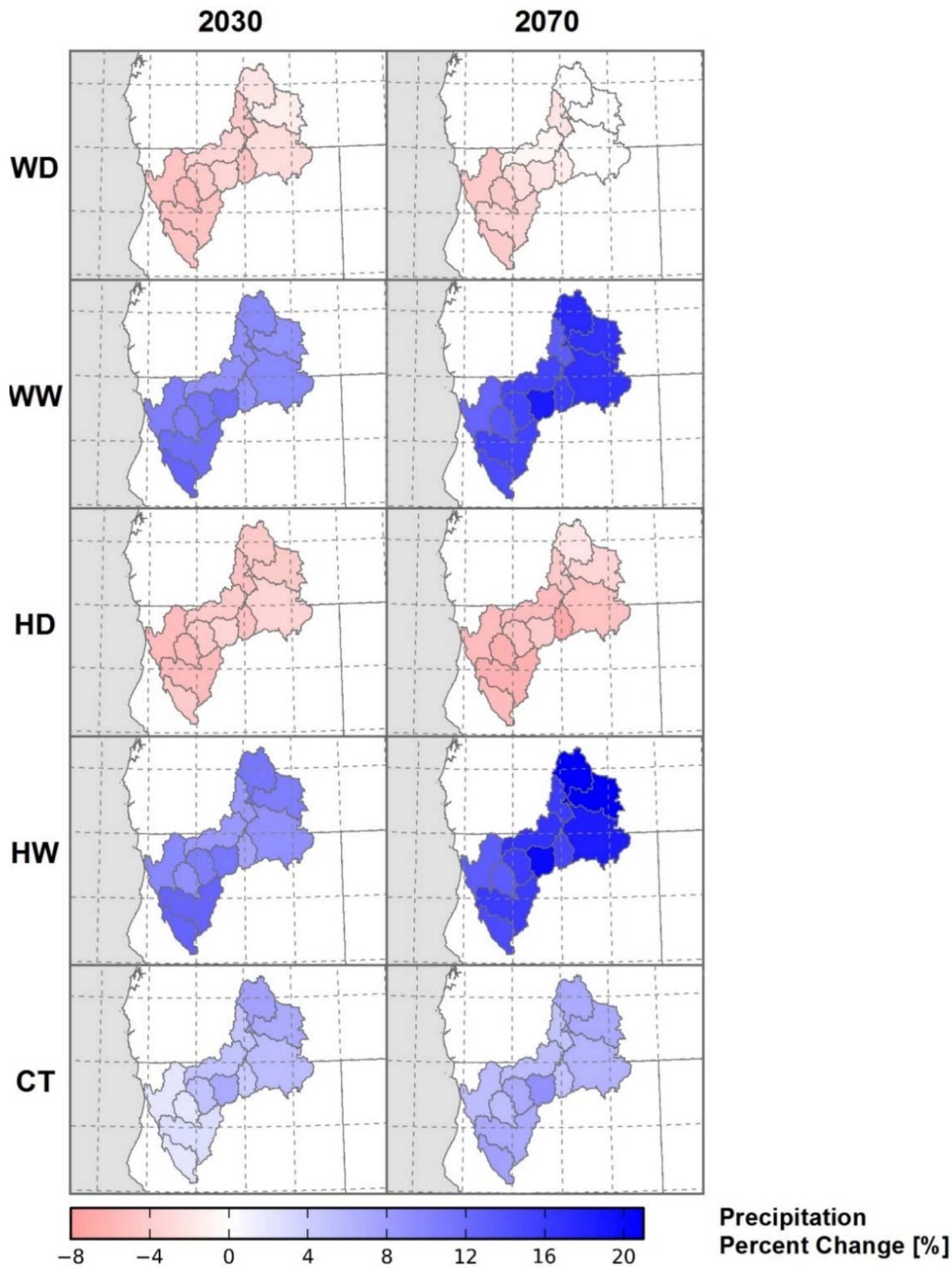

Figure 4-6.—Klamath River Basin - Spatial distribution of projected precipitation change for different climate scenarios and time periods (CMIP5 climate scenarios).

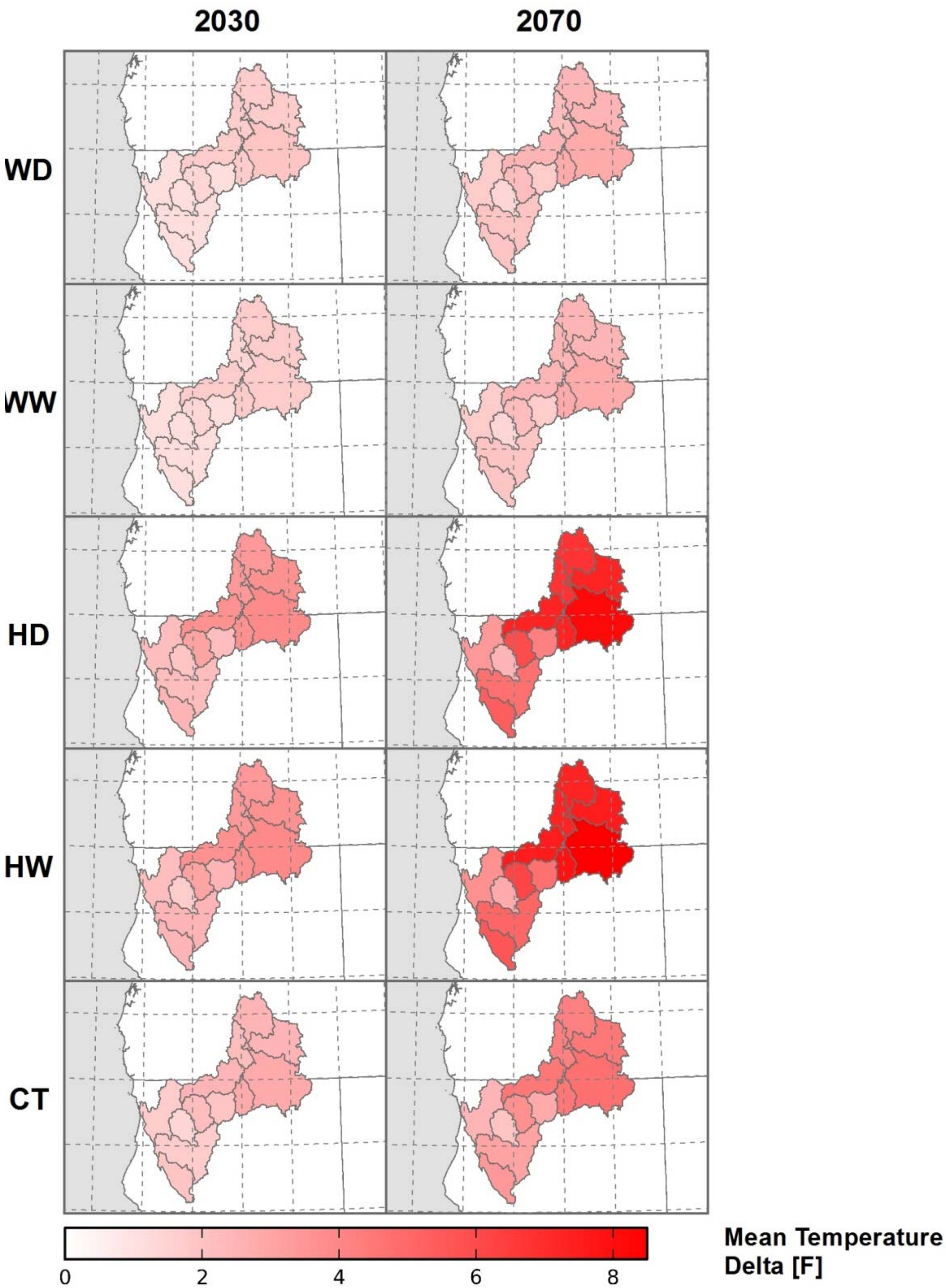

Figure 4-7.—Klamath River Basin - Spatial distribution of projected temperature change for different climate scenarios and time periods (CMIP5 climate scenarios).

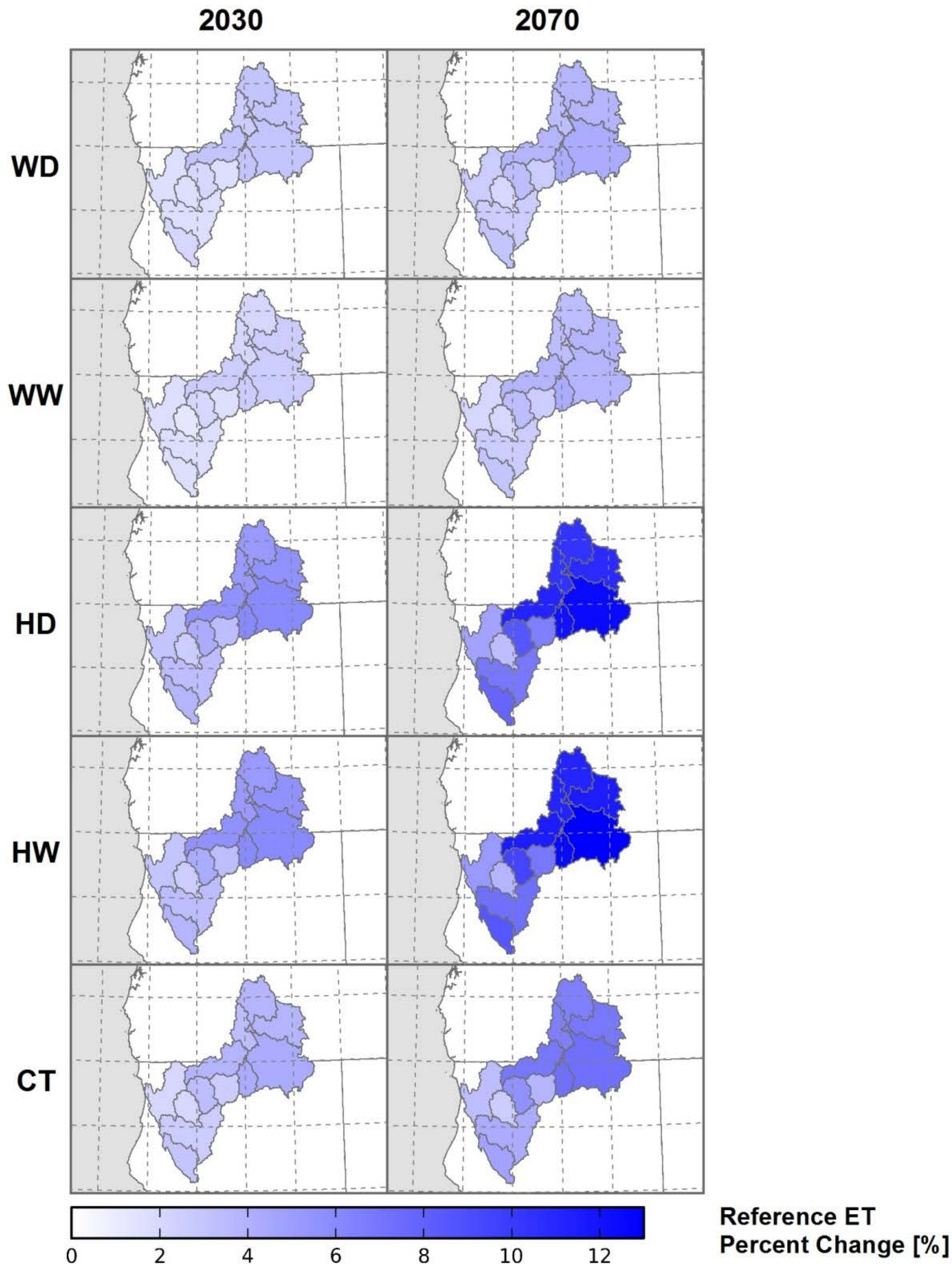

Figure 4-8.—Klamath River Basin - Spatial distribution of projected reference evapotranspiration percent change for different climate scenarios and time periods (CMIP5 climate scenarios).

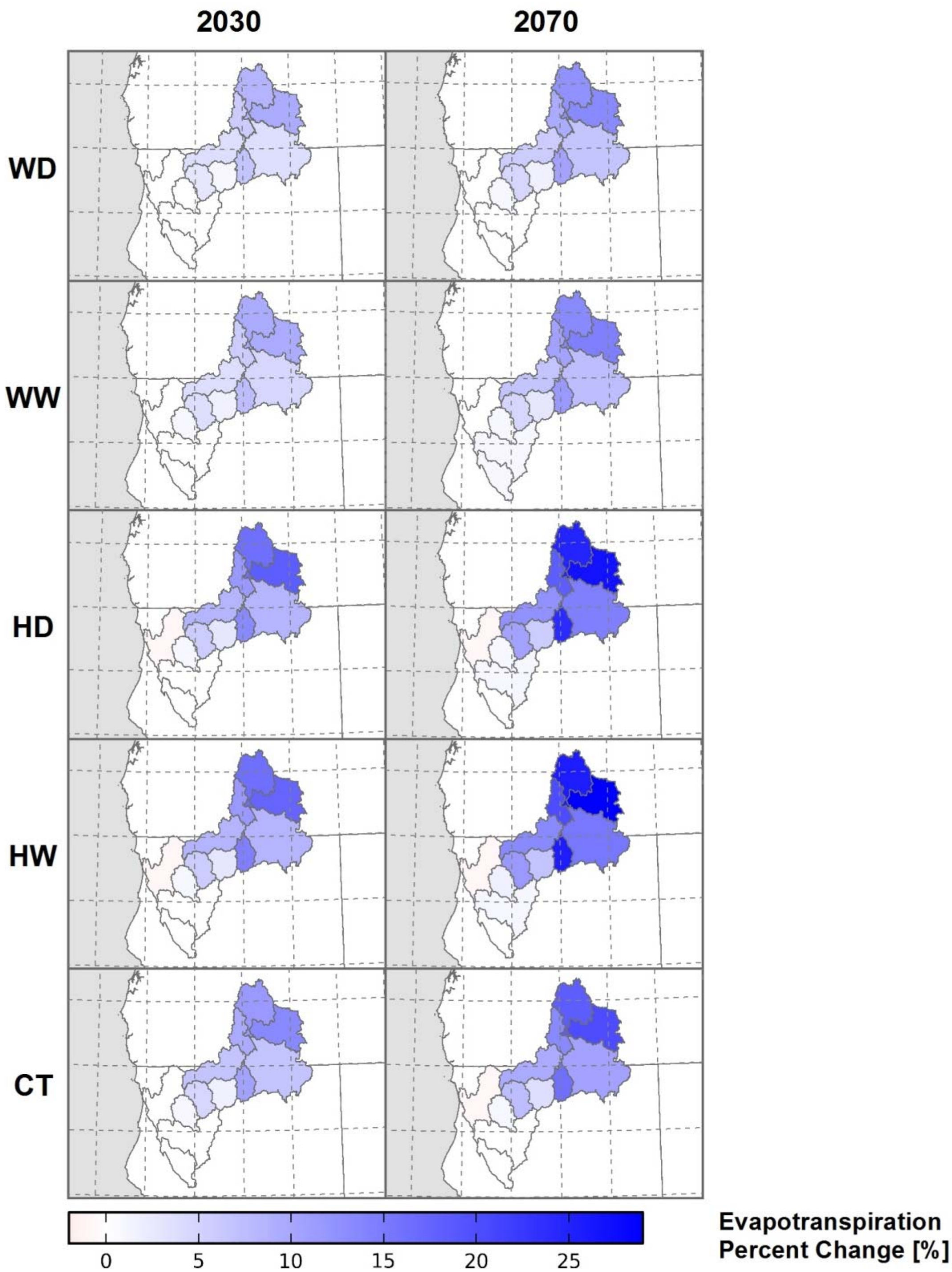

Figure 4-9.—Klamath River Basin - Spatial distribution of projected crop evapotranspiration percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios).

Table 4-19.—Comparison of projected changes in annual reference evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	3.3%	3.8%	5.9%	6.43%
HUC_18010202	Sprague	3.4%	4.0%	6.1%	6.7%
HUC_18010203	Upper Klamath Lake	3.2%	3.7%	5.7%	6.3%
HUC_18010204	Lost	3.6%	4.3%	6.7%	7.4%
HUC_18010205	Butte	3.7%	4.4%	6.6%	7.4%
HUC_18010206	Upper Klamath	3.5%	4.1%	6.1%	6.8%
HUC_18010207	Shasta	2.3%	2.7%	3.7%	4.2%
HUC_18010208	Scott	2.8%	3.4%	4.9%	5.5%
HUC_18010209	Lower Klamath	2.1%	2.4%	3.2%	3.4%
HUC_18010210	Salmon	2.0%	2.3%	2.8%	2.9%
HUC_18010211	Trinity	2.3%	2.7%	3.9%	4.3%
HUC_18010212	South Fork Trinity	2.5%	3.0%	4.4%	4.8%
Total Basin		3.4%	3.9%	6.0%	6.7%

Table 4-20.—Comparison of projected changes in annual crop evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	10.0%	11.9%	16.6%	18.3%
HUC_18010202	Sprague	11.6%	13.8%	18.54%	20.4%
HUC_18010203	Upper Klamath Lake	6.9%	9.9%	12.8%	14.0%
HUC_18010204	Lost	5.7%	6.8%	9.6%	10.7%
HUC_18010205	Butte	9.1%	10.8%	14.8%	16.1%
HUC_18010206	Upper Klamath	5.4%	6.6%	8.9%	9.7%
HUC_18010207	Shasta	2.2%	2.6%	3.9%	4.4%
HUC_18010208	Scott	4.2%	4.9%	6.6%	7.6%
HUC_18010209	Lower Klamath	-0.7%	-0.9%	-1.1%	-1.2%
HUC_18010210	Salmon	1.0%	1.1%	1.3%	1.4%
HUC_18010211	Trinity	0.7%	0.8%	0.8%	0.9%
HUC_18010212	South Fork Trinity	0.8%	0.9%	0.7%	0.6%
Total Basin		6.1%	7.5%	10.3%	11.4%

All HUC8 subbasins show positive ET_c increases or no change, with the exception of the western-most HUC8 subbasin which exhibits slight decreases in ET_c under all scenarios by 2070 due to earlier harvest of grass hay.

The spatial distribution of projected NIWR percent change for different climate scenarios and time periods is shown in Figure 4-10, and a comparison of projected changes in annual NIWR for the central tendency climate scenario is provided in Table 4-21. The NIWR incorporates growing season and non-growing season soil moisture gains and losses from precipitation, bare soil evaporation, and ET; therefore spatial variations in the distribution of NIWR percent change for different time periods and scenarios are a function of respective ET_c (Figure 4-9) and precipitation (Figure 4-6) distributions. For example, under the HD scenario precipitation is projected to decrease, whereas under the HW scenario precipitation is projected to increase. This results in NIWR increasing less in the HW scenario than in the HD scenario, though in both scenarios ETc changes are nearly identical.

Table 4-21.—Comparison of projected changes in annual NIWR for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins

HUC	Name	CMIP3 2030	CMIP5 2030	CMIP3 2070	CMIP5 2070
HUC_18010201	Williamson	16.1%	19.0%	26.1%	26.1%
HUC_18010202	Sprague	16.7%	18.4%	24.1%	25.0%
HUC_18010203	Upper Klamath Lake	10.5%	12.0%	17.2%	17.5%
HUC_18010204	Lost	8. 6%	9.4%	13.8%	14.2%
HUC_18010205	Butte	12.7%	13.9%	20.5%	20.4%
HUC_18010206	Upper Klamath	5.7%	5.7%	10.7%	10.4%
HUC_18010207	Shasta	3.5%	2.8%	4.8%	4.4%
HUC_18010208	Scott	5.5%	6.5%	8.7%	9.1%
HUC_18010209	Lower Klamath	-1.0%	-1.8%	-1.4%	-2.8%
HUC_18010210	Salmon	1.3%	1.4%	2.4%	1.8%
HUC_18010211	Trinity	0.8%	0.8%	1.1%	0.9%
HUC_18010212	South Fork Trinity	1.0%	0.1%	0.9%	-0.3%
Total Basin		9.0%	9.8%	14.1%	14.4%

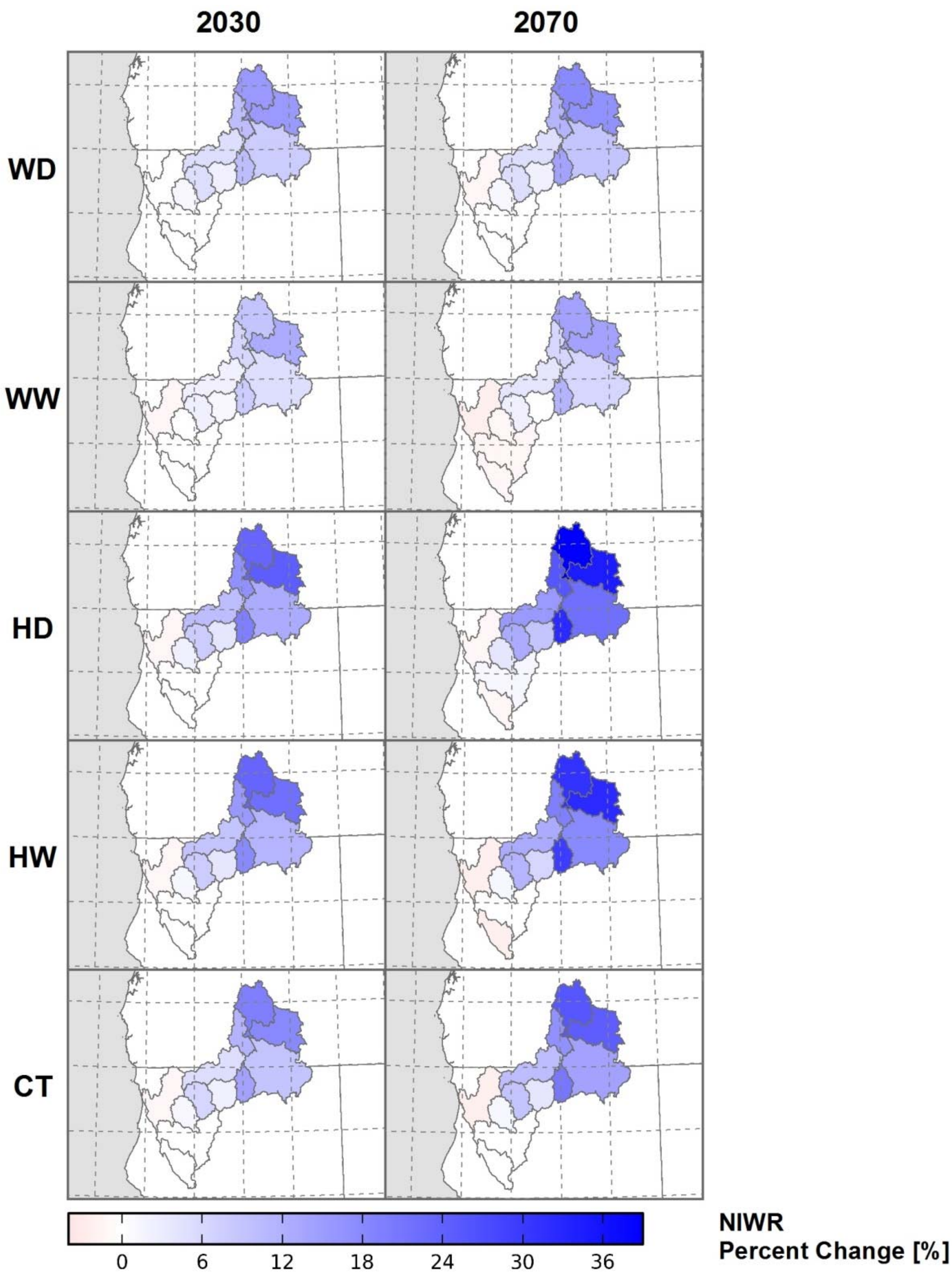

Figure 4-10.—Klamath River Basin - Spatial distribution of projected net irrigation water requirements percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios).

Figures 4-11, 4-12, and 4-13 illustrate the historical baseline and projected temporal distribution of mean daily ET_c for three perennial crops (alfalfa, pasture grass, and grass hay, respectively) under each CMIP5-based climate change scenario for the 2030s and 2070s. The values plotted in these figures are based on model results for Met Node OR4511 (NWS/COOP Klamath Falls Ag. Station).

Future Irrigation Demand Results

Assuming no change from current cropping patterns, the projected change in the central tendency scenario for the 2070s over the basin is 6-7% for reference ET (corresponding primarily to projected changes in temperature), while the projected change in crop ET is 10-11% (which incorporates changes in timing of crop growth and harvesting), and the projected change in NIWR is about 14% (which reflects changes in soil moisture throughout the year).

Figure 4-11 shows slight but noticeable shifts in the growing season length and alfalfa cutting cycles relative to historical baseline conditions by the 2030s (left). By the 2070s time period (Figure 4-11, right) significant shifts in growing season length, crop development, and cutting cycles are noticeable relative to baseline conditions, with the HW and HD scenarios exhibiting the most extreme changes. These simulations assume established crops rather than first year plantings. Projected changes in ET_c are primarily realized through earlier green-up of alfalfa hay and changes in its cutting pattern. Senescence of the crop is delayed somewhat, but is primarily driven by day length. Maximum mean daily ET_c during the warmest part of the year is not projected to increase substantially, primarily because plants have a maximum rate at which they can evapotranspire despite further increases in temperature.

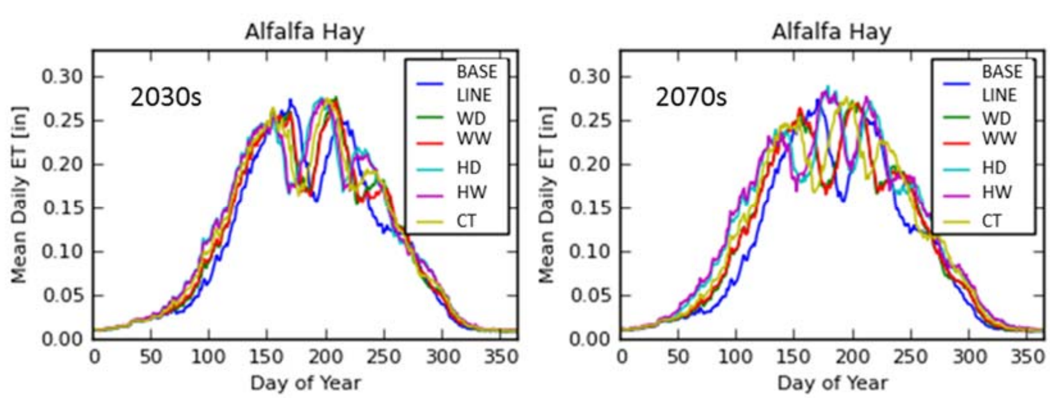

Figure 4-11.—Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily alfalfa evapotranspiration for all CMIP5-based scenarios and time periods.

Figure 4-12 shows simulated mean daily ET_c of pasture grass; similar changes in green-up and increases in growing season length and ET_c are projected when compared to alfalfa, with the HW and HD scenarios having the most extreme seasonal changes.

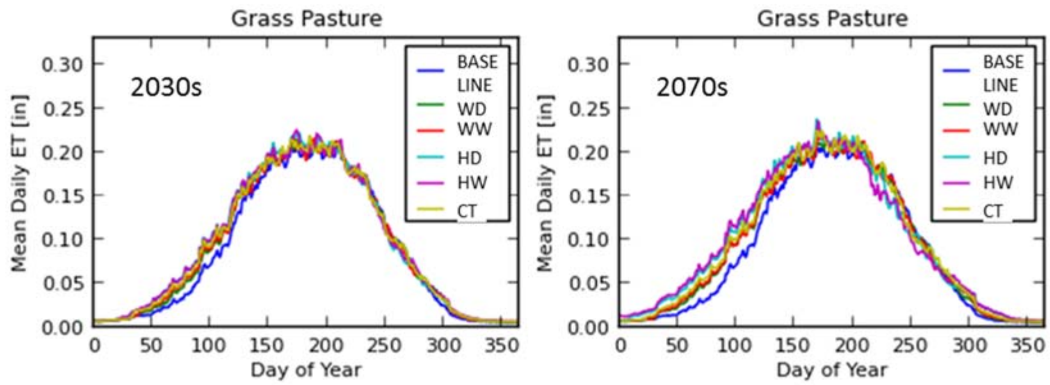

Figure 4-12.—Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily pasture grass evapotranspiration for all CMIP5-based scenarios and time periods.

Figure 4-13 shows simulated mean daily ET_c of grass hay. As with alfalfa and pasture grass, earlier green-up and increased mean daily ET_c are slight for the 2030s and more pronounced for the 2070s. However, for the 2070s HW and HD scenarios, the overall growth period shifts forward rather than increasing in length. This is apparently due to the crop maturing earlier because of increased ET_c early in the growing season under higher temperatures.

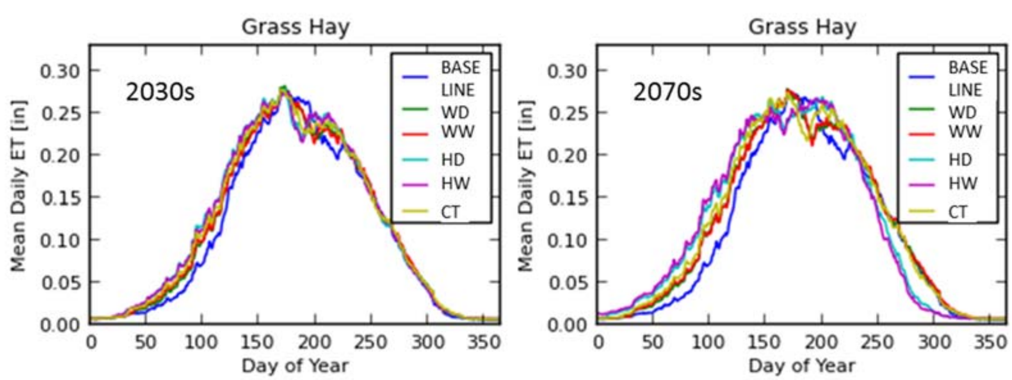

Figure 4-13.—Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily grass hay evapotranspiration for all CMIP5-based scenarios and time periods.

4.3.3.1.2 Municipal and Industrial

Future M&I demand estimates are based on population growth projections and climate change scenarios. It is assumed current per capita demands will change as a function of changes in landscape irrigation demands due to climate change.

Socio-economic factors that could cause changes in per capita demand, such as water conservation, reduced landscape areas, etc., are not accounted for in this chapter but are evaluated as potential adaptation strategies in Chapter 6. As previously discussed, 40 percent of total M&I use is assumed to be consumed through landscape irrigation.

The first step in estimating future M&I demands is to calculate the future base demands based on current demands and future population growth estimates (i.e., including growth scenario but no climate change scenarios). The base future demands are then adjusted for climate change effects on landscape irrigation. The adjustments were made using the same methods discussed previously for the future agricultural irrigation demand estimates. Specifically, the ET Demands model was used to calculate percent change in turf grass NIWR under the five climate change scenarios (WW, WD, CT, HW, and HD) using the two GCM projection datasets (CMIP3 and CMIP5). Forty percent of the base future demand estimate for a given period and scenario is increased based on the ET Demands model results.

The future M&I demand estimates for Klamath, Siskiyou, and Trinity Counties were calculated based on the 2005 USGS Water Use Program estimates and population growth rates published by the California Department of Finance[29] and Oregon Office of Economic Analysis.[30] Since the California and Oregon projections are for 2010 through 2060 and 2050 in five-year increments, respectively, it is assumed the growth rates from 2005 to 2015 are uniform as well for 2050–2070 (Oregon) and 2060–2070 (California). The product of the 2030 and 2070 county population growth rates and the 2005 county M&I estimates yields the base M&I demands for each county.

For the municipalities with domestic water supply systems in Del Norte, Humboldt, and Modoc Counties (Hoopa, Klamath, Newell, Orleans, and Willow Creek, all in California), county population growth rates published by the California Department of Finance were applied to the current (2010) population estimates for calculating future population estimates. The product of the 2030 and 2070 population projections and the current per capita demand estimates yields the base M&I demands for each of the systems in these municipalities.

As discussed above, each of the M&I base consumptive use estimates are adjusted for climate change. Figure 4-14 provides a summary of projected changes in M&I consumptive use for each county and each climate change scenario. The 2030 M&I consumptive use totals for all counties range from 9,759 AFY to 10,065 AFY and the 2070 estimate totals range from 11,003 AFY to 11,747 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

[29] http://www.dof.ca.gov/Forecasting/Demographics/Projections/
[30] https://www.oregon.gov/das/OEA/Pages/forecastdemographic.aspx

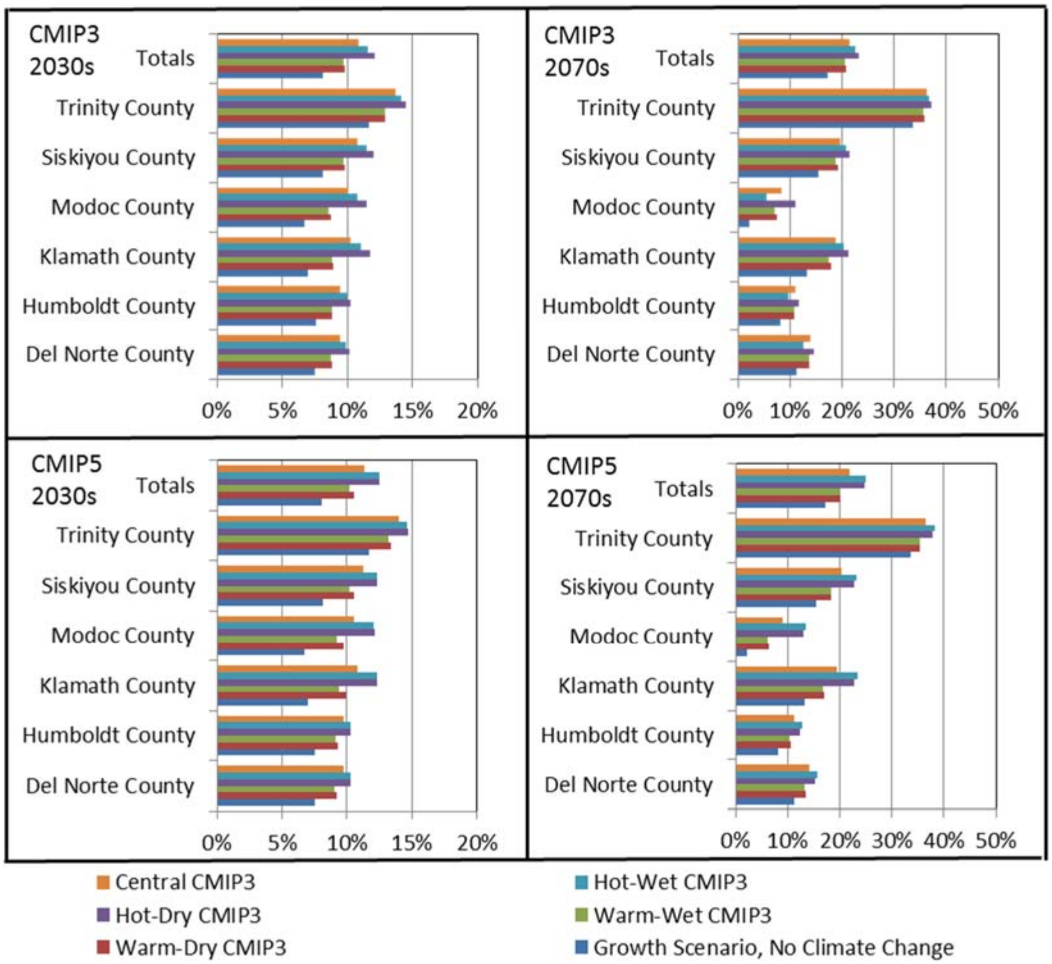

Figure 4-14.—Summary of future municipal and industrial consumptive use estimates (percent change).

4.3.3.1.3 Rural Domestic

Future rural domestic water demand estimates were calculated based on population growth projections and climate change scenarios in the same manner as the M&I estimates discussed above. The same portion of total use for landscape irrigation is assumed (40 percent). Therefore, projections of future rural domestic use include only the consumptive portion of total use.

As discussed under Section 4.2, Current Demand, it is assumed the demands associated with the limited number of rural domestic water users in the portions of the basin in Del Norte and Humboldt Counties in California and Lake and Jackson Counties in Oregon are negligible. Estimates were therefore calculated for Modoc, Siskiyou, and Trinity Counties in California and Klamath County in Oregon. The population projections used in the calculations are based on the 2005 USGS Water Use Program information and county population projections published by the California Department of Finance and Oregon Office of Economic Analysis.

Figure 4-15 provides a summary of projected change in rural domestic consumptive use for each county and each climate change scenario. The 2030s estimate totals for all counties range from 5,013 AFY to 5,190 AFY and the 2070s estimate totals range from 5,644 AFY to 6,030 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

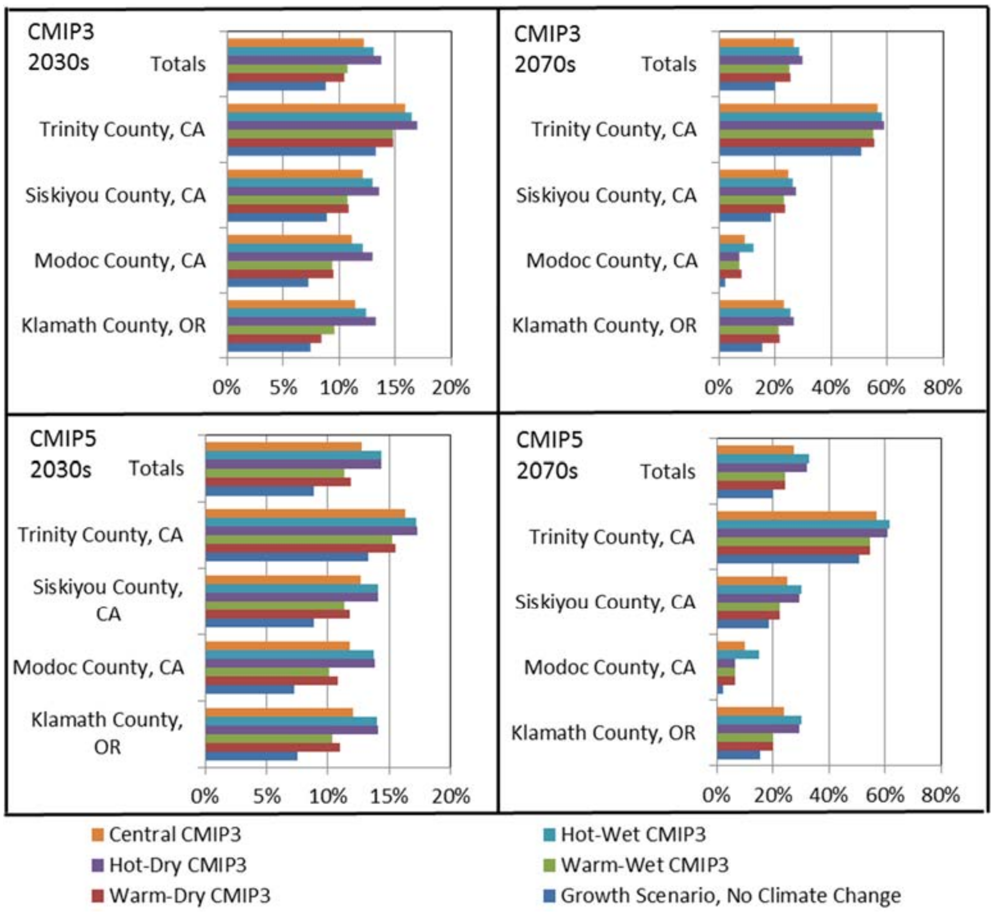

Figure 4-15.—Summary of future rural domestic consumptive water use estimates (percent change).

4.3.3.2 Wetlands

Future wetland ET was computed based on projected mean daily alfalfa ET and pasture ET, using the same approach defined in Section 4.21, Human Influenced Consumptive Uses–Wetlands. Climate change scenarios using the HDe approach for each of the five quadrants of change for the 2030s and 2070s (using both CMIP3- and CMIP5-based projections) were also incorporated. The same relationships between wetland ET and alfalfa and pasture ET, according to the findings of Stannard et al. (2013), were used to determine projected mean annual wetland ET. Wetland ET is about 7 percent less than alfalfa ET during its average growing season and wetland ET is also about 18 percent greater than pasture ET during its average growing season. Mean annual wetland ET was computed using both relationships and averaged together for a single estimate.

Table 4-22 provides a summary of the resulting future wetland ET for each climate change scenario. The 2030s estimates range from 1,144,230 AFY to 1,228,916 AFY and the 2070s estimates range from 1,192,224 AFY to 1,319,673 AFY, compared with 1,089,061 AFY estimated for the mean annual historical wetland ET.

Table 4-22.—Summary of basin-wide projected changes in wetlands ET

Future Period and Scenario	Mean Annual Wetland ET (AFY)	Mean Annual Wetland ET (Percent Change)
Historical	1,089,061	-
2030 Warm-Dry CMIP3	1,144,230	5%
2030 Warm-Dry CMIP5	1,155,489	6%
2030 Warm-Wet CMIP3	1,146,443	5%
2030 Warm-Wet CMIP5	1,163,648	7%
2030 Hot-Dry CMIP3	1,205,813	11%
2030 Hot-Dry CMIP5	1,228,916	13%
2030 Hot-Wet CMIP3	1,202,385	10%
2030 Hot-Wet CMIP5	1,225,025	12%
2030 Central CMIP3	1,175,143	8%
2030 Central CMIP5	1,191,936	9%
2070 Warm-Dry CMIP3	1,208,198	11%
2070 Warm-Dry CMIP5	1,192,224	9%
2070 Warm-Wet CMIP3	1,219,044	12%
2070 Warm-Wet CMIP5	1,203,335	10%
2070 Hot-Dry CMIP3	1,260,874	16%
2070 Hot-Dry CMIP5	1,300,472	19%
2070 Hot-Wet CMIP3	1,271,150	17%
2070 Hot-Wet CMIP5	1,319,673	21%
2070 Central CMIP3	1,237,064	14%
2070 Central CMIP5	1,246,884	14%

4.3.3.3 Lake and Reservoir Evaporation

The previously discussed CRLE model that was used to estimate historical baseline average evaporation rates was also used to estimate future average rates for the 2030s and 2070s periods. The same HDe climate change scenarios temperature and precipitation data described under the future agricultural irrigation demands discussion were input to the model. The model results include mean monthly evaporation and net evaporation (evaporation minus precipitation) rates for all of the reservoirs included in Table 4-14. The results for Upper Klamath Lake and Clair Engle Lake are discussed below, and the results for the other reservoirs are included in Appendix C, Section 5.0

Figures 4-16 and 4-17 show Upper Klamath Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and the historical baseline (1950–1999). The simulated impact of heat storage is negligible due to the shallow depth of Upper Klamath Lake. The magnitude of projected monthly evaporation and net evaporation increase is greatest during July, and least during fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Upper Klamath Lake is 5.5 and 5.4 percent (2.4 and 1.1 inches). Values for all scenarios are included in Appendix C, Section 5.0.

Figures 4-18 and 4-19 show Clair Engle Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and historical baseline (1950–1999). The simulated impact of heat storage due to the depth of Clair Engle Lake can be seen in the lag in peak evaporation relative to peak air temperatures (August versus July). Also, the relatively high precipitation rates result in negative net evaporation under all scenarios and the historical baseline. The magnitude of projected monthly evaporation and net evaporation increase is greatest during August, and least during the fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Clair Engle Lake is 5.7 and 9.0 percent (2.3 and -2.3 inches), respectively. Values for all scenarios are included in Appendix C, Section 5.0.

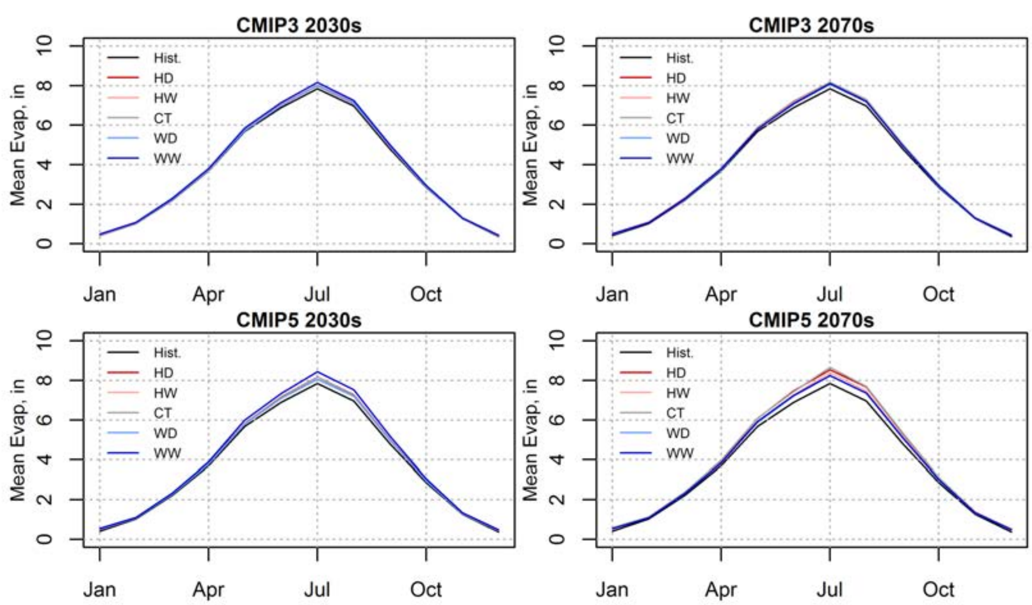

Figure 4-16.—Summary projected mean monthly evaporation at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s.

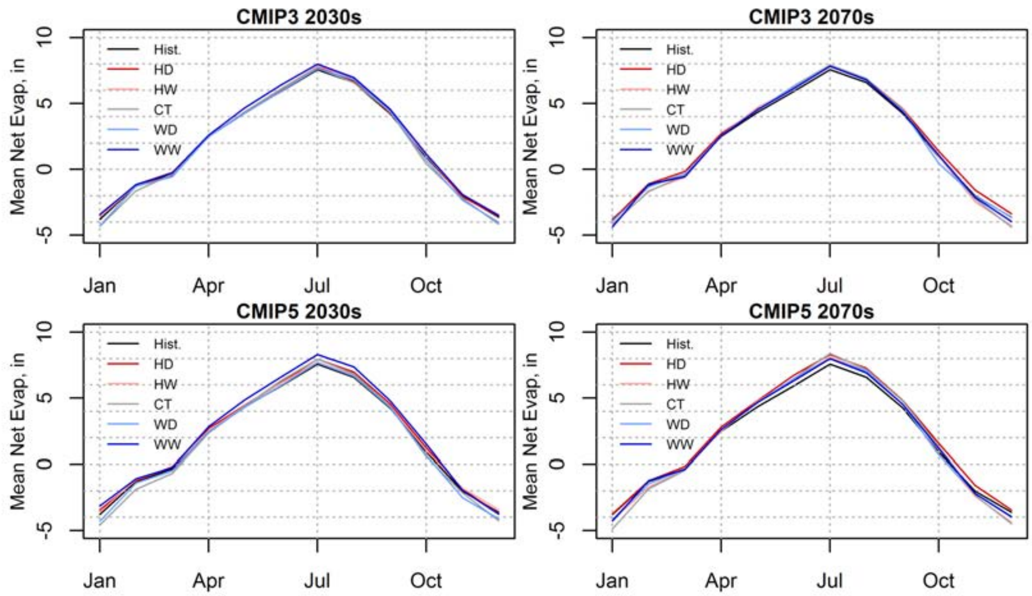

Figure 4-17.—Summary projected mean monthly net evaporation (evaporation – precipitation) at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s.

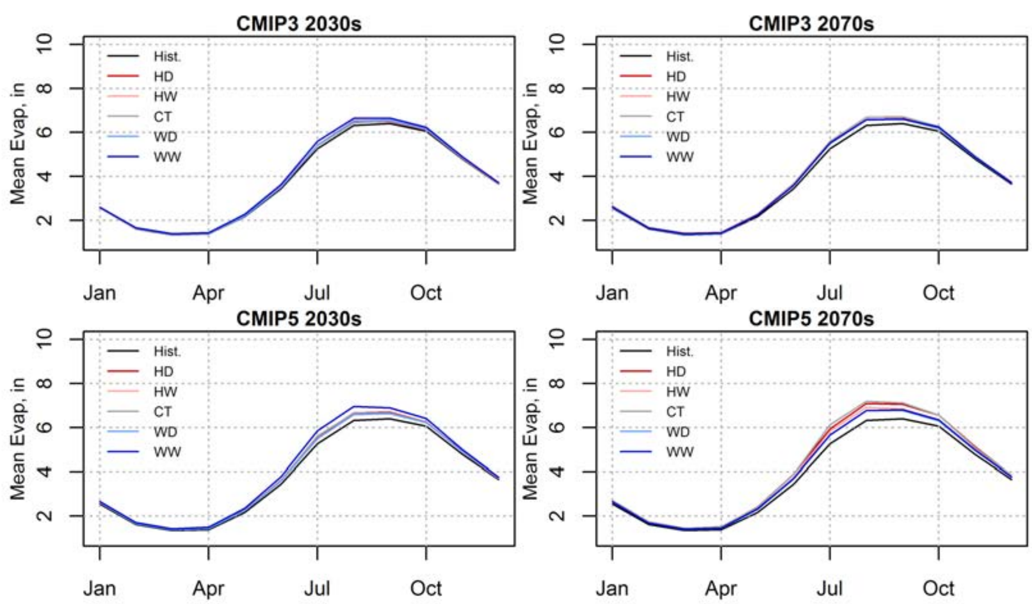

Figure 4-18.—Summary projected mean monthly evaporation at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s.

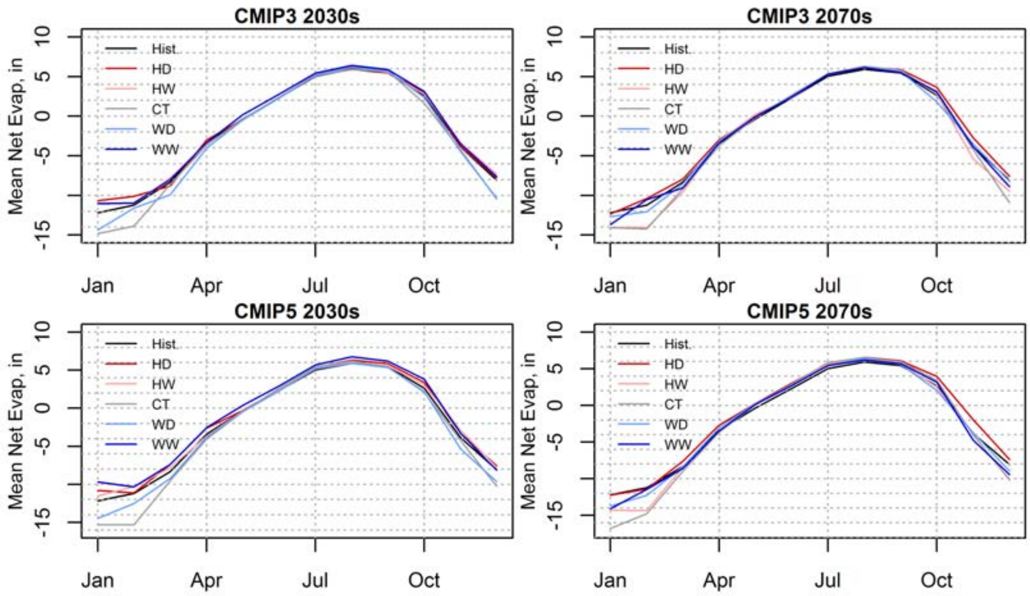

Figure 4-19.—Summary projected mean monthly net evaporation (evaporation – precipitation) at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s.

4.3.3.4 Non-Consumptive Uses

The effects of climate change on these uses (including recreation, environmental resources, hydropower, and aquaculture) are evaluated as part of the system reliability analysis in Chapter 5. In Chapter 5, the impacts are discussed in terms of factors such as exceedance of water quality criteria, flow or water level targets, and loss of power generation due to changing flows.

4.4 Uncertainties Associated with Impacts Assessment Approach

The Chapter 3 discussions on uncertainties associated with the various aspects of the Klamath River Basin Study water supply assessment covered many topics that also apply to the demands assessment. These topics include global climate forcing and simulation, climate projection bias correction and spatial downscaling, and climate projections from CMIP3 and CMIP5. Brief discussions of the limitations and uncertainties associated with quantification of water demands are presented below. A detailed discussion of uncertainties associated with the models used to estimate net irrigation water requirements (ET Demands) and reservoir evaporation (CRLE) are presented in Reclamation (2015) and are not detailed here.

4.4.1 Agricultural Irrigation

There are numerous uncertainties and limitations in modeling reference ET, crop ET, and net irrigation water requirements. One source of uncertainty is associated with underlying assumptions in modeling, such as static cropping patterns and farming practices. This study uses data provided by Reclamation's Klamath Basin Area Office for Klamath Project lands and the USDA crop land data layer for the remainder of the basin as the sources for quantifying the types of crops grown in the Klamath River Basin. It is assumed these crop types and quantities do not change in the modeling. Obviously, increases or decreases in the overall amount of irrigated area would result in respective changes in demands. Changes in crop choice may significantly affect future agricultural demands given the variability in water demand for different crop types.

Another source of uncertainty is the weighted average soil conditions used in the estimation of net irrigation water requirements. Precipitation runoff and soil water holding capacity are a function of soil type, and soil types can vary significantly even within a single irrigated parcel of land. The degree of uncertainty in the method used depends on the variability of soil types within each HUC8 subbasin for which a weighted average soil type was calculated, as described in Reclamation (2015).

Climatic data used in this basin study analysis were limited to daily maximum and minimum temperatures and daily precipitation; therefore solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Solar radiation was simulated for baseline and future periods based on empirical relationships of differences between daily maximum and minimum air temperatures, where maximum air temperature generally decreases during cloud cover, and minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Integration of potential changes in solar radiation, and evaluating the potential impact of such changes on irrigation water demands, were not addressed in this analysis.

Historical agricultural weather station data were used to estimate the spatial distribution of baseline and projected mean monthly dewpoint depression and windspeed. Given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there is considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using the assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET.

4.4.2 Municipal and Industrial and Rural Domestic

Uncertainties associated with M&I and rural domestic demands are related to the assumed population projections and per capita demand rates used, and the assumed landscape irrigation portion of the overall demand (40 percent).

4.4.3 Wetlands

Evapotranspiration from wetlands is difficult to quantify and a limited number of studies have been conducted in this area of research. Wetlands are biologically diverse and quantification of ET requires expensive long-term monitoring. Existing studies often based their findings on data collected over a limited time period, generally a few years, contributing to the uncertainty around their estimates. The Klamath River Basin Study utilizes available studies to estimate mean annual wetland ET. Although there is relatively high uncertainty surrounding the estimates of wetland ET in this study, they generally corroborate other existing studies and provide a best estimate of mean annual wetland ET.

4.4.4 Reservoir Evaporation

Uncertainties in estimated reservoir evaporation are largely centered on CRLE energy balance considerations, specifically heat storage and advection of heat in air and water into and out of the reservoir. One important limitation of the CRLE model is its reliance on energy balance without consideration of the effects of windspeed on evaporation. However, one could argue that using an approach that heavily relies on windspeed, and is therefore extremely sensitive to uncertainties in windspeed (i.e., the aerodynamic-mass transfer or combination approach), may actually increase evaporation uncertainty, especially under future climates where projections of near surface local scale windspeed estimates are extremely uncertain.

It is significant that reservoir evaporation and net evaporation (evaporation minus precipitation) demands were estimated in terms of annual rates or depths rather than volumes. These rates were estimated based on average historical conditions and a more rigorous analysis would be required to model evaporation under predicted future reservoir conditions. Future research in the Klamath River Basin could involve adjusting the CRLE model to accommodate projections of future reservoir conditions.

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Chapter 5
Klamath River Basin Study
System Reliability Analysis

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Chapter 5
System Reliability Analysis

5.1 Introduction

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to work toward future water security. Reclamation developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (P.L. 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management. Studies are typically completed within a three-year timeframe. The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances.

This chapter discusses the methodology for evaluating gaps in water supply and demand and summarizes the reliability of the Klamath River system in achieving numerous defined measures, based on both historical data and projected future conditions.

Previous chapters of the Basin Study include an introduction and background for the study (Chapter 1), a discussion of various interrelated activities in the watershed (Chapter 2), an assessment of historical and future water supply in the watershed (Chapter 3), and an assessment of historical and future water demand in the watershed (Chapter 4). Chapter 6 discusses the development and evaluation of adaptation strategies for reducing gaps in water supply and demand within the system reliability framework discussed in this chapter. Figure 5-1 provides an overall schematic of the Basin Study approach to provide context for Chapter 5.

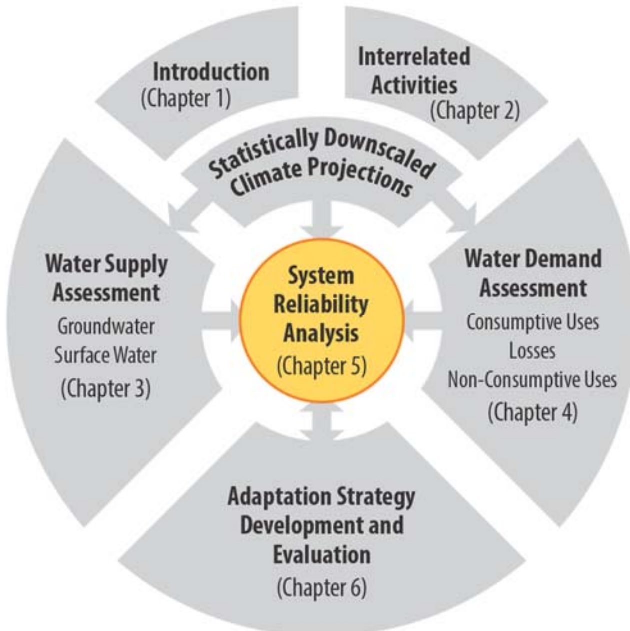


Figure 5-1.—Overall approach of Klamath River Basin Study, highlighting Chapter 5

5.2 System Reliability Methodology

The Basin Study developed a framework for evaluating projected future water supply and demand conditions in a changing climate. This framework includes scenarios for characterizing projected future conditions, along with development and implementation of connected modeling components, with the end goal of evaluating system risk and reliability in the basin. Additionally, the Basin Study system risk and reliability analysis evaluates impacts of climate change on non-consumptive uses, which are those that do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.) and water needs to support fish and wildlife and hydropower production, among others.

This section briefly reviews the scenarios developed and corresponding modeling components implemented to provide inputs to a water management model. More detailed discussions of historical and projected water supply and demand are provided in Chapters 3 and 4, respectively. This section then provides a detailed description of the tools developed to evaluate system reliability and potential vulnerabilities to climate change impacts. Results from the analysis are evaluated using basin-wide response variables and defined measures to quantify and summarize projected changes in system reliability due to climate change.

5.2.1 Characterizing Historical and Future Conditions

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020–2049) and the 2070s (represented by the mean from 2060–2089). Future projections are compared with a historical reference period of 1950–1999 to evaluate the effects of climate change on water supply.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. The same dataset was used for analysis of historical conditions in the Basin Study. Historical trends in April 1 SWE, total annual runoff, total annual ET, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model (described in detail in Chapter 3).

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50 year period). All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999. Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide. Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent. ET, as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide. Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole. The only statistically significant trend at the 95th percentile level computed with the historical data is mean annual temperature.

The development of climate change scenarios is described in Chapter 3, Section 3.5.1.1 Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). The Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes available climate projections to derive a smaller number of climate change scenarios to inform long term planning. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios for each of two sets of projections (CMIP3 and CMIP5). These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT). These scenarios were derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d).

Projections of future water supply and demand using the above-discussed climate change scenarios and evaluated in Chapters 3 and 4, respectively, are briefly summarized below. Following this brief summary is a discussion of the methodology used to evaluate projected changes in managed streamflow and water temperature at various locations throughout the basin.

5.2.1.1 Water Supply

- By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

- Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

- A decrease in April 1 SWE is projected on the order of 34 to 40 percent for the 2030s and close to 60 percent for the 2070s, and projected increases in annual runoff are 7 to 12 percent for the 2030s and 14 to 15 percent for the 2070s. Projected increases in mean annual runoff are offset by projected changes in April 1 SWE, primarily due to projected increases in mean annual precipitation,

- For sub-basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

- An increase in groundwater head is projected in mountainous recharge areas of the Upper Klamath Basin (less than 9 percent), as is a change in groundwater discharge to streams, while little change is expected in populated interior parts of the basin.

5.2.1.2 Water Demands (Human Influenced)

- Agricultural irrigation demand (surface and groundwater) is the largest human influenced consumptive use in the basin.

- Projected changes in total consumptive uses are 12 or 13 percent (CMIP3 and CMIP5 scenarios, respectively) for the 2030s and 17 or 18 percent for the 2070s. Consumptive uses include agricultural irrigation, net reservoir evaporation, municipal and industrial (M&I) and rural domestic demands, and wetlands.

- The effects of climate change on other non-consumptive uses including recreation, environmental resources, hydropower, and aquaculture are evaluated as part of this chapter.

5.2.2 Basin-Wide Responses

The evaluation of climate change impacts on system risk and reliability has two primary components: basin-wide system response at various basin locations, and specific performance measures that have been identified through discussions with regional resource managers, stakeholders, and others. Evaluation of basin-wide system response provides a general understanding of projected changes in managed conditions as a result of climate change and implemented adaptation strategies. Evaluation of system response to quantified measures provides a deeper understanding of climate change impacts on specific resources relevant to water management in the basin.

Basin-wide response variables include mean monthly conditions for the following locations:

- Mean monthly Upper Klamath Lake storage
- Mean monthly inflow to Klamath River at Keno
- Mean monthly streamflow, Klamath River at Iron Gate
- Mean monthly streamflow, Klamath River at Orleans, California
- Mean monthly streamflow, Klamath River near Klamath, California
- Mean monthly water temperature in the Klamath River near Klamath, California

This report includes analysis of historical and projected future changes in these basin-wide response variables, according to the developed Basin Study modeling framework. Subsequently, in Chapter 6, basin-wide response variables are evaluated for each of the adaptation strategies selected for exploring ways to reduce any identified water supply and demand gaps. Performance measures are described in more detail below.

5.2.3 Performance Measures

Performance measures are used to evaluate historical and future vulnerabilities to meeting water needs in the basin, and to facilitate the comparison of adaptation strategies to reduce any identified imbalances in water supply and demand. Performance measures have been identified in accordance with the Basin Study Framework guidance document (Reclamation, 2009c) and span numerous resource categories, which include:

- Water deliveries – the ability for water to be delivered to water users

- Hydroelectric power resources

- Recreational resources – including Reclamation facilities and parts of the watershed impacted by Reclamation operations
- Ecological resources – including fish and wildlife habitat; applicable species listed as an endangered, threatened, or candidate species under the Endangered Species Act of 1973; species and habitat of cultural importance; and flow and water dependent ecological resiliency
- Water quality resources
- Flood control

Measures for each category were arrived at based on input from stakeholders and resource managers in the basin. Table 5-1 summarizes the performance measures. The following paragraphs describe each measure in more detail.

Table 5-1.—General description of performance measures

Resource Category	Measure Description	Location(s)	Measure Details
Water supplies	Total Klamath Project supply	Klamath Project	Calculated under 2013 Biological Opinion operating criteria. Compare result with full season Klamath Project supply of 390,000 acre-feet.
	Total Upper Klamath Lake seasonal supply	Upper Klamath Lake	End of February storage plus actual March through September inflow at Upper Klamath Lake
	Mean annual tributary flow	Shasta River; Scott River	Mean annual flow at USGS gages (USGS 11517500 Shasta River near Yreka; USGS 11519500 Scott River near Fort Jones)
Hydroelectric power resources	Hydropower production	Sum of J.C. Boyle power, COPCO 1 power, COPCO 2 power, Iron Gate power	Mean annual hydropower production summed over these facilities[31]
	Volume of spill	J.C. Boyle, COPCO 1, Iron Gate	Mean annual spill volume based on water year[1]
	Frequency of spill	J.C. Boyle, COPCO 1, Iron Gate	Mean number of spill days per water year at these facilities[1]
Recreational resources	Mean fishing days per year	Various mainstem Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches
	Mean boating days per year	Various mainstem Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches

[31] Source: PacifiCorp

Table 5-1.—General description of performance measures

Resource Category	Measure Description	Location(s)	Measure Details
Ecological resources	Salmonid success	Shasta River; Scott River	Flow thresholds throughout the year[32]
	Delivery to refuge	Lower Klamath National Wildlife Refuge	Mean annual water delivery to refuge[33]
	Pool elevation	Clear Lake; Gerber Reservoir	Minimum elevation thresholds[34]
Water quality	Water temperature	Klamath River	Maximum weekly average temperature (MWAT)
Flood control	Frequency of flood control release	Upper Klamath Lake	Mean number of days per year that flood control releases are made from Upper Klamath Lake[35]
	Mean annual flood control release volume	Upper Klamath Lake	Mean annual volume of flood control releases from Upper Klamath Lake[5]
	Date of seasonal peak flow	J.C. Boyle, COPCO 1, Iron Gate	Mean date of the center of mass of the annual flow volume (by water year) at select locations[1]

5.2.3.1 Water Supplies – Klamath Project Water Supply

There are two measures associated with Klamath Project water supply. The first measure is computed as the mean annual water supply to the Klamath Project, expressed as a percentage. The value may be compared with a full supply quantified as 390,000 acre-feet.

The second measure is computed as the sum of the end of February Upper Klamath Lake storage and the actual March through September Upper Klamath Lake inflow, averaged across the simulation years and expressed in units of a thousand acre-feet. The measure represents the total seasonal availability of water supply to be distributed among project responsibilities.

5.2.3.2 Water Supplies – Mean Annual Tributary Flow in Shasta and Scott Rivers

This measure is computed for two locations: USGS gages Shasta River near Yreka (11517500) and Scott River near Fort Jones (11519500). The measure is computed as the mean annual streamflow at these two locations. Effectively, the simulated streamflows represent the balance of supply and demand in these two tributary watersheds to the Klamath River. Units are in cubic feet per second (cfs).

[32] Source: McBain and Trush (2014)
[33] Source: Klamath Basin National Wildlife Refuge Complex
[34] Source: Klamath Basin Area Office
[35] Source: Reclamation (2012d)

5.2.3.3 Hydroelectric Power Resources – Hydropower Production

This measure is computed as the sum of mean annual hydropower production at J.C. Boyle reservoir, COPCO 1 reservoir, COPCO 2 reservoir, and Iron Gate reservoir. Units of hydropower production are megawatts.

5.2.3.4 Hydroelectric Power Resources – Spill Volume

This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean spill per year in cfs.

5.2.3.5 Hydroelectric Power Resources – Spill Frequency

This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean number of days per year that each of the reservoirs have spill.

5.2.3.6 Recreational Resources – Mean Annual Fishing Days

This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow (by the surface water management model) is within the target ranges for fishing in each river reach. Table 5-2 lists the recommended flow ranges for fishing.

Table 5-2.—Recommended target flow ranges for fishing within select reaches of the Klamath River

River Reach	Flow Target Ranges (cfs)
Keno Reach	200-1,500
J.C. Boyle	200-1,000
Hell’s Corner Reach	200-1,500
COPCO 2 Bypass Reach	50-600
Iron Gate to Scott River	800-4,000
Scott River to Salmon River	800-4,000
Salmon River to Trinity River	800-10,000
Trinity River to ocean	1,000-18,000

Source: Interior and CDFG, 2012

5.2.3.7 Recreational Resources – Mean Annual Boating Days

This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow by the surface water management model is within the target ranges for river boating in each river reach. Table 5-3 lists the recommended flow ranges for river boating.

Table 5-3.—Recommended target flow ranges for boating within select reaches of the Klamath River

River Reach	Flow Target Ranges (cfs)
Keno Reach	1,000-4,000
J.C. Boyle	1,300-1,800
Hell's Corner Reach	1,000-3,500
COPCO 2 Bypass Reach	600-1,500
Iron Gate to Scott River	800-4,000
Scott River to Salmon River	800-7,000
Salmon River to Trinity River	800-10,000
Trinity River to ocean	1,000-18,000

Source: Interior and CDFG, 2012

5.2.3.8 Ecological Resources – Salmonid Success in Shasta and Scott Rivers

This measure is computed at two locations: USGS gages Scott River near Fort Jones (11519500) and Shasta River near Yreka (11517500). The measure compares simulated daily flow to quantified dry year flow targets recommended by McBain and Trush (2014) for the Shasta River. A dry year has an exceedance probability of between 61 and 100 percent. The measure is computed as the total number of days in a model simulation that dry year flow targets are met or exceeded, divided by the total number of days in the simulation and presented as a percentage. Dry year flow targets recommended by McBain and Trush (2014) are summarized below in Table 5-4. Note that the flow targets were developed for the Shasta River, where mean annual flow (188 cfs) is less than one third that of the Scott River (669 cfs). However, for purposes of this analysis the same threshold flows were applied for the Scott River to explore the frequency of meeting those same target flows in the Scott River.

Table 5-4.—Dry Year (61–100 percent exceedance) flow targets for salmonids

Time Period	Dry Year Target (cfs)
January 1 – March 31	135
April 1 – May 15	170
May 16 – June 15	150
June 16 – September 15	70
September 16 September 30	70-90
October 1 – October 16	125
October 17 – October 30	125-150
October 31 – December 31	150

Source: McBain and Trush 2014

5.2.3.9 Ecological Resources –Water Delivery to Lower Klamath National Wildlife Refuge

This measure is computed as the mean annual water supply to Lower Klamath National Wildlife Refuge as simulated by the surface water management model. The measure is expressed in acre-feet.

5.2.3.10 Ecological Resources – Pool Elevation at Clear Lake and Gerber Reservoirs

This measure is computed at two locations: Clear Lake and Gerber Reservoirs. The measure compares simulated pool elevations at these locations with minimum pool elevations quantified for survival of Lost River and shortnose suckers. Minimum pool elevation for Clear Lake is 4,520.6 feet, while the minimum pool elevation for Gerber Reservoir is 4798.1 feet. The measure is computed as the mean percent of days that simulated pool elevations are at or above target pool elevations.

5.2.3.11 Water Quality – Water Temperature

This measure is computed as the maximum weekly average temperature (MWAT) in the mainstem Klamath River. The MWAT is the highest seven-day moving average of the daily mean river temperature. This measure is computed using the RBM10 stream temperature model developed by Perry et al. (2011). Details of the river temperature modeling approach and implementation are discussed in Section 5.3.2, System Reliability Model Development – Water Temperature Model. The MWAT is computed for each year and the mean of these temperatures across the simulation years is presented as the measure. Table 5-5 summarizes classifications of Poor to Very Good conditions for fish, along with associated temperature ranges, provided in the SONCC ESU coho salmon recovery plan (NMFS 2012).

Table 5-5.—Maximum weekly average temperature recommendations from the SONCC ESU salmon recovery plan

Maximum Weekly Average Temperature (MWAT) Classification	Temperature Range (degrees C)	Temperature Range (degrees F)
Poor	> 17.6	> 63.68
Fair	16-17	60.8-62.6
Good:	15-16	59-60.8
Very Good	< 15	< 59

Source: NMFS 2012, Appendix B

5.2.3.12 Flood Control – Flood Control Release Frequency

This measure is computed as the mean annual percent of days where release from Upper Klamath Lake is specifically for flood control purposes. The unit of the measure is percent of days.

5.2.3.13 Flood Control – Flood Control Release Volume

This measure is computed as the mean annual volume of releases from Upper Klamath Lake specifically for flood control purposes. The unit of the measure is thousands of acre-feet (KAF).

5.2.3.14 Flood Control – Date of Seasonal Peak Flow

This measure is computed as the mean date of the center of mass of the annual flow volume (by water year) at select locations. The center of mass is defined as the time at which half of the mean annual flow has passed the location of interest. The measure is presented as the mean date over the simulation period.

5.3 System Reliability Model Development

This analysis utilizes developed historical and future water supply and demand as input to a system risk and reliability model framework. The modeling framework involves two main components: the implementation of a surface water management model to generate simulated managed streamflow throughout the basin, and the implementation of a river temperature model to generate simulated water temperature in the mainstem Klamath River. The modeling components are described below in more detail.

5.3.1 Surface Water Management Model

A RiverWare surface water management model (Zagona et al., 2001) was developed for use by the Klamath River Basin Study. The RiverWare software platform allows for evaluation of river flows based on rule-based operations, using logic statements and assigned rule priorities. The RiverWare platform has been used in many other studies conducted by Reclamation and others (e.g., Colorado River Basin Water Supply and Demand Study [Reclamation, 2012e]; St. Mary River and Milk River Basins Study [Reclamation, 2012f]).

The Klamath Basin RiverWare model is a daily timestep model based on two existing models for the Upper Klamath Basin and Lower Klamath Basin. The existing Upper Klamath Basin model, commonly referred to as the Klamath Basin Planning Model (KBPM), was developed to support the ESA consultations over the impacts of Klamath Project operations on the endangered SONCC ESU coho salmon (Reclamation, 2012d). The existing Lower Klamath Basin model was developed to support the environmental impacts assessment for removal of four of the mainstem Klamath River dams (Interior, Department of Commerce, NMFS, 2012).

The Klamath Basin RiverWare model encompasses the entire watershed including tributaries of Upper Klamath Lake, the Lost River system, and major Klamath River tributaries such as the Shasta River, Scott River, Indian Creek, Salmon

River, and Trinity River. The model includes representation of eight reservoirs: Upper Klamath Lake, Clear Lake, Gerber Reservoir, Lake Ewauna, J.C. Boyle Reservoir, COPCO 1 Reservoir, COPCO 2 Reservoir, and Iron Gate Reservoir.

The Klamath Basin RiverWare model was developed over a historical time period of water years 1961 through 2013 to facilitate comparison of results with the KBPM model. The historical model incorporates historical water demand information, and simulated water supply information from the water supply assessment in Chapter 3 in order for model validation to be performed. Once simulated flows were reached that sufficiently compared with results from the KBPM model, a separate historical model was developed using a period of record of water years 1969 through 1999. The latter model incorporates simulated historical information from the water supply and water demands assessments in Chapters 3 and 4, respectively. This model was used as the basis for comparison of simulated streamflows under the historical climate to those under climate change scenarios.

The level of detail of the Klamath Basin RiverWare model allows for evaluation of Klamath River flows and Klamath Project operations under the current 2013 non-jeopardy Biological Opinion for SONCC ESU coho salmon, as well as evaluation of climate change impacts on other parts of the basin, including the Lost River and major Klamath River tributaries listed above.

Inputs to the Klamath Basin RiverWare model include the following:

- simulated natural surface hydrology from the VIC hydrologic model at various locations within the basin
- simulated groundwater discharge to streams in the Upper Klamath Basin as produced by the Gannett et al. (2007) MODFLOW model
- agricultural irrigation water requirements by 8-digit hydrologic unit code (HUC) throughout the Klamath Basin as produced by the water demands assessment (Chapter 4)
- net reservoir evaporation rates as produced by the water demands assessment (Chapter 4)
- M&I and rural domestic demands as produced by the water demands assessment

Outputs from the Klamath Basin RiverWare model include the following:

- Simulated managed flow at various locations in the Klamath Basin
- Reservoir storage and elevations

- Deliveries to the Klamath Project, Lower Klamath National Wildlife Refuge (LKNWR), etc.
- Hydropower generation

5.3.2 Water Temperature Model

The Klamath River Basin Study incorporates analysis of historical and projected future Klamath River temperature using an existing river temperature model developed by Perry et al. (2011). The river temperature model, called River Basin Model-10 (RBM10), was developed for the Secretarial Determination on removal of four hydroelectric dams on the Klamath River. It simulates water temperatures in the mainstem Klamath River from the Link River to the mouth. In this application, water temperatures are computed at the Klamath River near Klamath, California.

RBM10 uses a simple equilibrium flow model, assuming discharge in each river segment on each day is transmitted downstream instantaneously. The model uses a heat budget formulation to quantify heat flux at the air-water interface. Inputs for the heat budget were calculated from daily-mean meteorological data including net shortwave solar radiation, net longwave atmospheric radiation, air temperature, wind speed, vapor pressure, and a psychrometric constant needed to calculate the Bowen ratio.

For the Klamath River Basin Study application, meteorological inputs used as part of the water supply assessment described in Chapter 3 were adjusted to match the statistics of the meteorological data used by Perry et al. (2011) in their study of the impacts of climate change and dam removal on Klamath River water temperatures. Input streamflows were taken directly from the Klamath Basin RiverWare model at locations consistent with the Perry et al. (2011) study. It should be noted that input streamflows were increased by 10 cfs in some Upper Klamath Basin reaches to prevent negative streamflows in the mainstem Klamath River. Negative Klamath River flows were possible due to the difference in handling of streamflow routing by the RBM10 and Klamath River Basin RiverWare models.

> **Impacts on Reservoir Storage**
>
> Mean end of month storage in Upper Klamath Lake generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, end of month reservoir storage did not historically fluctuate substantially through the year. Projections for the 2030s and 2070s indicate peak storage is likely to remain about the same or increase slightly.

5.4 System Reliability and Impacts Assessment

Historical and projected future reliability of the Klamath River Basin water supply is summarized in two ways: through basin-wide response variables, and through identified reliability measures that were defined for six resource categories. This methodology was previously described in Section 5.2, System Reliability Methodology.

This chapter summarizes historical and projected changes in system reliability due to climate change alone. Chapter 6 discusses how various basin-wide responses and select measures may change as a result of implementing adaptation strategies.

5.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of historical and projected future basin-wide responses to water supply and demand allows for a general understanding of how the basin may respond as a result of climate change. Historical and projected future changes in water availability of the managed Klamath River system are provided below. Data supporting the following figures are provided in Appendix D.

5.4.1.1 Upper Klamath Lake Storage

Mean monthly end of month (EOM) storage in Upper Klamath Lake is summarized in Figure 5-2. Maximum storage historically occurs at the end of May, while minimum storage occurs in November. Under the climate change scenarios, mean EOM storage generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s, or even two months under the HW scenario. In addition, all scenarios experience a deeper drawdown of Upper Klamath Lake (UKL) than under simulated historical conditions and show minimum elevations in October compared to November (historical). Results in Figure 5-2 show that projected mean EOM storage is less under all future scenarios than under the simulated historical reference period. This result is likely due to use of the 2013 BiOp management criteria for all scenarios. Many management decisions rely on static look-up tables, which lack the flexibility to respond to different hydrologic conditions such as changes in Upper Klamath Lake inflow timing.

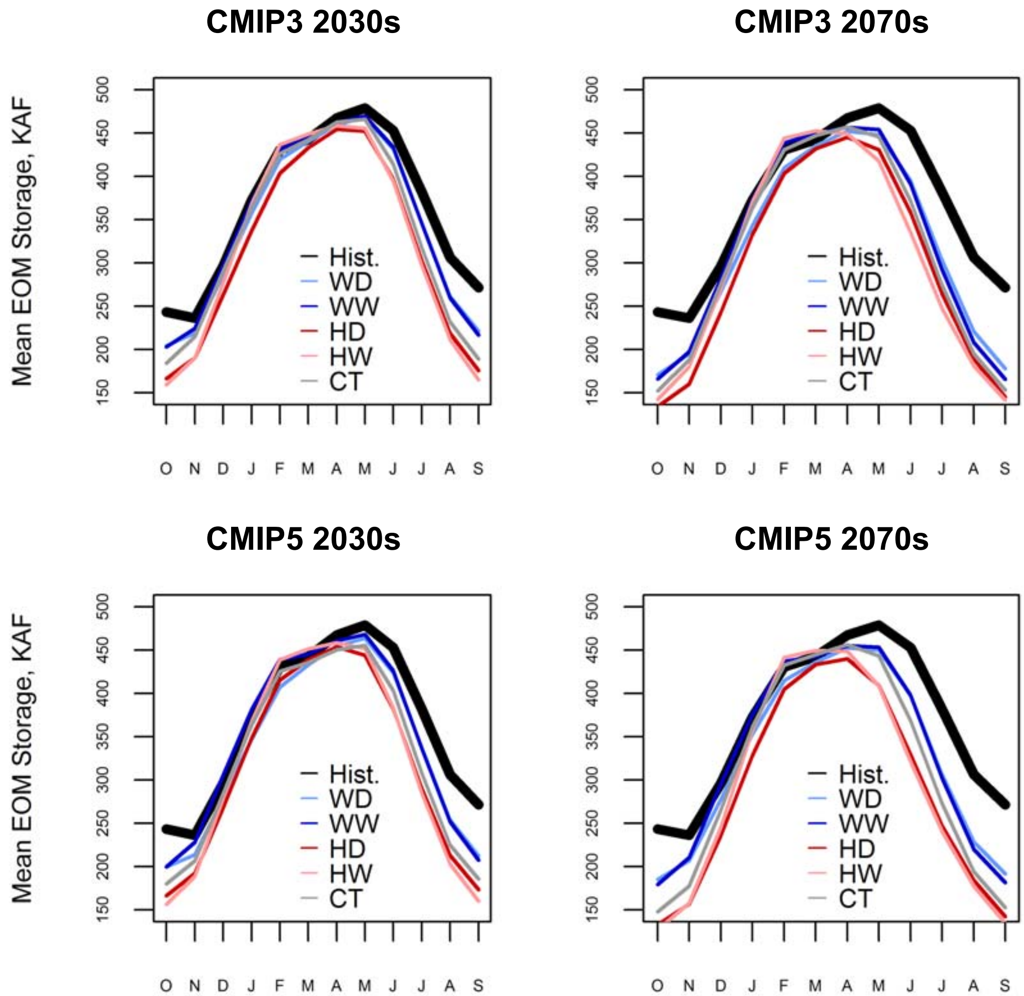


Figure 5-2.—Historical and projected future mean monthly Upper Klamath Lake storage (AF).

5.4.1.2 Keno Dam Inflow

Historical and projected future mean monthly inflow to Keno Dam is summarized in Figure 5-3. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. For the 2030s, the CT scenario indicates slightly higher peak flows while the HW and WW scenarios appear to have the highest increase in peak flow; the HD and WD scenarios show similar or slightly reduced peak flows. By the 2070s managed inflows to Keno Dam also appear to shift toward higher flows earlier in the year. Results indicate mean annual volumes increase under the wetter scenarios

> **Mean Monthly Flow**
>
> Projections indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

(HW and WW). Overall increases in Keno Dam inflow are primarily driven by increases in inflows to Upper Klamath Lake and thereby increases in Link River Dam outflows.

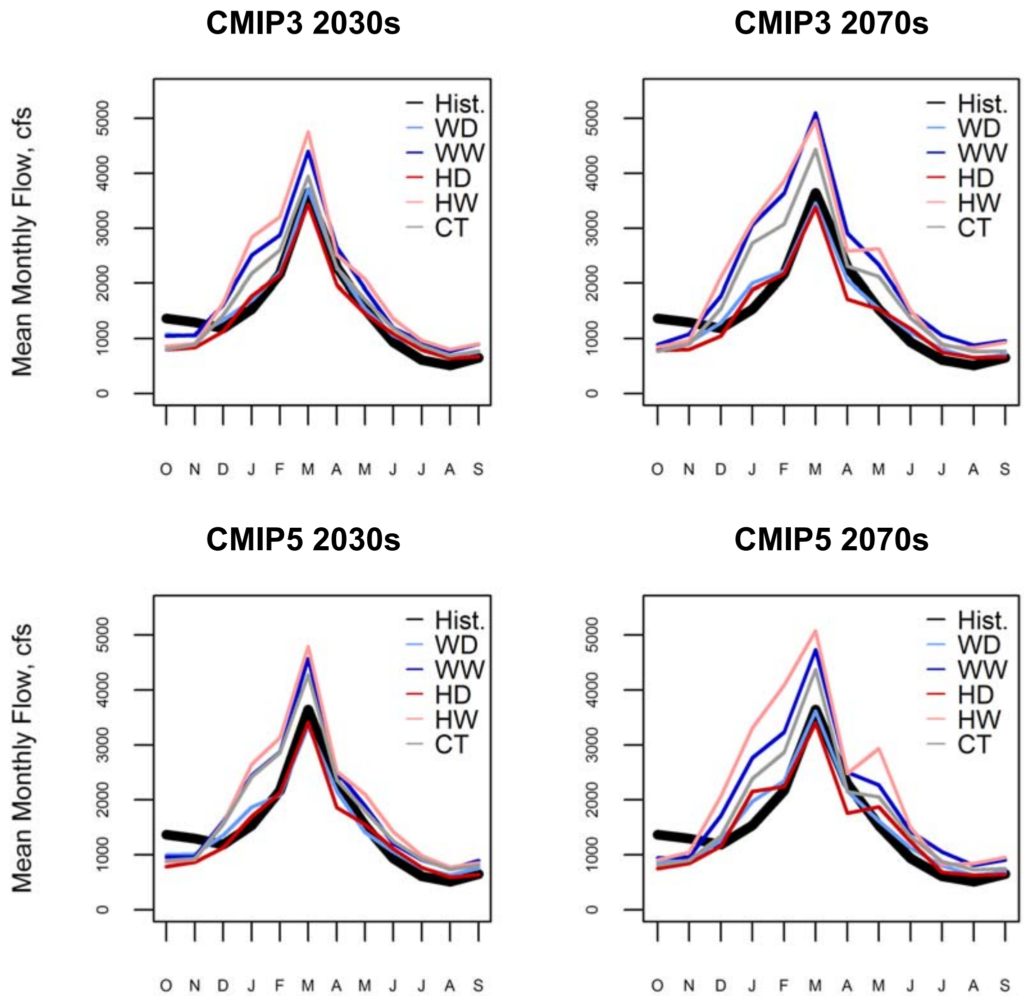


Figure 5-3.—Historical and projected future mean monthly managed inflows to Keno Dam (cfs).

5.4.1.3 Iron Gate Reservoir Storage

Historical and projected future mean monthly Iron Gate Reservoir storage is summarized in Figure 5-4. Historically, EOM reservoir storage would peak in March and have its lowest storage in the summer months. Reservoir storage historically did not fluctuate substantially through the year, generally varying between about 55,000 acre-feet and almost 57,000 acre-feet. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase; none of the climate change scenarios indicate a reduction in peak reservoir storage.

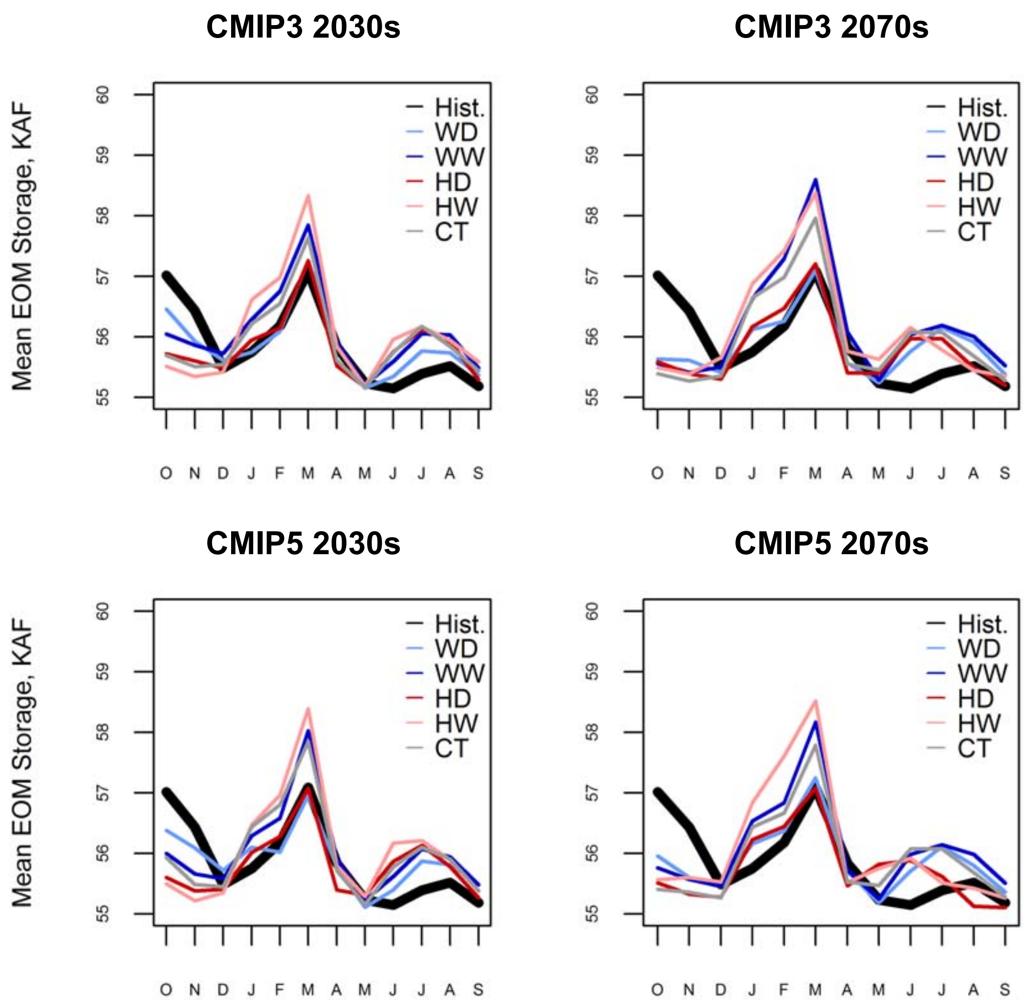


Figure 5-4.—Historical and projected future mean monthly Iron Gate Reservoir storage (KAF).

5.4.1.4 Iron Gate Reservoir Outflow

Historical and projected future mean monthly outflow from Iron Gate Dam is summarized in Figure 5-5. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. Historical and projected changes in outflow at Iron Gate Dam correspond with those found at Keno, primarily due to their conjunctive management under the 2013 Proposed Action for Klamath Project operations. Projected changes in peak outflow are similar to Keno inflow in that the WW and the HW scenarios suggest the greatest increases. Also, particularly for the 2070s, substantial increases in flow during the months of January and February are projected. Differences between mean monthly inflows at Keno and outflow at Iron Gate from about May through September, namely projected increases at Keno and projected decreases at Iron Gate, are due to a combination of operating criteria and hydrology. Local inflows between Keno and Iron Gate are projected to decrease, which may contribute to the differences during this period. Also during these months environmental flow requirements often govern operations, and these requirements are generally accounted for at Iron Gate Dam to maintain minimum flows. These operating criteria may result in differences in projected flows at the two locations.

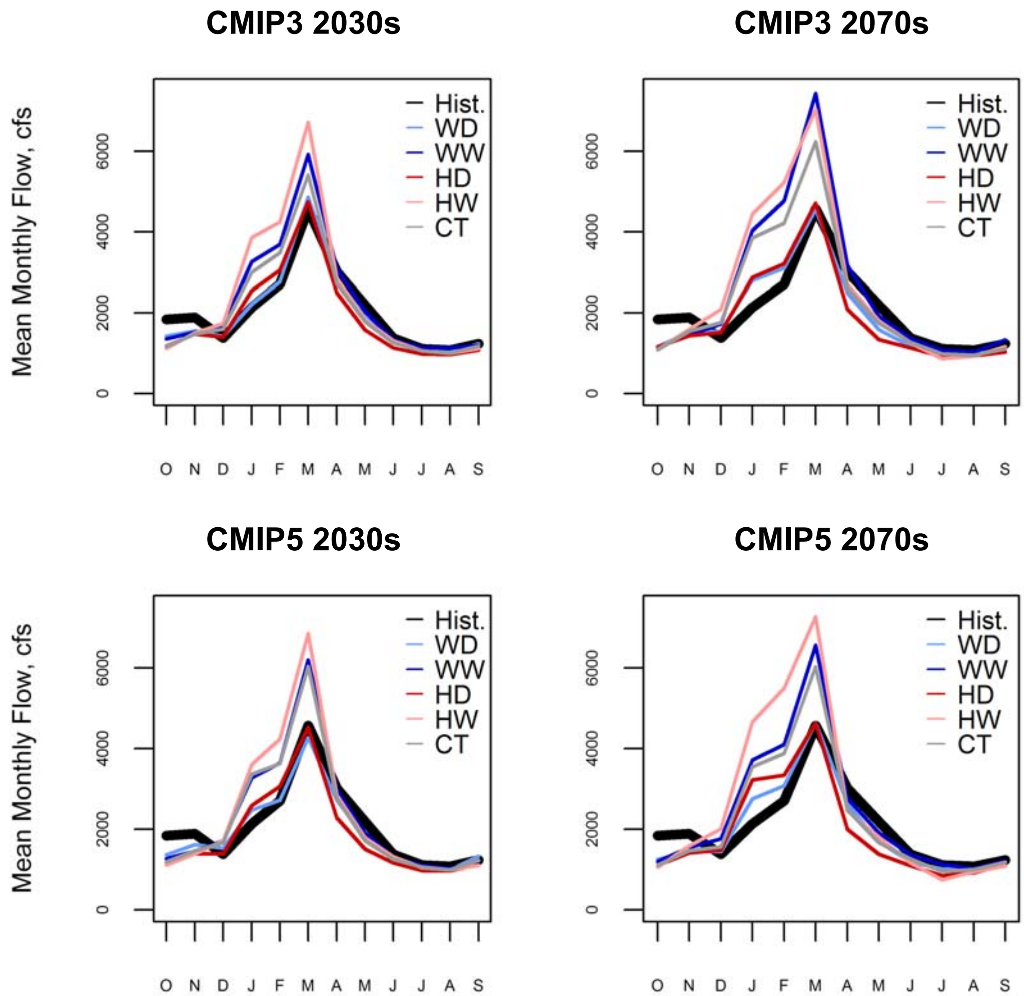


Figure 5-5.—Historical and projected future mean monthly Iron Gate Reservoir outflow (cfs).

5.4.1.5 Shasta River Flow

Historical and projected future mean monthly flows in the Shasta River near Yreka are presented in Figure 5-6. Historical mean monthly flows exhibit a double peak, in January and again in March, the first corresponding with the period of seasonal peak rainfall and the second corresponding with snowmelt. The lowest flows occur during August. Projections of climate change indicate a range of increased snowmelt runoff contributing to streamflow (HW and WW scenarios) to decreased snowmelt runoff for the drier scenarios (HD and WD), with the central tendency similar or slightly less than historical. Flows during the rainfall peak period are projected to increase for all but the WD scenario for the 2030s time period. By the 2070s, all scenarios project increased rainfall-driven peak flow in January. In addition, all but the WW scenario indicate reduced late spring flows, likely due to decreased snowpack (except for Mount Shasta, which is projected to experience increased snowpack due to increased precipitation and high elevations).

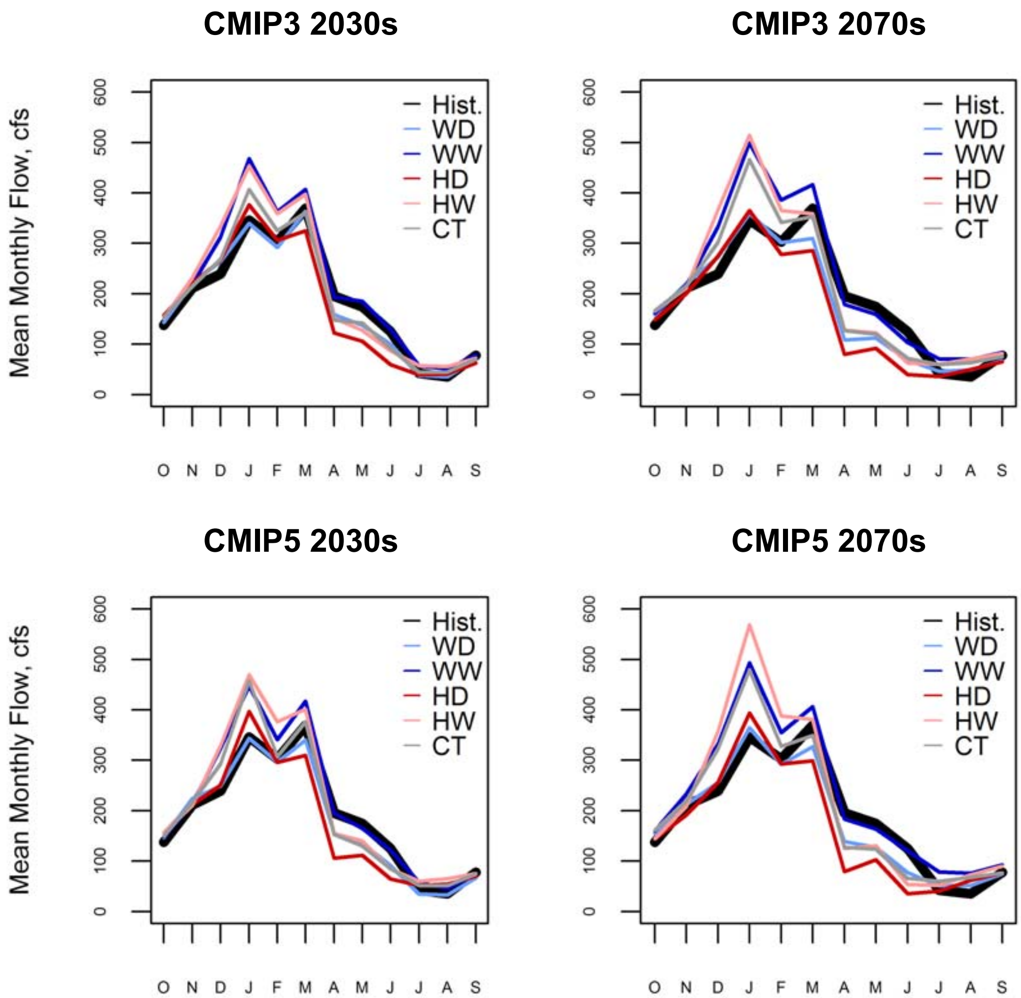


Figure 5-6.—Historical and projected future mean monthly flow in the Shasta River near Yreka (cfs)

5.4.1.6 Scott River Flow

Historical and projected future mean monthly flows in the Scott River near Fort Jones are presented in Figure 5-7. The Scott River is a more rain-dominated watershed than the neighboring Shasta River watershed to the east. Historical mean monthly flows reflect a mixture of rain and snow during winter and early spring months, with seasonal peak flows occurring in March but closely followed by January and February. Climate change projections for both the 2030s and 2070s time periods, for both CMIP3 and CMIP5 based projections, indicate increased winter flows as a result of corresponding projected increases in precipitation. Also, the snowmelt runoff contribution to flow in the late spring months is projected to decrease.

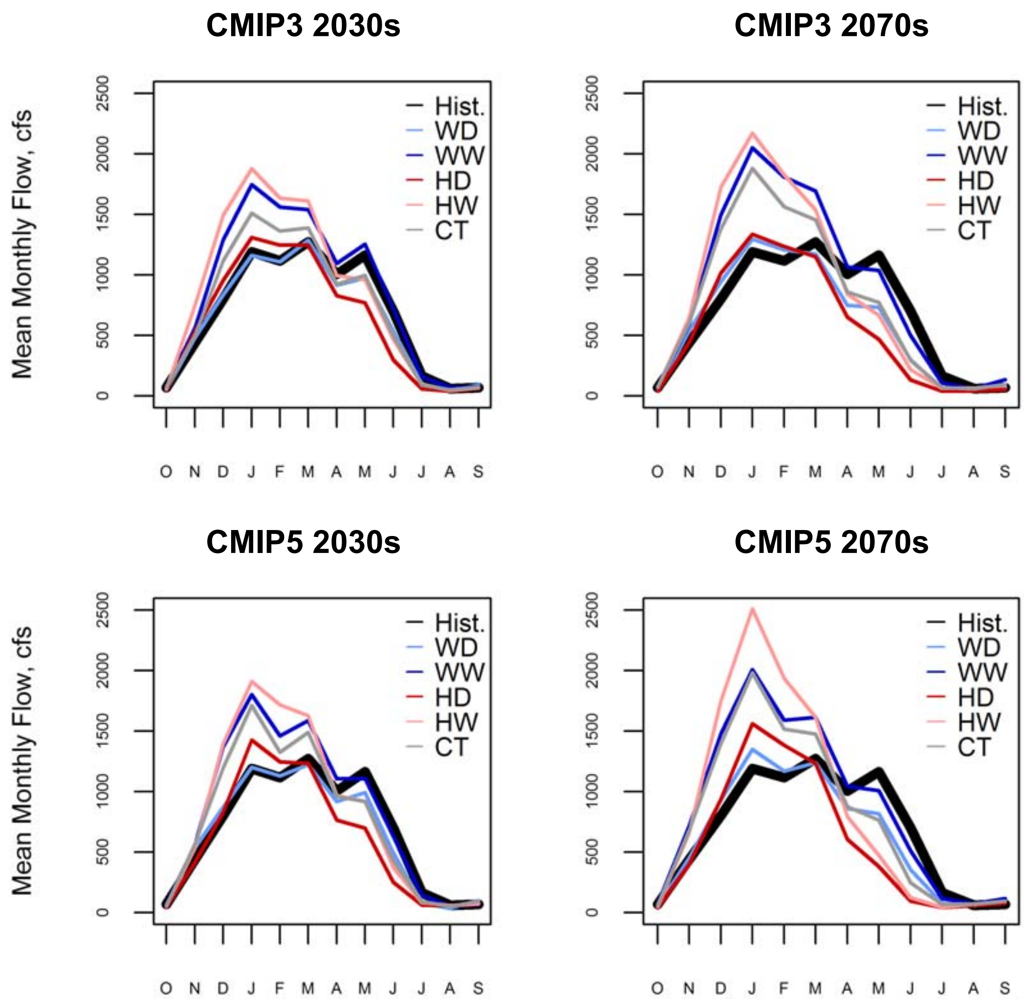


Figure 5-7.—Historical and projected future mean monthly flow in the Scott River near Fort Jones (cfs).

5.4.1.7 Flow at Klamath River near Orleans

Historical and projected future mean monthly flows in the Klamath River near Orleans are presented in Figure 5-8. Managed flow in the Klamath River at Orleans reflects Upper Klamath Basin management and the contribution of tributary flows upstream of the Trinity River confluence. Historical mean monthly flows have a primary peak in March as a result of snowmelt runoff and a secondary peak in January as a result of winter rainfall. Projections of future conditions indicate increased peak flows for all scenarios, with the driest scenarios (HD and WD) similar in magnitude to historical. For the 2070s, a projected shift in the peak flow to earlier in the year corresponds with the reduced influence of snowmelt runoff as the climate warms and snowpack declines.

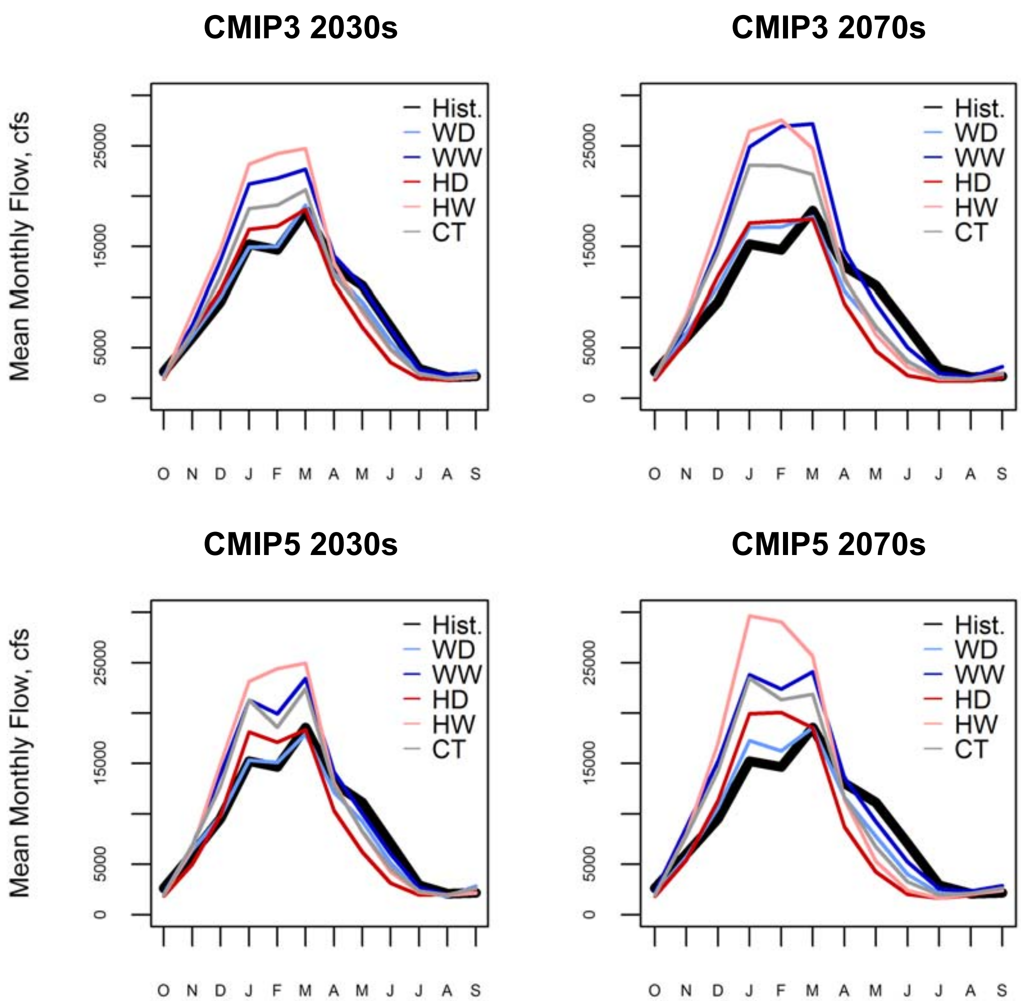


Figure 5-8.—Historical and projected future mean monthly flow in the Klamath River near Orleans (cfs)

5.4.1.8 Flow at Klamath River near Klamath

Historical and projected future mean monthly flows in the Klamath River near Klamath are presented in Figure 5-9. Simulated flows in the Klamath River at Klamath integrate managed flows in all of the Klamath River Basin, including contributions from the Trinity River which are affected by Central Valley Project exports to the Sacramento River Basin. Historical mean monthly flows at this location exhibit a double peak in January and March corresponding with rainfall and snowmelt runoff, respectively. Projected changes in mean monthly flows for all but the driest climate change scenarios for the 2030s indicate a shift toward a more rain dominated basin, with peak flows occurring January. Interestingly, projected mean monthly flows at Orleans (Figure 5-8) do not show the same shift, corresponding with a greater increase in January flows in the Trinity River, whose confluence with the mainstem Klamath River is located between Orleans and Klamath. This may be due to the methods used to develop Trinity River flows; Trinity and Lewiston reservoirs were not explicitly modeled and instead adjusted outflows were used as input to RiverWare based on relationships between simulated natural flows (developed in Chapter 3) and historical gage records.

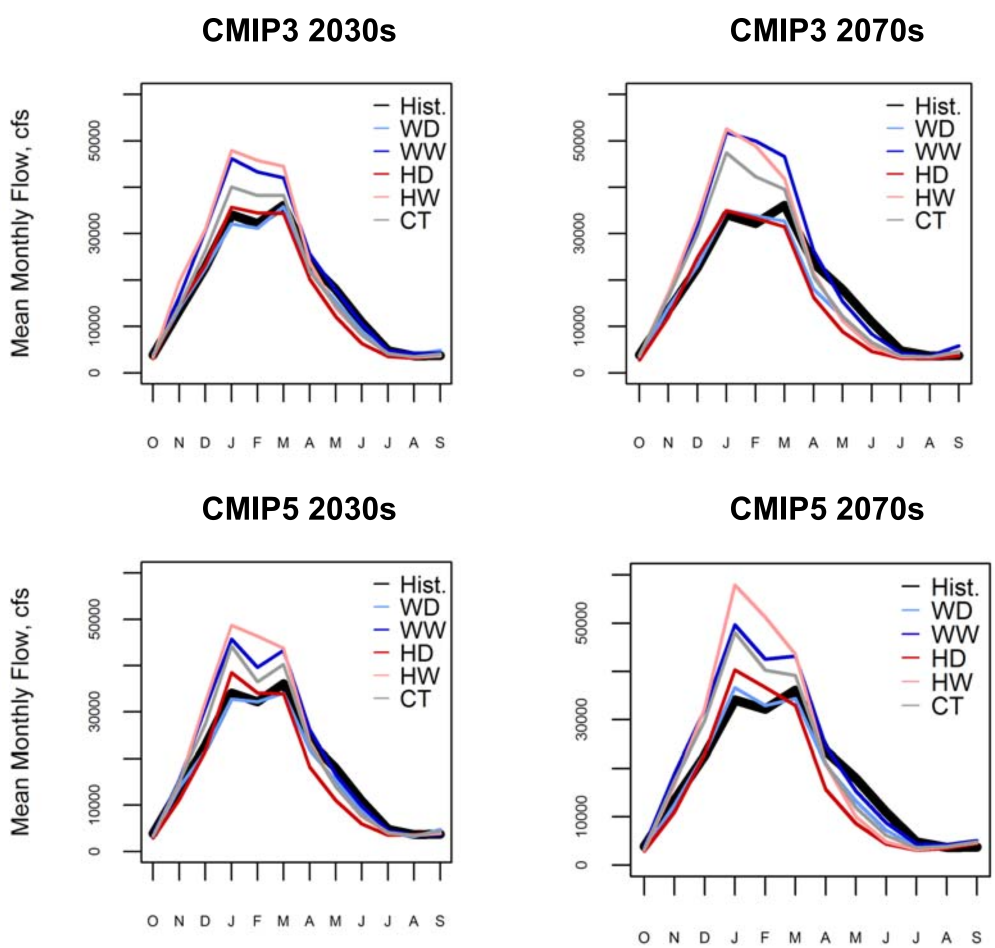


Figure 5-9.—Historical and projected future mean monthly flow in the Klamath River near Klamath (cfs)

5.4.1.9 Klamath River Water Temperature

Historical and projected future mean monthly temperatures in the Klamath River near Klamath, as simulated by the RBM10 model, are presented in Figure 5-10. Historical water temperatures are at their maximum in August and at their minimum in January. Water temperature is projected to increase under all climate change scenarios considered by the study for both CMIP3- and CMIP5-based projections, and for both future time periods. Water temperatures historically are not favorable for salmon and projected increases in temperature exacerbate this issue.

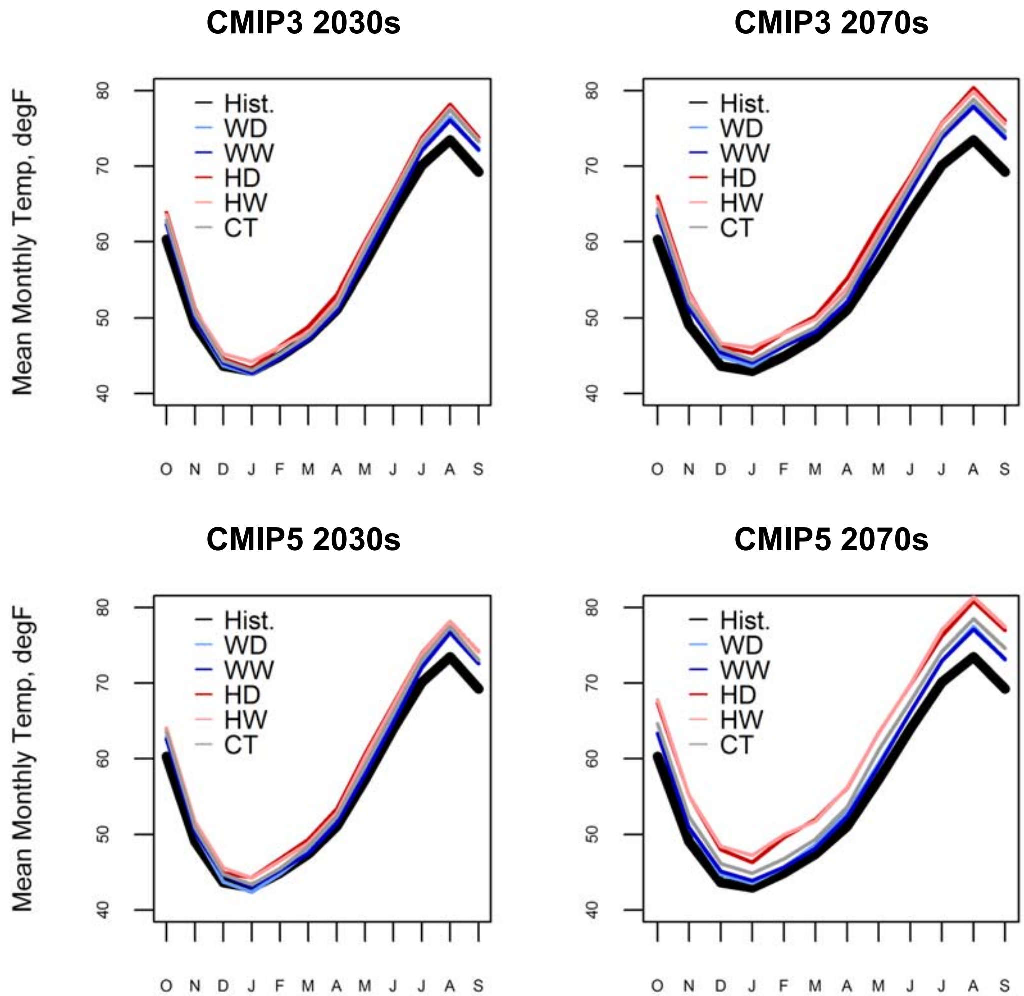


Figure 5-10.—Historical and projected future mean monthly water temperature in the Klamath River (degrees F).

5.4.2 Analysis of Impacts – Ability to Deliver Water

To evaluate the ability of the Klamath River Basin to supply water to meet human needs, this study focuses on four measures: the percent of full irrigation water supply to the Klamath Project (from April through September), the mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow, mean annual flows in the Shasta River near Yreka, and mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Projected Klamath Project Supply

Klamath Project irrigation deliveries average about 93 percent of full supply under historical hydrology according to simulations by the Klamath Basin RiverWare Model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Water supply measures under simulated historical conditions are provided in Table 5-6, while projected changes in these measures are illustrated in Figure 5-11. Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the simulation period, the sum of end-of February storage plus March–September inflows at Upper Klamath Lake (another indicator of total available supply from Upper Klamath Lake) was about 1.38 million acre-feet. Additional measures representing the total water supplies in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

Table 5-6.—Historical measures related to water supply.

Measure	Historical Value	Units
Mean Klamath Project supply	361.3	KAF
Mean annual UKL seasonal supply	1,378	KAF
Mean annual Shasta flow	187.7	cfs
Mean annual Scott flow	668.8	cfs

Notes: Changes are represented as percentages; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-11.—Projected changes in water supply measures.

In terms of the projected changes in water supply measures shown in Figure 5-11, projected changes in mean annual flow in the Scott and Shasta Rivers include increases for the wetter scenarios (WW and HW) close to about 20 percent for the 2030s and 30 percent for the 2070s and decreases for the drier scenarios (WD and HD) of less than 10 percent for the 2030s and 10 to 20 percent for the 2070s, with a central tendency scenario showing more modest increases than the wetter scenarios. For mean Upper Klamath Lake supply (end-of-February storage plus March-September inflow), again the wetter scenarios indicate projected increases, with greater increases for the 2070s, while drier scenarios indicate decreases. Similar results are shown for mean Klamath Project supply from April through September. Percent change in Upper Klamath Lake supply and Klamath Project supply (the bottom two measures listed in Figure 5-11) is computed based on projected and historical simulated values under the 2013 BiOp management criteria. No consistent differences are apparent in comparing CMIP3- and CMIP5-based scenarios. However, together they provide comprehensive information on the projected range of changes in these water delivery measures. Table 5-6 summarizes the data behind Figure 5-11.

5.4.3 Analysis of Impacts – Hydroelectric Power

To evaluate historical conditions and impacts of climate change on hydroelectric power production, the study focuses on the following measures: mean annual hydropower production (summed over J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities); mean annual spill volumes at J.C. Boyle, COPCO 1, and Iron Gate dams; and mean spill days per year at the same three dams. Measures are computed using results from the Klamath Basin RiverWare model.

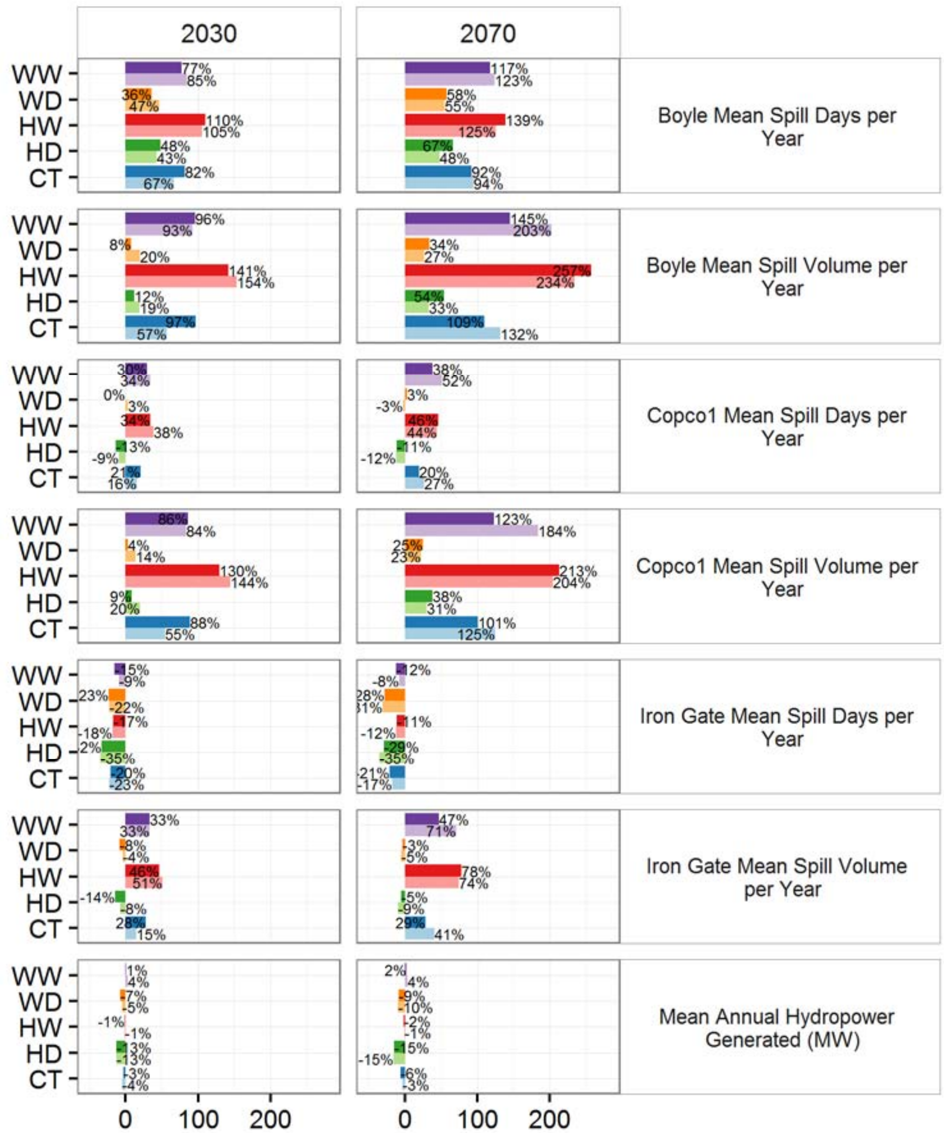
Historical hydropower measures are provided in Table 5-7, while projected changes in these measures are illustrated in Figure 5-12. Note that mean annual days with spill at the three facilities over the historical simulation period are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate.

Projected Hydropower Production

Hydropower production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. For all facilities, under almost all scenarios, frequency and volume of spill is likely to increase.

Table 5-7.—Historical measures related to hydroelectric power

Measure	Historical Value	Units
Mean annual hydropower generated (MW)	26,741	MW
J.C. Boyle mean spill volume per year	163.0	KAF
COPCO 1 mean spill volume per year	186.4	KAF
Iron Gate mean spill volume per year	533.9	KAF
J.C. Boyle mean spill days per year	105.9	days
COPCO 1 mean spill days per year	42.8	days
Iron Gate mean spill days per year	170.3	days



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-12.—Projected changes in hydropower measures.

Figure 5-12 illustrates the percent change in identified hydroelectric power measures. Consistent with results discussed for basin-wide response variables, namely increased seasonal peak flows, the number of spill days and the mean annual spill volumes are projected to increase for most scenarios for both future time horizons. However, at Iron Gate the projected changes in spill volume are generally increasing, while the projected change in the mean number of spill days per year is less substantially decreasing. Projected mean number of spill days at J.C. Boyle and COPCO1 are generally increasing, while generally decreasing at Iron Gate. This result may be due to the fact that Iron Gate Reservoir has greater storage and is therefore better able to absorb high inflows than J.C. Boyle or

COPCO1. Also, the management criteria allow inclusion of a rule to avoid spill at Iron Gate, but not at J.C. Boyle or COPCO1, due in part to the need to meet environmental flow requirements.

Also, projected changes in mean annual hydropower production are much smaller on a percentage basis than the other measures, with the wetter scenarios indicating increases, the drier scenarios indicating decreases, and the central tendency scenario indicating minimal increases. Changes are between +4 percent and -13 percent for the 2030s and between +4 percent and -15 percent for the 2070s. Appendix D, Table D-12 summarizes the data behind Figure 5-12.

5.4.4 Analysis of Impacts – Recreation

Recreation

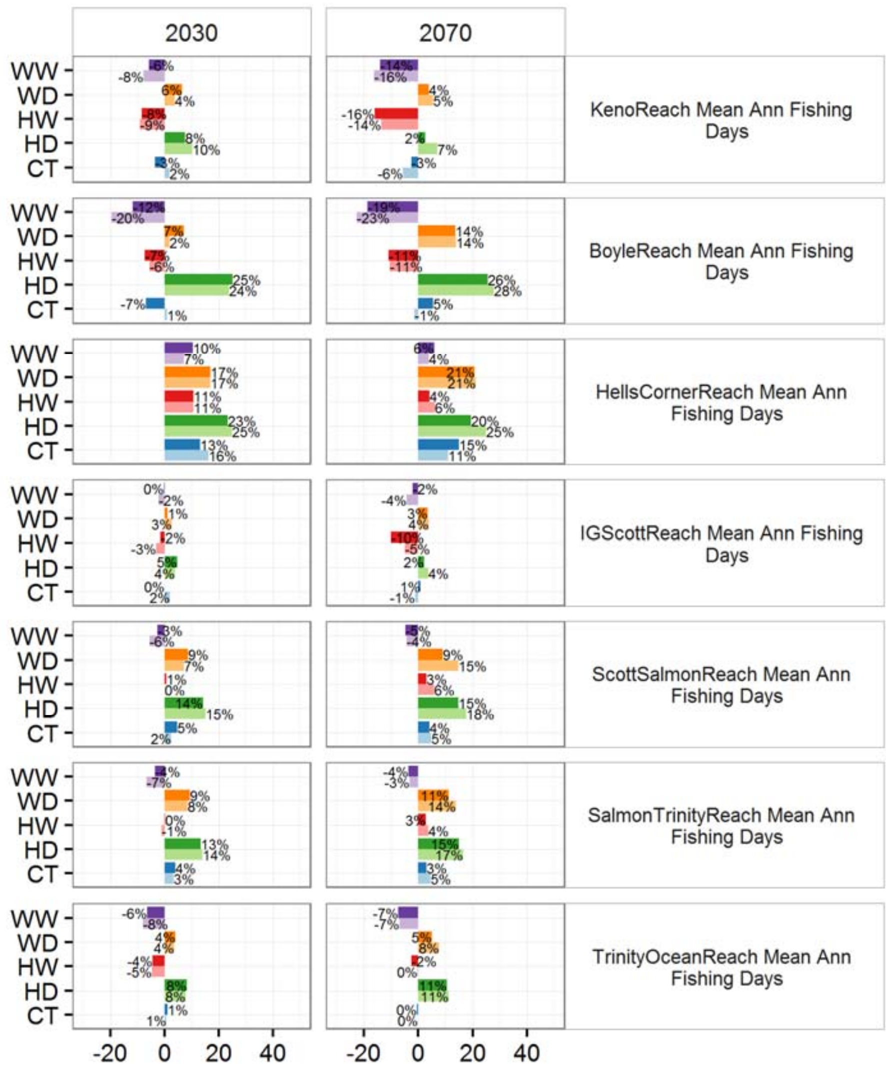
The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Recreational measures in the Klamath River Basin are summarized for two main categories, fishing recreation and river boating recreation. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in select Klamath River reaches fall within the recommended range for each activity. Measures are computed using results from the Klamath Basin RiverWare model.

Table 5-8 provides historical recreation measures for fishing and river boating, while projected changes in these measures are illustrated in Figure 5-13 (for fishing) and Figure 5-14 (for river boating). For the historical period, in general more days fall within the recommended range for fishing than for river boating.

Table 5-8.—Historical measures related to fishing recreation

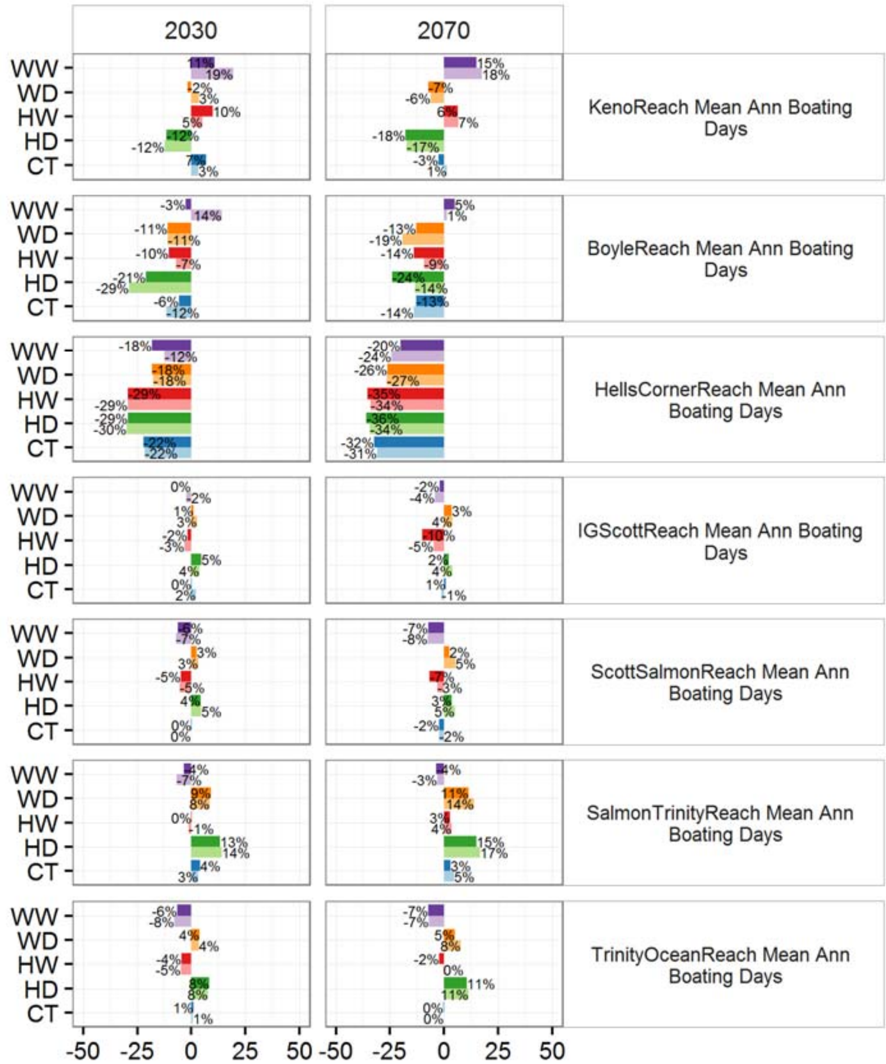
Measure	Historical Value	Units
Keno Reach mean annual fishing days	248	days
Boyle Reach mean annual fishing days	155	days
Hells Corner Reach mean annual fishing days	220	days
IG Scott Reach mean annual fishing days	275	days
Scott Salmon Reach mean annual fishing days	184	days
Salmon Trinity Reach mean annual fishing days	214	days
Trinity Ocean Reach mean annual fishing days	253	days
Keno Reach mean annual boating days	172	days
Boyle Reach mean annual boating days	59	days
Hells Corner Reach mean annual boating days	256	days
IG Scott Reach mean annual boating days	275	days
Scott Salmon Reach mean annual boating days	249	days
Salmon Trinity Reach mean annual boating days	214	days
Trinity Ocean Reach mean annual boating days	253	days



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-13.—Projected changes in fishing recreation.

For fishing recreation, the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios (WW and HW) indicate decreases in the number of fishing days for both future time horizons. Recommended flows for fishing are generally less than for boating, and overall projections of greater future flow volumes in the basin correspond with projected decreases in fishing days. The central tendency scenario indicates modest decreases in some reaches and modest increases in other reaches. Generally, the direction of change (increase or decrease) is consistent for both future time horizons within a given reach (except J.C. Boyle reach and Trinity Ocean reach). For some scenarios and measures, CMIP3-based projections indicate greater change, while for others they may indicate smaller change. There is no consistency between CMIP3- and CMIP5-based projections in terms of projected change across scenarios or measures.



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-14.—Projected changes in river boating recreation measures.

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. For instance, in the J.C. Boyle and Hells Corner reaches (from J.C. Boyle to COPCO 1) almost all scenarios indicate a decrease in the number of river boating days as a result of climate change, with the exception of the WW scenario for CMIP3 and the CT scenario for CMIP5. For the other reaches downstream of Iron Gate, the wetter scenarios (WW and HW) generally indicate a reduction in the number of river boating days, while the drier scenarios (WD and HD) indicate increases in the number of river boating days (although not consistent for all measures). The CT scenario for those reaches below Iron Gate indicates modest changes (increases for most of those reaches). Note that the boating recreation measures do not account for the ability to release flows from J.C. Boyle to assure a suitable boating recreation flow range.

5.4.5 Analysis of Impacts – Ecological Resources

Measures related to ecological resources in the Klamath River Basin primarily concern fish and wildlife habitat and applicable species listed under ESA. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in the Scott and Shasta Rivers meet or exceed recommended flow thresholds for dry year conditions by McBain and Trush (2014). Note that the target flows were developed for the Shasta River and the same targets were applied to the Scott River, though the Scott River generally has greater flow volume. For this reason, the historical frequency of meeting flow targets in the Scott River is much higher than in the Shasta River. However, the dry year targets are not met 100 percent of the time in the Scott River.

Historical conditions and climate change impacts are also measured by computing watersupply to the Lower Klamath National Wildlife Refuge via Ady Canal. Measures are computed using results from the Klamath Basin RiverWare model.

Historical measures relating to ecological benefits are provided in Table 5-9, while projected changes in these measures are illustrated in Figure 5-15. For the historical simulation period, neither dry year flow targets nor full demand at the LKNWR are met 100 percent of the time.

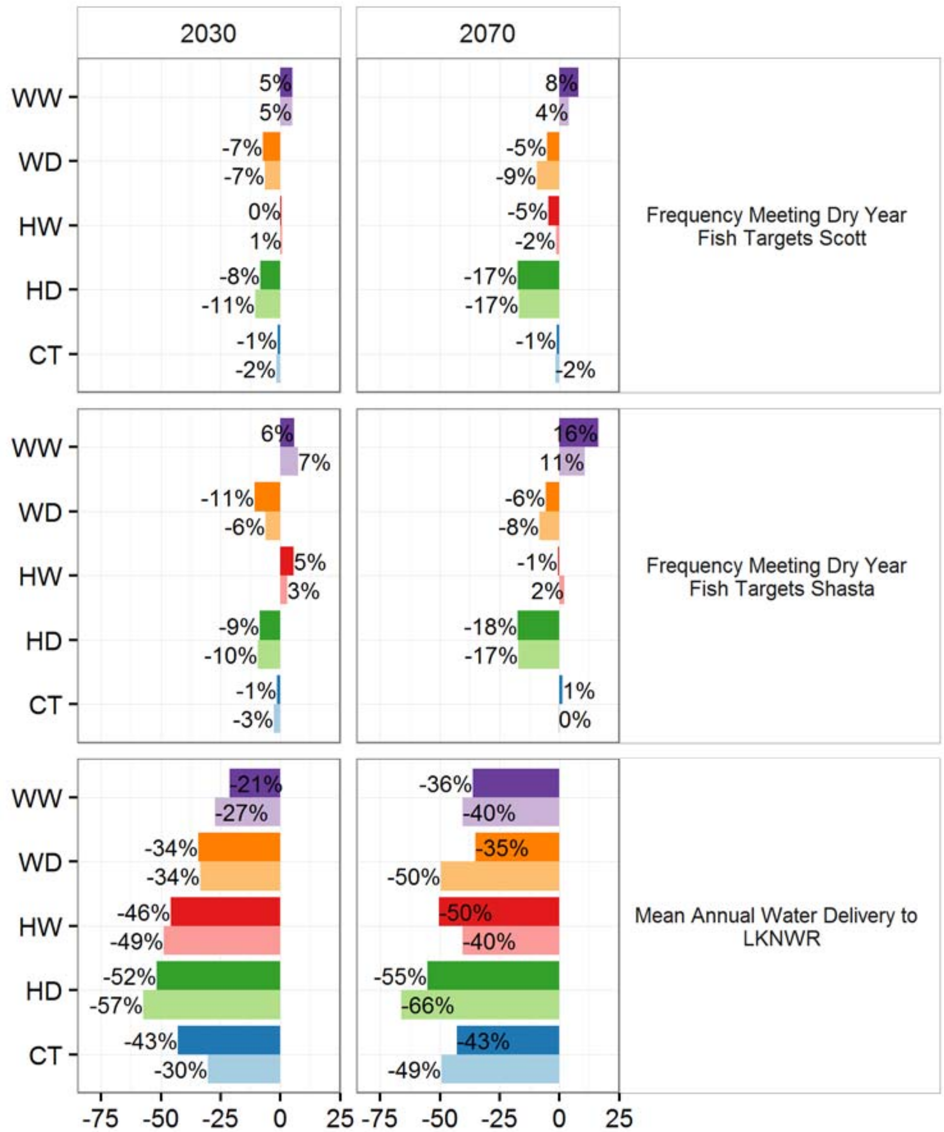
Ecological Resources Impacts

The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. Also, a decrease in deliveries to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

Table 5-9.—Historical measures related to ecological resources

Measure	Historical Value	Units
Frequency meeting dry year fish targets Scott	70.5	Percent of days
Frequency meeting dry year fish targets Shasta	56.9	Percent of days
Mean annual water delivery to LKNWR	24.6	KAF

Projected changes in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers, represented as a percentage, indicate increases for the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and HD), with greater change projected for the 2070s time horizon compared with the 2030s. CMIP3- and CMIP5-based projections are comparable, with one set of scenarios generally exhibiting more change (although not consistently one over the other). The CT scenario indicates a modest decrease in the frequency of ability to meet the dry year flow targets (i.e., negative change).



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-15.—Projected changes in ecological resources measures.

Figure 5-15, illustrating the percent change in the mean annual (water year) supply to the LKNWR, shows that for all climate change scenarios there is a decrease in supply to the LKNWR, more so for the 2070s compared with the 2030s future time horizon. CMIP3- and CMIP5-based scenarios are comparable, but do show some differences. For the 2030s CT scenario, the CMIP5-based scenario indicates a reduction of about 43 percent, compared to 30 percent for the CMIP3-based CT scenario. Note that model results indicate a decrease in deliveries to LKNWR for all scenarios, while they indicate projected increases or decreases in Klamath Project supply depending on the scenario. These results may in part be explained by a projected reduction in water supply from the Lost River. Also note that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Additionally, the LKNWR is not able to take advantage of spill water under these management criteria. The resulting effect of the management criteria and projected hydrologic changes is an overall reduction in LKNWR deliveries.

Frequency of meeting minimum recommended pool elevations in Clear Lake and Gerber Reservoir were also computed as performance measures for evaluating climate change impacts. These results are not illustrated, as minimum pool elevations are met or exceeded in all climate change scenarios considered by the Basin Study. Note that climate change scenarios represent adjusted historical climates that represent the statistics of future climate for two future time horizons, the 2030s and 2070s. Therefore, potential changes in the timing and frequency of drier years and wetter years are not represented. Potential future changes in drought or wet period frequency may affect the ability of operators to maintain minimum pool elevations in Gerber Reservoir and Clear Lake.

Water Quality Impacts

For historical hydrology conditions and all future climate scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

5.4.6 Analysis of Impacts – Water Quality

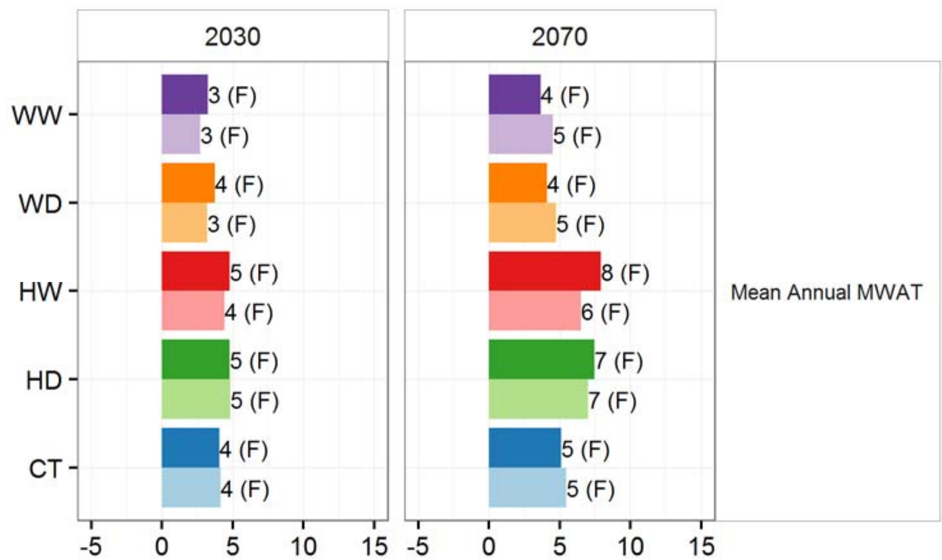
Water quality measures are presented in terms of meeting Klamath River temperature thresholds in the Klamath River near Klamath, California as recommended by the SONCC ESU salmon recovery plan (NMFS, 2012). Historical conditions and climate change impacts are evaluated by computing the mean across the simulation period of the MWAT at the Klamath River near Klamath and comparing values with those recommended in the salmon recovery plan. Analysis under historical hydrology showed that the MWAT fell within the "poor" classification for all years. Therefore, instead of reporting the frequency of the MWAT falling within the various categories ranging from "very good" to "poor," we instead report the computed MWAT and projected change in that value, as well as the degrees F by which the "poor" classification is exceeded. The "poor" classification threshold is 63.68 degrees F, or 17.6 degrees C.

Historical measures relating to water quality are provided in Table 5-10, while projected changes in these measures are illustrated in Figure 5-16. Historically the MWAT is computed as 75.7 degrees F, which is approximately 12 degrees higher than the "poor" classification threshold for the SONCC ESU coho salmon.

Table 5-10.—Historical measures related to water quality.

Measure	Historical Value	Units
Mean annual MWAT	75.7	degrees F
Mean exceedance of MWAT – Poor	12.1	degrees F

Figure 5-16 shows that for all climate change scenarios the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s. Results indicate that the temperature regime in the Klamath River is likely to become more challenging for coho salmon under warmer future climate scenarios. Identified cold water refugia and groundwater springs will continue to be critical for the survival of the species in the Klamath River Basin.



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-16.—Projected changes in mean annual maximum weekly average temperature.

5.4.7 Analysis of Impacts – Flood Control

Flood control in the Klamath River Basin and projected changes due to a changing climate are evaluated for two types of measures: flood control releases from Upper Klamath Lake, and the date of seasonal peak flow at the major mainstem Klamath River dams (J.C. Boyle, COPCO 1, and Iron Gate). Flood control rules at Upper Klamath Lake are defined by the 2013 Proposed Action for Klamath Project Operations (Reclamation, 2012d). It is recognized that flood control measures exist for other reservoirs in the Klamath River Basin (e.g., Trinity River basin); however, due to the level of detail of the Klamath Basin RiverWare model, we focus on Upper Klamath Lake.

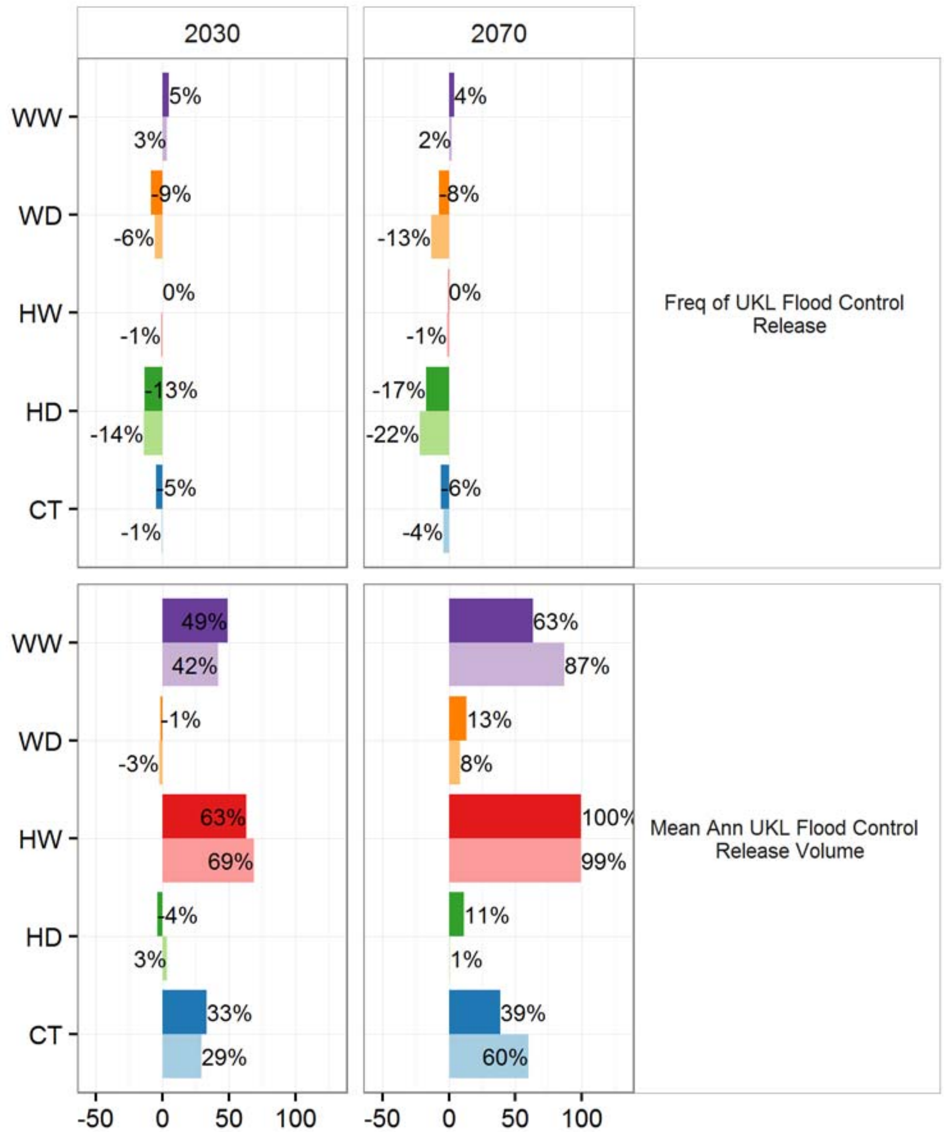
Historical recreation measures relating to flood control are provided in Table 5-11, while projected changes in these measures are illustrated in Figure 5-17. Under historical hydrology conditions, the frequency of flood control releases from Upper Klamath Lake is approximately 44 percent of days according to results from the Klamath Basin RiverWare model. The corresponding mean annual volume of flood control release water is approximately 224,000 acre-feet. Flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. The computations are consistent between the RiverWare model and the KBPM. However, it is acknowledged that the RiverWare model simulations generally indicate greater flows coming from the Lost River basin, thereby resulting in less demand by the Klamath Project for Upper Klamath Lake water, compared with the KBPM. This result may contribute to the seemingly high percentage of days of flood control release from Upper Klamath Lake. Greater flows from the Lost River basin may also explain some of the higher Keno Dam inflows in the winter time (refer to Figure 5-3). Future development of the model will further investigate these issues. The date of seasonal peak flow is the date of the center of mass of mean annual flow, or the average date by which half of the annual flow volume at the location has passed through. The historical seasonal peak flow at the three reservoirs mentioned ranges from early to mid-April.

Flood Control Impacts

The frequency of Upper Klamath Lake flood control releases is projected to increase for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest increase. All scenarios project an increase in the mean annual flood control volume.

Table 5-11.—Historical measures related to flood control

Measure	Historical Value	Units
Frequency of UKL Flood Control Release	44.1	Percent of Days
Mean Ann UKL Flood Control Release Volume	224	KAF
Date of Seasonal Peak Flow at J.C. Boyle Reservoir	April 9	Date
Date of Seasonal Peak Flow at COPCO 1 Reservoir	April 17	Date
Date of Seasonal Peak Flow at Iron Gate Reservoir	April 15	Date



Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 5-17.—Projected changes in flood control measures.

Figure 5-17 shows that the frequency of Upper Klamath Lake flood control releases is projected to increase or change minimally for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. Again, CMIP3- and CMIP5-based projections are generally consistent. Although there is a projected decrease in the frequency of flood control releases for several scenarios, the figure also shows that all scenarios show a projected increase in the mean annual flood control volume. Further, more water is being released in the future even though the occurrence of release may be decreasing. Minimal projected change in Upper Klamath Lake flood control release, along with projected increases in spill volumes at J.C. Boyle and COPCO1 (refer to Figure 5-12), may be explained by the different ways spill is accounted for at these locations. At Upper Klamath Lake, spill is considered the volume beyond that released for Klamath Project deliveries and environmental needs, whereas at the other locations it is more simply computed as the volume above which water can be released through the power facilities. Management criteria also play a role in the differing results. The projected change in the date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate dams ranges from little or no change to a shift toward an earlier peak by as many as 17 days (HW scenarios for CMIP3 and CMIP5 for the 2070s future time horizon). For the 2030s, the CT scenario indicates a shift toward earlier in the year by up to one week at COPCO 1 and Iron Gate, while for the 2070s the projected change for the CT scenario is about 7 to 10 days earlier. In general, projected changes in the date of seasonal peak flow at J.C. Boyle are less substantial than at the other two locations evaluated, with projected changes having ranging from 1 to 4 days later for the 2030s, and 4 days earlier to 3 days later for the 2070s depending on the scenario. Table D-13 in Appendix D summarizes the results for all scenarios and time periods.

5.5 Summary of Findings

This chapter evaluates the ability of the basin to meet historical and projected future water needs using a framework of models and associated measures that are used to quantify vulnerabilities. Simulations (with historical and future hydrology conditions) were performed using existing operational constraints, mainly associated with the current Proposed Action for Klamath Project operations (Reclamation, 2012d), which dictate operations throughout the Upper Klamath Basin and have implications for the river from Link River Dam to its mouth.

Performance measures for selected categories provide a basis for assessing two things: first, the ability of the modeling framework to identify and evaluate vulnerabilities to meeting the basin's water needs, and second, the ability to evaluate the impacts of climate change on the watershed. The results provide useful insights as to how climate changes, without adaptation responses, impact the Klamath Basin. The following paragraphs summarize the above analysis of managed historical and projected future conditions.

Analysis of climate change impacts using the Klamath Basin RiverWare model and USGS RBM10 water temperature model show that mean EOM storage in Upper Klamath Lake will experience earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, EOM reservoir storage historically did not fluctuate substantially through the year. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase slightly. Projections of mean monthly managed flows at various locations throughout the study area indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

Figure 5-2 showing simulated historical and projected UKL storage helps to illustrate the projected change. The simulations show historical peak storage around May. Projections indicate a shift toward earlier peak storage. In addition, the simulations indicate more flood control release (any release above Project needs and environmental requirements) in the future as well. Although none of the figures illustrate UKL inflow, it appears that Project supply is projected to decrease slightly for the drier scenarios and increase slightly for the wetter scenarios, with a small increase for the central tendency scenario. Therefore, any reduction in summer UKL inflow does not appear to affect Project supply by a large amount, on average.

Historical hydrology enables an annual average of 93 percent of full delivery to Klamath Project irrigation, according to simulations by the Klamath Basin RiverWare model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Hydropower production summed for the J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities has historically been about 26,800 MW, according to RiverWare model simulations. Production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. We evaluated frequency and volume of spill at J.C. Boyle, COPCO 1, and Iron Gate dams and found that historically the dams spilled an average of 106 days at J.C. Boyle, 43 days at COPCO 1, and 170 days at Iron Gate per year. For all facilities, frequency and volume of spill is likely to increase with climate change.

Historical fishing and boating recreation in the Klamath River Basin has been strong (on the order of 155 to 275 fishing days per year and 59 to 275 river boating days per year). The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Using flow recommendations for a dry year in the Shasta River (defined as 61 to 100 percent exceedance) from McBain and Trush (2014), we found that flow targets were met historically on an average of 57 percent of days in the Shasta River and 71 percent of days in the Scott River (which has about three times the mean annual flow of the Shasta River). The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. In the future, a decrease in water delivery to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

For historical conditions and all future scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

Finally, according to the Klamath Basin RiverWare model, the historical frequency of flood control releases from Upper Klamath Lake has been about 44 percent of days, with a mean volume of about 224,000 acre-feet. The frequency of these releases is projected to increase or show little change for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. All scenarios project an increase in the mean annual flood control volume. The date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate has historically been early to mid-July, according to the model simulations. Projections of future conditions show a general shift of this peak toward earlier in the year, although the degree to which this is the case varies by scenario and location. The most modest changes are projected for J.C. Boyle (on the order of 4 days later to 3 days earlier for the 2070s). Greater shifts are projected for COPCO 1 and Iron Gate, on the order of 1 day later to 9 days earlier for the 2030s and 2 to 16 days earlier for the 2070s.

Results of the system risk and reliability analysis support the common understanding that the Klamath River Basin has experienced difficulties in meeting the range of water needs. Projected increases in precipitation and flow volumes at many locations in the basin may reduce water supply gaps in some ways; however, greater challenges are projected for ecological resources such as fish and wildlife, as well as irrigators in the Upper Klamath Basin.

5.6 Uncertainties Associated with System Reliability Analysis

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study system risk and reliability analysis. The uncertainties primarily correspond to the modeling used to evaluate historical and future conditions. The modeling framework for this analysis includes development and implementation of the Klamath Basin RiverWare model, as well as implementation of the USGS RBM10 water temperature model for the mainstem Klamath River. Uncertainties associated with each of these modeling efforts are identified and described below. Further discussion of uncertainties associated with the Klamath Basin RiverWare model will be presented as part of a separate technical report documenting the development of the model.

The Klamath Basin RiverWare model was developed as a basin-wide tool for simulating current operations under the 2012 Proposed Action for Klamath Project operations (Reclamation, 2012d). Operating rules for the Proposed Action were translated from the original modeling platform of the Klamath Basin Planning Model into RiverWare. Because the KBPM modeling platform differs from the RiverWare platform, management rules in some instances were modified to accommodate the RiverWare platform. Calibration of the RiverWare model, using historical data consistent with KBPM data, was performed to the best of our ability. However, differences persist between historical hydrology-driven model simulations using the KBPM and the RiverWare models. Model calibration will continue to be addressed in the future as the model is applied to future projects.

The USGS RBM10 water temperature model was used in its original form as part of the Basin Study. Historical inputs consistent with the Basin Study water supply and demand assessments were used as input to the RBM10 model to maintain consistency within the Basin Study. Many of these inputs differed from those used in the original implementation of the RBM10 model for the dam removal studies. As such, we employed a bias correction technique for the meteorological data so it better represented the statistics of the original model data. This also facilitated use of the model in the Basin Study because, under this methodology, it was not necessary to recalibrate parameters of the water temperature model.

Simulated managed streamflows at boundary locations used by the RBM10 model were provided by the Klamath Basin RiverWare model. Original development of the RBM10 model used USGS gage data for these boundary inputs. Historical simulated RiverWare model output was, as expected, different from the inputs for the original model. Within the RiverWare model, it was possible to experience negative or close to negative flows in certain river reaches due to river routing and the computation of reach gains. The RBM10 model cannot compute water temperature provided negative river flows, so a 5 cfs adjustment was made to simulated boundary flow for those timesteps where negative flows occurred.

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Chapter 6
Klamath River Basin Study
Evaluation of System Reliability with Strategies

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Chapter 6 Evaluation of System Reliability with Strategies

6.1 Introduction

Chapter 6 presents the process that was developed and utilized to formulate and screen adaptation strategies for reducing identified gaps between water supply and demand. It also identifies the strategies carried forward for quantitative evaluation under the framework developed for the Basin Study, which is further described in Chapter 5, System Risk and Reliability Analysis. Figure 6-1 provides an overall schematic of the Basin Study approach.

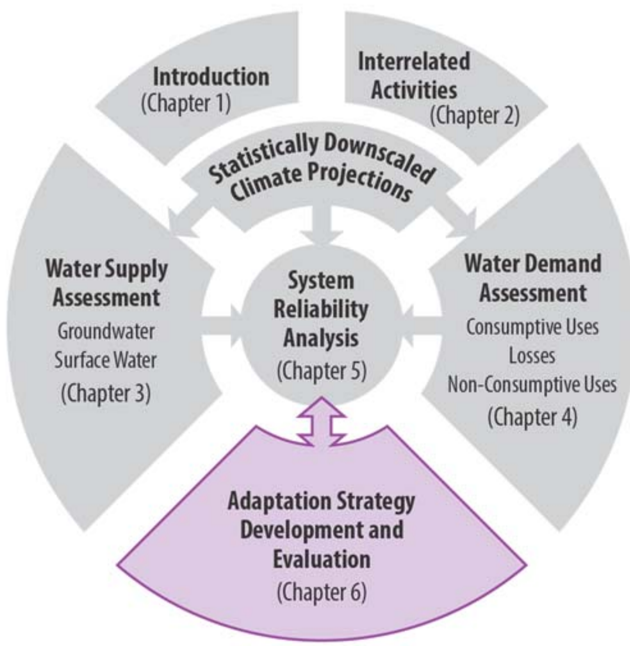


Figure 6-1.—Overall approach of Klamath River Basin Study, highlighting Chapter 6

6.2 Formulation of Adaptation Strategies

The overall approach for formulating adaptation strategies to be evaluated in the Klamath River Basin Study includes the following steps:

- Identify strategies that cover a range of options.

- Organize proposed strategies in general categories based on their primary function.
- Characterize strategies based on a set of criteria to facilitate strategy screening.
- Develop representative options that allow for simplified analysis and that avoid redundancy.

Each of these approach steps is further described below.

6.2.1 Approach to Adaptation Strategy Identification

Adaptation strategies were identified through a comprehensive literature review of studies on climate change and water supply issues specific to the Klamath River Basin as well as studies focused on the broader Pacific Northwest. In addition to this literature review, the Basin Study team completed outreach to Klamath River Basin agency representatives, tribal representatives, stakeholders, and residents through conference calls, attendance at water supply management and planning meetings in the basin, and outreach through the Basin Study website.

The literature review effort identified 49 reports, studies, agreements, doctoral dissertations, and masters' theses completed by federal and state resource agencies, tribal natural resource departments, and university researchers. From this literature review and stakeholder input, 185 unique adaptation strategies were identified and carried forward for evaluation in the screening process described below. The full list of identified adaptation strategies is presented in Appendix E.

6.2.1.1 Organization of Proposed Adaptation Strategies

The adaptation strategies were divided into categories to facilitate a comparison of the strategies with similar approaches to addressing water supply and demand changes. These categories – increase supply, decrease demand, modify operations, and governance and implementation – are each populated with multiple strategies. This same general approach was used for the Colorado River Basin Water Supply and Demand Study (Reclamation, 2001e). The four general categories are further described below:

> ***Increase Supply:*** This category encompasses strategies that result in an anticipated increase in water supply or that identify alternative water supplies. Strategy examples include creating groundwater recharge opportunities, increasing surface storage capacity, increasing the use of recycled water, developing conjunctive use programs, and implementing vegetation management actions.

Decrease Demand: This category encompasses strategies that result in an anticipated decrease in water demand either directly or indirectly. Strategy examples include M&I water conservation (direct reduction), agricultural water conservation (direct reduction), energy water use efficiency (indirect reduction), and reductions in environmental demand (direct reduction).

Modify Operations: This category encompasses strategies that involve alternative management decisions that may result in a change in water supply and/or demand. Strategy examples include improving infrastructure reliability and efficiency, reducing hillslope and/or bank erosion, improving water quality, improving preparedness for extreme events, reducing reservoir and lake evaporation, reducing out of basin transfers, improving intra-regional water transfers, or improving operational flexibility.

Governance and Implementation: This category encompasses strategies that involve changes in policy, management, legal structure, or future governance issues in the Klamath River Basin. Strategy examples include improvements to public education, developing and improving partnerships between stakeholders, improving research, modifying or developing new policies, developing decision support tools, providing for habitat protection, seeking funding, implementing watershed management, and improved land use practices.

Figure 6-2 indicates the number of proposed adaptation strategies identified per category.

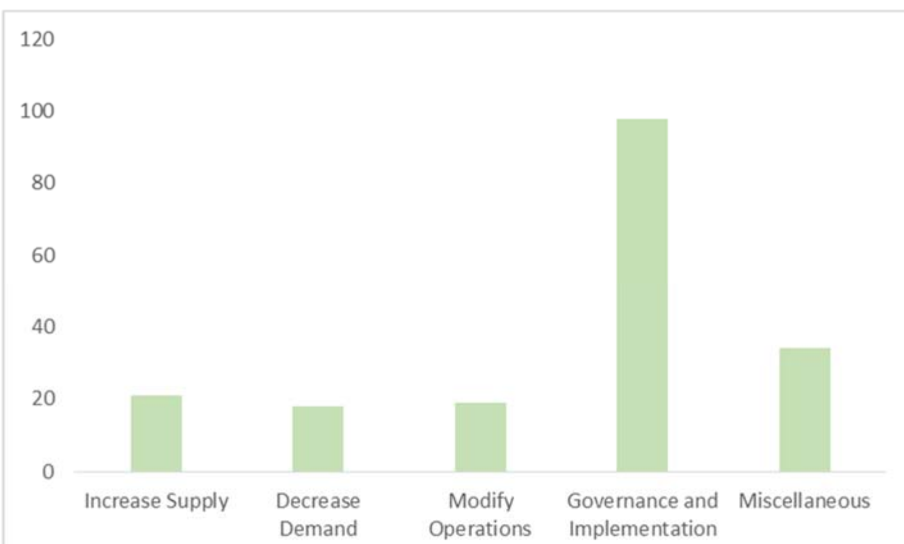


Figure 6-2.—Number of adaptation strategies identified.

6.2.1.2 Criteria for Adaptation Strategy Screening

Once the proposed strategies were organized into general function categories, they were evaluated and screened in a staged analysis effort. Evaluation measures were utilized to assess each adaptation strategy's capacity to address changes in water supply and demand. These evaluation measures were developed by Reclamation in consultation with the non-federal partners consistent with the selection criteria developed for the evaluation of options during development of the On Project Plan (Klamath Water and Power Agency, 2013). The On Project Plan screening criteria were formulated through an extensive stakeholder outreach process that resulted in wide acceptance of their use for the screening of the water conservation and efficiency, water storage, groundwater development and substitution, and demand management options identified in that planning effort. Reclamation and the non-federal partners relied on these widely accepted criteria during the development of evaluation measures for the Basin Study to incorporate the input already provided by these stakeholders.

The initial screening effort evaluated each strategy in each category to determine if it could be represented by the Basin Study models. Strategies that could be modeled could be quantitatively evaluated in this Basin Study Report; strategies that could not be modeled were evaluated qualitatively. The results of the first screening for each strategy are included in Appendix E.

Following the initial screening, the strategies that could be modeled were evaluated qualitatively, utilizing the criteria detailed below in Table 6-1, to assess the strategy's implementation risk and uncertainty, reliability, and environmental effect. Reclamation and the non-federal partners qualitatively evaluated these screening criteria, arriving at representative strategies that encompass the collective goals of the criteria, present the greatest potential for beneficial effect, and were identified as high priorities to the non-federal partners, while also involving a range of options for reducing identified vulnerabilities in the Klamath River Basin.

Table 6-1.—Description of criteria for assessing adaptation strategies

Provides verifiable, durable and implementable benefit to align water supply and demand for the Klamath River Basin
This criterion evaluates whether a strategy is capable of providing verifiable and affordable reductions in projected water supply/demand gaps and assures all associated administrative requirements are reasonable and not overly burdensome or complex. Strategies performing well under this criterion are expected to provide a measurable water supply increase, and strategies with low ratings are anticipated to deliver minimal increases in water supply that would be difficult to verify.
Consistency with legal and regulatory requirements
This criterion evaluates whether a strategy is implementable with respect to compliance with all existing laws, regulations, or contracts, or requires a relatively minor revision in such requirements that would allow for implementation. Strategies that performed well under this criterion had no identified legal and regulatory issues and strategies with low ratings would require major legal or regulatory actions, like new water rights and major environmental compliance investigations.

Table 6-1.—Description of criteria for assessing adaptation strategies

Affordability
This criterion evaluates whether a strategy furthers the objective of aligning demand with Klamath water supply availability in a manner that is commensurate with the cost, allowing for a comparison of the relative cost of alternative strategies. This criterion was rated with high ranking strategies requiring no new costs or investment and low performing strategies requiring large capital expenditures and/or high long-term operations and maintenance costs.
Flexibility
This criterion evaluates whether a strategy would have, or not unduly limit, the capability to be adjustable over time. This criterion was rated with high ranking strategies allowing for implementation to be adjusted over time and low ranking strategies implementing new infrastructure that could not be moved or have its operations modified.
Protection of water rights
This criterion evaluates whether a strategy would result in injury to existing water rights holders. This criterion was rated with high ranking strategies producing no effect on existing water rights and low ranking strategies potentially impacting neighboring surface and groundwater availability.
Environmental and third-party impacts and benefits
This criterion evaluates whether a strategy would comply with applicable environmental laws and not involve unacceptable environmental impacts. This criterion was rated with high ranking strategies producing no effect on environmental resources and low ranking strategies generating adverse impacts on water quality and other resources.

6.2.1.3 Summary of Selected Adaptation Strategies

The adaptation strategy screening process resulted in the identification of five strategy concepts that are carried forward for evaluation in the Basin Study models. This section summarizes these strategy concepts by category.

6.2.1.3.1 Increase Supply

Additional Surface Water Storage Capacity

This strategy concept includes quantification of potential surface storage opportunities in the Upper Klamath Basin. Some examples of proposals that fall within this strategy concept are listed in Appendix E. Additional surface water storage capacity is quantified as the incremental excess water defined in the Klamath Basin Planning Model. This excess water is quantified as the remaining water after releases are made to the Klamath Project and to meet environmental needs, including instream flow needs in the Klamath River and water stored in Upper Klamath Lake to maintain elevations. For this strategy, it is assumed that the remaining water could be stored for future use; however, it is acknowledged that the 2013 Klamath Project proposed action Biological Assessment and associated Biological Opinion consider this quantity to be part of the environmental water account.

6.2.1.3.2 Decrease Demand

Agricultural Water Conservation

This strategy concept includes reduction in overall agricultural water demand throughout the basin by a range of percentages (between 30 percent and 50 percent). One goal of this implemented strategy concept is to determine how much reduced agricultural demand would be needed to offset the impacts of climate change alone. Reductions in agricultural water demand might be obtained through means identified in the proposed strategy examples listed in Appendix E. These might include canal lining and pump operation optimization; crop idling, irrigated land retirement and rain-fed agriculture; shifting agricultural production to more drought tolerant crops; and converting irrigation systems to more efficient technologies along with the use of cover crops to improve soil productivity.

Additional Supply to Upper Klamath Lake

This strategy concept captures the additional 30,000 acre-feet of water provided for Upper Klamath Lake in the KHSA, KBRA, and Upper Klamath Basin Comprehensive Agreement as generated by land retirement actions in the Upper Klamath Basin. The strategy concept does not identify individual areas where water demand reduction would occur. However, this strategy assumes that the additional volume of water is made available proportionally between the Sprague River, the Williamson River upstream of its confluence with the Sprague River, and the local inflows between the confluence and Upper Klamath Lake. The proportions of the total 30,000 acre-foot volume are determined based on the relative contributions to Upper Klamath Lake inflows of mean annual flow from these three sources (Sprague River, Williamson River, and local inflows between the Sprague-Williamson confluence and Upper Klamath Lake). The goal of this strategy concept is to evaluate the effect of reductions in collective water use upstream of Upper Klamath Lake. This strategy also assumes that operating rules are not modified to compensate for the additional Upper Klamath Lake inflow.

6.2.1.3.3 Modify Operations

Two strategy concept options were developed to capture the adaptation strategy articulated in the screening process as “reduce environmental demand.” These strategy concepts were developed to facilitate the analysis in the Basin Study models of five strategy examples: protect cool water refugia; keep higher quality water in-stream to protect species and river ecosystems by using lower quality water for agricultural purposes; purchase water from water-rights holders and keep that flow in-stream to reduce demand on a short-term basis; curb demand with ecosystem restoration/improvements, water use effectiveness, and environmental water scarcity programs; and ensure adequate flows for fish and wildlife habitat.

Tributary Water Temperature Reduction

This strategy concept addresses the need for cold water refugia in summer months to support fish and wildlife, particularly salmonids, in the Klamath River Basin tributaries. This concept is based on existing emergency water management planning in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs. In this strategy concept, a 4 degrees Celsius (degrees C) reduction in water temperature (or about 7 degrees F) in the Scott and Shasta Rivers is assumed as input to the RBM10 stream temperature model for the Klamath River, and effects of that reduction on mainstem Klamath River temperature are evaluated.

6.2.1.4 Sensitivity of Simulated Water Temperature to Changes in Flow and Climate

This strategy concept includes exploring relationships between water temperature change and streamflow change, using historical and future climate change simulations of managed streamflow (using the Klamath RiverWare planning model) and river temperature (using the RBM10 model). By evaluating potential relationships between temperature and flow change, it may be possible to estimate the needed change in flow to obtain a desired change in Klamath River temperature. Such information may be valuable in determining what changes in water management may be needed to counter the impacts of climate change.

6.3 Uncertainties Associated with Strategy Selection

Adaptation strategies were intended to encompass a range of management actions. They were selected to be broad in scope with basin-wide implications, and not specific to any particular subbasin or singular project operation. Broad strategy concepts were selected, in part because numerous existing studies have evaluated some proposed actions in depth, and also because management conditions in the basin are dynamic. Strategies were selected with the intent that they noticeably reduce water supply and demand imbalances; however, they were selected without prior knowledge of their relative impact. Therefore, there is uncertainty as to whether the selected strategies have greater impact on system reliability than those that were not selected. In short, there may be additional strategies that could reduce water supply and demand imbalances but were not considered by the study.

In addition, strategies were initially screened on their ability to be modeled in the framework of the Basin Study. A strategy that could not be modeled by the Basin Study framework may in fact have substantial impact on system reliability; however, the impact could not be appropriately assessed with respect to that resulting from selected strategies.

6.4 Evaluation of System Reliability with Adaptation Strategies

In Chapter 5, projected response to climate change is evaluated by examining effects on basin-wide response measures and on several categories of performance measures. Basin-wide response measures include flows at key locations, river temperature, UKL storage, and Project delivery. Performance measures provide additional details on operational elements such as hydropower, flood control, recreation, and ecological resources. In the analysis described in Chapter 6, the potential for adaptation strategies to affect response to climate change is evaluated. Basin-wide response measures and system performance measures are examined, comparing the collective effects of both climate change and adaptation strategies to the effects of climate change alone.

An illustration of the model scenarios that capture these differences is visualized in Figure 6-3. The baseline scenario uses historical hydrology, and in Chapter 5 we compare results from model simulations using five future climate scenarios, for both the 2030 time horizon and the 2070 time horizon, as well as CMIP3- and CMIP5-based temperature and precipitation projections. The blue line in Figure 6-3 demonstrates this comparison. In this chapter (Chapter 6), the focus is on the effects depicted by the orange line and how these differ from the baseline comparison.

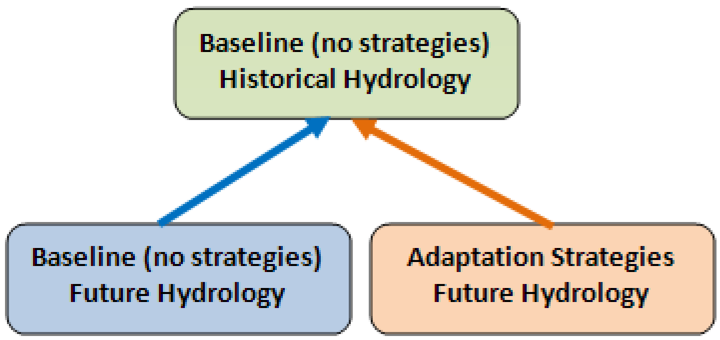


Figure 6-3.—Illustration of methodology for evaluating adaptation strategy concepts.

The following sections summarize projected changes in basin-wide response variables and system performance measures according to the baseline (i.e., with climate change scenarios but no adaptation strategy concepts) and adaptation strategy concepts previously discussed. Summary figures throughout this section illustrate changes in the strategy concepts associated with agricultural water conservation and additional supply to Upper Klamath Lake. The strategy concepts are defined as follows in the summary figures:

> **Baseline** – with climate change impacts, but no adaptation strategy concepts. This is similar in concept to a no action scenario.
>
> **Reduce ET 30% -** Reduction of agricultural demands throughout the basin by 30 percent
>
> **Reduce ET 50% -** Reduction of agricultural demands throughout the basin by 50 percent
>
> **Add 30KAF** – Addition of 30 KAF annually to Upper Klamath Lake inflow (contributed proportionally by Williamson River, Sprague River, and other gains, based on mean annual flow)

Results for additional strategy concepts are summarized for water quality measures. These additional strategy concepts are defined as follows in the summary figures under Section 6.4.6, Analysis of Impacts – Water Quality. Note that this adaptation strategy concept only affects the water quality measures. Therefore, results for this measure are only summarized for these measures.

Reduce Shasta Scott 4degC – Reduction of Shasta and Scott River temperatures by 4 degrees C (about 7 degrees F) year round

Add Flow 10% - Addition of flow by 10 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

Add Flow 20% - Addition of flow by 20 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

Reduce Tribs 4degC - Reduction of temperatures by 4 degrees C (about 7 degrees F) year round in all tributaries represented in the RBM10 water temperature model. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

Reduce Dam Outflow 4degC - Reduction of temperatures by 4 degrees C (about 7 degrees F) year round from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

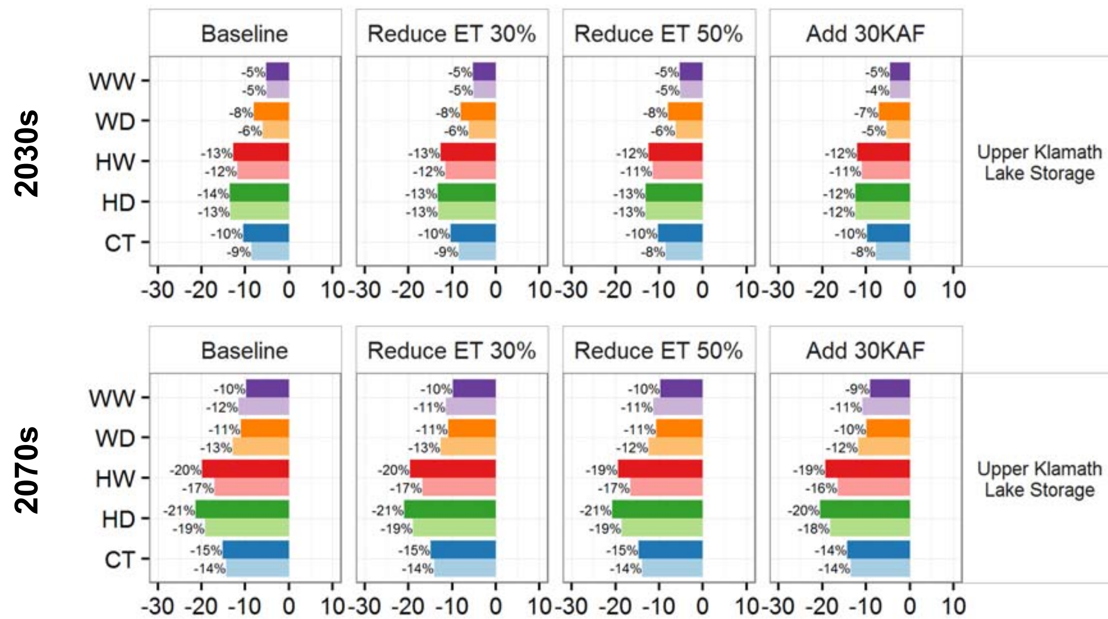
Results for the strategy concept to quantify additional surface water storage capacity are summarized under Section 6.4.7, Analysis of Impacts – Flood Control, where the mean annual Upper Klamath Lake flood control volume is quantified and evaluated. This strategy concept does not identify any specific location for additional surface water storage; however, the location for quantifying additional water is at Upper Klamath Lake.

6.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of system reliability under baseline and scenarios with adaptation strategy concepts allows for an understanding of how strategies may reduce the basin's vulnerability to climate change. Similar to Chapter 5, we explore projected change in managed river flow at various locations within the basin, as well as mainstem Klamath River stream temperature.

6.4.1.1 Upper Klamath Lake Storage

Projected changes in mean annual end of month (EOM) storage in Upper Klamath Lake under baseline and strategy scenarios are summarized in Figure 6-4. Under the baseline scenario (climate change only), mean annual storage is projected to decline under all scenarios, more so for the 2070s than for the 2030s. Neither of the strategy concepts for reducing agricultural water demand (by 30 percent and 50 percent) reduce climate change impacts substantially. Percent reductions in storage conditions are minimally affected, except for the HD climate change scenario for the 2030s and for the warmer scenarios (WW and WD) for the 2070s. Adding 30 KAF of inflow to Upper Klamath Lake does reduce the impacts of climate change by 1 to 2 percent under all climate change scenarios for both the 2030s and 2070s. Table 6-2 summarizes projected changes in storage volume under the CT scenario for both future time periods. Implementing the Add 30KAF strategy concept results in a 26 or 33 KAF reduction in mean annual storage for the 2030s, compared to 29 or 35 KAF for the baseline for CMIP3- and CMIP5-based projections, respectively. For the 2070s, the projected reduction is 46 or 48 KAF, compared to 48 or 51 KAF for the baseline.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

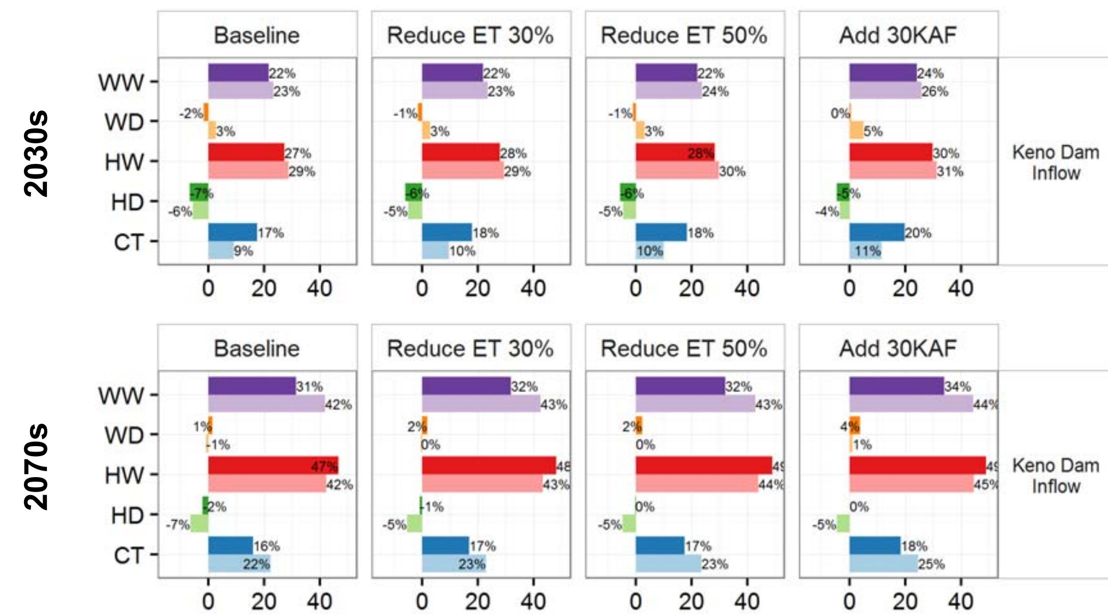
Figure 6-4.—Projected change (percent) in mean annual Upper Klamath Lake storage.

Table 6-2.—Summary of projected change in mean annual Upper Klamath Lake Storage for the Central Tendency scenario in units of KAF

Central Tendency Scenario	CMIP	Baseline (KAF)	Reduce ET 30% (KAF)	Reduce ET 50% (KAF)	Add 30KAF (KAF)
Historical		337			
2030	CMIP3	-29	-29	-28	-26
	CMIP5	-35	-35	-34	-33
2070	CMIP3	-48	-47	-47	-46
	CMIP5	-51	-50	-50	-48

6.4.1.2 Keno Dam Inflow

Projected changes in mean annual inflow to Keno Dam under baseline and strategy scenarios are summarized in Figure 6-5. Under the baseline scenario (climate change only), mean annual inflow is projected to increase under the wetter scenarios (WW and HW) for both future time periods and decrease modestly under the drier scenarios (WD and HD), with an increase under the CT scenario projected to be 9 or 17 percent for the 2030s and 16 or 22 percent for the 2070s, depending on consideration of CMIP3- or CMIP5-based projections. Implementation of each of the strategy concepts would maintain or increase the mean annual inflow at Keno, and by similar percentages. Addition of 30 KAF of inflow to Upper Klamath Lake appears to have a larger effect on Keno inflow than does reduction in agricultural demands in the regions upstream of Keno.

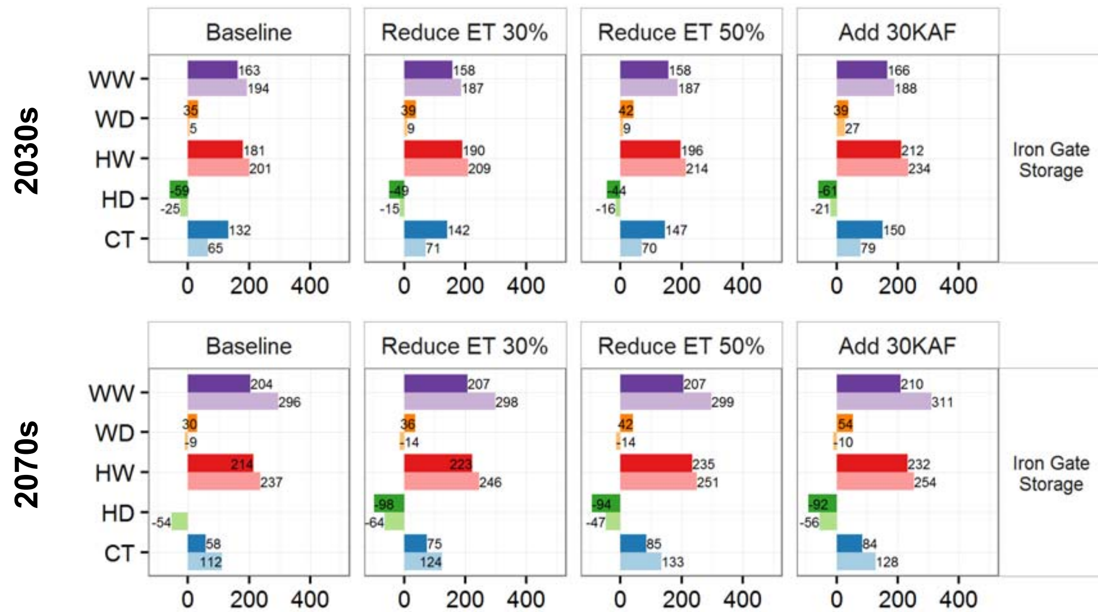


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-5.—Projected change (percent) in mean annual inflow to Keno Dam.

6.4.1.3 Iron Gate Reservoir Storage

Projected changes in mean annual Iron Gate Reservoir storage under baseline and strategy scenarios are summarized in Figure 6-6. Under the baseline scenario (climate change only), mean annual storage is projected to change very little on a percentage basis compared with the historical simulation. Iron Gate Reservoir elevations have not fluctuated much historically, typically staying between 55,000 acre-feet and 57,000 acre-feet. Projected changes shown in Figure 6-6 are reported in units of acre-feet. Mean annual storage is projected to increase under all scenarios and strategies, with the exception of the HD scenario for both the 2030s and 2070s time periods. Reduction of agricultural demand provides some additional storage at Iron Gate, but generally the addition of 30 KAF inflow to Upper Klamath Lake has a larger impact on Iron Gate storage. Still, all adaptation strategy concepts do not substantially change Iron Gate storage and do not generally counter the effects of climate change.

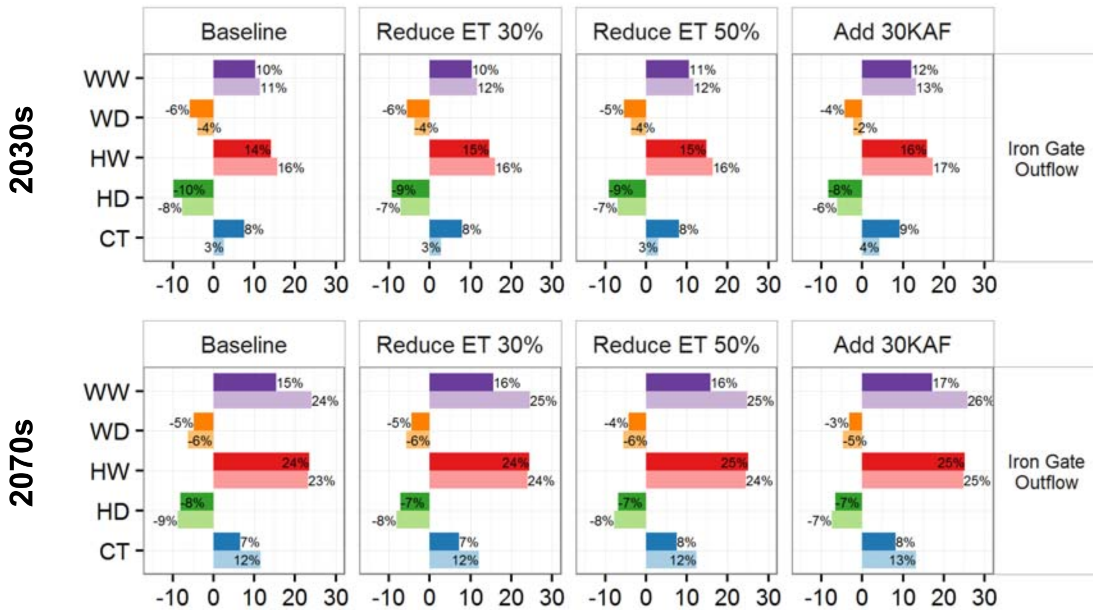


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-6.—Projected change (acre-feet) in mean annual Iron Gate Reservoir storage

6.4.1.4 Iron Gate Reservoir Outflow

Projected changes in mean annual Iron Gate Reservoir outflow under baseline and strategy scenarios are summarized in Figure 6-7. Under the baseline scenario (climate change only), mean annual outflow is projected to increase under wetter scenarios (WW and HW) and decrease modestly under drier scenarios (WD and HD), with the CT scenario indicating increases of 3 or 8 percent for the 2030s and 7 or 12 percent for the 2070s. Implementation of adaptation strategies does not substantially counter climate change impacts. Reduction of agricultural demand increases the effect of additional outflow at Iron Gate, but only by about one percent for most climate change scenarios considered. Additional inflow to Upper Klamath Lake (Add 30KAF) increases the additional outflow at Iron Gate by up to 2 percent over the baseline response to climate change alone.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-7 Projected change (percent) in mean annual inflow to Iron Gate Reservoir.

6.4.1.5 Shasta River Flow

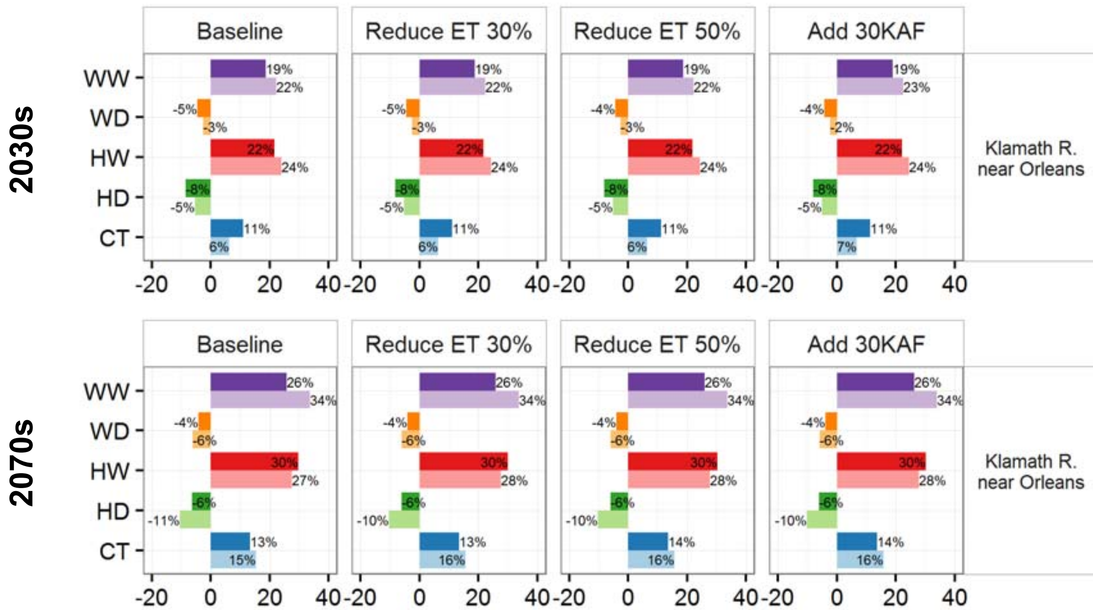
Projected changes in mean annual flow in the Shasta River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

6.4.1.6 Scott River Flow

Projected changes in mean annual flow in the Scott River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

6.4.1.7 Flow at Klamath River near Orleans

Projected change in mean annual flows in the Klamath River near Orleans under baseline and strategy scenarios is summarized in Figure 6-8. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 6 or 11 percent for the 2030s and 13 or 15 percent for the 2070s, according to model simulations. Similar to other upstream locations, reduction of agricultural demand in the contributing area to the basin upstream of Orleans results in no change for the 2030s and little change for the 2070s in simulated managed flow on a percentage basis. Additional Upper Klamath Lake inflow of 30 KAF annually has only a slightly greater impact than agricultural demand reduction.

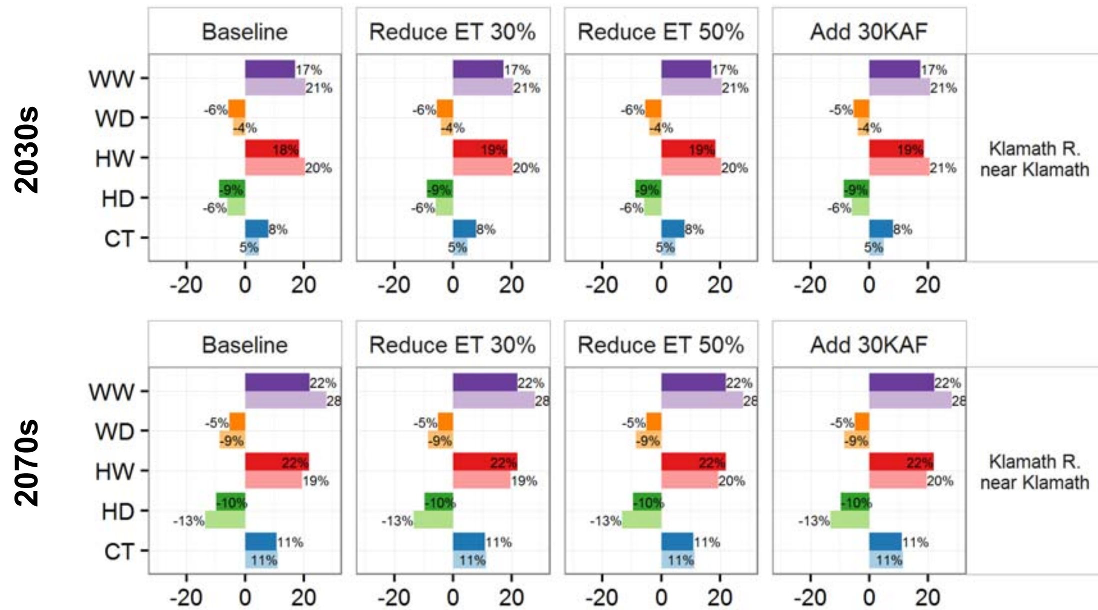


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-8.—Projected change (percent) in mean annual flow at Klamath River near Orleans.

6.4.1.8 Flow at Klamath River near Klamath

Projected changes in mean annual flows in the Klamath River near Klamath under baseline and strategy scenarios are summarized in Figure 6-9. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 5 or 8 percent for the 2030s and 11 percent for the 2070s, according to model simulations. Generally, the adaptation strategies either have no influence or increase flows on a mean annual basis, about one percent or less for the 2030s and no noticeable change for the 2070s. This result is in part due to the fact that any change in flow volume is a small percentage of the overall river flow at Klamath, which is close to the mouth of the basin.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-9.—Projected change (percent) in mean annual flow at Klamath River near Klamath

6.4.2 Analysis of Impacts – Ability to Deliver Water

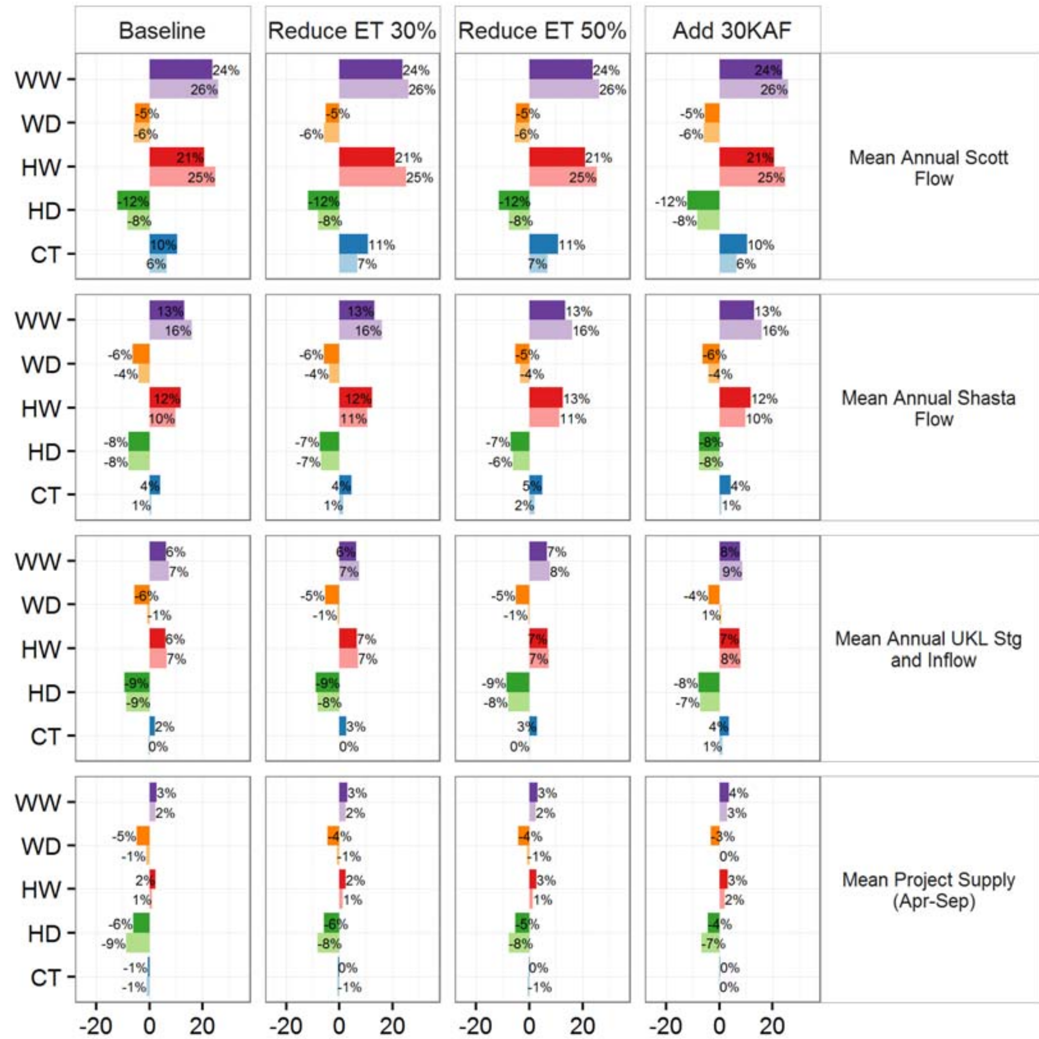
As discussed in Chapter 5, measures of the ability of the Klamath River Basin to supply water to meet human needs include (1) the April through September irrigation water supply to the Klamath Project (Project Supply), (2) mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow (Upper Klamath Lake Supply), (3) mean annual flows in the Shasta River near Yreka, and (4) mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the historical simulation period, the Upper Klamath Lake Supply parameter was about 1.38 million acre-feet. Additional measures representing the overall hydrology conditions in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

Projected changes in water supply measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-10 and for the 2070s in Figure 6-11. For the Scott and Shasta Rivers under the baseline scenario (climate change only), mean annual flow is projected to increase under wetter scenarios (WW and HW) and decrease under drier scenarios (WD and HD), with the CT scenario indicating a modest increase. For all scenarios, projected changes are greater for the 2070s time period than for the 2030s. For both rivers, reduction of agricultural demand (by 30 or 50 percent) does not appear to provide a substantial amount of additional flow volume, as indicated by no change or small change in the percent increase or decrease of mean annual flow. As expected, additional 30 KAF of inflow to Upper Klamath Lake does not impact mean annual flow in these rivers.

Projected Klamath Project Supply

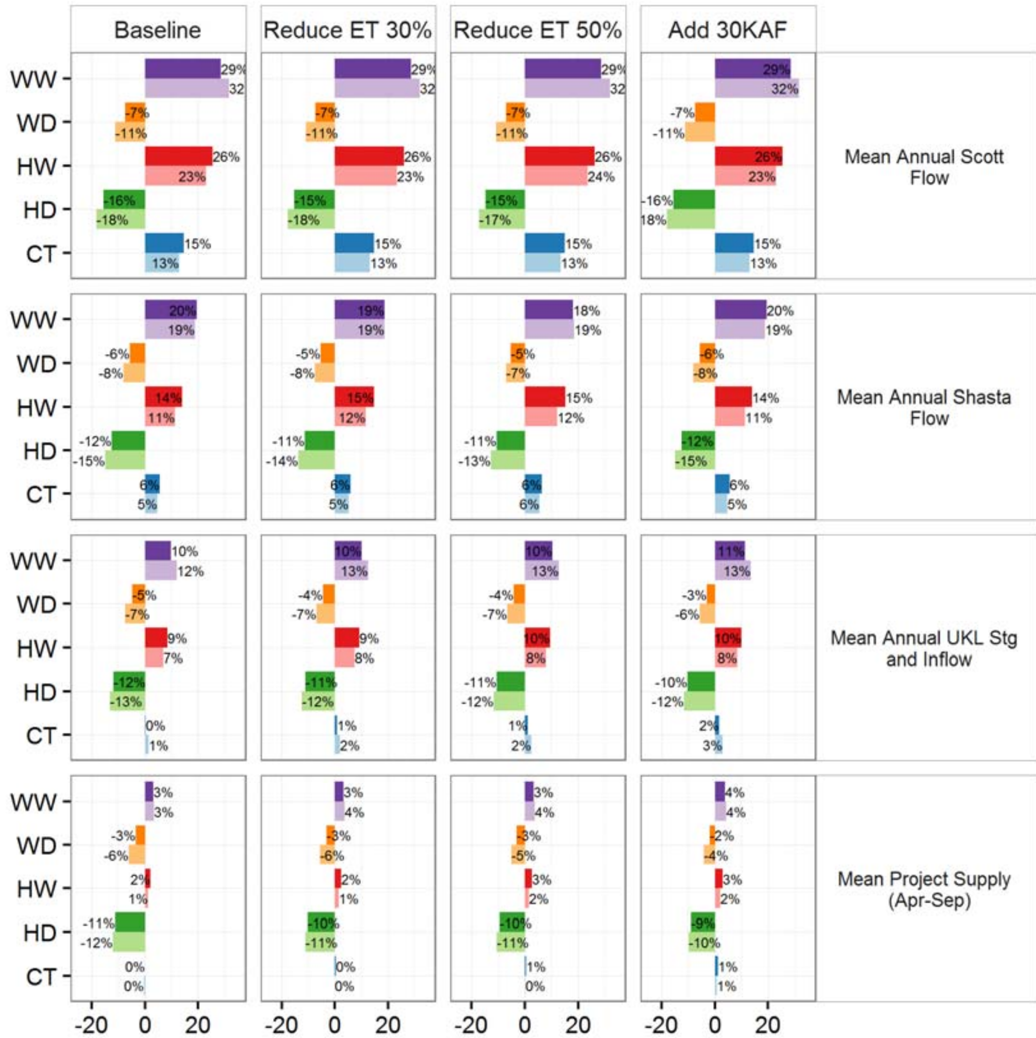
Neither reduction of agricultural demands nor additional 30 KAF inflow to Upper Klamath Lake have substantial impacts on mean Klamath Project water supply (April – September). However, the additional 30 KAF inflow does provides slightly greater additional supply than a reduction in agricultural demands.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-10.—Projected change in water supply measures for the 2030s with strategies in place, expressed as percent change.

For the Upper Klamath Lake Supply measure, adaptation strategy concepts either result in no change or result in small increases in this value, thereby adding to increases in the measure for those climate change scenarios where there are increases (generally wetter scenarios), or decreasing the reduction for other scenarios (generally drier scenarios). Similarly, reduction of agricultural demands and additional inflow to Upper Klamath Lake do not have substantial impacts on mean April through September Klamath Project water supply. However, an additional 30 KAF provides greater additional supply than a reduction in agricultural demands, as indicated by greater increases in supply for the wetter scenarios and small decreases for the drier scenarios, compared with the historical simulation.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-11.—Projected change in water supply measures for the 2070s with strategies in place, expressed as percent change.

6.4.3 Analysis of Impacts – Hydroelectric Power

As discussed in Chapter 5, hydroelectric power measures considered in this study include mean number of spill days per year and mean annual spill volume at the major mainstem Klamath River power facilities (J.C. Boyle, COPCO 1, and Iron Gate), as well as mean annual hydropower generation summed over the four mainstem dams (those listed above plus COPCO 2). For the historical simulation period, mean annual days with spill at the three facilities are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate. The number of spill days and the mean annual spill volumes for J.C. Boyle and COPCO 1 are projected to increase for most scenarios for both future time horizons under the baseline (climate change with no strategies in place). At Iron Gate the projected spill volume generally increases, although by a lower percentage than at J.C. Boyle and COPCO 1, and the projected mean number of spill days per year shows a small decrease.

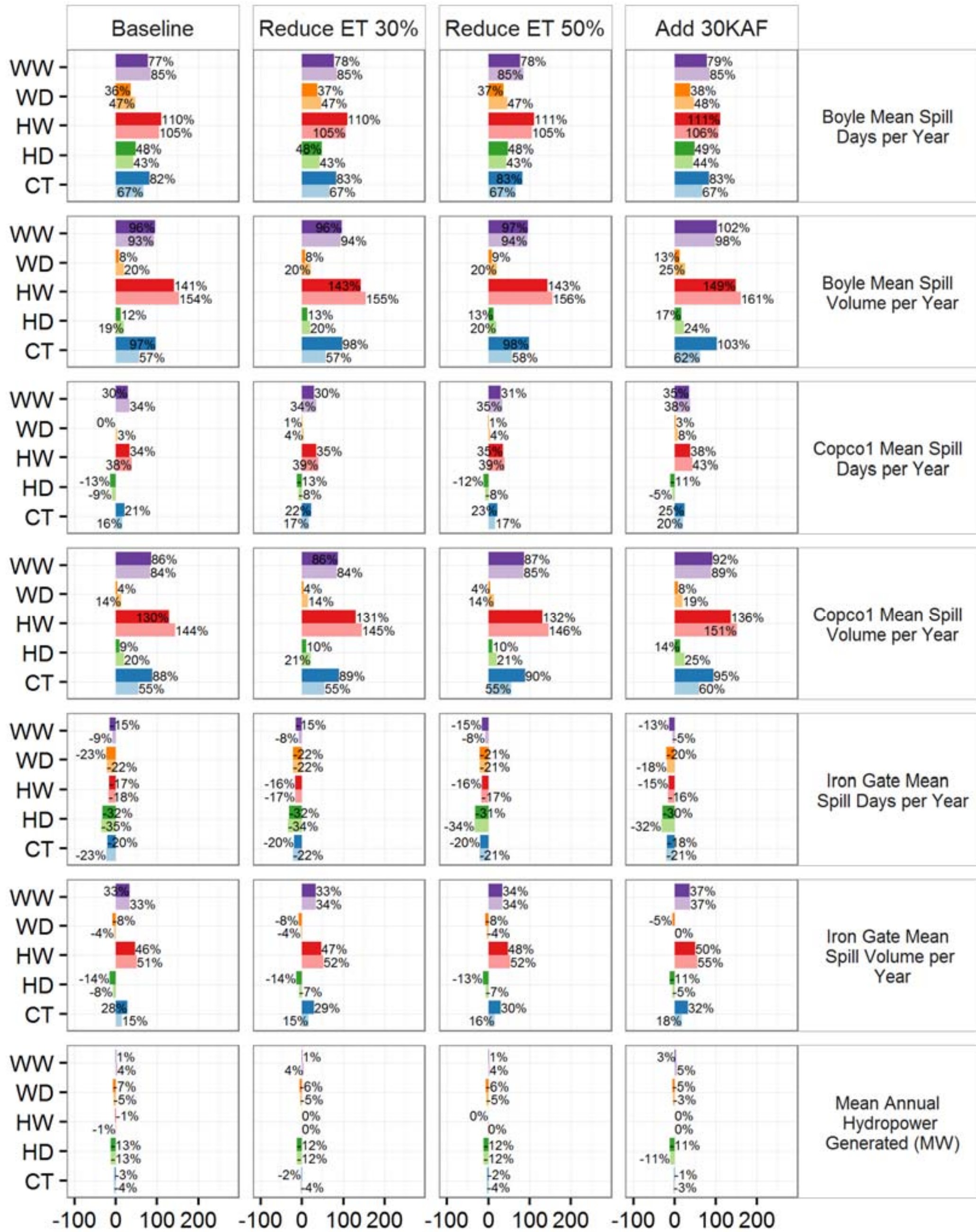
Projected changes in hydropower measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-12 and for the 2070s in Figure 6-13. The adaptation strategy concepts considered generally provide additional water to the mainstem Klamath River, thereby contributing to greater projected increases in mean number of spill days per year, mean annual spill volume, and mean annual hydropower production, more so for the 2070s than for the 2030s future time periods. Again, the addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes than does the decrease in agricultural demands. Projected changes in hydropower production are generally quite small compared with historical simulations, primarily because production under the historical simulation is on the order of 27,000 MW. In other words, hydropower production as a percentage does not change substantially due to the magnitude of hydropower production. Table 6-3 summarizes projected changes in mean annual hydropower production under the CT scenario for both future time periods. Implementation of the Add 30KAF strategy concept results in a 714 or 352 MW reduction in mean annual production for the 2030s, compared to 1,146 or 749 MW for the baseline (depending on consideration of CMIP3- or CMIP5-based projections). For the 2070s, the projected reduction is 468 or 1,209 MW, compared to 818 or 1,593 MW for the baseline.

Projected Hydropower Production

The addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes in hydropower production than does the decrease in agricultural demands. Hydropower production as a percentage does not change substantially due to the magnitude of hydropower production (27,000 MW, according to historical simulations).

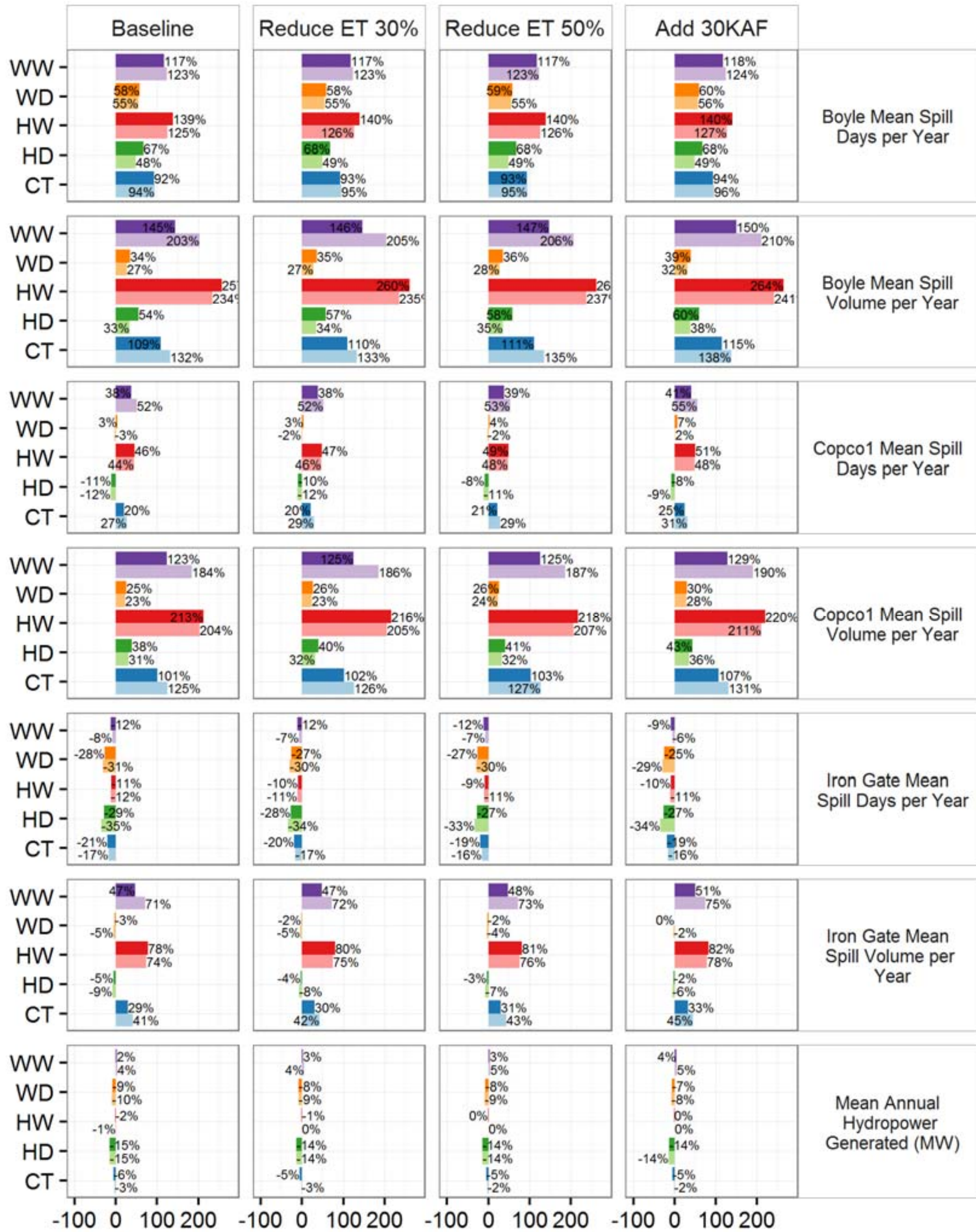
Table 6-3.—Summary of projected change in mean annual hydropower production for the Central Tendency scenario in units of MW

Central Tendency Scenario	CMIP	Baseline (MW)	Reduce ET 30% (MW)	Reduce ET 50% (MW)	Add 30KAF (MW)
Historical		26,741			
2030	CMIP3	-1,146	-1,026	-959	-714
	CMIP5	-749	-637	-569	-352
2070	CMIP3	-818	-672	-585	-468
	CMIP5	-1,593	-1,410	-1,290	-1,209



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-12.—Projected change in hydroelectric power measures for the 2030s with strategies in place, expressed as percent change.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-13.—Projected change in hydroelectric power measures for the 2070s with strategies in place, expressed as percent change.

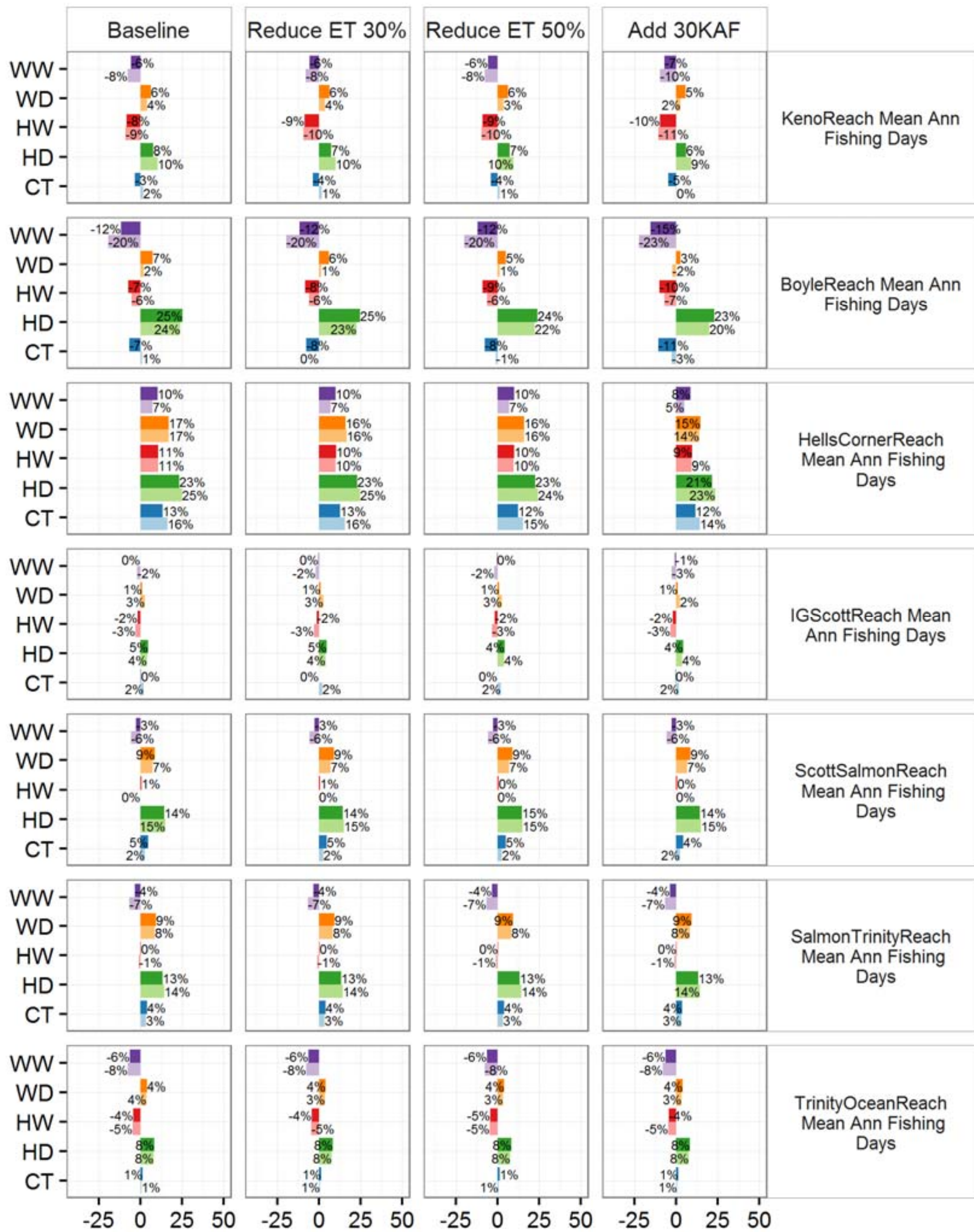
6.4.4 Analysis of Impacts – Recreation

Recreation impacts are measured based on mean annual river boating days and mean annual fishing days in various reaches of the Klamath River. As discussed in Chapter 5, recommended flow ranges were summarized in the Environmental Impact Statement/Report for dam removal (Interior and CDFG, 2012). For the historical simulations, mean annual number of fishing days are generally greater than mean annual number of river boating days. Projected changes in fishing measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-14 and for the 2070s in Figure 6-15, while projected changes in boating measures are summarized similarly in Figure 6-16 and Figure 6-17. For fishing under the baseline scenario (climate change with no strategies in place), the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios indicate decreases in the number of fishing days for both future time horizons. These results show that recommended flow ranges for fishing do not favor high flows. Because the adaptation strategy concepts generally result in greater mainstem river flows, their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The projected changes are small on a percentage basis (on the order of 1 to 2 percent). Implementation of the strategies does not counter the effects of climate change on fishing days.

Recreation

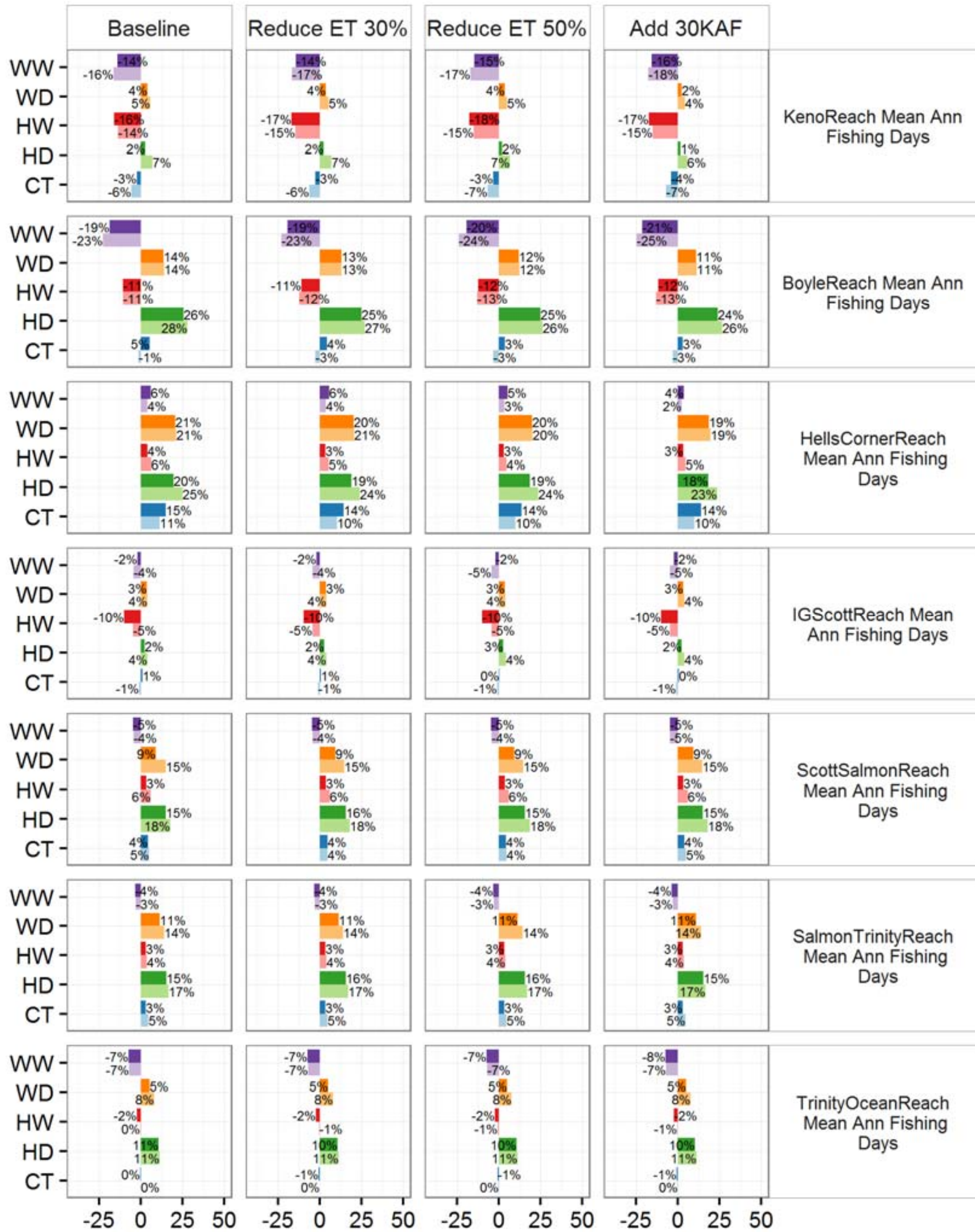
Adaptation strategy concepts generally result in greater mainstem river flows and their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The implementation of adaptation strategy results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario.

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. The implementation of adaptation strategy concepts (both agricultural demand reduction and additional inflow to Upper Klamath Lake) results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario. The strategies do not have a noticeable impact on boating recreation measures downstream of Iron Gate Dam. Upstream of Iron Gate, the strategies cause changes in the boating recreation measures by up to 2 percent for the 2030s and up to 4 percent for the 2070s, and more so for the Add 30KAF strategy scenario than for the agricultural demand reduction scenarios.



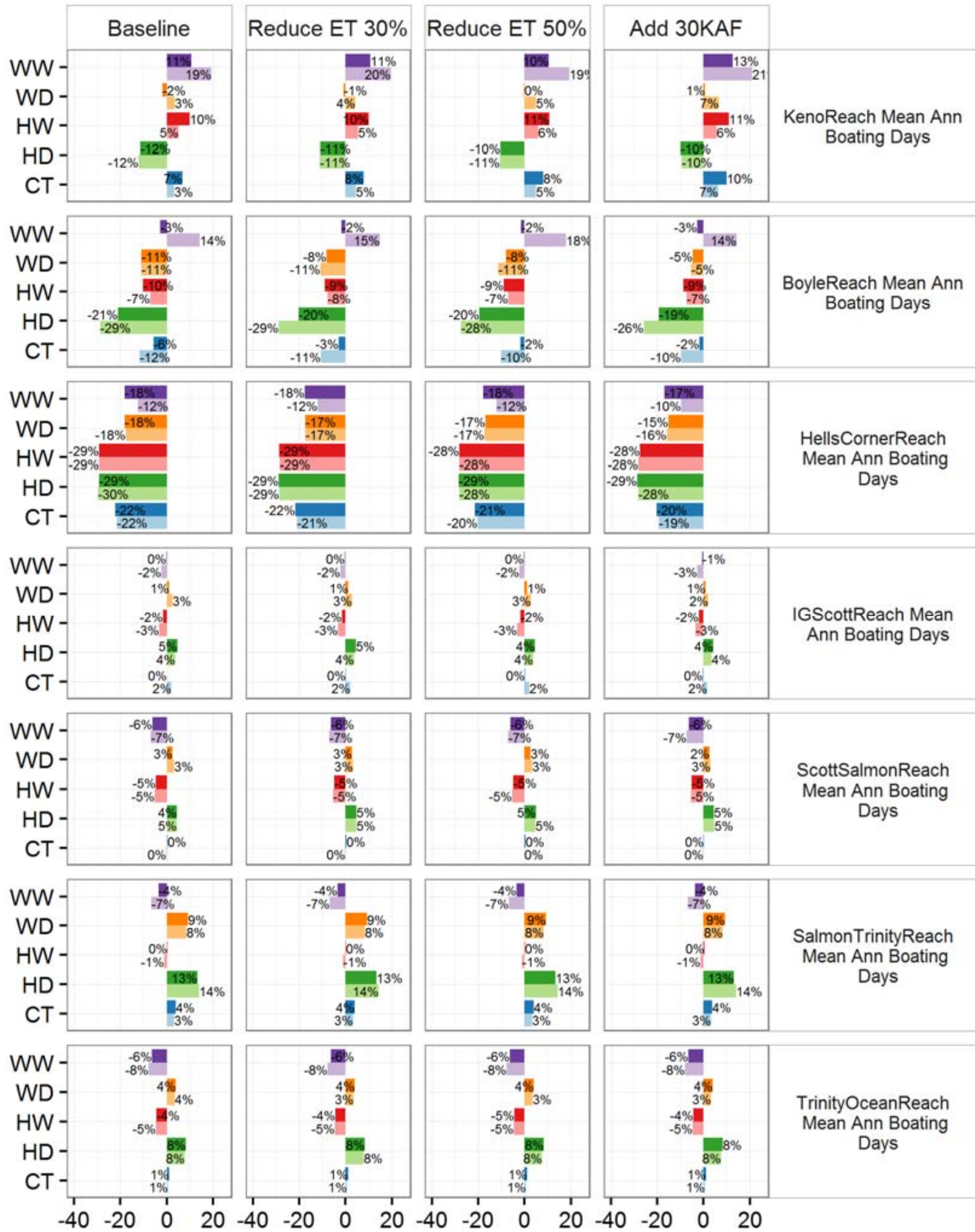
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-14.—Projected change in fishing recreation measures for the 2030s with strategies in place, expressed as percent change.



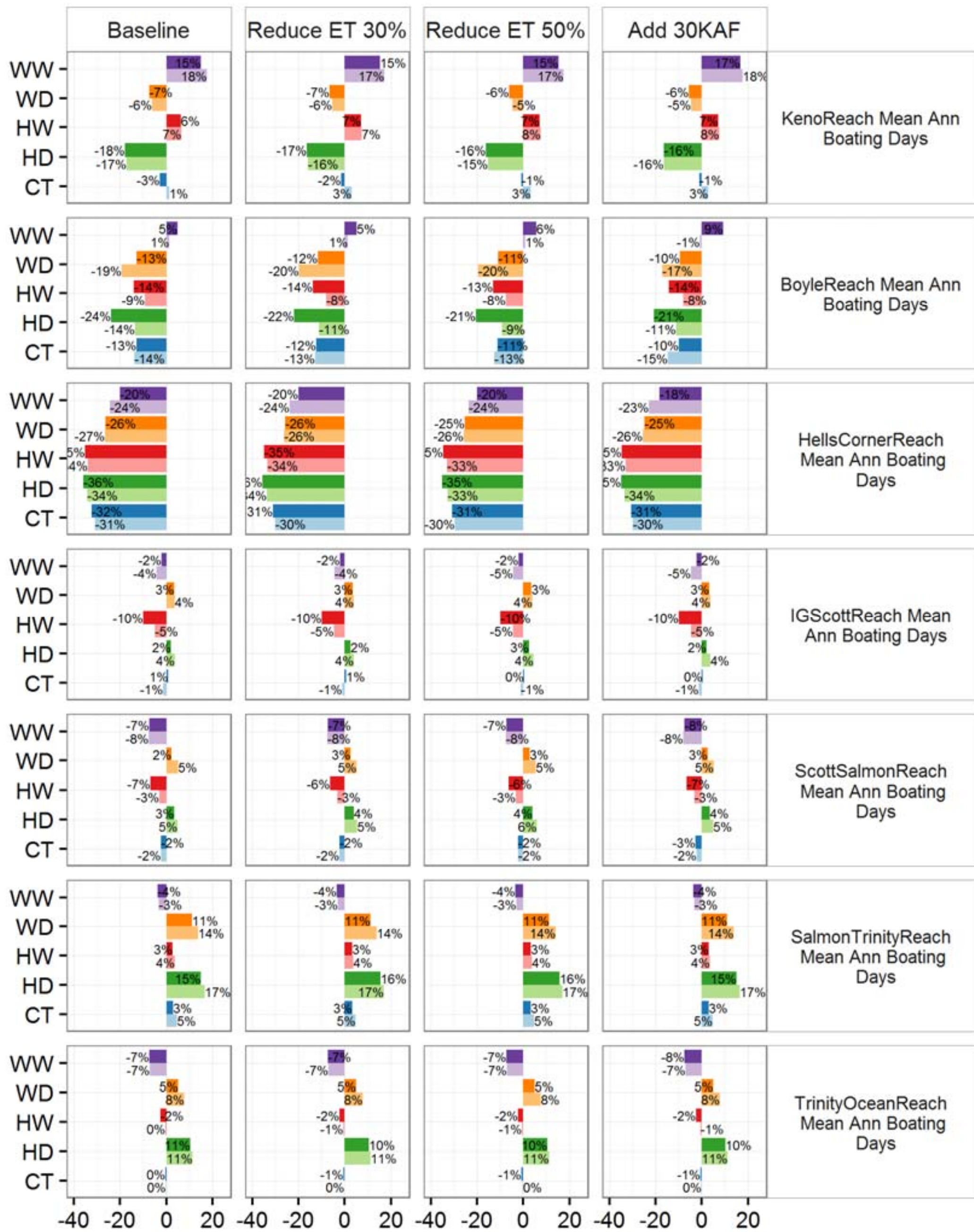
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-15.—Projected change in fishing recreation measures for the 2070s with strategies in place, expressed as percent change.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-16.—Projected change in river boating recreation measures for the 2030s with strategies in place, expressed as percent change.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-17.—Projected change in river boating recreation measures for the 2070s with strategies in place, expressed as percent change.

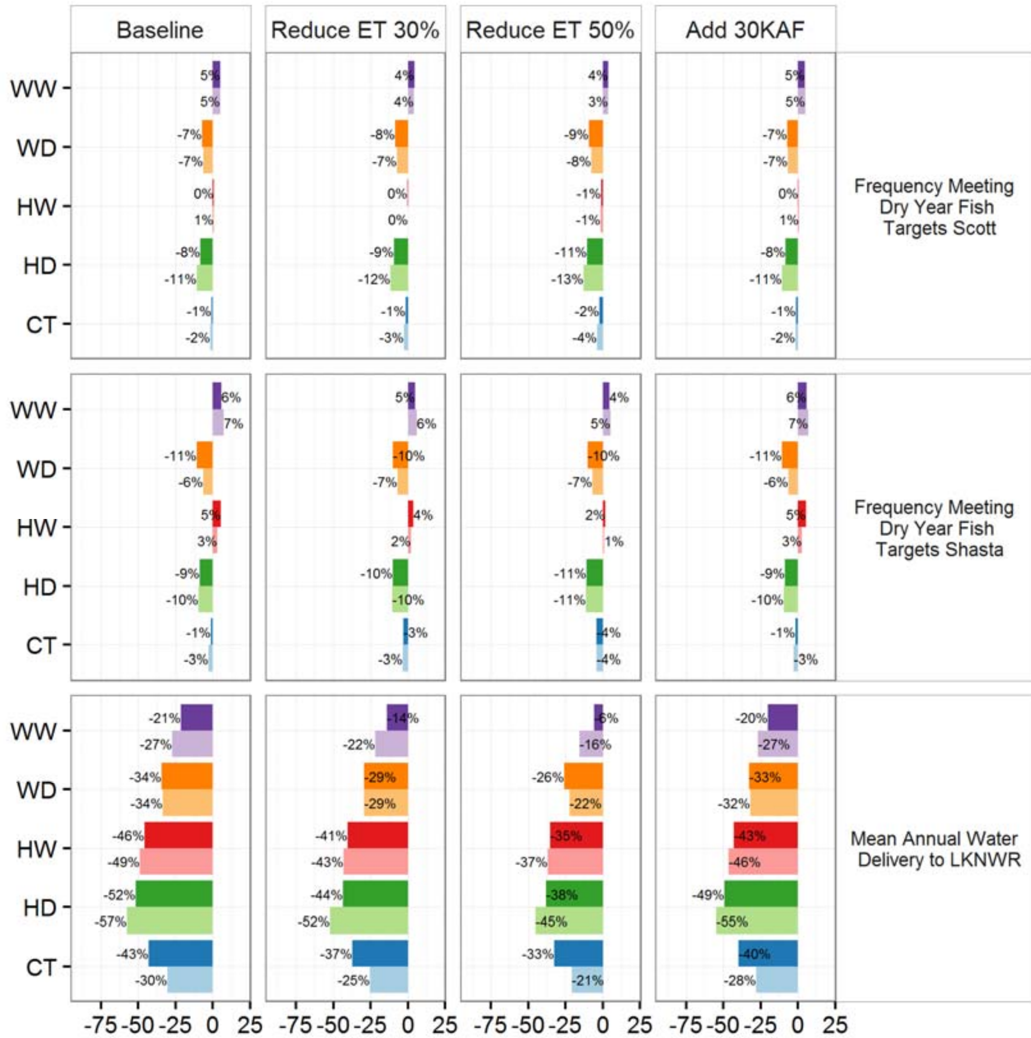
6.4.5 Analysis of Impacts – Ecological Resources

As discussed in Chapter 5, ecological resources measures considered in this study are related to needs for fish and wildlife habitat, including flow targets for SONCC ESU salmon and water supply to Lower Klamath National Wildlife Refuge (LKNWR). According to model simulations under historical hydrology, recommended flow targets that were developed specifically for the Shasta River Basin were met 57 percent of days for the Shasta River and 71 percent of days for the Scott River (which has higher mean annual flow than the Shasta River).

Projected change in water supply measures under Baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-18 and for the 2070s in Figure 6-19. Projected changes under the baseline in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers indicate increases on a percentage basis for the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and WD), with greater change projected for the 2070s time horizon compared with the 2030s. The baseline CT scenario indicates modest decreases in the frequency of meeting recommended flow targets. The Add 30KAF strategy does not impact flows in the Scott and Shasta Rivers, so the percent change under this strategy is identical to that of the baseline scenario. A reduction in agricultural demand in these basins appears to improve the ability to meet dry year fish targets for some scenarios, but not all.

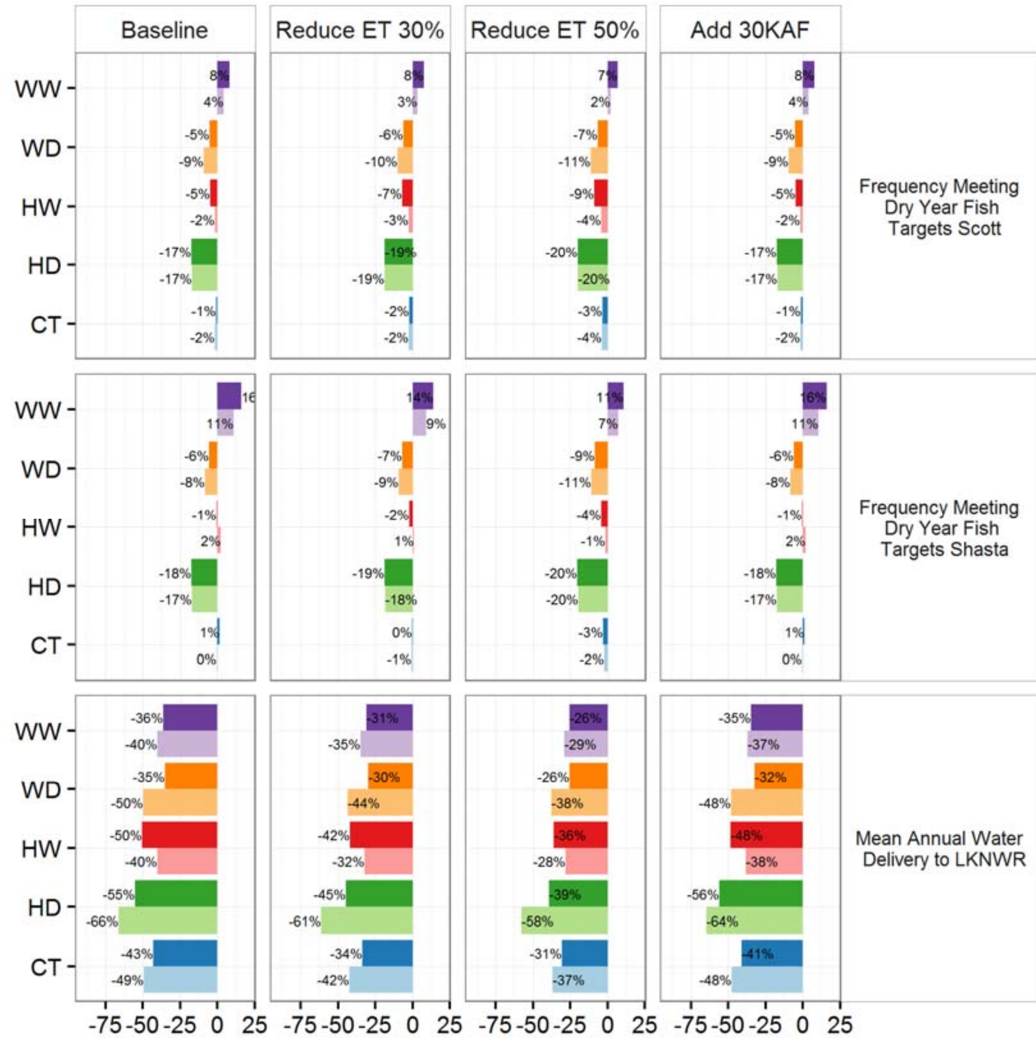
Ecological Resources Impacts

The addition of 30 KAF of inflow to Upper Klamath Lake does not impact flows in the Scott and Shasta Rivers. Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. The additional Upper Klamath Lake inflow scenario also results in greater supply to the refuge, although to a lesser degree.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-18.—Projected change in ecological resources measures for the 2030s with strategies in place, expressed as percent change.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-19.—Projected change in ecological resources measures for the 2070s with strategies in place, expressed as percent change.

Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. For the 2030s, the projected reduction in water supply to LKNWR under the CT climate change scenario goes from a reduction of 30 or 43 percent (depending on the use of CMIP3 or CMIP5 scenarios) to a reduction of 21 or 33 percent if agricultural demands are cut in half. The Add 30KAF scenario also results in greater supply to the refuge, although to a lesser degree. For the 2070s, a 50 percent reduction in agricultural demands results in a change in the measure from 43 or 49 percent (under the baseline scenario) to 41 or 48 percent.

It may be noted that model results indicate a decrease in deliveries to LKNWR under all adaptation strategy concepts, albeit to a lesser extent than the baseline scenario (climate change only). These results may in part be due to the fact that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Since Klamath Project supply is not projected to change substantially as a result of adaptation strategies, projected additional releases from Upper Klamath Lake may provide a greater benefit to the refuge.

6.4.6 Analysis of Impacts – Water Quality

As discussed in Chapter 5, water quality measures considered in this study are related to Klamath River temperature. The SONCC ESU salmon recovery plan (NMFS, 2012) provides a classification of river conditions based in part on the maximum weekly average temperature (MWAT). River temperatures were simulated using the RBM10 water temperature model developed by Perry et al. (2010). According to model simulations under historical hydrology, the river temperatures (as defined by the MWAT) for all simulated years were classified as "poor" under the salmon recovery plan. The "poor" classification threshold is 63.68 degrees F, or 17.6 degrees C. The measure considered by the basin study is the mean annual MWAT.

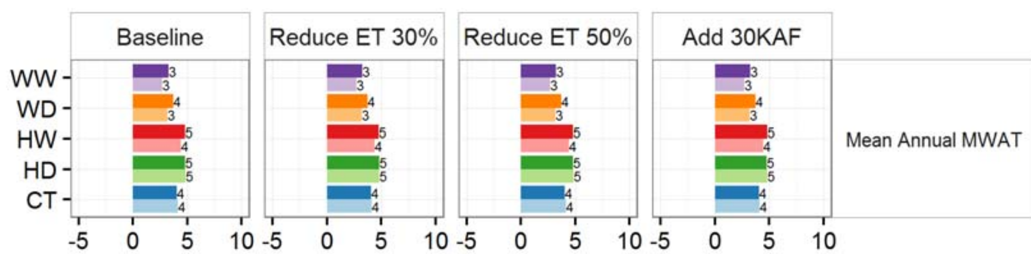
> **Water Quality Impacts**
>
> Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on water quality measures. Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow.

Projected changes in water quality measures under baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-20 and Figure 6-21 and for the 2070s in Figure 6-22 and Figure 6-23. It should be noted that additional adaptation strategy concepts were considered that affect river temperature. One additional strategy (labeled "Reduce Scott Shasta 4degC") focuses on reducing river temperature in the Scott and Shasta rivers by 4 degrees C (about 7 degrees F), in accordance with an existing emergency water management plan in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs.

Other additional strategies fall under the adaptation strategy concept of evaluating the sensitivity of river temperature to changes in tributary river temperature or streamflow. These strategies include adding 10 or 20 percent of flow to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River. These strategies are labeled as "Add Flow 10%" and "Add Flow 20%", respectively. They also include reducing input river temperatures in different locations represented in the RBM10 model. These strategies are labeled "Reduce Tribs 4degC" and "Reduce Dam outflow

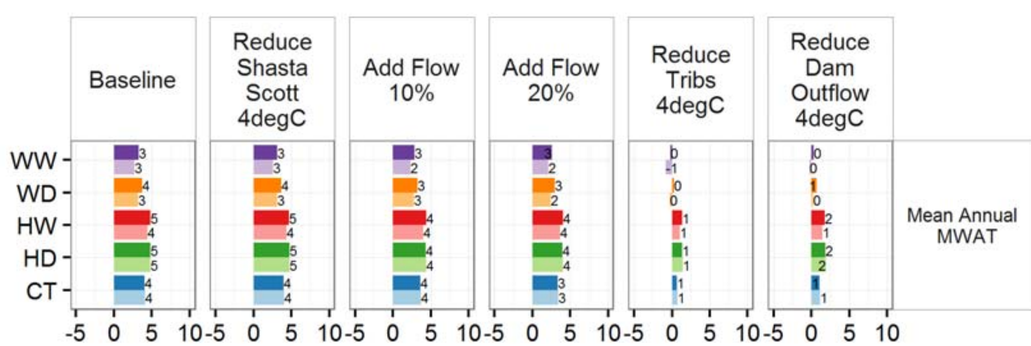
4degC." "Reduce Tribs 4degC" includes reduction in temperature for all tributaries represented in the RBM10 model. "Reduce Dam Outflow 4degC" includes reducing outflow temperatures by 4 degrees C from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River.

Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on either water quality measure. The 2030s time period (summarized by Figure 6-20) shows no change, while the 2070s time period (summarized by Figure 6-22) shows no change based on reduction of agricultural demand by 30 percent and minimal change for the other two strategies. Figures 6-21 and 6-23 illustrate that Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow. Increasing tributary flows by 20 percent has a minimal impact on Klamath River temperatures, while reducing river temperature at specific locations (where possible) results in countering climate change effects substantially, although less so by the 2070s.



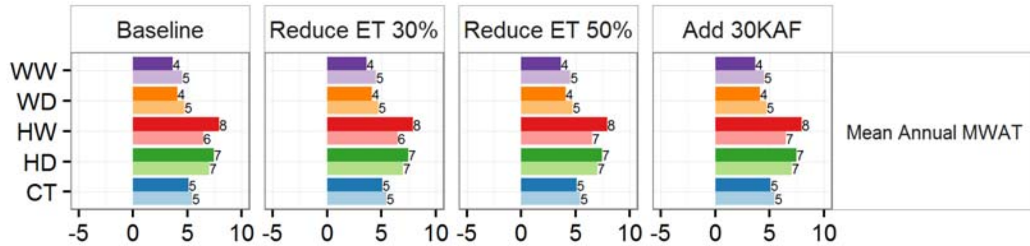
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-20.—Projected change in water quality measures for the 2030s with strategies in place, expressed as degrees C.



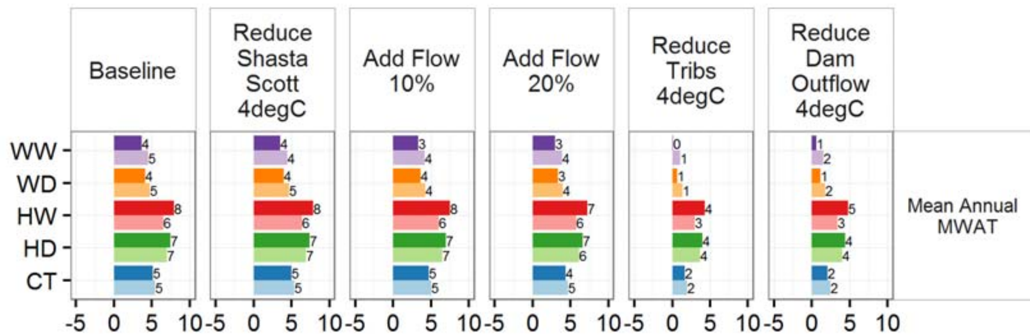
Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-21.—Projected change in water quality measures for the 2030s with additional strategies in place, expressed as percent change.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-22.—Projected change in water quality measures for the 2070s with strategies in place, expressed as degrees C.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-23.—Projected change in water quality measures for the 2070s with additional strategies in place, expressed as percent change.

6.4.7 Analysis of Impacts – Flood Control

As discussed in Chapter 5, flood control measures include (1) the frequency (mean number of days per year) of flood control releases from Upper Klamath Lake, (2) the mean annual flood control release volume (based on water year) from Upper Klamath Lake, and (3) the date of seasonal peak flow at three locations (J.C. Boyle Reservoir, COPCO 1 Reservoir, and Iron Gate Reservoir). Measures are computed using results from the Klamath Basin RiverWare model. Again, flood control release from Upper Klamath Lake is defined in the 2012 Proposed Action for Klamath Project Operations (Reclamation, 2012d), which is quantified as the release beyond that made to meet Klamath Project deliveries and to meet instream flow needs. Projected change in Upper Klamath Lake flood control measures under baseline and adaptation strategy concept scenarios are summarized in Figure 6-24 (2030s) and Figure 6-25 (2070s). Table 6-4 quantifies the difference between projected flood control release volume in units of KAF and the historical baseline, which addresses the question of how much additional surface water may be available for future storage under the “Additional Surface Water Storage Capacity” strategy concept.

The frequency of Upper Klamath Lake flood control release under the historical simulation is about 44 percent of days, while the corresponding mean annual flood control release volume is approximately 224 KAF. As previously discussed, flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. Even under historical hydrology, 44 percent of days may seem high for the percent of days of flood control release from Upper Klamath Lake. The characterization of flood control release is consistent between the RiverWare model and the KBPM. However, greater simulated flows in the Lost River system, compared with KBPM, may result in smaller demand from Upper Klamath Lake for Klamath Project supply, and therefore greater flood control release. Projected changes indicate minimal change for the wetter scenarios (WW and HW) and a decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. At the same time, for all scenarios there is a projected increase in the mean annual flood control volume, suggesting that more water is being released in the future even though the occurrence of release may be decreasing.

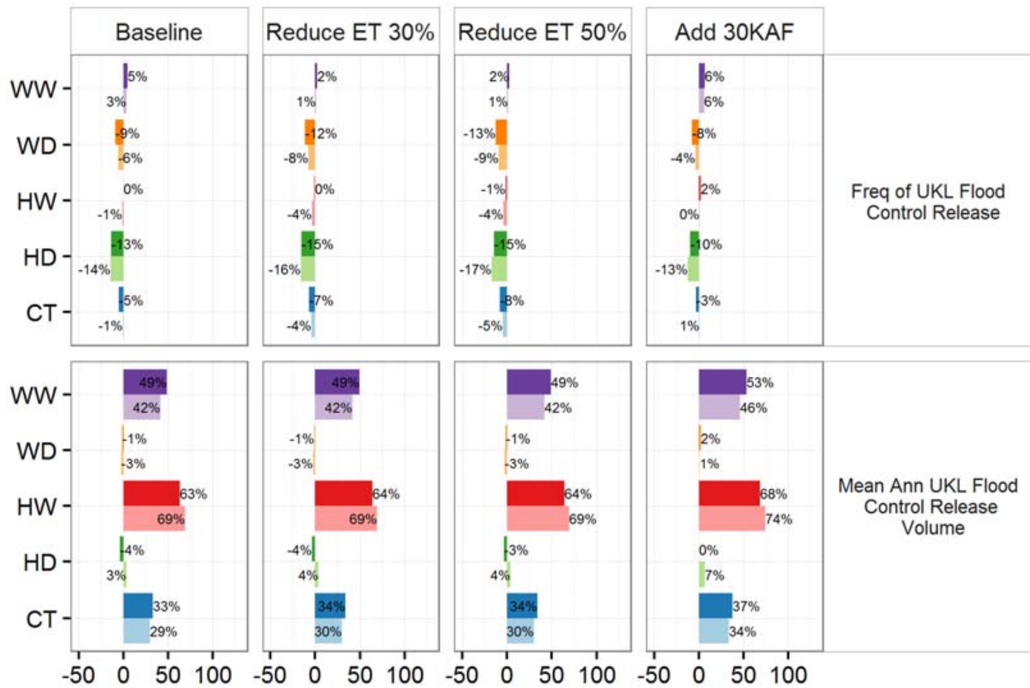
Flood Control Impacts

The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume. Model results indicate substantial surface water available for storage in a future climate, due to a combination of decreased snowpack and increased precipitation on an annual basis. Adaptation strategy concepts have small effects on the mean date of seasonal peak flow, indicating a difference of 2 days or less.

Under adaptation strategy concepts in which there is a reduction in agricultural demands, additional water causes greater increases in flood control release for the wetter scenarios, and smaller decreases for the drier scenarios. The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume.

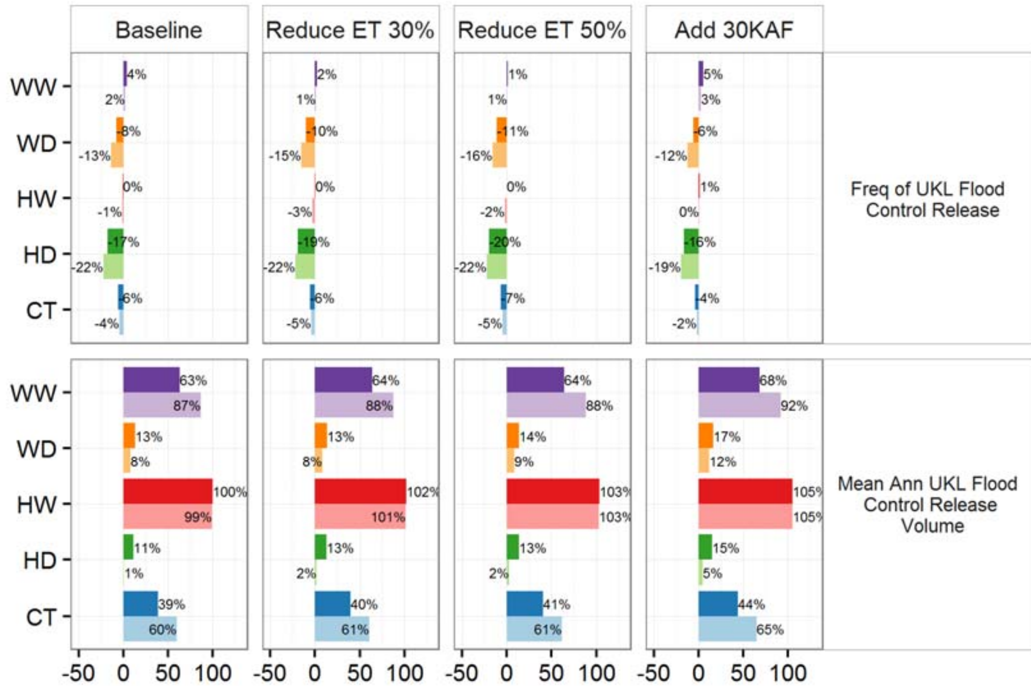
Projected changes in the date of seasonal peak flow are less substantial at J.C. Boyle Reservoir than at COPCO 1 and Iron Gate dams (refer to Table 6-5 through Table 6-7). The baseline scenario dates of seasonal peak flow are April 9 at J.C. Boyle, April 17 at COPCO 1, and April 15 at Iron Gate. Projected baseline scenario climate change effects at J.C. Boyle range from 1 to 4 days later for the 2030s to 4 days earlier to 3 days later for the 2070s, depending on the climate scenario. For COPCO 1 and Iron Gate, projected changes range from 1 day later to 9 days earlier for the 2030s and about 2 days to 2 weeks earlier for the 2070s.

Considering the adaptation strategy concepts and their effect on mean date of seasonal peak flow, both reduction of agricultural demand and addition of 30 KAF of inflow to Upper Klamath Lake have small effects, generally resulting in peak flow dates that are different by 2 days or less from the baseline. This is true at all three dam locations evaluated.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-24.—Projected change in flood control measures for the 2030s with strategies in place, expressed as percent change.



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

Figure 6-25.—Projected change in flood control measures for the 2070s with strategies in place, expressed as percent change.

Because the mean annual Upper Klamath Lake flood control release volume is a system performance measure and is also the variable used to quantify the adaptation strategy concept pertaining to additional storage volume, we summarize the projected flood control release volume for all climate change scenarios at both future time horizons. According to model simulations and the means of quantifying flood control release (i.e., that release volume beyond Klamath Project deliveries and environmental flow releases), there may be substantial additional surface water available for storage under future climate conditions. This volume may be due to projected increases in precipitation and/or the reduction in snowpack storage as temperatures are projected to warm.

Table 6-4. Projected change in mean annual Upper Klamath Lake flood control release volume, computed as difference (in units of KAF) between scenario and historical baseline

Scenario	Period	BCSD Projection	Baseline (KAF)	Reduce ET 30% (KAF)	Reduce ET 50% (KAF)	Add 30KAF (KAF)
Historical	Historical	-	224			
Warm Dry	2030	CMIP-3	-6	-5	-5	2
Warm Dry	2030	CMIP-5	-3	-2	-2	5
Warm Wet	2030	CMIP-3	94	94	94	103
Warm Wet	2030	CMIP-5	110	111	111	120
Hot Dry	2030	CMIP-3	8	9	9	16

Hot Dry	2030	CMIP-5	-9	-8	-7	1
Hot Wet	2030	CMIP-3	155	156	156	167
Hot Wet	2030	CMIP-5	142	144	145	153
Central Tendency	2030	CMIP-3	67	67	68	76
Central Tendency	2030	CMIP-5	75	76	77	84
Warm Dry	2070	CMIP-3	19	19	20	27
Warm Dry	2070	CMIP-5	30	31	31	38
Warm Wet	2070	CMIP-3	195	197	198	207
Warm Wet	2070	CMIP-5	143	144	144	153
Hot Dry	2070	CMIP-3	2	5	6	12
Hot Dry	2070	CMIP-5	25	29	31	35
Hot Wet	2070	CMIP-3	224	228	231	236
Hot Wet	2070	CMIP-5	224	230	232	236
Central Tendency	2070	CMIP-3	135	137	138	147
Central Tendency	2070	CMIP-5	87	89	92	99

Table 6-5. Projected change in date of seasonal peak flow at J.C. Boyle Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle	Mean Date of Seasonal Peak Flow at J.C. Boyle
Historical	Historical	-	April 9	-	-	-
Warm Dry	2030	CMIP-3	4	4	4	4
Warm Dry	2030	CMIP-5	4	4	4	3
Warm Wet	2030	CMIP-3	2	2	2	2
Warm Wet	2030	CMIP-5	2	2	2	2
Hot Dry	2030	CMIP-3	4	4	4	3
Hot Dry	2030	CMIP-5	4	4	4	3
Hot Wet	2030	CMIP-3	1	1	1	1
Hot Wet	2030	CMIP-5	2	2	2	2
Central Tendency	2030	CMIP-3	3	3	3	3
Central Tendency	2030	CMIP-5	2	2	2	1
Warm Dry	2070	CMIP-3	2	4	3	2
Warm Dry	2070	CMIP-5	3	3	3	3
Warm Wet	2070	CMIP-3	2	2	2	1
Warm Wet	2070	CMIP-5	2	2	2	2
Hot Dry	2070	CMIP-3	3	4	3	2
Hot Dry	2070	CMIP-5	1	2	2	1
Hot Wet	2070	CMIP-3	-2	1	-2	-3
Hot Wet	2070	CMIP-5	-4	-3	-3	-4

Central Tendency	2070	CMIP-3	0	3	0	0
Central Tendency	2070	CMIP-5	2	2	2	2

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

Table 6-6. Projected change in date of seasonal peak flow at COPCO 1 Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1	Mean date of seasonal peak flow at COPCO 1
Historical	Historical	-	April 17	-	-	-
Warm Dry	2030	CMIP-3	1	1	1	1
Warm Dry	2030	CMIP-5	0	0	0	0
Warm Wet	2030	CMIP-3	-4	-4	-4	-5
Warm Wet	2030	CMIP-5	-5	-5	-5	-5
Hot Dry	2030	CMIP-3	-4	-3	-3	-4
Hot Dry	2030	CMIP-5	-3	-3	-3	-3
Hot Wet	2030	CMIP-3	-9	-9	-9	-9
Hot Wet	2030	CMIP-5	-8	-8	-8	-8
Central Tendency	2030	CMIP-3	-3	-4	-3	-4
Central Tendency	2030	CMIP-5	-6	-6	-6	-6
Warm Dry	2070	CMIP-3	-5	-5	-4	-5
Warm Dry	2070	CMIP-5	-2	-2	-2	-2
Warm Wet	2070	CMIP-3	-7	-7	-7	-7
Warm Wet	2070	CMIP-5	-7	-7	-7	-7
Hot Dry	2070	CMIP-3	-8	-7	-7	-8
Hot Dry	2070	CMIP-5	-8	-8	-8	-8
Hot Wet	2070	CMIP-3	-15	-15	-14	-15
Hot Wet	2070	CMIP-5	-17	-17	-17	-17
Central Tendency	2070	CMIP-3	-10	-10	-10	-11
Central Tendency	2070	CMIP-5	-7	-7	-7	-7

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

Table 6-7. Projected change in date of seasonal peak flow at Iron Gate Reservoir

Scenario	Period	BCSD	Baseline	Reduce ET 30%	Reduce ET 50%	Add 30KAF
		Projection	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate	Mean date of seasonal peak flow at Iron Gate
Historical	Historical	-	April 15	-	-	-
Warm Dry	2030	CMIP-3	1	1	1	0
Warm Dry	2030	CMIP-5	0	0	0	0
Warm Wet	2030	CMIP-3	-4	-4	-4	-4
Warm Wet	2030	CMIP-5	-5	-5	-5	-5
Hot Dry	2030	CMIP-3	-4	-4	-4	-4
Hot Dry	2030	CMIP-5	-3	-3	-3	-3
Hot Wet	2030	CMIP-3	-9	-9	-9	-9
Hot Wet	2030	CMIP-5	-8	-8	-8	-8
Central Tendency	2030	CMIP-3	-4	-4	-4	-4
Central Tendency	2030	CMIP-5	-6	-5	-5	-6
Warm Dry	2070	CMIP-3	-5	-5	-5	-5
Warm Dry	2070	CMIP-5	-2	-2	-2	-2
Warm Wet	2070	CMIP-3	-7	-7	-7	-7
Warm Wet	2070	CMIP-5	-7	-7	-7	-7
Hot Dry	2070	CMIP-3	-7	-7	-7	-7
Hot Dry	2070	CMIP-5	-8	-8	-7	-8
Hot Wet	2070	CMIP-3	-14	-14	-13	-14
Hot Wet	2070	CMIP-5	-16	-16	-15	-16
Central Tendency	2070	CMIP-3	-10	-10	-10	-10
Central Tendency	2070	CMIP-5	-7	-7	-7	-7

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

6.5 Key Findings and Next Steps

Klamath River water users and stakeholders have long have long called for a comprehensive and integrated approach to water management to balance the needs of all water users. The Basin Study Report evaluates current and projected future water supply and demand assessments to refine existing projections of climate change's effect on the Klamath River Basin, and provide stakeholders in the region the opportunity to identify and evaluate potential adaptation strategies which may reduce identified imbalances. These adaptation strategies provide water users, stakeholders, and Reclamation with understanding of the degree to which actions including those to increase supply, decrease demand, and modify operations could reduce supply and demand imbalances that are projected to increase as a result of climate change. The Basin Study builds on earlier work and is the next significant step in developing a comprehensive knowledge base and suite of tools and options that could address the risks posed by Klamath River Basin water supply-demand imbalances.

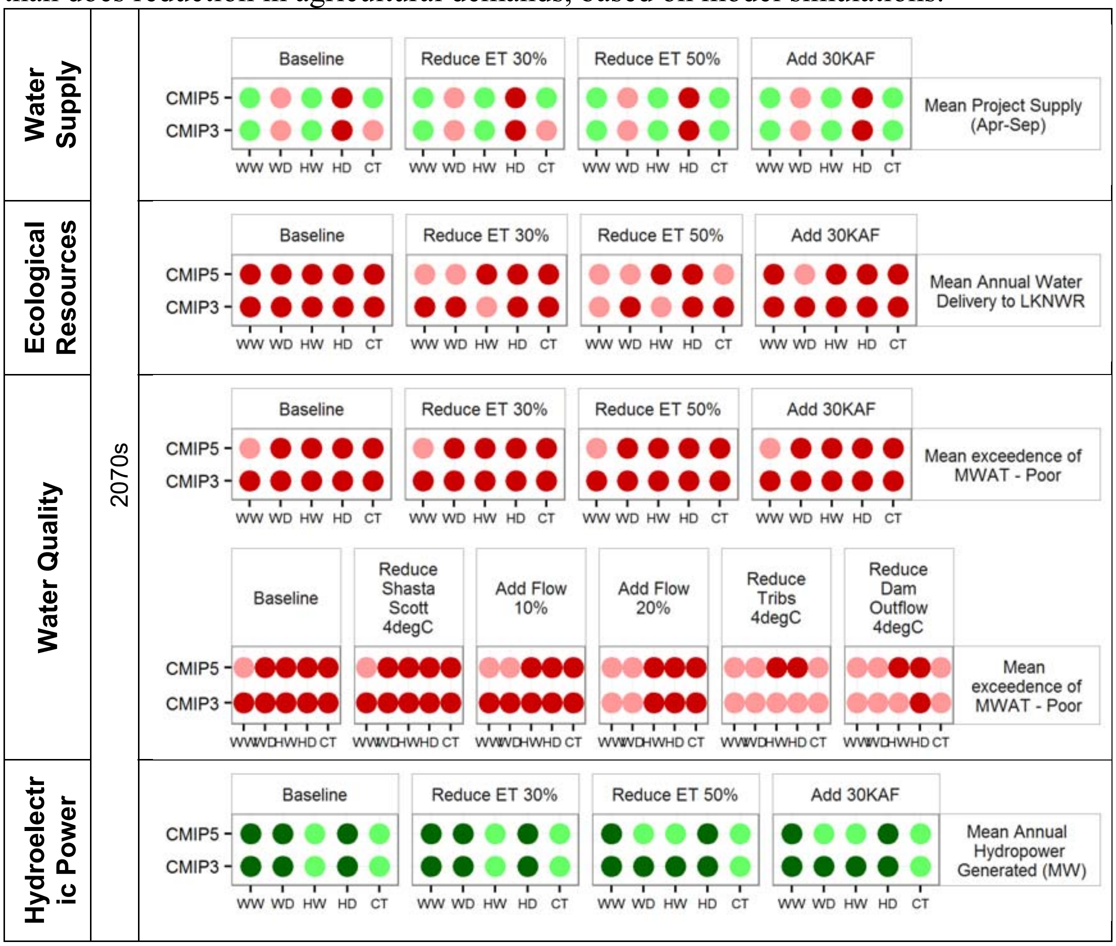
Results from model simulations with and without adaptation strategy concepts in place indicate that the strategies have modest abilities to reduce climate change impacts. Considered strategies include agricultural water conservation, additional inflow to Upper Klamath Lake, quantification of potential surface water storage, and evaluation of changes in flow and tributary temperature on Klamath River temperature at Klamath, California.

The addition of inflow to Upper Klamath Lake appears to result in the greatest change in computed basin-wide response variables and selected performance measures. With respect to sensitivities of river temperature, the reduction in tributary temperature has a greater impact than does change in flow. Also, according to model simulations, substantial surface water may be available for storage in the future due to reduction in snowpack storage and projected changes in precipitation timing and volume. The location for quantification of additional storage is at Upper Klamath Lake; however, this study does not explore locations for future surface water storage.

Figure 6-26 summarizes projected changes in four select system performance measures for the 2070s future time period, compared with the historical simulation. Projected changes are computed using CMIP3- and CMIP5-based projections, and for each of the five climate change scenarios. The baseline scenario represents climate change only, without adaptation strategy concepts in place. The other scenarios represent changes with adaptation strategy concepts. For this figure, projected changes on a percentage basis were divided into four bins: two bins for positive change and two bins for negative change. Darker circles represent the bin with greater change. Green circles indicate an improvement in the selected measure, while red circles indicate a worsening of the measure. The results summarized in the figure allow for a high level understanding of the direction of change, and highlight which strategies provide the greatest change compared with the baseline scenario.

In Figure 6-26, with respect to mean April–September Klamath Project supply, neither reduction in agricultural demand nor additional Upper Klamath Lake inflow of 30 KAF cause a substantial change compared with the baseline scenario. For mean annual water supply to LKNWR, reduction in agricultural demands results in a meaningful improvement, compared with the baseline scenario. For mean exceedance of the “poor” water quality classification (through calculation of the MWAT), reduction in tributary water temperatures has a greater influence on resulting river temperatures than changes in streamflow. It is likely not realistic to expect a reduction in temperatures in unmanaged tributaries, but changes in managed flows (i.e., Link River, Shasta River, Scott River, Trinity River) still have a meaningful impact, compared with the baseline scenario. For mean annual hydropower generation, it is apparent that climate change, and adaptation strategy concepts, result in greater hydropower production. Reduction of agricultural demands by 50 percent and additional Upper Klamath Lake inflow of 30 KAF result in noticeable change from the baseline, while a less substantial reduction in agricultural demands (30 percent) does not provide substantial additional benefit.

Overall, climate change adversely affects mean annual deliveries to LKNWR and river temperatures; it may adversely affect or may be favorable to mean Klamath Project Supply (April–September) depending on the climate change scenario, and is likely to be favorable to mean annual hydropower production. Adaptation strategy concepts evaluated in the Basin Study do not substantially counter the effects of climate change. However, in general the addition of 30 KAF inflow to Upper Klamath Lake appears to have a greater benefit to the system reliability than does reduction in agricultural demands, based on model simulations.



Notes: Green circles indicate an improvement in the measure for the future, while red circles indicate a worsening in the measure for the future. Darker circles indicate greater change than lighter circles.

Figure 6-26. Summary of projected changes in select measures for the 2070s, with and without strategies in place

6.5.1 Refinement of Adaptation Strategies and Next Steps

The Basin Study Report indicates that implementation of projects to improve water supply, decrease demand, and modify operations can provide some improvement in the reliability and sustainability of the Klamath River system to help meet current and future water demands. The adaptation strategies evaluated in this Basin Study would all need to be further studied to refine the understanding of these potential benefits and develop plans for their implementation. Similar to this Basin Study, the agencies and stakeholders that would need to be involved in that refinement process would need to include all those potentially affected by their implementation.

The Klamath River Basin Study relied on projected future conditions that were developed utilizing existing model frameworks and inputs. Identified adaptation strategies evaluated by the Basin Study are general (i.e., not specific proposed projects) by design and are intended to identify sensitivities of the Klamath Basin to various types of potential actions. Moving forward, a number of tasks have been identified to further enhance our understanding of climate change impacts on the Klamath River Basin.

- Refinement of ecosystem demands and vulnerabilities – Additional analysis of the relationship between changes in the climate, changes in the demands of aquatic, wetland, and riparian ecosystems that result from changes in the climate, and the ability to accommodate these demands with existing supplies would further support and refine the findings in this study. Additionally, incorporation of developing river temperature modeling for the Trinity River by the U.S. Geological Survey could enhance our understanding of climate change impacts and implemented adaptation strategies on river temperatures.

- Coupled groundwater/surface water model development – Expansion of existing groundwater models for the Scott and Shasta rivers to cover broader portions of the basin would further support the analysis completed in this Basin Study.

- Reservoir Operations Refinement – Current funding by the Bureau of Reclamation Office of Policy for a Klamath River Basin reservoir operations pilot study on Upper Klamath Lake will enhance the ability to quantify Upper Klamath Lake inflows and provide for an improved understanding of Upper Klamath Lake operations.

- Effects of future policy changes – Evolving policy conditions are anticipated in the Klamath River Basin relating to future ESA consultations and potential removal of the four mainstem Klamath River dams. Continued analysis of future policies using the Basin Study modeling framework will allow for comparisons to be made, and for greater understanding of potential climate change impacts.

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