Appendices

Klamath River Basin Study

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Appendix A - Summary of Previous and Current Studies

This appendix of this Klamath River Basin Study (Basin Study) summarizes existing literature relevant to the Klamath River Basin. The literature synthesis is organized into sections according to category. Primary categories consist of the following:

- hydrology
- water management
- environmental studies
- groundwater studies
- land management
- economic evaluations
- water rights
- studies related to Klamath Basin Restoration Agreement/Klamath Hydroelectric Settlement (KBRA/KHSA) Agreement
- regulations
- planning activities

The Klamath River Basin has a rich history and humans have resided in the region since time immemorial due to its diverse natural resources. Westward settlement in the United States (U.S.), beginning in the late 20th century and continuing through the present, has caused significant changes in the landscape (Beckham, 2006), and as a result, various water management and socioeconomic challenges. Most (2006) provided an account of the development of the Klamath River Basin primarily through individual stories and interviews. The Water Education Foundation, a non-profit organization seeking to create a better understanding of water resources and to facilitate understanding of water resource related issues, produced the Layperson’s Guide to the Klamath River (2011). That document provides general background as well as a summary of water management issues and challenges and proposed management activities associated with the KBRA. This literature synthesis aims to summarize existing literature to help accomplish the goals of this Basin Study, which are namely to assess current and future water supply and demand in the entire watershed, to evaluate system reliability, and to identify and evaluate potential adaptation strategies that may reduce any identified supply/demand imbalances. To that end, the literature synthesis is organized chronologically within general topic areas for greater readability.

A.1 Hydrology

The California Department of Water Resources (CDWR) produced Bulletin 83 in 1960, in which they conduct a survey of water resources in Siskiyou and Modoc Counties in California as well as the remainder of the Klamath River Basin (CDWR, 1960). That document also contains an inventory of the water resources of the basin and presents a master plan for water development, in which some recommendations have never come to pass (e.g., construction of Boundary Dam on Lost River) while others have (e.g., water storage development on the Trinity River). CDWR (1966) built upon the hydrology summarized by CDWR (1960) and summarized regional climatology, regional unimpaired surface runoff, and unimpaired surface runoff at proposed dam sites.

Numerous studies have been conducted to estimate pre-settlement flows (i.e., natural flows) in the Klamath River and tributaries for the purpose of understanding the impacts of settlement (notable diversions and impoundments) on the river system. The State of California also quantified natural flows for the Klamath River and its major tributaries in California (Fua, 1997). Cooper (2004) described methodology and summarized natural flows, computed for various sites in the Upper Klamath basin in Oregon, as part of the adjudication for the Klamath Basin. These naturalized flows are values of 50 percent exceedance by month, as opposed to timeseries. Bureau of Reclamation (Reclamation,2005b) quantified natural flows in the Upper Klamath Basin (upstream of Keno, Oregon) and later provided an estimate of natural flows for sites in the Lower Klamath Basin to inform the instream flow study by Hardy et al. (2006).

Balance Hydrologics, Inc. produced a report in 1996 summarizing initial findings of how Reclamation’s Klamath Irrigation Project (Klamath Project) has changed flows in the Klamath River below Iron Gate Dam. They found that the overall effects of the Klamath Project include an increase in winter flows and a decrease in late spring and summer flows (Balance Hydrologics, 1996).

Weddell (2000) characterized flows in the Klamath River and Lower Klamath Lake prior to 1910 through evaluation of available data and anecdotal evidence such as oral histories. The author recognized their complex interaction and the difficulty in determining their exact interactions due in part to inaccuracies in personal historical accounts.

Garen et al. (2008) evaluated the use of spatially distributed hydrologic models in the Sprague River Basin within the Upper Klamath Basin, by implementation of the U.S. Geological Survey (USGS) Precipitation-Runoff Modeling System (PRMS) model and the University of Washington’s Distributed Hydrology Soil and Vegetation Model. They found these models to have practical value despite the complex hydrology in the basin.

Van Kirk and Naman (2008) estimated the relative contributions of climatic and non-climatic factors to the decline in the Klamath River Basin snow water equivalent (SWE) and base flows from a historical period (defined as 1942 to 1976) to the present (defined as 1977 to 2005). From their comparative basin approach, they concluded that 39 percent of the observed decline in the Scott River flows is due to regional climate factors (i.e., shift in the Pacific Decadal Oscillation and climate change) as opposed to increases in irrigation.

Mayer and Naman (2011) evaluated streamflow response to historic climate and hydrologic changes in the Klamath River Basin. Their results indicated that absolute decreases in late summer (July-September) base flows are significantly greater, by an order of magnitude, in basins with large groundwater influence compared to basins with largely surface water influence. Upper Klamath Lake (UKL) April-September net inflows have decreased an estimated 16 percent or 84 thousand acre-feet (103.6 Mm3) since 1961, with the summer months showing proportionately more decline, which has important implications for water supply for agriculture and natural resources in the region.

A.1.1 Water Demands

Oregon State University et al. (1999) summarized crop water requirements for Oregon State by quantifying evapotranspiration (ET) by identified crops. ET was computed using the modified Blaney-Criddle Method (Doorenbos and Pruitt, 1977; Cuenca, 1989). The report identifies the growing season in the Klamath River Basin area to be from approximately May 15 through August 30 for alfalfa hay, May 10 through September 15 for spring grain, April 5 through August 10 for winter grain, April 1 through October 15 for pasture, and May 15 through October 15 for potatoes. The report summarizes estimated crop ET and net irrigation requirements for each of the above-mentioned crops in the Klamath River Basin area. It also provides reference ET contour maps by month for the State of Oregon.

A 2005 report by Roseberg and Smith compared the yield and quality performance of about 50 alfalfa varieties over several years in a high output production area of the Klamath Basin. In 2005, crop water needs were fully met through precipitation and irrigation was applied on 16 occasions during the season. Three cuttings were made yielding about 2.8 tons/acre for the first cutting, 2.4 tons/acre for the second cutting, and 1.6 tons/acre for the third cutting. The first and third cuttings were found to be generally of higher quality than the second cutting. That annual report suggested additional dryland trials to evaluate variety performance in moisture-limited conditions, in part due to growing concerns of reduced water availability.

A.2 Water Management

A.2.1 General

In the Klamath River Basin, water resources are primarily managed for Federal irrigation projects and to sustain the basin’s threatened and endangered species (Congressional Research Service, 2005). Two significant Federal projects that are located within the Klamath River Basin are Reclamation’s Klamath Project and the California Central Valley Project (which receives trans-basin flows from the Trinity River Diversion through the Clear Creek tunnel to the Sacramento River). A lesser-known Reclamation project includes water diversion at Emigrant Lake, built in 1926 as a part of the Talent Irrigation Division. Whenever there is surplus water available on the Klamath side of the Cascade divide, it is diverted into Emigrant Lake via the Keene Creek Diversion Dam, the Cascade Divide Tunnel, and the Ashland Lateral Canal for use in the Rogue River Basin (Atlas of Oregon Lakes, 2013).

The Congressional Research Service (2005) developed an overview of issues and activities in the Klamath River Basin since the well-known water management issues of 2001 and 2002 (further discussed in section I.B.2 – Upper Klamath Basin). The report also discussed water rights issues and the ongoing Klamath River adjudication in Oregon, which began in 1975 and includes evaluation of Federal or trust rights, Tribal rights, and those associated with national forests and national wildlife refuges. The issues that are summarized in the 2005 report remain outstanding issues today. The Congressional Research Service discussed potential options for improving instream flows as identified in various studies, which include water banks, increased storage, land retirement, groundwater pumping, and modification of dam operations or dam removal, all options that continue to be considered or implemented.

At the time of the Congressional Research Service (2005) report, the Federal Energy Regulatory Commission (FERC) licenses on the PacifiCorp dams had not yet expired, but potential removal of these dams and a cooperative river restoration effort was being discussed. In addition, Chiloquin Dam on the Sprague River was proposed to be removed, which ultimately occurred in 2008. That report, as well as reports by the National Research Council (2002, 2004, 2008), called for more coordination among various agencies and stakeholder groups with respect to future Klamath River management.

Water War in the Klamath Basin (Doremus and Tarlock, 2008) is a discussion of legal institutions, water resources management issues, and environmental laws “that make ecosystem conservation so difficult in small areas with deeply entrenched property rights.” The book outlines major themes of environmental conflict as “the power of history, culture differences, framing disputes in scientific terms (with its inherent uncertainties) and excluding human values from analysis.”

In October 2012, the CDWR issued a guidebook for agricultural water users (defined as those providing water to 10,000 or more irrigated acres) to develop a 2012 agricultural water plan and comply with the California State law. The plans were to be completed by the end of December 2015. Requirements differ depending on whether users are a Reclamation contractor, an AB 3616 memorandum of understanding (MOU) signatory, or neither (CDWR, 2012a).

A.2.2 Upper Klamath Basin

Water management in the Upper Klamath Basin primarily involves securing water supplies for irrigation, while providing adequate instream flows for fish and wildlife and downstream uses. As a result, numerous studies have been conducted to evaluate potential new water storage facilities, given that U KL and other reservoirs have little carryover storage from year to year. In 50 Years on the Klamath, John C. Boyle, the Vice President and Director of the Pacific Power and Light Company (later acquired by PacifiCorp) and for whom J.C. Boyle Dam was named, described (in 1976) early development plans by the U.S. Army Corps of Engineers (USACE) to divert water from the Klamath River, via Tule Lake, out of the basin, via the Shasta Valley, to the Pit River in the Sacramento Valley. This plan was ultimately voted down in the California State Legislature in 1945 (Boyle, 1976). The increasing demand for power in the late 40s and early 50s resulted in construction of the Big Bend (Oregon) Power Plant renamed the John C. Boyle Reservoir and Hydro Power Plant in 1962. Boyle, as well as others at that time, believed there was enough water to supply all needs in the Basin.

In late 2000, the U.S. Congress enacted the Klamath Basin Water Supply Enhancement Act (Public Law (P.L.) 106-498). It directed Reclamation to undertake feasibility studies of certain actions that could enhance the water supply in the Upper Klamath Basin. Such studies include increasing the storage capacity and/or yield of Klamath Project facilities, development of additional Upper Klamath Basin groundwater supplies, and the potential for further innovations in the use of existing water resources. Reclamation's Upper Klamath Basin Offstream Storage Study Initial Alternatives Investigation Report (IAIR) (Reclamation, 2011e) discussed a number of alternatives for increased storage capacity, including options developed in the late 1990s with stakeholder involvement (via the Klamath Basin Water Supply Initiative). The IAIR recommended that the planning process should move forward to the appraisal phase to continue to investigate the Long Lake Valley storage reservoir alternative and its variations. A reservoir in Long Lake Valley, located just west of Klamath Falls, Oregon, could store water that nearby UKL would otherwise spill during certain times of the year. The Long Lake Valley appraisal report (Reclamation, 2011a) found that although a new storage reservoir would be technically feasible and could provide up to an additional 350,000 acre-feet of potential storage, the benefit cost analysis showed that the project would not be beneficial, so the project was not recommended for further feasibility level study. Other options, also not economically viable, included an aquifer storage and recovery (ASR) groundwater option at Gerber Reservoir, a hybrid option involving ASR (groundwater) at Clear Lake, and surface storage at a new Boundary Dam and Reservoir (Reclamation, 2011a).

In another study, LaMarche (2001) evaluated two options for increasing storage in UKL. The first option consisted of raising the dikes surrounding the lake. The second option consisted of breaching certain dikes to allow for increased storage via greater surface area. The study found that in average and wet years, increased storage provided additional water supply. However, in dry years, estimated inflows were insufficient for filling the additional capacity.

Despite various efforts to explore additional water supplies through new storage or improved operations, operation of Reclamation's Klamath Project remains a difficult balance of meeting various and often opposing water needs. The U.S. Fish and Wildlife Service (USFWS) completed the Final Environmental Assessment for increasing groundwater supplies to the Lower Klamath National Wildlife Refuge (LKNWR) in order to offset reduced deliveries from Reclamation's Klamath Project (Hainline, 2001). In accordance with the Endangered Species Act (ESA) section 7, Reclamation must provide Biological Assessments (BA) of the proposed operations of the Klamath Project. Biological Opinions (BiOp) are then issued from the National Marine Fisheries Service (NMFS), which is responsible for the Southern Oregon Northern California Coast (SONCC) Evolutionary Significant Unit (ESU) Coho salmon population, and the USFWS, which is responsible for the lost river and shortnose suckers. In recent years, the NMFS and USFWS have issued a number of jeopardy opinions, which require Reclamation to pursue recommended reasonable and prudent alternatives and revise their operations plan.

Since 2001, Reclamation has operated the Klamath Project under annual operations plans due to lack of a comprehensive and agreed upon long-term operations plan (Reclamation, 2004a, 2005a 2006, 2007, 2008a, 2009a, 2010a, 2011f, and 2012a). NMFS (2010) stated that NMFS and Reclamation had conducted three ESA section 7 consultations regarding the potential effects of Reclamation's proposed Klamath Project operations on SONCC ESU Coho salmon and its designated critical habitat since 1999. NMFS issued BiOps in 1999, 2001, and 2002. Through agreements with PacifiCorp, the Reclamation consultations have guided specific flow releases below Iron Gate Dam instead of FERC minimum flows. NMFS issued a no-jeopardy BiOp in 1999. NMFS recommended reinitiating consultations in 2000 to Reclamation, but Reclamation responded that flows were sufficient to avoid consultation. The parties entered consultations again in 2001, and NMFS this time issued a jeopardy opinion saying that proposed Klamath Project operations would likely jeopardize SONCC ESU Coho salmon and adversely modify designated critical habitat. That opinion included a reasonable and prudent alternative that included recommended minimum instream flows at Iron Gate Dam during April to September 2001.

At that time, focus was redirected toward a long-term operations plan, following an incomplete effort to produce a Klamath Project Long-Term Operations Plan Environmental Impact Statement (EIS) (Reclamation, 2000b). An EIS could not be completed due to rapidly changing events, including changes in the listing status of various species and BiOps, acting on the Klamath Project operations modified proposed action. In March 2002, Reclamation finalized a new BA that covered Klamath Project operations from May 31, 2002, to March 31, 2012, and requested consultation with NMFS and USFWS. In its BiOp finalized on May 31, 2002, NMFS concluded that Reclamation's proposed operations would likely jeopardize the continued existence of SONCC ESU Coho Salmon. In coordination with Reclamation, the BiOp also included a reasonable and prudent alternative that consisted of Reclamation operating the Klamath Project to ensure that Iron Gate Dam minimum flows increased gradually over 3 phases of the eight-year period, and developing a water bank. Subsequent lawsuits resulted in a court ruling in 2006 that said NMFS and Reclamation must reinitiate consultations and, in the meantime, Reclamation would limit Klamath Project irrigation deliveries if they would cause flows in the Klamath River, at and below Iron Gate Dam, to fall below 100 percent of the Phase III flow levels specifically identified by NMFS in its 2002 BiOp, until the new consultation for the Klamath Project was completed. Reclamation, NMFS, and USFWS reinitiated consultations in 2007 and 2008.

Reclamation issued a revised BA for proposed Klamath Project operations for 2008 through 2018 (2008b). Among other operational changes, that BA proposed to eliminate the water year type classification as a means of setting river flows and instead using an interactive management process. It also proposed discontinuation of certain elements of the former pilot water banking program and pursuing other efforts to increase project storage such as storage in Agency Lake Ranch and Barnes Ranch.

NMFS (2010) issued another jeopardy opinion on Reclamation's 2008 through 2012 BA (2008b), providing reasonable and prudent alternative recommendations, namely including increased fall and winter flow variability, increased spring discharge in select average and wet years, and a more coordinated effort to develop an operations plan that would be acceptable to all parties. This led to Reclamation issuing a revised BA in 2010(b) for Klamath Project operations from 2010-2018.

The USFWS (2008) issued its own BiOp on Reclamation's 2008-2018 BA of proposed Klamath Project operations and found that it was not likely to jeopardize the continued existence of the endangered suckers or adversely modify their critical habitat. However, they still included a reasonable and prudent measure, and terms and conditions, pertaining to concerns over entrainment of suckers in the Link River Dam. In response to both the 2010 NMFS BiOp and the 2008 USFWS BiOp, Reclamation developed a variable baseflow procedure to be used for operations, designed to help meet the needs of Coho salmon during critical periods of the year.

Reclamation completed a 10-year operations plan BAthat would apply for years 2013-2022 (Reclamation, 2012d), which resulted in a coordinated non-jeopardy BiOp from NMFS and USFWS. This management approach included a defined flow volume for environmental uses, which varies based on gaged flows in the Williamson River and the level of UKL.

In another aspect of its long-term planning approach for Klamath Project operations, Reclamation completed a drought planning effort in 2012 (Reclamation, 2012b). The Klamath Project Drought Plan outlines actions that can be taken by Reclamation to conserve water when conditions indicate there may be potential drought conditions. The plan outlines a phased approach depending on updated water supply forecasts starting in March and continuing through the irrigation season. It summarizes different classes of water users (A through C) where within each group users have close to the same water right priority. Class A users generally include those whose land was first developed in the Klamath Project for irrigation, with some exceptions. Class B users are generally those who obtained water rights through the Warren Act (1911), which authorized Reclamation to contract for conveyance and storage of non-project irrigation water in Klamath Project facilities. Class C users are generally those users of leased land, and these are the first users to have their supply reduced in a shortage situation. Irrigators within in the Lost River system follow a separate plan based on forecast supplies in Clear Lake, Bonanza Springs, and Gerber Reservoir areas. The plan also describes a Water Use Mitigation Program, which is a funded program to provide for the substitution of surface water in times of drought through groundwater pumping, or forbearance of surface water through land idling (Reclamation, 2012b).

An important factor in predicting and managing for drought is the use of forecasted streamflow ahead of the irrigation season. Hay et al. (2009) evaluated the use of ensemble streamflow prediction forecasts of streamflow for the Sprague River in the Upper Klamath Basin, particularly using calibrated hydrologic model parameters that coincide with the forecasted year type. The authors were seeking improved methods of streamflow forecasting over standard Natural Resources Conservation Service (NRCS) streamflow volume forecasts.

Stakeholder groups such as the Klamath Water Users Association closely monitor current operations plans, water supply outlooks, and reflect on past irrigation seasons through their active membership and annual reports (Klamath Water Users Association 2010; Klamath Water Users Association, 2012).

A.2.3 Lower Klamath Basin

Although the Lower Klamath Basin has significantly less irrigated acreage than the Upper Klamath Basin, irrigated agriculture is still a primary component of the livelihoods of residents and has no fewer management activities. For example, the Shasta Valley Resource Conservation District serves central Siskiyou County, California. This conservation district has a range of ongoing projects for improving habitat and water quality for salmonids, including, but not limited to, removal of an agricultural flashboard dam in the Shasta River, historically used to facilitate irrigation diversions.

Cannon (2011), on behalf of the Karuk Tribe, summarized Shasta River hydrology and four alternatives for allowing anadromous fish species to access the reach of the river above Dwinnell Dam, which currently has no fish passage capability. The considered alternatives consist of installing a fish ladder on the dam, trapping and hauling fish around the reservoir, dam removal, and providing a bypass route around the reservoir. Water diversions are extensive on the lower Shasta River taking up to 90 percent of the river flow in the irrigation season. Shasta River water quality issues include high water temperature, high turbidity, high nutrient loads, and low dissolved oxygen; consequently, Coho and chinook salmon runs have significantly declined (e.g., 1,000 Coho in the late 1950s with now less than 100; chinook have decline from over 80,000 in the 1930s to now less than 10,000).

A number of studies have evaluated ways of augmenting water supplies in the Lower Klamath Basin. For example, in 1991 the Klamath River Basin Fisheries Task Force, a program established by the Klamath River Basin Fishery Resources Restoration Act of 1986 (16 U.S.C. § 460ss, October 27, 1986, as amended 1988) for the purpose of maintaining anadromous fish populations in the Klamath River Basin for the next 20 years, requested the CDWR conduct a flow augmentation study for the Scott River. The report identified a number of viable options for augmenting Scott River flows and mitigating the high summer water temperatures (CDWR, 1991). Specific recommendations included purchase of available water rights in the basin, increasing streamflow gauging sites, and a review of the Scott River adjudication process with individual water rights holders. Additional options that were identified, but called for further study include pumping of groundwater to supplement instream flows, reduce irrigation water conveyance losses, and conducting of a comprehensive study to evaluate various flow augmentation alternatives on flow as well as water temperature (CDWR, 1991).

A.2.4 Trinity River Basin

The Trinity River is the largest tributary of the Klamath River and provides water and sustains habitats for humans and various fish and wildlife species in the Klamath River Basin, as well as the Sacramento River Basin. Diversion of flows from the Trinity River to the Central Valley Project was authorized in 1955 and completed in 1963. It is reported that, initially, Reclamation informed the Congress that it would divert approximately 50 percent of Trinity River water into the Sacramento River. However, until the 1992 enactment of the Central Valley Project Improvement Act, P.L. 102-575, an average of 90 percent of the Trinity

River was diverted, causing significant declines in the Trinity River fishery and ultimately led to a cooperative restoration agreement between the Department of the Interior (Interior) and the Hoopa Valley Tribe.

The Central Valley Project Improvement Act of 1992 (H.R. 429, P.L. 102-575) directed the completion of the 12-year study (Trinity River Flow Evaluation Study, CDWR, 2013) to establish permanent instream fishery flow requirements, Trinity River Diversion operating criteria, and procedures for restoration and maintenance of the fishery. The Trinity River Flow Evaluation Final Report recommends specific annual flow releases, sediment management, and channel rehabilitation to provide necessary habitat (USFWS and Hoopa Tribe 1999). Generally, during the winter, Reclamation maintains lower levels in Trinity Lake to provide a buffer in the event of an extremely large winter storm to protect the dam and downstream areas.

A.3 Environmental Studies

This section summarizes environmental studies conducted within the Klamath River Basin, related to fish, water quality, ecosystem components (not including fish), and those studies related to the die-off of salmonids in September 2002. Water quality studies are further categorized by monitoring and data analysis studies; modeling studies of various elements such as temperature, dissolved oxygen, and nutrients; and studies quantifying water quality criteria and total maximum daily loads (TMDLs).

The Klamath River Basin provides habitat for numerous fish species. Fish species have been cataloged in the Klamath River Basin since at least the late 19th century. Gilbert (1898) provided an inventory of fish observed over four days of sampling in 1894. Among the fish observed were the Lost River and shortnose suckers. Beyond inventories, a number of studies have been conducted to improve understanding of historical salmonid populations in the basin. Craig (1992) described salmonid abundance from the third year of monitoring using rotary screw traps. Traps were placed at one location in the Trinity River and one location in the Klamath River. The program was intended to provide information concerning returning adults for use in managing harvest and estimating fall returns.

Trihey and Associates, Inc. worked on behalf of the Yurok Tribe to quantify instream flow needs for Reclamation’s Klamath Project Operations Plan in 1996 (Trihey and Associates, Inc., 1996). They quantified the monthly flow requirements of Tribal Trust fish species in the mainstem Klamath River between Iron Gate Dam and the river mouth. Instream flow requirements were developed using the Tenant Method, a hydrology based method, which is based on a percentage of the streamflow hydrograph. Using this method, they determined that 60 percent of the average annual flow is the required instream flow, which according to the method would generally allow for “outstanding habitat” (Trihey and Associates, Inc., 1996). This percentage was chosen because 1) several important life history activities occur throughout the year, 2) the species of concern are severely depleted, and 3) the FERC licensed flow regime for Iron Gate Dam at the time was not seen as adequate for recovery or stability of the species of concern.

In 1997, the five Northwestern California Counties of Del Norte, Humboldt, Mendocino, Siskiyou & Trinity formed the Five Counties Salmonid Conservation Program with the primary goal to “protect the economic and social resources of Northwestern California by providing for the conservation and restoration of salmonid populations to healthy and sustainable levels and to base decisions on watershed rather than county boundaries.” In 2009, this program was transferred to the Northwest California Resource Conservation and Development Council where members coordinate on numerous fish passage improvement, sediment reduction, habitat enhancement, and water quality improvement projects in the Program's area (Northwest California Resource Conservation and Development Council, 2009).

Beeman et al. (2012) evaluated the effects of Iron Gate Dam discharge and other factors on the survival and migration of juvenile Coho salmon in the Lower Klamath River. In part, that study sought to determine whether fish survival is related to river flows. Their conclusions were based primarily from results of hatchery fish. Their evaluation supported positive effects of water temperature, streamflow, and fish weight as factors influencing survival in the Klamath River above the Shasta River confluence, but not further downstream, and water temperature had the greatest influence.

Hewitt et al. (2012) summarized results and analysis from a continuing monitoring program of shortnose and Lost River suckers between 1995 and 2011. Through analysis of tagged suckers, the authors concluded that despite relatively high survival in most years, both species have experienced substantial declines in the abundance of spawning fish because losses from mortality have not been balanced by recruitment of new individuals. In fact, they found that all populations are largely comprised of fish that were present in the late 1990s and early 2000s.

A.3.1 Water Quality Studies

This section summarizes literature related to water quality including monitoring and analysis of historical data, past modeling efforts, and established water quality criteria and TMDLs. The next paragraphs of this section summarize literature describing regional water quality programs.

The Surface Water Ambient Monitoring Program (SWAMP) is a program administered by the California State Water Resources Control Board. SWAMP is tasked with assessing water quality in all of California’s surface waters. The program conducts monitoring directly and through collaborative partnerships and provides numerous information products, all designed to support water resource management in California. California State Water Resources Control Board works on this program in cooperation with several Statewide and local work groups including the Klamath Basin Water Quality Monitoring Coordination Group (CDWR, 2013a).

The Klamath Settlement Group Water Quality Sub Team (2011) evaluated water quality changes resulting from KBRA, KHSA, and TMDL programs. This qualitative analysis of potential water quality improvements, under the proposed action and the no action alternative, focused on nutrients (nitrogen and phosphorus) and organic matter reductions as water quality targets to reduce water quality-related stressors to fish populations. The group identified uncertainty with respect to whether water quality could be improved using only existing or proposed projects under a no action alternative. In contrast, full implementation of KBRA and KHSA, in conjunction with TMDL implementation projects, would provide greater opportunities for water quality improvements.

A.3.1.1 Monitoring and Data Analysis Studies

Regional water bodies (e.g., UKL) are naturally rich in nutrients, and as a result, water quality has been monitored for decades to evaluate its effects on fish and wildlife in the region, particularly since the listing of three fish species (SONCC ESU Coho salmon, Lost River sucker, and shortnose sucker) under the ESA. Numerous studies have also been done to evaluate collected data. This section describes past monitoring and data analysis studies.

In 1990, a literature review of Shasta Valley Water Quality was completed (Bogener, 1990). This review summarized groundwater quality with respect to minerals, nutrients, metals, and toxic substances. It also summarized surface water quality with respect to minerals, nutrients, minerals, coliform, pesticides, and benthic macroinvertebrates. The review found that groundwater quality was generally good for irrigation. However, potential impairments were identified in groundwater and surface waters for irrigation and domestic uses. The study found groundwater quality monitoring data to be inadequate due to spotty sampling and insufficient sampling sites.

Risley and Laenen (1999) compared flows from the Williamson and Sprague Rivers with the precipitation and air temperature records collected at Klamath Falls to assess the effect of climate on flow variations. That study reported on period changes in historical flows compared with other basins; however, relating specific land-use activities to changes in flow was not possible to assess due to the geologic complexity of the basin and to the lack of data.

Low dissolved oxygen concentrations (less than 4 milligrams per liter) have been documented in Upper Klamath and Agency Lakes, where they are detrimental to the survival of endangered sucker species in the lakes. Reclamation and the

Klamath Tribes have been collecting water-quality data in Upper Klamath and Agency Lakes since 1988. The scope of this work is the quantification of one piece of the oxygen budget— sediment oxygen demand[1]. Sediment oxygen demand operates on a longer time scale than the highly dynamic processes of algal photosynthesis and respiration. Managers at Reclamation can establish minimum lake levels in the hope of reducing sediment re-suspension and/or providing more water volume to dilute the effects of the sediment oxygen demand. Wood (2001) evaluated sediment oxygen demand measurements taken in 1999 and found that Safety of Dams $(SOD)_{20}$ values (sediment oxygen demand at 20 degrees Celsius) were well within the range of values in the literature for sites with similar sediment characteristics. Over most of the lake there appears to be relatively little variation in sediment oxygen demand. There was no correlation between SOD_{20} and the sediment characteristics measured in this study: percent fines, organic carbon, and residue lost on ignition.

Wood et al. (2006) described a study in which continuous water-quality monitors installed between 2002 and 2004, measuring pH, dissolved oxygen, temperature, and specific conductance, were placed in UKL to support a telemetry tracking study of endangered adult shortnose and Lost River suckers. Observations of hydrogen-ion concentration (pH) greater than 9.7 percent were common during times when the *Aphanizomenon flos-aquae* bloom was growing rapidly, indicating pH may be a source of chronic stress to fish. In the historical context of 15 years of climate and water-quality data, 3 out of 4 of the recent fish die-off years (1996, 1997, and 2003) were characterized by low winds and high temperatures in July or August coincident with the start of the die-off. High temperatures accelerate the demand for oxygen, creating low dissolved oxygen conditions. Although not proven, low winds may change circulation patterns in the lake and cause stratification.

Bartholow (2005) evaluated trends in historical water temperatures in the Klamath River and found that temperatures have increased about 0.5 degrees Celsius per decade between the 1960s and 2000s, and the period of high temperature that may be stressful for salmon has increased by one month. These increases are related to climatic changes in air temperature, either via changes in natural climate variability or anthropogenic climate change, or both.

Reclamation requested Morace (2007) to examine water-quality data collected by the Klamath Tribes for relationships with UKL level. This analysis evaluated a 17-year dataset (1990–2006) and updated a previous USGS analysis of a 5-year dataset (1990–94). In general, the author found a lack of statistically significant correlations between water-quality conditions, lake level, and climatic factors. Morace concluded that it does not necessarily show that these factors do not

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[1] Sediment oxygen demand (SOD) is the rate at which dissolved oxygen is removed from the water column during the decomposition of organic matter in streambed or lakebed sediments.

influence water-quality conditions. It is more likely that these conditions work in conjunction with each other to affect water quality. The dynamic nature of these

variables and their interactions from year to year, within a season, and between sites around the lake confounds the ability to explain or predict water-quality conditions in UKL.

The USGS, in cooperation with Reclamation, began monitoring water quality in UKL in 2002. Lindenberg et al. (2009) evaluated data from multi-parameter continuous water quality monitors, physical water samples, and meteorological stations. Data analysis was conducted for Upper Klamath and Agency Lakes, Oregon, primarily comparing 2006 data to previously collected data in 2005. They found that conditions potentially harmful to fish were influenced by seasonal patterns in bloom dynamics and the measure/depth of water.

Kuwabara et al. (2009) evaluated water quality data collected during late spring and summer of 2006. In their analysis of the data, they found that dissolved iron might be a limited nutrient in primary productivity. In addition, groundwater transport of nutrients may be a significant contributor to internal nutrient loading in UKL.

Reclamation (2011j, 2009b) conducted a study to provide quantitative estimates of the concentration and distribution of potentially toxic compounds contained within sediment currently trapped behind the four PacifiCorp dams being considered for removal under the KHSA. CDM and Stillwater Sciences (2011) conducted a Screening-Level Evaluation of Contaminants in Sediments from Three Reservoirs and the Estuary of the Klamath River, 2009-2011, prepared for the Interior Klamath Dam Removal Water Quality Sub-Team. They found that the quality of the Reservoir and estuary sediments did not appear to be highly contaminated and there would be only a minor or limited degree of effects, which would be further reduced if sediments are released under a dam removal scenario.

Arismendi et al. (2012) evaluated correlations between low streamflow and high stream temperatures using historical data for 22 watersheds in the Western U.S. over the period 1950-2010. They found low flows and high stream temperatures to be statistically linked and concluded that aquatic biota may be increasingly experiencing narrower time windows to recover or adapt between these extreme events of low flow and high temperature.

A.3.1.2 Water Quality Modeling Studies

Modeling experiments have also been conducted to evaluate effects of modified irrigation practices and reservoir operations on regional water quality. In their 1986 Shasta/Klamath Rivers Water Quality Study, CDWR summarized the hydrology and water quality in the watersheds and noted, as do various later studies, that nutrient levels support high productivity and that large diurnal ranges in flow, temperature, and dissolved oxygen ought to be considered in regional water resources management planning (CDWR, 1986).

Deas and Orlob (1999) described a modeling effort through the University of California, Davis to evaluate water quality and quantity in the Klamath River between Iron Gate Dam and Seiad Valley. Various flow, operational, and system modification alternatives were evaluated. Among other things, they found that selective withdrawal proved to be a much more efficient use of cold-water supplies stored in the reservoir, and increased flows increased reservoir release temperatures and adversely affected hatchery release temperature.

Hanna and Campbell (2000) described the water quality modeling component of the System Impacts Assessment Model, which was developed by the USGS to study the effects of Basin-wide water management decisions on anadromous fish in the Klamath River. The USACE Hydrologic Engineering Center (HEC)5Q water quality modeling software was used to simulate water temperature, dissolved oxygen, and conductivity in 100 miles of the Klamath River Basin in Oregon and California. In general, the System Impacts Assessment Model (SIAM) is comprised of MODSIM computer model to simulate water quantity, HEC5Q to simulate water quality, and SALMOD computer model to simulate ecosystem health. This study primarily focused on the model development, calibration, and validation of the water quality model within SIAM. The primary finding was that the water quality model is very effective at describing water quality throughout the basin as a result of water management changes.

Deas and Lowney (2000) reviewed temperature modeling for Central Valley water management, in response to the interest and concern associated with selection and application of temperature models and the biological and ecological effects of temperature regimes. The review includes four general areas specific to water temperature modeling: theoretical considerations; components and design of water temperature studies; implementation, calibration and validation, and use of models; and conclusions and recommendations. That study is applicable to the Klamath Basin because a review of temperature modeling in the Trinity River is included, due to trans-basin diversions from the Klamath River to the Central Valley. More recent (up to time of study, 2000) modeling efforts primarily used the HEC and Reclamation’s modified HEC 1-dimensional models for the Trinity River Basin.

Sullivan et al. (2000) develop a risk-based approach to analyze summertime temperature effects on juvenile salmon species in the Pacific Northwest, but it focused on Columbia River Basin species in Oregon and not Klamath River Basin species.

Doyle and Lynch (2005) evaluated sediment oxygen demand in Lake Ewauna (Oregon) during June 2003. Measurements were made at sites used in similar previous studies in order to evaluate the change in sediment over time. It was previously thought that unusually high oxygen demand rates in the Klamath River were due to the presence of large amounts of woody debris in bottom sediments from past and ongoing sawmill operations. However, results showed that sediment oxygen demand and water-column oxygen demand can more than account for the severe hypoxia that develops in this reach of the Klamath River from July into October. From this study, it does not appear that sediment oxygen demand variability can be readily determined from SOD_{20} (corrected to 20 degrees C) or organic matter.

PacifiCorp (2004), as part of their FERC relicensing application for the PacifiCorp Hydroelectric Project, evaluated potential effects of project operations on water quality associated with aesthetics. That study indicated that water quality was generally poorest in the Klamath River Basin upstream of Keno and it generally improved downstream. Although there is general improvement in turbidity in the downstream direction through the project area, occasional maintenance activities on project facilities may be a potential source of increased turbidity.

Bartholow and Henriksen (2006) parameterized and applied a deterministic salmon production model to infer the degree to which river flows and temperatures may limit freshwater production potential of the Klamath River in California. Water temperature was important in determining predicted production in some years, but overall was not predicted to be as important as physical microhabitat. The authors conclude that following their approach using the SALMOD model (which is the biological component of the SIAM) one can begin to explore potential alternatives to reduce production limitations.

Stillwater Sciences (2011) evaluated short-term variations in dissolved oxygen due to sediment releases associated with the proposed removal of one or more of four dams PacifiCorp dams (J.C. Boyle, COPCO 1, COPCO 2, or Iron Gate). They found that oxygen demand is expected to be greatest during the initial period of reservoir drawdown, in preparation for dam removal. Oxygen demand would be reduced, if not eliminated, during subsequent months and years and that the Klamath River could experience oxygen deficiencies for several river miles downstream of Iron Gate Dam in the initial days and weeks following dam removal.

Perry et al. (2011) evaluated Klamath River temperatures using U.S. Environmental Protection Agency’s (EPA) River Basin Model (RBM)10 model for no action and full dam removal alternatives under historical climate conditions (1961–2010) and six future climate scenarios (2012–2061) as part of the Secretarial Determination process(described in section I.H). Potential changes in seasonal water temperatures resulting from proposed dam removal, with or without future climate change, have a direct impact on fisheries in the Klamath Basin. Water temperature changes are of particular interest in spring (April through May) when salmon smolts out-migrate to the Pacific Ocean, and in fall (October through November) when Chinook salmon return upstream to spawn.

Risley, Brewer, and Perry (2012) simulated stream temperatures in the Klamath River by employing EPA's RBM-10 model for two management scenarios, called the dams in and dams out scenarios. Both simulations used flow requirements that were formulated in the NMFS 2010 BiOp and climate conditions based on the period 1961 through 2009. That study generally found simulated water temperatures between J.C. Boyle Reservoir and the Pacific Ocean were higher for the "dams out" scenario than for the "dams in" scenario from January through June, but lower from August to December.

An existing hydrodynamic, water temperature, and water-quality model for the Klamath River reach between Link River and Keno, Oregon was developed by the USGS using the CE-QUAL-W2 water quality model and was updated in 2013 to account for enhanced pH buffering due to macrophytes (Sullivan et al., 2013).

A.3.1.3 Water Quality Criteria and TMDLs

Numerous efforts to develop water quality criteria and TMDLs for reaches of the Klamath River and tributaries have taken place in recent years particularly through Oregon and California TMDL efforts, but this has been an ongoing process for many years. CDWR (1960) suggested water quality criteria for the Klamath River for maintenance of fresh water fish life by the California Department of Fish and Game (CDFG now called the California Department of Fish and Wildlife (CDFW)). Criteria include dissolved oxygen content not less than 85 per cent of saturation; hydrogen-ion concentration (pH) ranging between 6.5 and 8.5.3; and conductivity between 150 and 500 micromhos at 25° C and in general not exceeding 1,000 micromhos.

TMDL criteria have been established for various parts of the Klamath River Basin since about 2001. The first TMDLs were developed for the Trinity River (2001) and tributaries to UKL (2002). 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 Stateline) 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. In development of TMDLs, water quality criteria are established for sustaining fish and wildlife species.

A.3.2 Ecosystem Studies

There have been a number of studies conducted in the region to better understand ecosystem response to water management. As one example, Kreis and Johnson

(1965) evaluated the response of benthic macroinvertebrates (bottom organisms) to irrigation return flows. Their study found macroinvertebrate populations in the Lost River and Klamath River similar to those for industrial and domestic return flows. In another example, Chopin et al. (2002) evaluated the dependency of riparian plant communities upon infrequent flooding and found that there is a strong dependency of riparian plant communities on overbank flows.

Bortleson and Fretwell (1993) described potential causes for eutrophication of UKL, including: 1) conversion of marshland to agricultural land, 2) agricultural drainage from the Basin, and 3) reservoir regulation. They further described hypothetical causes for the decline in endangered sucker populations.

Dileanis et al. (1996) discussed how extensive hydrologic modifications and hyper-eutrophic conditions in Klamath Basin waterways have degraded the quality of aquatic habitat and altered aquatic communities. They conducted a detailed survey of water quality of areas affected by irrigation drainage from Reclamation's Klamath Project.

The Yurok Tribe Environmental Department (2006a) conducted a study to quantify the occurrence and extent of blue-green algae in the portion of the Klamath River within Yurok Tribe boundaries, based on data collection during the 2005 water year (October 2004 to September 2005). In that study, cyanobacterium *Microcystis aeruginosa* and its resultant toxin, microcystin, was detected, with some levels exceeding World Health Organization (WHO) risk guidelines. The study found that all salmon tissue samples (livers and filets) collected within that study did not contain detectable levels of microcystin, but two steelhead liver samples did contain measurable levels of microcystin.

Similarly, the Karuk Tribe (Kann and Corum, 2006) commissioned a study to evaluate 2005 Toxic *Microcystis aeruginosa* trends in COPCO and Iron Gate Reservoirs, because toxic algal blooms occurred in these water bodies in 2004 and 2005. This study was conducted in cooperation with the California State Water Resources Control Board based on a 1-year EPA funded nutrient loading study. It was found that bloom conditions in COPCO 1 and 2, and Iron Gate Reservoirs in 2005 represented a clear public health risk with respect to water contact recreation, but there were no reported illnesses or animal deaths due to the event. The report identified the need for management guidelines, protocols for public advisories, and continued monitoring of the sites.

The Klamath Basin Science Conference (Thorsteinson et al., 2010) was convened for the purpose of informing and updating Klamath Basin stakeholders about areas of scientific progress and accomplishment during the last 5 years and to identify outstanding information needs and science priorities as they relate to whole watershed management, restoration ecology, and possible reintroduction of Pacific Ocean salmon associated with the KBRA. Sessions of the conference included watersheds and ecosystems, forest management, aquatic habitats, fish health, climate change, ecosystem services, ecosystem restoration, a South Florida case study, resource management concerns, focal species for restoration planning, non-salmonid threatened and endangered species, salmon and steelhead adaptive management and long-term monitoring (Thorsteinson et al., 2010).

The USFWS in Yreka and Arcata, California contracted the USGS to analyze a variety of water management concerns associated with the FERC relicensing of the Klamath hydropower projects or with ongoing management of anadromous fish in the mainstem Klamath River. Using the SIAM tool developed by the USGS, they found March 15 through April 30 of any year as the optimal period for pulse flows and 4,000 cubic feet per second (cfs) was the target flow release that provided near-optimal juvenile fall Chinook salmon rearing habitat. The authors also found that changes in reservoir operations yielded only small effects on water temperatures in the Klamath River below Iron Gate Dam. However, innovative water management alternatives and/or multi-level intake retrofits at Iron Gate Dam could have beneficial effects on water temperature for salmon for some distance downstream during certain months of the year, particularly early fall.

Duffy et al., (2011) assessed ecosystem services derived from conservation measures taken in California's Central Valley and Upper Klamath River Basin as part of U.S. Department of Agriculture's (USDA) Wetlands Reserve Program (established in 1990). Restored wetlands in the Upper Klamath Basin primarily were riparian and dominated by grasses. Among other things, they found that the survey indicated a high proportion of the Upper Klamath Basin fish community utilizes Wetlands Reserve Program wetlands, including endangered fish.

A.3.3 Studies Related to 2002 Fish Die-off

This section summarizes studies that were conducted in relation to the largest fish die-off on record for the Klamath River Basin, which occurred in September 2002. Reclamation briefly described the events leading up to the die-off to provide some context for related studies. Reclamation is required to comply with the ESA by consulting on the on-going operations of its Klamath Project with the USFWS (with jurisdiction over the snortnose and Lost River suckers) and NMFS (with jurisdiction over the SONCC ESU Coho Salmon) to ensure Klamath Project operations do not jeopardize listed species or listed or proposed critical habitat. Reclamation prepared a BA for the proposed Klamath Project operations in 2001, which was forecasted to be one of the driest years of record. In April 2001, the FWS and NMFS each issued BiOps 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 would harm, but not jeopardize, the continued existence of bald eagles. NMFS recommended release of additional water from UKL for Coho salmon, while FWS simultaneously recommended maintaining higher lake levels. Because of severe drought conditions, there was not enough water to implement both BiOps simultaneously, even without providing irrigation water for farmers. Reclamation responded on April 6, 2001 stating that the normal deliveries would be available for lands receiving water from Clear Lake and Gerber Reservoirs (70,000 to 75,000 acre-feet [AF]) but that no water would be available from UKL e for deliveries to irrigators nor to the LKNWR (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 AF would be released from UKL to assist farmers; however, this came too late in the season to provide significant assistance.

The National Research Council (part of the National Academy of Sciences founded in 1916 to advance scientific knowledge and advice the Federal Government in the areas of science, engineering, and medicine) reviewed the scientific decisions of the controversial 2001 BiOps. It concluded that scientific data were insufficient to support the UKL level management regimes proposed by the 2001 USFWS BiOp. Releases from UKL were made to meet minimum stream flows; however, the Klamath Project was operated to modified minimum elevations for UKL, which deviated from the minimums prescribed in the USFWS BiOp. In 2002, another forecasted dry year but not as severe as 2001, Reclamation made close to full deliveries to its Klamath Project and provided the lake levels and river flows recommended in the two BiOps. 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 water temperatures were warmer. These conditions contributed to more than 33,000 adult salmon dying of epizootic disease in the first 40 miles of the river, primarily Chinook[2] but also Coho, steelhead, and others (CDFG, 2004b; CRS, 2005).

The National Research Council's external review of the scientific basis for the BiOps, which resulted in changes in water management in 2001, occurred in two phases. The first phase resulted in an interim assessment completed in February 2002 and focused on the effects of Reclamation's Klamath Project (National Research Council, 2002). The second phase completed in 2003 consisted of a broader and longer term view of the continued survival of the Klamath River Basin ESA listed species (National Research Council, 2004). In the interim report, the National Research Council concluded that the USFWS BiOp had substantial scientific support except for the recommendation regarding minimum lake levels of UKL. The National Research Council found a lack of consistent evidence linking lake levels with survival of ESA listed Shortnose and Lost River suckers and found no scientific basis for operating UKL to the minimum levels proposed in the USFWS BiOp. The National Research Council also concluded that the NMFS BiOp had scientific support except for the recommendation regarding increased minimum flows in the mainstem Klamath River. They found that changes in water management would not have a large impact on amount of habitat for threatened SONCC ESU Coho in dry years. In addition, they found

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[2] Chinook salmon are not listed under either the State or Federal ESAt in the Klamath Basin, but were recently petitioned for listing and are now considered a Candidate Species (Federal Register Vol. 76 No. 70. April 12, 2011 (76 FR 20302; Cannon, 2011).

Reclamation's Klamath Project operations would not affect tributary conditions, which were deemed the most critical for the species survival. At the same time, the National Research Council found Reclamation's proposed minimum Klamath River flows outside the range over the previous 10 years and, therefore, result in an unknown risk to the population.

The second phase review of the 2001 NMFS and USFWS BiOps and Reclamation's BA corroborated with the interim first phase findings. Additionally, it provided a broad set of recommendations for the recovery of threatened and endangered species in the Basin, beyond the jurisdiction and boundaries of Reclamation and its Klamath Project. The recommendations included: expanding the scope of ESA actions by the NMFS and USFWS, planning and organization of research activities and monitoring, identification of specific high priority recovery actions for endangered suckers (e.g., removal of Chiloquin Dam), identification of information needs related to SONNC ESU Coho salmon, and remediation measures that can be implemented based on current information (National Research Council, 2004).

The National Research Council later reviewed two additional studies at the request of the Bureau of Indian Affairs and Reclamation (National Research Council, 2008). One study aimed at estimating the historical natural flows in the Upper Klamath River Basin (called the Natural Flow Study, Reclamation, 2005b). The other study aimed at evaluating hydrology and its impacts on aquatic ecosystems that support the river's fish populations (called the Instream Flow Study Phase II, Hardy et al., 2006).

The Natural Flow Study was intended to characterize the natural hydrology of the Upper Klamath Basin (upstream of Keno Dam) prior to implementation of Reclamation's Klamath Project and other water diversions and withdrawals. It was not designed to be used in the 2002 ESA consultations with the NMFS and USFWS, although this was the public perception given their coincident timing. The Natural Flow Study eventually served the purpose of informing the Instream Flow Phase II Study.

National Research Council (2008) found the conceptual model of the Natural Flow Study to be thorough and detailed. It acknowledged the Upper Klamath Basin as a complex hydrologic system that has been highly modified, and it further acknowledged the model as a reasonable representation of the system given various constraints on that study. It had a number of recommendations for improvement. It said the model needed further testing, calibration, error analysis, and sensitivity assessment, and a needed to better address related uncertainties. It also stated that the model needed to explicitly represent the interaction between the Klamath River and Lower Klamath Lake instead of using a regression approach as an approximation and needed to account or land cover influences on hydrologic processes instead of using static pre-development land cover;

moreover, it suggested improvement or even incorporation of a physically based precipitation-runoff model for simulating natural flows and ET. It also said that a monthly timestep model might not be sufficient to capture important processes.

The National Research Council also reviewed the Instream Flow Study Phase II by Hardy et al. (2006) in its 2008 review report (National Research Council, 2008). The Instream Flow Study Phase II was a collaborative effort involving Utah State University, the USFWS, the NMFS, the USGS, the Bureau of Indian Affairs, Reclamation, CDFG, Oregon Water Resources Department (OWRD), the Karuk Tribe, the Hoopa Tribe, and the Yurok Tribe. That study evaluated the behavior of salmon fry and the suitability of reaches in the mainstem Klamath River for several life stages of Chinook and Coho salmon. That study used naturalized flows developed in Reclamation’s Natural Flow Study as well as natural flow scenarios statistically derived from the Natural Flow Study to explore the uncertainty associated with their use to derive flow estimates downstream of Keno Dam. The Instream Flow Study combined derived monthly flow information with habitat suitability to develop their instream flow recommendations. Modeling by Bartholow et al. (2005) and Henriksen (2006) were used to examine the robustness of the instream flow recommendations.

Based on its review of the Instream Flow Study Phase II, the National Research Council made a number of recommendations for that study’s improvement. Overall, the National Research Council found that the study made use of new techniques and improved the understanding of the fluvial complexities of salmon in the river (National Research Council, 2008). However, the National Research Council made a number of recommendations including:

- the modeling be redone using daily naturalized flow data instead of monthly
- a more integrated modeling approach for habitat assessment, including sediment dynamics and water quality, and fish population dynamics as part of the hydrodynamic modeling
- statistical testing of model predictions and comparing results to observed fish distributions
- analysis of the life stages of the pertinent salmonid species to allow for comparisons to be made between simulated and observed seasonal differences in usable habitat
- aligning the instream flow recommendations with the current operations procedures for the Upper Klamath Basin, namely its breakdown of year type, as opposed to frequency exceedance

The National Research Council also questioned the stochastic model used to generate multiple natural flow timeseries and questioned its ability to characterize uncertainty in observed naturalized flows. The National Research Council stated that the study should not be used as a specific guide to specific flow recommendations, but may be useful as a general guide.

At least two studies sought to evaluate the events of 2001 and 2002 and investigate the cause of the fish die-off. For example, Braunworth Jr. et al. (2002) synthesized existing information and provided a discussion of various issues surrounding the events of 2001/2002, including ecological, economic, social, and policy. CDFW (2004) aimed to identify the contributing factors to the fish die-off and to make recommendations for minimizing their occurrence in the future. Upon analysis, they concluded that more than 33,000 adult salmon (perhaps up to two times that number) died of epizootic disease, contributed by: 1) an above average number of chinook salmon entered the Klamath and Trinity Rivers in late August to early September of 2002; 2) unusually low river flows due to drought; and 3) high stream temperatures, which were not unprecedented, but allowed ideal conditions for pathogens to infect salmonids (CDFG, 2004). A larger percentage of Trinity River salmon were impacted than Klamath River salmon. Lynch and Risley (2003) summarize hydrologic conditions in the Klamath River prior to the record die-off of salmon.

Two studies sought to evaluate the reviews of the National Research Council of the 2002 NMFS and USFWS BiOps. Doremus and Tarlock (2003) interviewed a NMFS scientist who pointed out that BiOps must be made even when the level of supporting information would not meet typical peer review requirements. Decisions must take into account scientific judgment, extrapolation from limited data, decisions about the most viable and effective strategies, and judgments about social goals. Fein (2011) evaluated case studies of the Klamath River Basin and others (e.g., Point Reyes and Bay Delta) where regulatory peer reviews have had significant impacts, and they revealed a trend of increased politicization and decreased utility for the role of the National Research Council. They recommended several ways to maximize the benefits and minimize the costs of the National Research Council’s future regulatory peer reviews. For example, in a case where there is a pending or expected litigation, they recommended the National Research Council might be better off leaving the dispute to the judicial and political branches for resolution.

A.4 Groundwater Studies

The following section summarizes past groundwater management planning and related studies conducted primarily in the Upper Klamath Basin. Studies are organized into two categories, namely: 1) monitoring and data analysis studies and 2) modeling studies. However, this section begins with a discussion of regional groundwater programs and past groundwater management studies.

California has Statewide groundwater management planning and monitoring regulations. In 1992, the California Water Code was amended to allow specifically defined local agencies to adopt groundwater management plans. CDWR (1999) summarized what groundwater management plans had been adopted across the State, but did not identify any agencies within the Klamath River Basin as having developed a groundwater management plan. At the time, the Scott River valley was the only system in the California portion of the Klamath River Basin where groundwater rights had been adjudicated.

Gates (2001) summarized options for increasing water supply through ground water development. The report provides a detailed review of previous geologic and hydrologic studies of the Klamath Basin, and follows with more detailed sections on the hydrogeologic characteristics and present conditions in four project areas: the Shasta View Irrigation District, Ady District, Fort Klamath, and Langell Valley areas. In each region, they reported results from available regional well monitoring and well log analysis. The extent and amount of available data differed by region considered.

A.4.1 Monitoring and Data Analysis Studies

CDWR was under contract with Reclamation from 1999 through 2003 to monitor water groundwater levels in about thirty-five wells throughout Tule Lake and Lower Klamath Lake sub-basins. Monitoring initially occurred twice per year, but increased to monthly frequency in 2001 due to regional drought conditions. The California Governor’s Office of Emergency Services also tasked CDWR to begin monitoring groundwater levels in an additional 100 wells. The total number of wells monitored has fluctuated over the years, but approximately 70-75 wells continued to be monitored from 2001 through 2011. Monitoring results showed little change over the 13-year monitoring period in a shallow well in the Lower Klamath Lake area, while it showed significant depletion in the deeper well nearby. In the Tule Lake Basin, groundwater monitoring data from about 2006-2011 show that deep groundwater levels have declined significantly (4-16 feet in the latter 5 year period), and the shallow aquifer levels have begun to show impacts due to lowering of groundwater levels in the deep aquifer. The monitoring study concluded that by stating the sustainability of groundwater in the basin is unknown because of factors such as drought, continued delivery, and distribution of surface water supplies (Reclamation and CDWR, 2011).

A.4.2 Modeling Studies

Gannett et al. (2007) described a cooperative study between the USGS and OWRD to quantitatively characterize regional groundwater in the Upper Klamath Basin and develop a groundwater flow model to test management options. In their 2007 report, the authors characterized the basin and reported on available surface and groundwater monitoring data. In general, they stated that groundwater discharge is a primary contributor to inflow to UKL, and the groundwater system is very sensitive to pumping.

Gannett et al. (2012) expanded upon their 2007 report by building a groundwater system model using the USGS Three-dimensional (3-D) Finite Difference Groundwater Model (MODFLOW). Simulations showed that the discharge features most affected by pumping in the area of Reclamation's Klamath Project are agricultural drains, and impacts to other surface-water features are small in comparison. Optimization model results demonstrated that a certain amount of supplemental groundwater pumping could occur without exceeding defined limits on drawdown and stream capture. In general, this modeling framework could help identify strategies to meet water demand in the Upper Klamath Basin while keeping negative impacts of extraction within prescribed limits. The model study area included a southwestern boundary near Iron Gate Dam while other boundaries generally corresponded with watershed divides between the Klamath and neighboring basins (e.g., Deschutes and Pitt).

A.5 Land Management

The following section summarizes literature related to land management activities in the Klamath River Basin. The preparation of forest plans by the USFS is required by the Forest and Rangeland Renewable Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976, and the implementing regulations are found in the Code of Federal Regulations (36 CFR 219, issued September 30, 1982). The USFS (1995) completed a land and resource management plan, which would provide guidance for the protection and use of the Six Rivers National Forest (intersecting part of the Lower Klamath Basin) over the subsequent 10 to 15 years. The forest plan, which continues to be in effect, includes recommendations and results from a corresponding EIS that assesses the forest plan's environmental impact.

The USFS Six Rivers National Forest (Orleans Ranger District) also conducted a watershed analysis in 2003, whose primary goal was 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 watershed analysis report provided general and qualitative recommendations with respect to forest management for restoration of anadromous fish populations (USFS, 2003).

The Bureau of Land Management (BLM) conducted a number of activities related to management of BLM lands within the Klamath River Basin and designation of river reaches in the Wild and Scenic River system. In 1995, the BLM produced a Resource Management Plan, which resulted in a Record of Decision for its implementation (BLM, 1995). In 1990, the BLM produced an eligibility and suitability report on the designation of the Upper Klamath River as part of the National Wild and Scenic River system (BLM, 1990). This report found that the reach met the requirements for designation, but did not actually recommend the reach be classified. In the end, this reach remained with a “scenic” designation by the State of Oregon and a recreational river (since 1981) under the National Wild and Scenic Rivers Act.

The BLM revised a previously outdated EIS in 2003 for proposed recreational activities in the Klamath River reach between Lake Ewauna (Oregon) and Iron Gate Dam. The preferred alternative was to maintain all outstandingly remarkable values, while placing emphasis on restoration and enhancement of the values related to natural resources (BLM, 2003). The BLM also produced annual program summary and monitoring reports for the Klamath Falls Resource Area.

A.6 Economic and Socioeconomic Evaluations

The following section summarizes studies conducted to evaluate economic and socioeconomic impacts of water management. Not included in this section are studies related to the economic impacts related to implementation of the KBRA/KHSA or various scenarios of dam removal under the draft EIS/EIR.

The need for improved water management was recognized well before the events in 2001 and 2002, which led to significant economic impacts in the Klamath River Basin. ECONorthwest (2001) summarized strategies for pursuing a healthier ecosystem and improved economy in the Klamath River Basin, including these main strategies for accommodating the growing competition for water:

- resist the reallocation of water to those with ecological demands
- develop new sources of water or water-storage infrastructure
- retain the general scale and pattern of current out-of-stream water uses, but reduce the ecological harm
- change the general scale and pattern of current out-of-stream water uses

Poff et al. (2003) envisioned a new approach to river science, emphasizing the need for partnerships between scientists and other stakeholders to develop shared visions use experimental approaches to advance scientific understanding at the scales relevant to whole-river management. They identified four elements for this new model, including:

- conducting ecosystem-scale experiments
- more cooperative interactions among scientists, managers, and other stakeholders

- synthesize experimental results across various studies
- new, innovative funding partnerships to engage scientists and government agencies, the private sector, and non-governmental organizations

Burke et al. (2004) examined the use of water banks in a system such as the Klamath River Basin. They found that water banks are a potentially cost-effective way to meet environmental needs, but modifications to the proposed bank were needed to achieve cost efficiency, for example expanding of trade inside and outside Reclamation's Klamath Project.

Slaughter and Wiener (2007) examined Snake and Klamath Rivers institutions for their ability to resolve conflict due to demand growth, drought, and environmental constraints on water use. One of the primary differences they found between the two basins, with respect to water management challenges, is the fact that irrigation in the Upper Klamath Basin is controlled by a single entity (Reclamation) while the Snake Basin is comprised of various landowners and districts that have been accustomed to negotiating resolutions. They concluded that implementation of water markets promotes negotiations as opposed to politics, as a way of resolving water management challenges.

Exploration of the decision making process and the public perception of dam removal is documented in at least one study. Jørgensen and Renöfält (2012) performed a qualitative analysis of numerous pending dam removals in Sweden. They found that public opposition to dam removal is not based on lack of knowledge, but instead, a case of different understandings and valuation of the environment and the functions a dam provides. They also found that representation of information in the news media shapes the understanding of conflicts surrounding dam removal.

A.7 Water Rights

This section summarizes the status of water rights adjudications in the Klamath River Basin and literature discussing water rights issues in the basin. A 1954 report by the Oregon Klamath River Commission aimed to summarize the water resources issues at the time to gain understanding and background for negotiations leading to the Klamath River Compact (ORS 542.620; CA Water Code § 5900 *et seq.*; P.L. 85-222), later ratified in 1957.

Water rights adjudication in California was completed for the Shasta Valley in 1932 and for the Scott Valley in 1980 (via the Scott River Adjudication Decree No 30662). The mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing (California State Water Resources Control Board, 1980). However, ORWD (2013) completed the first phase of the process, which entails the review and determination of water rights claims. The most senior determined claims in the Klamath River Basin Adjudication are claims held by the U.S. in trust for the Klamath Tribes.

A.8 Studies Related to KBRA/KHSA

This section summarizes numerous studies produced to inform the Secretary of the Interior of the Secretarial Determination process involving potential implementation of the KBRA and KHSA. First, brief overviews of the KBRA and KHSA are provided to supply some context for the supporting studies. The KBRA is an agreement signed by 42 Klamath Basin stakeholder groups in 2010 (and extended in 2012), which attempts to resolve complex issues in the Basin 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 KHSA is a corresponding agreement that lays out the process for the possible removal of the lower four dams on the Klamath River (Iron Gate, California Oregon Power Company (COPCO) 1, COPCO 2, and JC Boyle) owned by PacifiCorp, beginning in 2020. This process requires approval by the Congress and a decision by the Secretary of the Interior (Secretarial Determination) on whether implementation of the KHSA would advance restoration of the salmonid fisheries of the Basin and be in the public interest (Klamath Settlement Group, 2009b). The KBRA was originally set to expire December 31, 2012, but was extended through December 31, 2014.

A joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis has been performed and a draft Environmental Impact Statement/Environmental Impact Report (EIS/EIR) has been prepared (Interior and CAFG, 2011) to evaluate the impacts of the KBRA and KHSA and to inform a future Secretarial Determination. A draft EIS/EIR is complete and further described in section I.H.14.

In addition, the KBRA includes a provision for completion of a drought plan (KBRA Drought Plan Lead Entity, 2011) to address drought and extreme drought conditions in the Basin under the agreement. The KBRA provides for the establishment of a drought fund to be administered by the National Fish and Wildlife Foundation. Potential for drought or extreme drought is monitored beginning in January of each year and is based on a threshold volume for UKL, precipitation, and other factors. OWRD would determine, by April 5 of each year, whether drought or extreme drought conditions exist. The plan outlines a layered drought response, starting with voluntary measures and continuing with reductions in surface water irrigation and other water management measures.

Another document prepared to inform the Secretarial Determination process, the Secretarial Determination Overview Report (Interior et al., 2012), summarized the findings of peer-reviewed studies conducted by a team of scientists.

Four questions that were posed to the science team (Interior et al., 2012):

- Will dam removal and KBRA implementation advance salmonid and other fisheries of the Klamath Basin over a 50-year time frame?

- What would dam removal entail, what mitigation measures may be needed, and what would these actions cost?

- What are the major potential risks and uncertainties associated with dam removal?

- Is dam removal in the public interest, which includes, but is not limited to, consideration of potential effects on local communities and tribes?

The team of scientists addressed these questions by evaluating effects of three scenarios, including complete dam removal and full implementation of KBRA, partial dam removal (i.e., removal of dams, but not the secondary infrastructure), and no action (i.e., continuation of annual FERC license renewals). The no action scenario assumes that the current NMFS and USFWS BiOps (2010 and 2008, respectively) are in effect. The overview report provides a summary of findings in several research areas, namely:

- Detailed dam removal plan, cost, and associated risks
- Physical, chemical, and biological processes supporting fish species
- Economics, including National, regional, and tribal
- Prehistoric and historic cultural resources
- PacifiCorp analysis of dam relicensing versus facilities removal
- Effects on the Wild and Scenic River
- Recreation, including boating and fishing
- Real estate
- Wildlife refuges
- Sediments, including reservoir and channel
- Algal toxins
- Greenhouse gas emissions
- Societal views

In this document, studies were summarized to inform the Secretarial Determination process within many of these research areas. Findings from the Klamath Dam removal overview report (Interior et al., 2012) were briefly summarized for each category. The primary risks identified with dam removal include impacts to fish species associated with high sediment loads, costs exceeding estimated amount, flood risk during dam removal, and impacts to cultural resources.

A.8.1 Dam Removal Studies – Dam Removal Plan

The dam removal plan was designed to minimize impacts on fish species. It generally calls for the J.C. Boyle and COPCO 1 dams to be removed first (early 2020), followed by COPCO 2 (spring 2020), and later Iron Gate Dam (after spring runoff in 2020). The upper end forecasted cost (less than the one percent probability) for full facilities removal was estimated to be $493,100,000. Dam removal would be accompanied by a revegetation plan for areas previously inundated by reservoirs. Infrastructure modifications would be implemented for those facilities that would be impacted by dam removal (e.g., municipal water supply intakes). Other mitigation measures would also be implemented; for example, temporary relocation of fish species to avoid high sediment loads, protection of culturally significant sites, and revising 100-year floodplain maps (Interior et al., 2012).

A.8.2 Dam Removal Studies – Physical, Biological Processes

Overall, dam removal would improve salmonid fish populations and associated fisheries primarily by increasing access to historical habitat and thermal refuge areas in the Upper Klamath Basin, restoring mainstem and tributary habitat, and improving key biological and physical factors heavily influencing the health and survival of these fish populations. For example, dam removal is expected to decrease instances of disease related to high water temperature and toxic algae. These related impacts of dam removal are expected to increase the resilience of ESA listed Coho, shortnose and Lost River suckers, and other species (e.g., steelhead, redband and rainbow trout; Interior et al., 2012).

A.8.3 Dam Removal Studies – Economics

An evaluation of economic impacts, including national economic development, regional economic development, tribal effects, and irrigated agriculture, was completed to inform whether dam removal is in the public interest (Interior et al., 2012; Reclamation 2011g). The national economic development account measured the beneficial and adverse monetary effects of each alternative in terms of changes in the value of the national output of goods and services. The regional economic evaluation included impacts of each alternative on the regional economy including income and employment measures, as well as analysis of secondary impacts related to spending of income associated with jobs affected by alternatives. The tribal analysis focused on fishing opportunities, related cultural and social practices, standard of living, and health for the federally recognized Tribes. Additional technical reports were completed by Reclamation to further detail the various categories of the economic analysis, but they are not detailed in this literature review. The categories consist of:

- Irrigated agriculture
- Commercial fishing

- Hydropower
- Ocean sport fishing
- In-river sport fishing
- Reservoir recreation
- Refuge recreation
- Whitewater recreation
- Nouse values
- Real estate

Resulting benefit/cost ratios for full and partial removal of the dams were:

- Full removal: 8.1 to 1 (low) 47.6 to 1 (high)
- Partial removal: 8.9 to 1 (low) 48.3 to 1 (high)

Impacts to the six federally recognized Tribes in the Klamath River Basin (Klamath Tribes, Karuk Tribe, Resighini Rancheria, Yurok Tribe, Hoopa Valley Tribe, and Quartz Valley Tribe) with respect to their fishing opportunities, related cultural and social practices, standard of living, and health were evaluated separately for each tribe as each is a sovereign nation with its own government, and due to their non-quantitative nature. Dam removal would have beneficial effects on water quality, fisheries, terrestrial resources, and traditional cultural practices. In addition, removal of the dams would enhance the ability of Indian tribes in the Klamath River Basin to conduct traditional ceremonies and other traditional practices. Implementation of the KBRA would provide funds to the signatory tribes for restoration projects that would create jobs for tribal members.

Some sites that may be eligible under the National Register of Historic Places could be impacted by dam removal. Therefore, consultations under section 106 of the National Historic Preservation Act would continue, as appropriate, throughout planning and implementation of dam removal and mitigation measures would need to be taken to avoid or minimize impacts to these sites (Interior et al., 2012; Reclamation 2012g).

A.8.4 Dam Removal Studies – Prehistoric and Cultural Resources

This section encompasses two topics covered by the Klamath River Basin dam removal overview report, namely tribal and non-tribal cultural resources. Fish, water, and other natural resources are incorporated into the traditional cultural practices of the Tribes in the Klamath Basin. Dam removal and implementation of the KBRA would help protect trust resources and address various social, economic, cultural, and health problems identified by the Tribes in the Klamath River Basin (Interior et al., 2012).

There are numerous sites in the watershed that are associated historical uses, such as Indian tribal use, gold mining, logging, agriculture and ranching, and hydroelectric development. Some of these sites are either eligible for, or would likely be eligible for, inclusion on the National Register of Historic Places. Planning and mitigation measures would be required to minimize any impact of dam removal on these cultural resource sites (Interior et al., 2012).

A.8.5 Dam Removal Studies – Dam Relicensing

In review of impacts associated with full or partial dam removal, potential outcomes of the FERC relicensing of the four dams under consideration was also evaluated as an option. Changes would likely include new operational requirements for the four facilities, capital expenditures for fish passage (such as fish ladders and screens) and water quality 401 certifications, and additional operational and maintenance expenses. Analyses from the California and Oregon Public Utility Commissions found that implementing the KHSA with customer surcharges would result in the best financial outcome for PacifiCorp's customers when compared to the estimated costs and future risks of relicensing the four facilities (Interior et al., 2012).

A.8.6 Dam Removal Studies – Wild and Scenic River

Consideration was also taken to evaluate impacts of potential dam removal on the Klamath River's National Wild and Scenic River designation. An 11-mile segment of the Klamath River in Oregon was designated as a component of the National Wild and Scenic River System in September 1994. A 189-mile segment of the Klamath River in California was designated as a component of the system in January 1981. It was designated primarily to protect and enhance its outstandingly remarkable anadromous fishery. The California Klamath River Wild and Scenic River includes portions of its three principal tributaries, the Scott and Salmon Rivers and Wooley Creek, for a total of 286 miles. Analysis showed that the Klamath Wild and Scenic River in California would benefit from dam removal with respect to boating, scenery, fish, and wildlife value. The Klamath Wild and Scenic River reach in Oregon would likely experience reduced whitewater boating value, but other recreational values, plus scenery, fish, and wildlife, would likely improve (Interior et al., 2012).

A.8.7 Dam Removal Studies – Recreation

The major recreational resources analyzed were open water recreation, camping and day-use recreation, whitewater boating, flat-water fishing, and in-river fishing. Open water recreation, fishing, and camping at the Klamath Hydroelectric Project reservoirs would permanently be lost following dam removal, but may be compensated for at nearby lakes and reservoirs. Whitewater boating would be reduced in the reach between J.C. Boyle and COPCO dams and may shift in seasonality in other reaches. Finally, habitat improvements for salmonid and other anadromous fish species would likely increase in-river fishing opportunities (Interior et al., 2012).

A.8.8 Dam Removal Studies – Real Estate

With respect to land ownership, dam removal would affect lands inundated by the reservoirs and other properties owned by PacifiCorp, lands required temporarily or permanently for dam and facility removal, and private land (other than PacifiCorp) influenced by the reservoirs. Dam removal may cause the loss of scenic value and recreational opportunities, thereby decreasing the value of properties with frontage on the four reservoirs. However, other increased recreational opportunities, such as river recreation, could have a positive effect of property values as a result of the dam removal (Interior et al., 2012).

A.8.9 Dam Removal Studies – Refuges

Dam removal and KBRA implementation would provide an allocation of water to the refuges within Reclamation’s Klamath Project for the first time, increasing certainty about water deliveries and flexibility in water deliveries. The allocation – and the increased predictability of deliveries – would mean that greater numbers of migratory waterfowl, non-game water birds, wintering bald eagles, and other sensitive species would be supported by the refuges (Interior et al., 2012).

A.8.10 Dam Removal Studies – Sediment

With respect to fish in the short-term, reservoir drawdown associated with dam removal would result in the release of high-suspended sediment concentrations, lethal to some fish; however, excess sediments would be transported downstream from January through March 15 when Coho salmon, as well as several other native species, are not present in large numbers in the mainstem river. Evaluation of dredging to remove reservoir sediment led to the conclusion that this option is not feasible for many reasons including cost and regional disturbance (Reclamation, 2011i).

A study of concentrations and distribution of potentially toxic compounds contained within sediment currently trapped behind the four PacifiCorp dams was conducted by Reclamation as part of the Secretarial Determination process. Overall, it was determined that the reservoir sediments are relatively clean. In the future, if there is an Affirmative Determination, detailed plans, and permitting processes for dam removal would consider conditions, such as the expected dilution and mixing, in more detail (Reclamation, 2011j).

A.8.11 Dam Removal Studies – Algal Toxins

Dam removal would eliminate large, seasonal blooms of nuisance toxic algae in COPCO 1 and Iron Gate Reservoirs and facilitate the use of the Klamath River for multiple human health related beneficial uses including traditional Indian cultural practices, recreation, agriculture, shellfish harvesting, and commercial and sport fishing (Interior et al., 2012).

A.8.12 Dam Removal Studies – Greenhouse Gas Emissions

Removing the four dams would result in a substantial increase in greenhouse gas emissions from replacement power sources due to efficiency upgrades to turbines and generators that PacifiCorp is currently making and would continue to make in the future if the facilities were to remain in place until 2061. With removal of the dams, approximately 526,000 metric ton of carbon dioxide equivalent per year would be emitted from replacement power assuming PacifiCorp's current resource generation mix (Interior et al., 2012).

A.8.13 Dam Removal Studies – Societal Views

Public views of dam removal and the associated agreements (KBRA and KHSA) were expressed through household surveys as well as ballot measures in the 2010 Klamath County elections. A majority of respondents were concerned with the overall decline of salmonids and ESA listed suckers in the Klamath River Basin; however, they preferred full or partial removal of the four dams over a no action alternative. A ballot measure in Siskiyou County, CA, showed a majority of voters did not favor dam removal (Interior et al., 2012).

A.8.14 FERC Licensing

PacifiCorp in 2004 submitted a report and application for relicensing of the Klamath Hydroelectric Project (FERC Project No. 2082). The project consists of the seven mainstem hydroelectric developments on the Upper Klamath River and one tributary hydroelectric development. In this application, PacifiCorp sought a renewed license because the 50-year license existing at the time was set to expire on March 1, 2006. In that application, PacifiCorp outlined some proposed facility modifications, but acknowledged ongoing collaborations to determine needed fish passage facilities, etc. The application included an analysis of potential impacts of facility modifications on water use, water quality, fish resources, wildlife and botanical resources, cultural and recreational resources, land management and aesthetics, and socioeconomics.

A number of stakeholders provided feedback on PacifiCorp's FERC relicensing application. The NOAA Fisheries Southwest Region (2004) expressed concern regarding the slow pace of analysis, and lack of thoroughness surrounding FERC relicensing. OWRD (2004) also provided comments related to PacifiCorp's relicensing application, expressing concerns about water quality issues and fish survival. The California Coastal Conservancy (2006) evaluated sediment supplies under potential dam decommissioning scenarios. Recommendations by the Hoopa Valley Tribal Council (2006) and NMFS (2006) include construction of fish passage facilities. Karuk Tribe (2006), Resighini Rancheria (2006), and Yurok Tribe (2006b) in their responses called for FERC to order removal of the four lower mainstem dams, while NMFS (2006) suggested that they may recommend removal of the four dams as a preferred alternative. The Quartz Valley Indian Community (2006) called for the need for more information on water quality implications of the project.

A.8.15 EIS/EIR

An EIS/EIR was developed in accordance with the requirements of the NEPA /CEQA) to analyze the potential impacts to the environment from removing four PacifiCorp Dams (J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate) on the Klamath River under the Klamath Hydroelectric Settlement Agreement (KHSA) and implementation of the KBRA. Five alternatives were evaluated as part of the EIS/EIR and these include: 1) no action/no project alternative, 2) full facilities removal of all four dams, 3) partial facilities removal of the four dams, leaving behind secondary infrastructure, 4) providing fish passage at the four dams, 5) providing fish passage at J.C. Boyle and COPCO 2 dams, while removing COPCO 1 and Iron Gate dams.

NEPA requires the Lead Agency to identify the alternative or alternatives that are environmentally preferable, which generally refers to the alternative that would result in the fewest adverse effects to the biological and physical environment. It is also the alternative that would best protect, preserve, and enhance historic, cultural, and natural resources. Although this alternative must be identified in the Record of Decision, it need not be selected for implementation. The Draft EIS does not identify a preferred alternative under NEPA. CEQA Guidelines require agencies to identify the environmentally superior alternative in a draft EIR. CDFG has identified Alternative 3 (Partial Facilities Removal of Four Dams) as the environmentally superior alternative under CEQA. Alternative 3 is the environmentally superior alternative when compared with the Proposed Action (full removal of the four dams). This EIS/EIR relied on information developed through the dam removal studies, but included additional source material as well.

The EIS/EIR addressed implications of the five alternatives on the following areas:

- Water quality
- Aquatic resources
- Algae
- Terrestrial resources
- Flood hydrology
- Groundwater
- Water supply/water rights
- Air quality
- Greenhouse gases/global climate change
- Geology, soils, and geologic hazards
- Tribal trust resources

- Cultural and historic resources
- Land use, agricultural, and forest resources
- Socioeconomics
- Environmental justice
- Population and housing
- Public health and safety, utilities and public services, solid waste, power
- Scenic quality
- Recreation
- Toxic/hazardous materials
- Traffic and transportation
- Noise and vibration

For example, the Klamath Settlement Group Water Quality Sub Team (2011) evaluated water quality changes resulting from KBRA, KHSA, and TMDL programs. This analysis relied on resources from a variety of sources.

A.9 Regulations

This section summarizes literature pertaining to the National Wild and Scenic Rivers Act of 1968 (16 USC 1271-1287 – Public Law 90-542). It is recognized that numerous other regulations that affect the Klamath River Basin could be discussed, and that this section is not meant to be an exhaustive summary all regulations related to regional natural resources.

The Bureau of Land Management (BLM) considered three segments for eligibility and suitability for designation under the National Wild and Scenic Rivers Act of 1968. BLM determined segment 1 (just below the J.C. Boyle Dam and ends at the J.C. Boyle Powerhouse - river mile 224.5 to 220.3) ineligible, and segments 2 (beginning at the powerhouse and ending at the Oregon-California State line, river mile 220.3 to 209.3) and 3 (a 5.3- mile segment in California from the Stateline to the slack water of COPCO Reservoir, river mile 209.3 to 204) both eligible and suitable for designation with a "scenic" classification (BLM, 1990). These reaches (2 and 3) did not meet the criteria for a “wild” classification. This document discusses how in November 1988, Ballot Measure 7 was passed by Statewide vote, amending the Oregon State Scenic Waterways Act such that the Klamath River from J.C. Boyle Dam to the State line was designated the Klamath Scenic Waterway (BLM, 1990).

In addition to the National Wild & Scenic Rivers Act of 1968 designation of 11 miles of the Klamath River as “scenic,” segments of the Scott and Trinity Rivers are protected under the California Wild & Scenic Rivers Act (Public Resources Code Sec. 5093.50 et seq.) which was passed in 1972.

A.10 Planning Activities

This section summarizes various regional, State, and Federal planning activities in the Klamath River Basin. Subsections include restoration-planning efforts in the Klamath River as a whole; those focused more on the Trinity River, efforts related to salmon recovery, habitat conservation planning, and efforts undertaken by tribes.

The CDWR issued a plan of study for its Water Plan Update 2013, in which it describes a scenario planning approach to characterize water supply reliability, primarily in the Central Valley region, although the document suggests that climate change and water demand scenarios may be available for other regions within the State. A robust decision making model is being used to evaluate vulnerabilities of current management activities and develop strategies to mitigate them. Volume 2 of the update contains regional reports, including one for the North Coast Region including the Klamath River Basin (CDWR, 2013). This report includes some background discussion of hydrology and water resources development within the Klamath River Basin.

The North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) aimed 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 main themes of the plan include salmonid recovery, the beneficial uses of water, and intraregional cooperation. It relied upon an adaptive management approach – providing for ongoing data gathering, planning, design, implementation and evaluation at a variety of scales in a long-term, iterative, community-based process. This plan summarized the primary natural resource issues that the North Coast Region of California faces and laid out 127 proposed projects and project priorities that could be taken to alleviate stresses on these resources.

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 into 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.

A.10.1 Klamath River Basin Restoration Planning

The Klamath Basin Restoration Fisheries Task Force, formed in 1986 through the Klamath River Basin Fishery Resources Restoration Act (Public Law 99-552), was comprised of 14 appointed members and was charged with developing a Klamath River Basin Conservation Area Fishery Restoration Program. In 1991, the Task Force issued their 20-year long range plan for restoring the fisheries of the Klamath River Basin, which included a review of the Interior's Klamath River Basin Fisheries Resource Plan completed in 1985. The Klamath Basin Restoration Fisheries Task Force held public meetings in the watershed during which they received about 700 comments from over 200 attendees regarding restoration strategies. In general, the plan emphasized the need for both fish habitat protection and fish habitat restoration from a whole watershed perspective, a recommendation that is still made today. The plan outlined numerous actions ranging from broad to focused, centered around the following themes: habitat protection and management, habitat restoration, fish population protection, fish population restoration, education and communication, and program administration (Klamath Basin Restoration Fisheries Task Force, 1991).

A.10.2 Trinity River Restoration Planning

This section describes planning activities in the Trinity River Basin, which is the largest tributary of the Klamath River. The first section describes numerous activities associated with the Trinity River Restoration Program. The second section below summarizes past watershed analyses, which are one key component of agency land management planning in the Pacific Northwest.

A.10.2.1 Trinity River Restoration Program

The Trinity River Diversion is operated by Reclamation and started operating in 1963 to provide water to Reclamation's Central Valley Project through a series of tunnels connected to the Sacramento River system. In subsequent years, the trans-basin diversion became approximately 90 percent of the annual flow in the Trinity River. The expectation was that this was essentially surplus water and fish and wildlife would not be impacted. It took approximately 10 years for detrimental effects on habitat and salmonid species to be evident. The Secretary of the Interior formed a Trinity River Basin Task Force and directed the Trinity River Flow Evaluation Final Report (USFWS and Hoopa Tribe 1999). The recommended strategy was to use an adaptive management approach that integrates riverine processes and flow-dependent needs of fish and vegetation. The Trinity River Flow Evaluation Final Report became the foundation for the Trinity River Restoration Program (established in 2000). The Trinity Restoration Program is generally carried out by Reclamation and the USFWS to help restore the Trinity River to more natural conditions.

The Trinity River Mainstem Fishery Restoration EIS (USFWS et al., 2000) was completed and the Record of Decision was signed on December 19, 2000, establishing the current Trinity River Restoration Program (McBain and Trush, 2000). The EIS called for implementation of the Trinity River Flow Evaluation Final Report, including recommendations for physical/mechanical restoration actions in the basin, as well as an increase from approximately 25 to 48 percent of the average annual inflow to Trinity Lake to be released to the River. In 2000, the NMFS issued a BiOp on the preferred alternative of the draft EIS and Trinity

River Flow Evaluation Final Report and concluded that they would not jeopardize continued existence of SONCC ESU Coho Salmon, Sacramento River Winter-run Chinook, Central Valley Spring-run Chinook, or Central Valley steelhead. The BiOp allowed for the Record of Decision issued by the Secretary of Interior. The Trinity River Flow Evaluation Final Report and subsequent Record of Decision provided a restoration strategy for the Trinity River Restoration Program but did not specify methods for assessing the effectiveness of their recommended actions. An Integrated Assessment Plan (Trinity River Restoration Program and ESSA Technologies Ltd., 2009) was completed to fill this need. The Integrated Assessment Plan proposed a sampling framework for conducting the major assessments across subsystems that are required at site, reach, and system scales. The Integrated Assessment Plan described what assessments would be required to evaluate the response of key ecosystem components to Trinity River Restoration Program actions, using contrasts over time (e.g., before/after 15 comparisons) as well as contrasts over space (e.g., above, at and below rehabilitation sites) to assess the effects of management actions.

The Trinity River Restoration Program is a multi-agency program with eight partners that form the Trinity Management Council, plus numerous other collaborators. The Trinity Management Council Partners include the California Resources Agency, Hoopa Valley Tribe, Trinity County, Reclamation, USFWS, USFS, NMFS, and the Yurok Tribe.

The Trinity River Flow Evaluation Final Report (USFWS and Hoopa Valley Tribe, 1999) developed a restoration strategy for mainstem fisheries (pursuant to the Trinity River Basin Fish and Wildlife Management Act of 1984). The recommended management actions (annual and interannual flow management, mechanical channel rehabilitation, and coarse sediment augmentation) were expected to create a river system with enhanced channel morphology features and riverine processes. The river would then provide and maintain the diversity and abundance of habitats necessary to restore the anadromous salmonid and other riverine dependent fish and wildlife populations of the Trinity River. The Trinity River Mainstem Fishery Restoration EIS/EIR (USFWS et. al., 2000) evaluated the Trinity River Flow Evaluation Final Report strategy and other alternatives, along with a no-action alternative. On 15 December 19, 2000, the Secretary of the Interior signed a Record of Decision (Interior, 2000) selecting the report recommendations, plus a watershed restoration component, as the preferred alternative for restoring the mainstem fishery resources of the Trinity River. (Trinity River Restoration Program and ESSA Technologies Ltd., 2009).

McBain and Trush (1997) reviewed research from 1991 through 1997 in the Trinity watershed as a basis for their maintenance flow study, prepared for the Hoopa Valley Tribe. The purpose of the study was to understand the dynamics of the river system prior to the Trinity River Diversion to the Central Valley. The study was conducted in coordination with the Trinity River Basin Fish and Wildlife Task Force and recommendations focused on recommended flows during classified year types, sediment management, and channel restoration.

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. Under the direction of the planning group, Berol (1995) compiled the beginnings of a socio-environmental study for the South Fork Trinity River, which consisted of personal interviews and a summary of historical geologic, soils, and channel information. The planning group also completed a final draft management plan in 1996 (Patrick Truman & Associates and Pacific Watershed Associates, 1996). Recommendations in the plan were centered on the following three issues:

- improve water quality and water quantity
- reduce ongoing and potential erosion and sediment yield from roads and hillslopes
- provide for streamside riparian protection and improvements

Trinity River Restoration Program, with the help of ESSA Technologies, in 2009 completed an Integrated Assessment Plan in which they provided recommendations for actions to evaluate the effectiveness of the Trinity River Restoration Program. Recommendations included monitoring and periodic assessments of the following (Trinity River Restoration Program and ESSA Technologies Ltd., 2009):

- population of both natural and hatchery components of salmon runs
- number of adults returning to spawn (escapement) and juvenile production of key species to provide feedback on annual management actions and allow evaluation of long-term program goals for natural fish production
- changes over time in the amount, distribution and quality of habitat, and improve our understanding of the linkages between river channel complexity, quantity of fish habitat, fish use of habitat and fish production
- geomorphic conditions that create and maintain complex habitat that support the production of anadromous salmonids in the Trinity River - developing metrics and inventories that effectively quantify the abundance and quality of those geomorphic conditions
- management actions related to promoting healthy riparian vegetation within the Trinity River corridor, inhibiting detrimental riparian vegetation encroachment within the river’s active channel, and recovery of riparian vegetation that has been directly removed by bank rehabilitation

- success in establishing the amount and characteristics of riparian habitat that meet the needs of wildlife species

Despite existing efforts by the Trinity River Restoration Program, water temperatures have continued to exceed objectives below Lewiston Dam (Reclamation, 2004b). Reclamation is therefore conducting a Lewiston Temperature Study with the goals of:

- improve habitat on the Trinity River
- improve cold water transmission upstream of Lewiston Dam
- increase salmon production
- maintain existing level of recreational benefits and minimize impacts to same

In the intermediate technical memorandum for the study (Reclamation, 2012c), Reclamation summarized the seasonal timing of current trans-basin exports from the Trinity River to the Central Valley Project as well as other management aspects including hydropower operations, recreation, and fish and wildlife requirements, as part of their Central Valley Project long term operations criteria and plan. It also provided descriptions and preliminary level cost estimates for five alternatives identified to meet the objectives and goals of the study. The memorandum was not intended to analyze impacts or recommend alternatives to be carried forward for further analysis. The five alternatives that were considered include:

1b. Removal of Lewiston Dam - Pump Station Water Supply
2. Dredging of Lewiston Reservoir
3a. Tunnel from Trinity Dam to Lewiston Dam
3b. Pipeline from Trinity Dam to Lewiston Dam
4. Raise Lewiston Dam

The Trinity River Restoration Program et al. (2013) completed a draft Environmental Assessment/Initial Study for a Phase 2 channel rehabilitation project under the Trinity River Restoration Program. This project consists namely of reconnecting the stream channel to the floodplain in two reaches of the river not previously included in the Trinity River Restoration Program EIS. Hence, environmental review was required. The document summarizes environmental effects of the proposed project implementation as well as potential mitigation measures to reduce identified impacts.

A.10.2.2 Watershed Analysis

Watershed analyses are interdisciplinary studies conducted by land management agencies in the Pacific Northwest as a step toward ecosystem management, synthesizing biological, physical, and socio-economic information. BLM was involved in a mainstem Trinity River watershed analysis in 1990 (BLM, 1990). This analysis compiled existing knowledge in various areas including channel morphology, fish habitat and populations, sediment, land use and human values, vegetation and soils, geology, and climate.

The National Resources Management Corps (2003) conducted a watershed analysis for the Trinity River with the goal of assessing the effects of human activities, including fuels reduction and timber harvesting, on the physical, biological, and human processes within the mainstem Trinity watershed analysis area. This area includes the Trinity River and its tributaries from the Lewiston Dam downstream to the confluence of, but excluding, the North Fork Trinity River. The analysis was completed as part of the Land and Resource Management Plan (USFS, 1995). Recommendations relied heavily on documented sources and include projects related to the following areas:

- erosion processes and water quality
- hydrologic regime
- soil productivity
- riparian areas
- aquatic species and habitat
- vegetation
- fire
- vegetation
- wildlife and habitat
- socioeconomic
- heritage resources
- tribal trust resources
- timber production
- forest products
- recreation and transportation

Watershed analyses have been completed for approximately 70 percent of National Forest lands in the California portion of the Basin including two for the mainstem Trinity River (BLM, 1990; National Resources Management Corps ,2003), one for the upper Trinity River (USFS, 2005), and one for the Mazama watershed in the Chemult Ranger District of the Winema National Forest (USFS, 1996). These analyses identify opportunities that indirectly or directly relate to protection and restoration of aquatic habitats on National Forest system lands to promote recovery of ESA-listed salmonids.

A.10.3 Salmon Recovery Planning

This section summarizes literature related to past and continuing salmon recovery planning efforts. The Pacific Coast Management Plan (Pacific Fisheries

Management Council, 1997) outlined harvest controls and data needs for various salmonid species including those in the Klamath River Basin. Five amendments to the plan have been approved and adopted since the date of the original plan in 1997.

The NMFS summarized its primary activities in the Klamath Basin that have occurred over the 5 years preceding 2003 (the year in which the report was produced) as well as planned future activities as of 2003 (NMFS, 2003). These activities include:

- various ESA section 7 consultations related to projects in the Klamath Basin (over 250 from 1998-2003)
- consultations regarding essential fish habitat designated by NOAA (addressing salmonid species not listed under ESA)
- the NMFS Klamath Project BiOp (NMFS, 2010)
- FERC relicensing of the Klamath Hydroelectric Project
- activities through the Trinity River Restoration Program
- activities through the Klamath River Basin Conservation Area Program
- activities through Federal and State Coho salmon recovery plan efforts
- activities through the Five County Roads Program
- ESA section 4d rule regarding Tribal Resource Management Plans
- activities through the Simpson Habitat Conservation Plan
- activities by the Pacific Fisheries Management Council (as part of the Pacific Coast Salmon Plan – Pacific Fisheries Management Council, 1997).
- activities by the Klamath Fisheries Management Council
- activities through the Steelhead Restoration and Monitoring Program (McEwan and Jackson, 1996)
- activities through the Salmon River Learning and Understanding Group
- activities surround potential listing of the green sturgeon as threatened or endangered
- various restoration grant programs

The NMFS (2007) completed the Klamath River Coho Salmon Recovery Plan (and updated it in 2012 - NMFS, 2012) in accordance with the Magnuson-Stevens Reauthorization Act of 2006, which governs marine fisheries management in the U.S. The NMFS relied heavily on the existing recovery strategies developed by CDFG (2004b) and the State of Oregon for Coho salmon, incorporating substantial local stakeholder participation in its development of the plan. Several conclusions and outstanding needs from their planning report are summarized here (NMFS, 2007; NMFS, 2012):

- Resources and incentives are necessary to improve forestry practices, agricultural practices, remove artificial barriers, and curb potential habitat threats from urbanization in the Klamath River Basin.

- Funding for multi-year disease studies in the Klamath River Basin remains a critical resource need to allow more scientifically-supportable management decisions and enable effective habitat restoration actions.

- Despite the need for a basin-wide centralizing tool or instrument to guide, collaboratively coordinate, and prioritize monitoring, restoration, and research efforts, no such tool exists.

- Fundamental to the SONCC ESU Coho Salmon recovery plan developed under the ESA is a comprehensive “threats assessment.” The threats assessment, in conjunction with the population viability criteria and integrated with conservation and management actions underway, will facilitate the development of focused and prioritized recovery actions for SONCC ESU Coho Salmon.

- Two high priority action items include fish passage upstream of the Klamath River mainstem dams and full implementation of the Trinity River Restoration Program.

The NMFS produced reports to the Congress in 2009 and 2011 in accordance with the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006, which required NMFS to develop a recovery plan for Klamath River Coho salmon, Federal and California ESA listed species, as well as to report annually on other Klamath River anadromous fish species. In the first 2009 report (NMFS, 2009), NMFS reported on a number of completed or ongoing projects including:

- installation of a series of boulder step pools in place of the gravel push-up dams in a partnership between Scott Valley Resource Conservation District and local landowners

- developing the “Water Quality and Stream Habitat Protection Manual for County Road Maintenance in Northwestern California Watersheds” (NMFS-Southwest Region)

- purchase by the Nature Conservancy California Program of the 1,700-acre Nelson Ranch in 2005, which includes five miles of the Shasta River

- enhancing cover in the mainstem Klamath River and improving access at the confluence of tributary mouths by installing wood, willow, and brush structures and opening up access corridors, through a partnership between the Karuk Tribe and the Mid-Klamath Watershed Council

- removing three of the fish migration barrier dams in the Shasta Valley by the Western Shasta Resource Conservation District to facilitate unimpeded fish passage to upstream rearing habitat

- establishing the Scott River Water Trust to improve stream-flow in priority reaches of fish habitat through incentive-based voluntary leases with agricultural water users in the Scott Valley

- implementing the Indian Creek Trinity River Channel Rehabilitation Project in the summer 2007 to increase juvenile salmonid rearing habitat and reduce Trinity River flow impacts to homes and structures adjacent to the River

- implementing watershed-wide agricultural management best practices for salmonids and prioritize restoration efforts under the Shasta and Siskiyou Resource Conservation District’s Incidental Take Permit and the State’s Stream Bed Alteration Permit Programs (NMFS and CDFG, now CDFW)

- producing the draft SONCC ESU Coho Salmon recovery plan

- completing and implementing an Aquatic Habitat Conservation Plan in June 2007, through a partnership between the Green Diamond Resource Company, NMFS, and the USFWS

- developing TMDLs or the Klamath River in California by the North Coast Regional Water Quality Control Board

- release in January 2008 of the proposed KBRA

NMFS’ corresponding 2011 report (NMFS, 2011) included discussion of the following additional projects:

- completion of the Lower Klamath tributary restoration project by the Yurok Tribe which included tree planting in McGarvey and Terwer Creeks; expansion of the Yurok Tribe’s native plant nursery; and instream structure installation, bank stabilization, and off-channel pond construction in Terwer Creek

- constructing of off-channel ponds by the Mid-Klamath Watershed Council and Karuk Tribe
- removal of the Grenada Irrigation District diversion dam in 2011 through the Shasta River Fish Passage Project
- signature of the KBRA and KHSA

A.10.4 Habitat Conservation Planning

Habitat conservation plans are planning documents required as part of an application for an incidental take permit for non-federal parties. Incidental take refers to the unintended death of fish/animals/organisms by the implementation of an existing or proposed project. Habitat conservation plans describe the anticipated effects of the proposed taking, namely how those impacts will be minimized, or mitigated, and how the plan is to be funded. This section summarizes two habitat conservation plans that pertain to species residing in the Klamath River Basin.

The NMFS and the USFWS have held technical and policy discussions with Simpson Resource Company regarding the development of a habitat conservation plan under section 10(a) of the ESA for much of its industrial timber operations in northern California over the past three years. The draft habitat conservation plan was completed in 2002. The plan and its associated permits have a 50-year=term (Simpson Resource Company, 2002).

PacifiCorp (2012) issued a habitat conservation plan in part as a response to the NMFS BiOp in 2007 (NMFS, 2007) that incidental taking of endangered fish may be occurring as a result of Klamath Hydroelectric Project operations, but also in an effort to show their commitment to habitat conservation. The habitat conservation plan was intended to cover the interim operations period, prior to implementation of fish passage through either FERC relicensing or implementation of KBRA/KHSA. Strategy measures included actions such as improving access by Coho to important tributary areas downstream of Iron Gate Dam, improved research, monitoring, and operations at downstream fish hatcheries, flow management, gravel augmentation, and enhancing downstream water quality through modified hydropower operations.

A.10.5 Tribal Planning Activities

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. On August 28, 2012, the Karuk Tribe and the USFS signed a MOU regarding the land management of the Katimiin Cultural Management Area near Somes Bar, CA. The management strategies outlined in the MOU are consistent with both Karuk cultural environmental management practices and the Klamath National Forest Land and Resource Management Plan, which is administered by the Six Rivers National Forest (USFS, 1995). The Katimiin Cultural Management Area is where the Tribe's Pikyawish, or World Renewal, ceremonies are concluded each year (CDWR, 2013).

A.11 Climate Change Studies

This section summarizes previous studies or reports (and findings) that are either focused on climate change and impacts on the Klamath River Basin, or utilize climate change information to inform the study. This section is divided into three subsections and each includes a discussion of related studies. Subsections are namely: historical climate trends, projected climate change, and the Secretarial Determination Overview Report and EIS/EIR for dam removal (including a summary if climate change impacts discussions in these documents).

A.11.1 Historical Climate Trends

One important component of understanding changes in climate is to evaluate historical trends. Historical temperature trends over California's mid-pacific region show increases (Bonfils et al., 2007; spring temps, Cayan et al., 2001; winter temps Dettinger and Cayan, 1995;), while historical precipitation trends are not consistent. Moser et al. (2012) reported an average temperature increase by about 1.7°F from 1895 to 2011 over the State of California. Furniss et al (2012) found an increase of 0.2-1.5 °F for the Shasta-Trinity National Forest, when comparing means for 1991-2007 and 1961-1990. Over the same domain, Furniss et al (2012) found no apparent increase in precipitation variability, but an increase in winter (0.1 to 7.9 inches) and growing season precipitation (0.1-2.1 inches). Historical trends in snowpack and runoff over the same domain 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). Reclamation's report summarizing climate change impacts on the water resources of seven major western watersheds (the Klamath River Basin being one) found a weak to insignificant trend in Klamath River Basin runoff (Reclamation, 2011c). 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). However, the glaciers on Mount Shasta are among few in the world that are increasing in size (Furniss et al., 2012).

It should be noted that linear trends are dependent upon the time period of analysis and are a direct result of the combined influences of natural climate variability and climate change (Reclamation, 2011k). Attribution studies have aimed to distinguish the trends due to climate change versus trends due to natural climate variability (Bonfils et al. 2007; Cayan et al. 2001; Gershunov et al. 2009).

One study found that natural internal climate variability, and model-predicted responses to variability in solar irradiance and volcanic activity, cannot fully explain the increase in daily minimum and maximum temperatures, the sharp decline in frost days, and the rise in temperature-driven snowmelt over the Western United States for the period 1950-1999 (Bonfils et al., 2008).

Another study found that about half of the reductions in the fraction of annual precipitation falling as snow, observed in the Western United States from 1950 to 1999, are the result of anthropogenic climate changes (Pierce et al., 2008). Studies show that statistical significance of the anthropogenic signal in temperature is greatest over the scale of the Western United States, and weak or absent at the watershed scale (Reclamation, 2011k). Hidalgo et al. (2009) found statistically significant trends toward earlier streamflow center of timing (the date at which 50 percent of annual streamflow has passed) since 1950 over the Columbia River Basin, and these trends are detectably different from natural variability. The strongest changes in winter runoff and the fraction of precipitation accumulated as snow have occurred at medium elevations (750–2500 m and 500–3000 m, respectively) close to the freezing level and these are not likely to be associated with natural variability. Attribution of any apparent trends in precipitation due to climate change remains difficult (Hoerling et al. 2010). Further, Villarini et al. (2009) found no monotonic temporal patterns of the annual maximum instantaneous peak streamflow for 50 USGS streamflow gage sites in the United States, in part due to the significant influence of river regulation and land use change in these watersheds.

A.11.2 Projected Climate Change

The Intergovernmental Panel on Climate Change (IPCC) summarizes the state of science on climate change and related impacts on a cycle of about every seven years. Projections of future climate impacts have been utilized in assessments for the Klamath River Basin, and beyond, since the third IPCC assessment in 2001. Hayhoe et al. (2004) evaluated the range of climate projections from the lowest to highest emissions scenarios, summarized in the IPCC's Fourth Assessment Report (IPCC, 2007). The Fourth Assessment Report is based on results from the Coupled Model Intercomparison Project (CMIP) Phase 3 (Meehl et al., 2007). They found that that annual temperature increases over California nearly double from the lower B1 to the higher A1fi emissions scenario before 2100 and that increases in summer temperatures are greater than winter. Furniss et al. (2012) project an increase in mean annual temperature of 0.1 to 6.3°F for a 2030-2060 future period, compared with 1950-2006.

There is generally more confidence in projections of temperature over precipitation (Reclamation, 2011k). Findings for California suggest less snowfall and more rainfall, less snowpack development and earlier runoff, more intense and heavy rainfall interspersed with longer dry periods (CBO 2009; Lundquist et al., 2009; Moser et al., 2009; Rauscher et al., 2008; Maurer, 2007). Projections of climate change over the Klamath River Basin are geographically complex. Projected increases or decreases in cool season precipitation could somewhat offset or amplify changes in snowpack; however, it is apparent that the projected warming in the Klamath River Basin tends to dominate projected effects (Reclamation, 2011c). Seasonal shifts toward earlier seasonal peak streamflows are also projected, as illustrated through the results for five locations in the Klamath River Basin in Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2011d). Null et al., 2010 also projected increases in vegetation ET.

Climate change could affect the frequency or severity of ENSO events, which would change precipitation patterns in the Klamath Basin (Kiparksy and Gleick, 2003). In addition, the Klamath Basin is at the southern edge of a low-pressure cell during ENSO events, with the primary effect being a shift of storms southward towards southern California. Climate change could move the low pressure area northward, which could change the types of El Niño/southern oscillation (ENSO) effects within the Basin from producing a drier winter to producing more intense winter storms (Interior and CDFG, 2011).

Risley et al. (2012) and Markstrom et al (2011) evaluated climate change impacts on streamflow in the Sprague River Basin. The authors applied downscaled climate projections from five global climate models and three emissions scenarios, upon which IPCC's Fourth Assessment Report is based. Mean annual projections in streamflow are highly variable with the range in projections showing both increases and decreases in mean annual streamflow and other water balance variables. Their results showed no discernible trend in annual streamflow, but winter streamflow was expected to increase and peak streamflow was projected to shift one month earlier. The Oregon Climate Assessment Report (OCCRI, 2010) produced by the Oregon Climate Change Research Institute, summarized climate change impacts on various sectors within the State of Oregon (using climate scenarios summarized in the IPCC Fourth Assessment Report). Key findings for general Statewide changes include a decrease in summer water supply as a result of reduced snowpack and summer precipitation. Availability, quality, and cost of water will likely be the most limiting factors for agricultural production systems under a warmer climate. Other important sectors that are likely to experience impacts include the coastal zone, forests, plant and animal species, and the economy.

Moser et al. (2012) summarized impacts from the Third Climate Change Assessment for California. In addition to summarizing general climate change impacts, it focused on reducing vulnerabilities to climate change, for example by water conservation. The study stated that many of California's 121 native freshwater fish species are already in decline and are particularly vulnerable to climate change, with 83 percent being at high risk of extinction as the climate changes.

The National Center for Conservation Science and Policy provided a summary of climate change impacts for the Klamath River Basin based on downscaling and modeling by the Mapped Atmosphere-Plant-Soil System team at the USFS' Pacific Northwest Research Station. Projections of precipitation and temperature are consistent with other regional studies, namely indicating warmer temperatures and reductions in snowpack, but an uncertain picture with respect to precipitation. This report also provides a summary of potential adaptation strategies, developed with stakeholder input (National Center for Conservation Science & Policy, 2010). Koopman et al. (2009) summarized the same climate projections, but in more detail.

With respect to management, a number of studies have investigated the implications of climate change on water management of the region, suggesting management of reservoir systems would become more challenging (Lettenmaier et al., 2008; Vicuna and Dracup, 2007). An impacts study by Harou et al. (2010) indicates the impacts to be expensive but not catastrophic for California. Baldocchi and Wong (2006) found that projected temperature and CO_2 increases may extend growing seasons, stimulate weed growth, increase pests, and may impact pollination. Available studies suggest significant increases in irrigation demands for corn and alfalfa, and increases in water demand due to crop failures caused by pests or disease (Reclamation, 2011k).

In addition, an increasing number of studies have investigated the impacts of climate change on fish, wildlife, and habitat. Using findings from previous studies and information from the IPCC Third Assessment Report, Fick et al. (2006) cited the general likely effects of climate change on freshwater systems will be increased water temperatures, decreased dissolved oxygen levels, and the increased toxicity of pollutants. Studies show adverse impacts to fish species due to increased summer temperatures, changes in flood frequency or intensity, and increased wildfires and related sediment issues (Williams, 2009 and Haak et al. 2010). Wetlands habitats will likely see diminished native biodiversity due to the stresses of climate change, much like they have due to other existing stresses such and land use change and habitat degradation (Allan et al., 2005). Increasing temperatures may exacerbate invasive species issues (Reclamation, 2011k) and affect water quality. Climate change may also impact the productivity and growth of forest species. A number of studies have documented increases in wildfire fire season duration and fire frequency (Westerling et al., 2006) and project increases in the probability of large wildfires (Brown et al., 2004). Climate change may also trigger synergistic effects in ecosystems through complex interactions (Allen, 2007).

Stream temperatures in many areas are increasing due to air temperature increases and reduced summer flows that make streams more sensitive to warmer air temperatures (Haak et al. 2010). The authors of this study summarized general impacts of climate change on various salmonid species of the inland Western United States. They suggested policy makers consider adjusting management strategies to accommodate a warmer and possibly drier future.

Flint and Flint (2012) used a regression modeling approach simulating net solar radiation, vapor density deficit based on air temperature, and mean daily air temperature. The study evaluated temperature effects at six sites in the Lower Klamath Basin and 18 sites in the upper Klamath Basin. Study results showed a projected mean change of 1.2°C from the baseline historical period of 1950–99 to the projected future period of 2070–99, with a range from 3.4°C for the Shasta River to no change for Fall Creek and Trout Creek. Also, the baseline historical period mean temperature (1950-1999) was about 2.3°C cooler than the historical period used for model calibration (1999-2008), indicating that warming conditions have already occurred in many areas of the Klamath River Basin. The authors of this study also acknowledged that the existing decision support system models for the Secretarial Determination process, namely SIAM/SALMOD (Bartholow et al., 2005), need to be migrated to a more advanced modeling framework for the future. They also argue that air and stream temperatures are dominant drivers for water-quality simulations for decision support systems for addressing potential effects of dam removal in the Klamath Basin.

The USFWS (2012) released its draft climate adaptation strategy in early 2012. This report summarized nine principles to guide adaptation, including collaborating across all levels of government, working with non-government entities such as private landowners and other sectors like agriculture and energy, and engaging the public. They also stated that it is crucial to carefully monitor actual outcomes in order to adjust future actions to make them more effective, an iterative process called adaptive management.

Furniss et al. (2012) reports on pilot vulnerability assessments, performed by eleven National Forests from throughout the U.S., related to the impacts of change on forest and aquatic species. One pilot assessment evaluates the relative risk of impact from climate change to aquatic resources and infrastructure on the Shasta Trinity National Forest. This assessment considered increase in water temperature considered the primary risk to aquatic species and habitat. The assessment provides a preliminary list of management actions to improve resiliency to ongoing and projected climate change in this National Forest. PRBO Conservation Science (2011) summarized climate change impacts on California's ecoregions. The Klamath River Basin intersects California's Northwestern and Cascade Range ecoregions. Projections (based on IPCC's Fourth Assessment Report) include mean annual temperature increases of 1.7 to 2.2°C by 2070, a decrease in mean annual rainfall from 7 percent to 32 percent, a decrease in snowpack accumulation by about 70 percent, and reduction in instream flows, among others.

National Research Council (2012) summarized past and projected sea-level rise for the coasts of California, Oregon, and Washington. It states that sea level is likely to rise at a greater rate during the 21st century than it has over the 20th century. This study reports that northern California may experience sea level rise of 37.3–76.1cm by 2100 (compared with 2000).

The IPCC Fifth Assessment Report (associated with CMIP5) was to be completed in late 2013 to early 2014. When complete this assessment will take advantage of more sophisticated and higher resolution earth system models and will take a different approach to scenarios of future emissions (Taylor et al., 2012). Although the Fifth Assessment Report is not yet complete, the model projections are already available. The Basin Study aims to take advantage of these new projections, while using studies based on Fourth Assessment projections for comparison.

A.11.3 Secretarial Determination Overview Report and EIS/EIR for Dam Removal

The Secretarial Determination Overview Report (Interior et al., 2012) and the EIS/EIR for proposed dam removal rely on many of the same sources for their summaries of project impacts of climate change on water quantity (surface and groundwater) and quality in the Basin. The analysis of climate change impacts relied primarily on the following sources:

- the second National Climate Assessment produced by the United States Global Climate Change Research Program (US Global Climate Change Research Program, 2009)
- The Washington State Climate Change Impacts Assessment, which includes climate projections for the Pacific Northwest region including part of the Klamath River Basin (Salathe et al. 2010)
- Preparing for Climate Change in the Klamath Basin, a report by the National Center for Conservation Science and Policy and the Climate Leadership Initiative (Barr et al., 2010)
- Report on Regional climate change effects: useful information for transportation agencies (Federal Highway Administration, 2010)
- Oregon Climate Assessment Report (OCCRI, 2010)
- Hydrology, Hydraulics, and Sediment Transport Studies for the Secretary’s Determination on Klamath River Dam Removal and Basin Restoration (Reclamation, 2011i)

A summary of general projections are provided for both reports, followed by more specific summarized impacts on proposed alternatives in the EIS/ Environmental Impact Report (EIR). Numerous climate change models predict that air temperatures in the Pacific Northwest and the Klamath River Basin will increase by approximately 1.1 to 2.2°C (2 to 4°F) over the next 50 years and by approximately 2.2 to 3.9°C (4 to 7°F) by the end of the century.

By the end of the 21st century, projections in the Klamath River Basin exhibit a wide range of annual precipitation changes, from an 11 percent reduction to a 24 percent increase, depending on the climate model. Similar to other studies, these sources project reduced snowfall and increased precipitation falling as rain, resulting in earlier and higher winter and spring (December - March) streamflows and lower late spring and summer flows.

Projected changes to groundwater hydrology under climate change may also decrease late summer stream flows in the Klamath River Basin, including alterations of the timing and amount of recharge, increases in ET, declines in the groundwater table, and increases in pumping demand. In general, an increased risk of watershed vegetation disturbance is anticipated due to increased wildfire potential.

Climate change will likely produce warmer water temperatures and earlier spring runoff. Stream temperature modeling results, including climate change, indicate that the annual temperature cycle downstream of Iron Gate Dam would shift earlier by approximately 18 days within the first year following dam removal, with 1–2°C warmer temperatures in spring and early summer and up to approximately 4°C cooler temperatures in late summer and fall immediately downstream of the dam (Perry et al., 2011). The return of cooler water temperatures during the late summer and early fall will more closely mimic natural daily and seasonal conditions favorable to support rearing, migration, and earlier spawning and incubation for anadromous salmonids, particularly fall-run Chinook salmon. Additional impacts to water quality in the Klamath Basin may include the following (Barr et al., 2010):

- Decreased and fluctuating dissolved oxygen content from more rapid cycling of detritus
- Increased nutrients, turbidity and organic content from increased runoff and wildfire
- Earlier, longer, and more intense algae blooms due to warmer water temperatures and increased nutrient availability.

The Secretarial Determination Overview Report (Interior et al., 2012) suggests that dam removal with KBRA implementation could improve ecosystem resilience to climate change by offsetting a variety of anticipated impacts such as decreased summertime flow, increased water temperature, and negative effects on water quality, and would therefore be a benefit to aquatic species in the Klamath Basin. Dam removal would also provide thermal refuge from generally increasing water temperatures under climate change by allowing fish to access mainstem cold groundwater springs and spring-dominated tributaries in the Upper Klamath Basin.

The analysis related to climate change in the EIS/EIR (Interior and CDFG, 2011) was organized into two categories, namely the impact of climate change on the Proposed Action, and the quantification of projected greenhouse gas emissions. This summary focuses on climate change impacts on the Proposed Action. As previously mentioned, the summary of projected impacts in the EIS/EIR relies on the same sources as described in the Secretarial Determination Overview Report. Impacts of climate change on the system, assuming no action, is likely to reduce or possibly eliminate thermal refugia, making the temperature in the mainstem of the river unsuitable for fish rearing and movement during critical times of the year. In addition, under no action, the system would likely be less capable of responding to or absorbing changed flow regime. Warmer water temperatures associated with climate change could increase the frequency and duration of stressful water temperatures for cold-water species, including all anadromous fish and salmonids in the basin.

The most relevant consequences of climate change related to the Proposed Action (i.e., full dam removal) include changes to stream flow; temperature, precipitation, groundwater, and vegetation changes; and flow. The Proposed Action would begin to offset these projected changes.

Benefits include:

- additional floodplain and riparian zone to reduce peak flooding impacts
- improved water quality by removing large quiescent water areas that are subject to temperature increases and evaporation
- increased woody debris and restored natural sediment budget to improve in-channel habitat diversity
- more available stream channel habitat
- a migration corridor for fish to move further upstream to find cooler water
- access to the largest concentration of cold springs and spring dominated tributaries in the Klamath Basin
- improved habitat quality, water quality, and riparian and floodplain functionality in and above UKL.

A.12 Data

This section summarizes data collection and evaluation efforts in the Klamath River Basin. Risley and Gannett (2006) evaluated water-use estimates for the Lower Klamath and Tule Lake NWRs based on two approaches, one using evaporation and ET estimates, and the other using measured inflow and outflow data. They also assessed the quality of the inflow and outflow data, including streamflows at the Ady Canal at State Line Road, Klamath Straits Drain at State Line Road, and D Pumping Plant. On the basis of USGS flow-record criteria, all three flow records were rated as “poor” because 95 percent of the daily flows in the record could be in error by more than 15 percent.

Risley et al. (2006) evaluated records of diversion and return flows for water years 1961 - 2004 along a reach of the Klamath River between Link River and Keno Dams in south-central Oregon to determine the cause of a water-balance inconsistency in the hydrologic data. This study was prompted by a 2005 USGS assessment of Reclamation’s Klamath Pilot Water Bank Program that found inconsistencies in the river and canal flow records from sites along the Klamath River between Klamath Falls and Keno, Oregon, for water years 1961–2004. Risley et al. (2006) found the most likely cause of the water-balance inconsistency was flow measurement error in the eight non-USGS flow records. This resulted in the data showing that this reach was losing flow in the 1960s and 1970s and gaining flow in the 1980s and 1990s. With the exception of the USGS Klamath River at Keno record, which was rated as “good” or “excellent,” the eight other flow records, all from non-USGS flow-measurement sites, were rated as “poor” by USGS standards.

The Off-Project Water Program, one component of the KBRA, has, as one of its purposes, to permanently provide an additional 30,000 acre-feet of water per year on an average annual basis to UKL through “voluntary retirement of water rights or water uses or other means as agreed to by the Klamath Tribes, to improve fisheries habitat, and also provide for stability of irrigation water deliveries.” The Off-Project Water Program area is defined as including the Sprague River drainage, the Sycan River drainage downstream of Sycan Marsh, the Wood River drainage, and the Williamson River drainage from Kirk Reef at the southern end of Klamath Marsh downstream to the confluence with the Sprague River. Irrigation in the Off-Project area is used almost entirely for pasture. To assist parties involved with decision-making and implementation of the Off-Project Water Program, the USGS, in cooperation with the Klamath Tribes and other stakeholders, created five hydrological information products. These products include Geographic Information System (GIS) digital maps and datasets containing spatial information on ET, subbasin irrigation indicators, water rights, subbasin streamflow statistics, and return-flow indicators (Snyder et al. (2012).

Watercourse Engineering (2012) completed a water quality sampling annual report as part of an interagency cooperative effort outlined in the KHSA to characterize water quality conditions in the Klamath River Basin. The program was implemented in 2010 and this was the first year of cooperative monitoring, which continues today. Sampling sites include the Klamath mainstem USGS gage locations, numerous other mainstem Klamath River sites, and major tributary sites (24 in total).

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Appendix B - Supplemental Information for Assessment of Water Supply

B.1 Introduction

Appendix B for Chapter 3 – Water Supply Assessment of the Klamath River Basin Study (Basin Study) summarizes additional details of the approach for the water supply assessment. The sections of this appendix include discussions of climate projections and associated derivation of ensemble hybrid delta (HDe) climate change scenarios, approach details for use of the Variable Infiltration Capacity (VIC) surface water hydrology model for assessment of surface water supplies, and approach details for use of the Upper Klamath Basin U.S. Geological Survey's (USGS) three-dimensional Finite-Difference Groundwater Model (MODFLOW) groundwater model and development of statistical groundwater screening tools for the Scott and Shasta Valleys, both of which are used or assessment of groundwater supplies.

B.2 Climate Projections

In general, Basin Studies such as the Klamath River Basin Study, rely on data and modeling from Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2011d). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 Western United States that fall within Reclamation's management domain. The projections developed through the WWCRA were statistically downscaled in space from General Circulation Model (GCM) grid resolution to 1/8th degree. This database of projections is based on GCM simulations compiled by the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP).

The downscaled projections may be accessed through the following website: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html. Among the available climate and hydrologic projections available on the above-mentioned website, there are monthly bias-correction and spatial disaggregation (BCSD) projections of precipitation and temperature, which are utilized in the Klamath River Basin Study. Bias correction generally involves correcting systematic errors in GCM historical simulations based on finer scale observed data. Spatial disaggregation generally involves translating coarse scale GCM simulations to the 1/8th degree spatial resolution. Projections based on CMIP

Phase 3 (CMIP3) and CMIP Phase 5 (CMIP5) are both included in the analysis of future water supply impacts in the Klamath River Basin and are further described below.

CMIP3 projections (Meehl et al., 2007) are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), completed in 2007 (IPCC, 2007). Generally, climate projections are based on an assemblage of GCM simulations of coupled atmospheric and ocean conditions, with a variety of initial conditions of global ocean – atmosphere system and distinct “storylines” about how future demographics, technology and socioeconomic conditions might affect the emissions of greenhouse gases. There are four families of emissions scenarios (A1, A2, B1, and B2 – described in the IPCC Special Report on Emissions Scenarios,[SRES], Naki´cenovi´c, 2000), in which the scenarios are potential futures based on assumptions of global economic activity and growth. Projected global warming associated with CMIP3 SRES scenarios is shown in the left panel of figure 3-A1. Projections based on three CMIP3 emissions scenarios are available via the website mentioned above (A1B, A2, B1) and are used as a basis for the Basin Study projected climate scenarios.

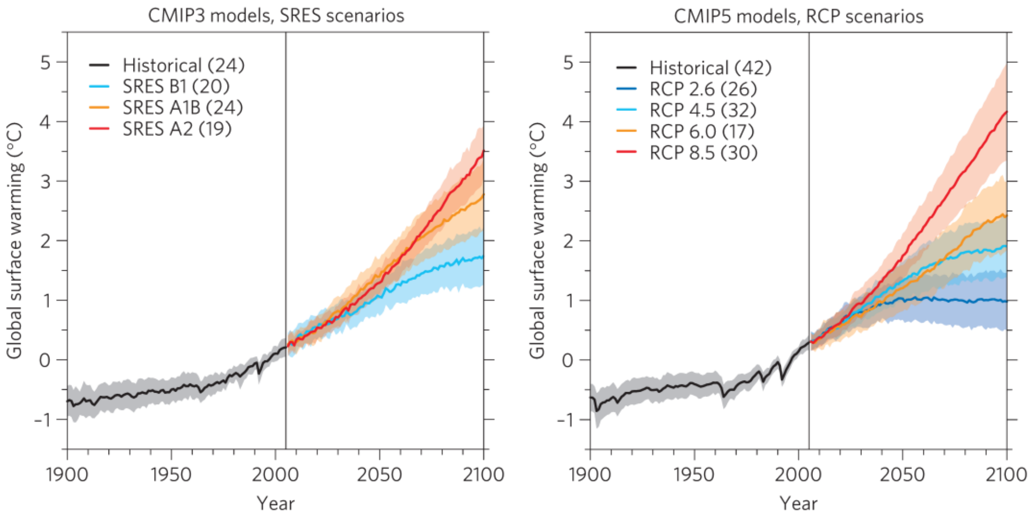

Figure B-1.—Figure 1 from Knutti et al (2012) Global temperature change (mean and one standard deviation as shading) relative to 1986–2005 for the SRES scenarios run by CMIP3 and the RCP scenarios run by CMIP5. The number of models is given in brackets. The box plots (mean, one standard deviation, and minimum to maximum range) are given for 2080–2099 for CMIP5 (colors) and for the MAGICC model calibrated to 19 CMIP3 models (black), both running the RCP scenarios.

CMIP5 projections are similar in concept but incorporate improvements in modeling and physical understanding of the Earth system since the CMIP3 effort. These simulations have been available since early 2011 and have been increasingly used in climate change impacts studies, alongside those from CMIP3.

The corresponding IPCC Fifth Assessment Report was completed in 2013. These GCMs rely on greenhouse gas storylines called Representative Concentration Pathways (RCP). Each RCP is representative of a particular amount of radiative forcing (2.6, 4.5, 6.0, and 8.5 W/m^2 respectively) occurring by the year 2100. The right panel of figure B-1 illustrates projected global warming according to the CMIP5 RCP scenarios. The figure shows that the range of emissions scenarios considered by CMIP5 result in a greater range projected global warming than by CMIP3 emissions scenarios. Additional comparisons between CMIP3 and CMIP5 are discussed in section – Comparison between CMIP3 and CMIP5. The website identified above contains 112 BCSD downscaled CMIP3 projections and 234 BCSD CMIP5 projections, among other available products. Projections based on four CMIP5 emissions scenarios are available via the website mentioned above (RCP2.6, RCP4.5, RCP6.0, RCP8.5) and are used as a basis for the Basin Study projected climate scenarios.

B.2.1 Deriving Climate Change Scenarios from Climate Projections

The Basin Study primarily utilizes climate scenarios that are derived using an ensemble informed 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. This method is described in detail below.

The HDe 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 Basin Study utilizes an ensemble of climate projections based on both CMIP3 and CMIP5.

The ensemble informed 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.

The development of HDe scenarios entails three primary steps. These steps include:

1. generation of statistically downscaled monthly time series of precipitation and temperature at the spatial resolution of the model(s) to be used in the Basin Study water supply assessment

2. development of ensembles of projections that inform the HDe scenarios
3. generation of HDe scenarios using statistical mapping of future projections onto historical data

The first component in development of HDe scenarios involves removing the systematic biases in the individual GCM projections at the spatial scale of the GCM, and then spatially disaggregating the result to the spatial scale of the regional modeling efforts. This step is referred to as the bias-correction and spatial disaggregation (BCSD) approach. This step has been performed as part of Reclamation's WWCRA and the monthly timeseries of precipitation and temperature, described as the result of this step, are available in the data archive.

The second component in development of HDe scenarios involves defining the ensemble(s) of climate projections that will inform the scenarios to be considered in the study. 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, ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions were chosen for a total of five ensembles of climate scenarios. These are namely, warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT).

For each scenario, change in mean annual temperature (degrees Fahrenheit [°F]) and precipitation (percent) is calculated between the base period, 1970-1999, and future time horizons. The Basin Study considers two future time horizons, the 2030s (2020-2049) and the 2070s (2060-2089). Change in mean annual precipitation is plotted against change in mean annual temperature to generate plots such those illustrated in figure B-2. Panels (a) and (b) illustrate changes based on CMIP3 projections for the 2030s and 2070s, respectively. Panels (c) and (d) illustrate changes based on CMIP5 projections for the same time periods. Notice that there are 112 dots in each of panel (a) and (b), representing the number of available individual GCM projections from CMIP3, while there are 234 dots in each panel (c) and (d), representing the number of available individual GCM projections from CMIP5.

The ensemble scenarios representing five quadrants of change (WW, WD, HW, HD, CT) are developed by selecting the 10 individual climate projections that fall closest to the intersections of the 10th, 50th (median), and 90th percentiles of change[3]. The 10th, 50th, and 90th percentile lines are illustrated by red (10th and 90th) and black lines (50th) in the figures. The figures show the selected individual climate projections for each quadrant (WW=purple, WD=blue, HW=orange, HD=green, CT=yellow).

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[3] The distance between plotted precipitation and temperature change and the 10th, 50th, and 90th percentile change values was computed using the Mahalanobis distance.

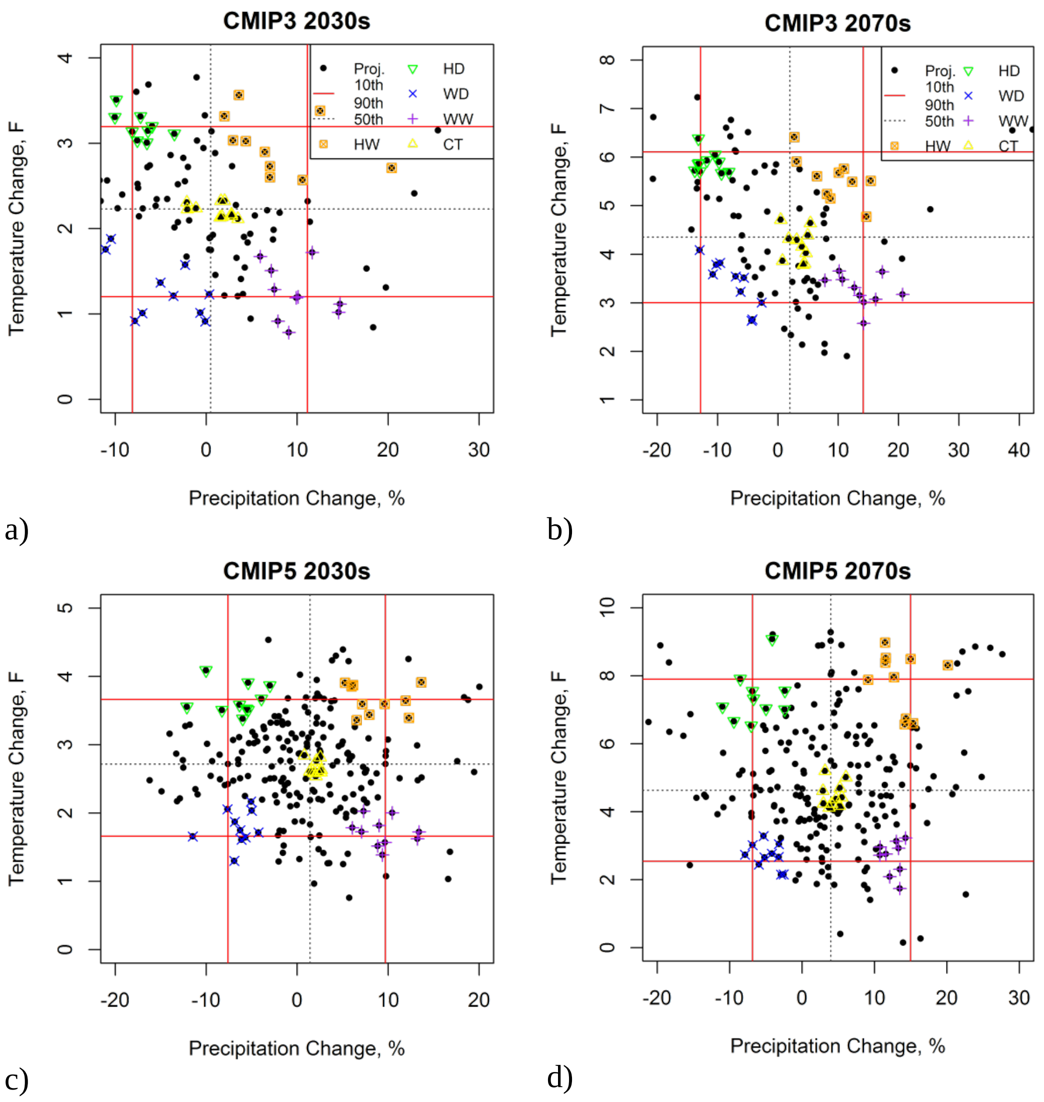


Figure B-2.—Change in mean annual temperature (°F) versus percent change in mean annual precipitation between the 2030s and historical (panels a and c) and 2070s and historical (panels b and d). The top row (panels a and b) illustrate projected changes using statistically downscaled CMIP3 GCM simulations, while the bottom row (panels c and d) illustrate projected changes using statistically CMIP5 GCM simulations.

The third component of the development of HDe scenarios involves generating perturbed historical timeseries, informed by the pooled projections (10 nearest neighbors) for each of the five defined quadrants of change. Monthly data for a future time horizon (for example, the 2030s), at each 1/8th degree grid cell location, are segregated into individual calendar months (i.e., all the Januarys, Februarys, etc.) and these data are then ranked from highest to lowest value. In this step, all 10 ensemble members in each quadrant are lumped together resulting in a single cumulative distribution function.

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 the future conditions. The entire observed time series of temperature and precipitation at each 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.

HDe scenarios have a number of distinguishing features, which have their 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).

Table B-1 summarizes projected precipitation and temperature using the HDe approach for the two future time periods of the study, namely the 2030s and 2070s. The table includes both CMIP3 and CMIP5 based projections for the five quadrants of change described above.

Table B-1.—Projected Change in Mean Annual Basin Wide Temperature and Precipitation for 5 Quadrants of Change, Two Future Time Periods, and for Both CMIP3 and CMIP5 Based Climate Change Scenarios

Scenario	Period	BCSD Projection	Projected Change in Basin Mean Temperature (°F)	Projected Change in Basin Mean Precipitation (%)
Simulated Historical	1950-1999	-	45°F	37 inches
Hot Dry	2020-2049	CMIP-3	+3.2	-6.2
Hot Dry	2060-2089	CMIP-3	+5.8	-9.8
Hot Dry	2020-2049	CMIP-5	+3.7	-5.0
Hot Dry	2060-2089	CMIP-5	+7.4	-5.1
Hot Wet	2020-2049	CMIP-3	+3.0	+9.6
Hot Wet	2060-2089	CMIP-3	+5.5	+11.4
Hot Wet	2020-2049	CMIP-5	+3.7	+10.3
Hot Wet	2060-2089	CMIP-5	+7.9	+15.4
Central Tendency	2020-2049	CMIP-3	+2.2	+2.4
Central Tendency	2060-2089	CMIP-3	+4.2	+5.2
Central Tendency	2020-2049	CMIP-5	+2.7	+4.1

Table B-1.—Projected Change in Mean Annual Basin Wide Temperature and Precipitation for 5 Quadrants of Change, Two Future Time Periods, and for Both CMIP3 and CMIP5 Based Climate Change Scenarios

Scenario	Period	BCSD Projection	Projected Change in Basin Mean Temperature (°F)	Projected Change in Basin Mean Precipitation (%)
Central Tendency	2060-2089	CMIP-5	+4.5	+6.1
Warm Dry	2020-2049	CMIP-3	+1.3	-2.6
Warm Dry	2060-2089	CMIP-3	+3.4	-5.5
Warm Dry	2020-2049	CMIP-5	+1.8	-3.9
Warm Dry	2060-2089	CMIP-5	+2.7	-2.8
Warm Wet	2020-2049	CMIP-3	+1.3	+11.8
Warm Wet	2060-2089	CMIP-3	+3.2	+15.9
Warm Wet	2020-2049	CMIP-5	+1.7	+10.4
Warm Wet	2060-2089	CMIP-5	+2.7	+13.9

B.2.2 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, provide 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.

To develop a long-term understanding of drought variability across North America, Cook et al. (2004) developed an extended record of summer time Palmer Drought Severity Index (PDSI) 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) time-series (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 Basin Study water supply assessment, a representative grid location (see figure B-3) 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 north and longitude 120.0 degrees west. It is shown by a green triangle in figure B-3. The PDSI time-series used from this grid extended from 1400-1999.

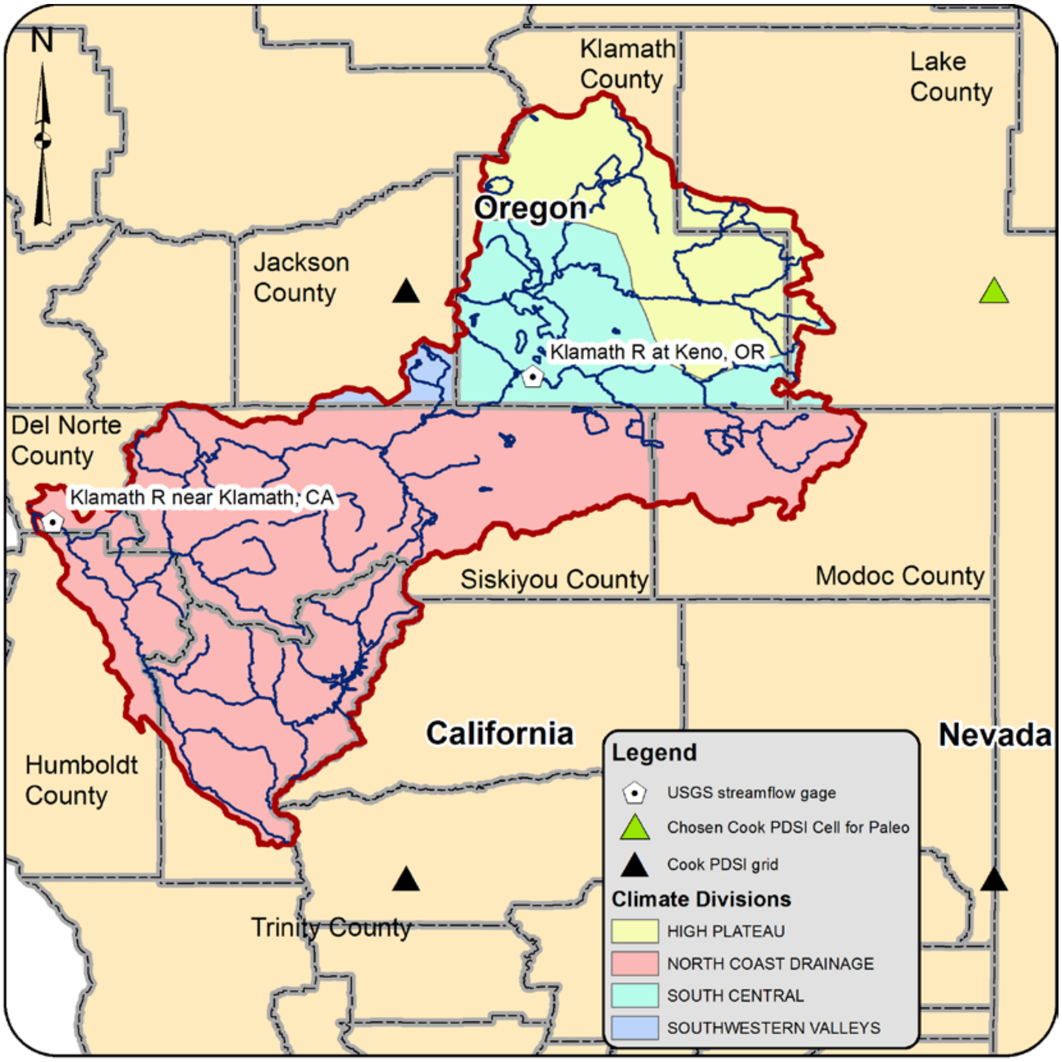


Figure B-3.—Overview map of the Klamath River Basin with respect to the Cook PDSI grid and two USGS streamflow gages used in the analysis of paleo-hydrology: Klamath River near Klamath, CA, and Klamath River at Keno, OR.

To understand the time-varying nature of wet and dry spells, a set of transient (i.e., changing with time, or time varying) transition probabilities was estimated. Transition probabilities provide estimates of probability when a system (in this case the regional hydrology) shifts from one state to another. So, prior to estimating transition probabilities, a definition of hydrologic states is required. 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). Given these PDSI state definitions, the time-series from 1400-1999 can be represented as a binary time series (i.e., a time-series of zeros and ones). Next, with this binary time-series it is possible to count using a moving window of specified length in time units, the fraction of times when the system – hydrologic conditions in the Klamath River Basin shifted from a dry state to a dry state (dry-dry), dry to wet (dry-wet), wet to dry (wet-dry) and wet to wet (wet-wet) states.

Prairie et al. (2008) provides an algorithm to develop the transient transition probabilities, and this approach was used in the Klamath River Basin Study. The overall concepts in this algorithm are described in the previous paragraph, and the algorithm provides a measure to select the optimal time window width to be used through a cross-validation step.

The estimated two-state transient transition probability for the Klamath River Basin using the representative PDSI grid is shown in figure B-4. The key finding from this figure is that the system goes through periods where the transition from one state to another is higher or lower than in another period. For example, in the 18th century, the probability of the hydrologic state switching from a dry to a wet state ranged between 0.6 and 0.7. That is, if the system was in a dry state, there was a 60-70 percent chance that the system would move into a wet state. Similarly, in the 19th century, the same transition probability, dry-wet, drops to a range between 0.45 and 0.50. This type of variability is intuitive as the climate system cycles through time, large-scale climate conditions, such as ENSO and Pacific decadal oscillation (PDO) phases impact the basin scale dry and wet regimes.

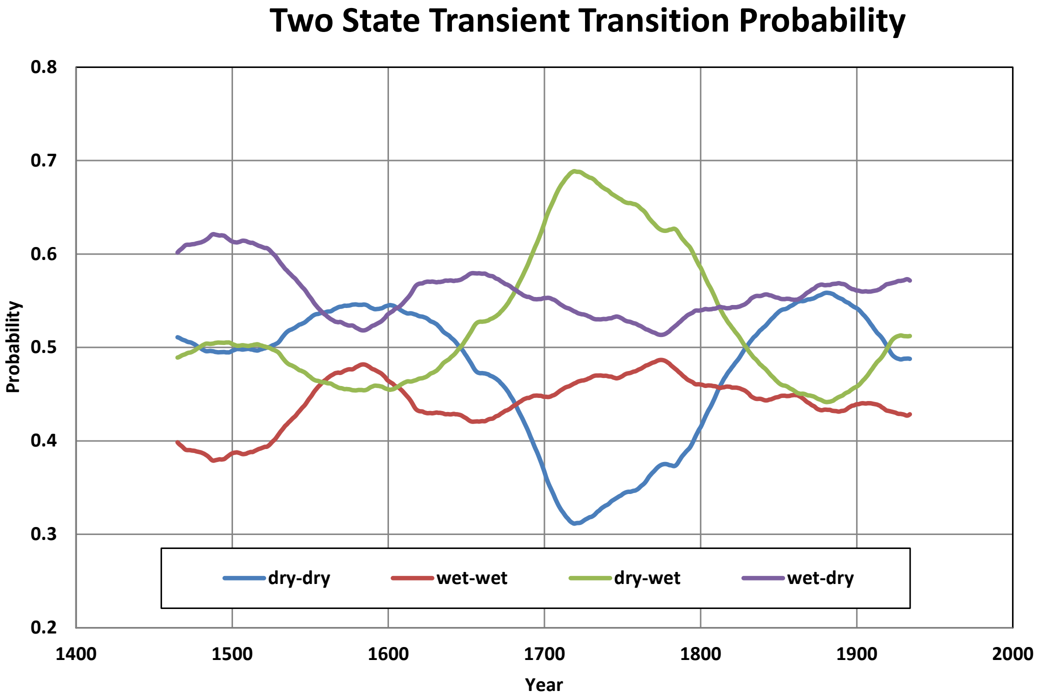


Figure B-4.—Two state transient transition probability.

This transient transition probability framework thus provides an opportunity to develop a rich variety and distribution of hydro-climate states which can be analyzed to develop system condition metrics. Specifically, a sequence of flows can be resampled using the transient transition probabilities (refer to figure B-4) to derive surplus, and drought statistics. In order to derive the drought (surplus) statistics, a set of flow values is necessary. Figure B-3 shows two key streamflow gage locations in the main stem of the Klamath River. Several sets of simulated flows for these gage locations were developed using the VIC hydrologic model (including several other locations as part of the water supply assessment). These simulated flow time-series include:

- one historical 50-year (1950 1999) simulated flow;
- flows for five quadrant HDe climate scenarios corresponding to the 2030 period based on CMIP3;
- flows for five quadrant HDe climate scenarios corresponding to the 2070 period based on CMIP3;
- flows for five quadrant HDe climate scenarios corresponding to the 2030 period based on CMIP5;
- flows for five quadrant HDe climate scenarios corresponding to the 2070 period based on CMIP5;

for a total of 21 flow simulations. Note that, since the approach adopted for the assessment of future climate impacts uses a period change methodology (HDe), all the climate adjusted flow time series are also 50 years long. Given this set of 21 flow simulations, it is possible to resample the flow magnitudes conditioned on the transient transition probabilities. Fundamentally, given a starting system state, dry (wet), a sequence of states can be generated based on the transition probabilities shown in figure B-4. After generating the system state, flow magnitudes can be assigned corresponding to each of the flow simulations. The actual implementation algorithm used in the resampling process is a bit more nuanced, and the reader should refer to section 3.3 in Prairie et al. (2008).

Following the process described above, a set of 1,000 simulations/realizations, each 50 years long, was developed for each of the cases. Subsequently, each case was analyzed to develop drought and surplus statistics. As an example, consider the case where the historical simulated flow magnitudes are rearranged based on the transient transition probabilities. The historical sequence of flows is a single realization of a stochastic process, and the stochastic process here is guided by the sequences (a string of wet and dry years) generated using the transient transition probabilities. Essentially, the same historical flow magnitudes, but coming up in an order different from the historical timeseries.

The drought and surplus statistics estimated for each of the cases includes a set of four statistics: 1) length of surplus, 2) length of drought/deficit, 3) surplus volume, and 4) deficit volume. The threshold used to define drought (surplus) is the median of the simulated historical flow. Also, surplus and deficit volumes are computed over the length of the events. Subsequent discussions are based on simulated flows for the Klamath River near the Klamath, CA, USGS gage (refer to location in figure B-3).

Figure B-5 provides an example of the paleo-conditioned historical case, and presents the distribution (shown as a boxplot) of four statistics – (1) average length of surplus (AvgLS), (2) average length of drought (AvgLD), (3) average surplus volume (AvgS), and (4) average deficit (AvgD) estimated from the 1,000 realizations. The historical case is shown as a triangle. The box in the boxplot represents the quantiles corresponding to the 25th and 75th percentiles. The horizontal line within the box is the median (50th percentile) and the whiskers correspond to the 5th and 95th percentiles. Outlier values (values outside the 5th and 95th percentiles) are shown by open circles.

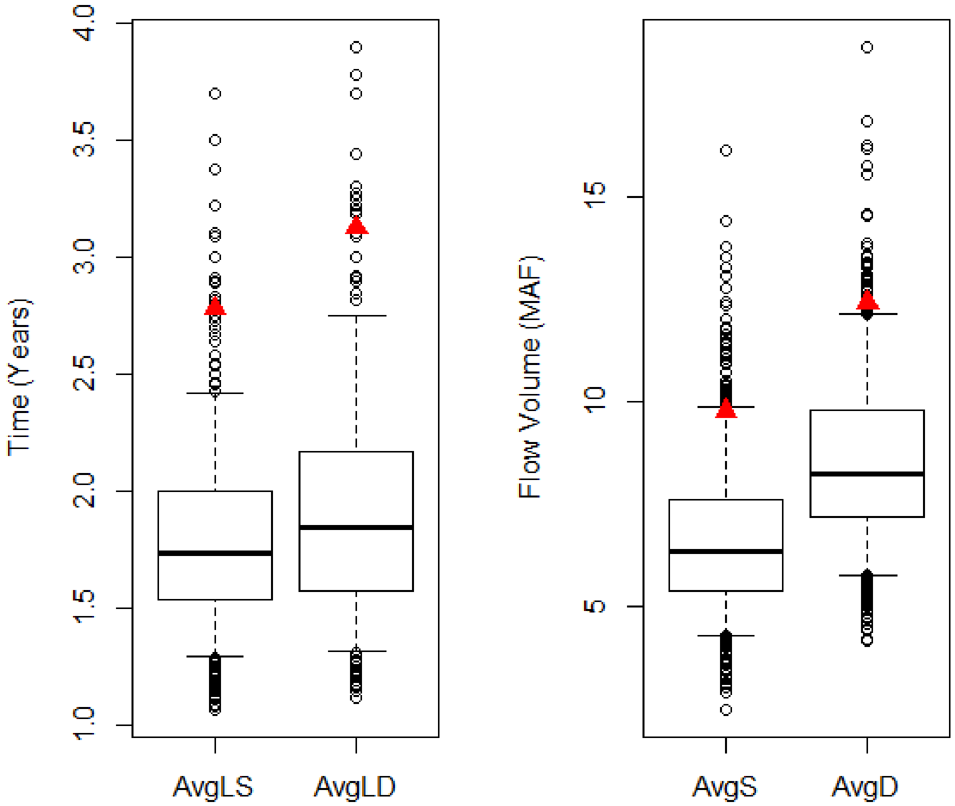


Figure B-5.—Summary of paleo conditioned historical streamflow at Klamath River near Klamath, CA (USGS ID 11530500). Mean historical streamflow is indicated by red triangles. Heavy black line represents median of values, while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values. Outliers are shown as open circles. AvgLS: average length of surplus; AvgLD: average length of drought; AvgS: average surplus, AvgD: average drought; MAF: million acre-feet.

The median values of the drought statistics, AvgLS, AvgD, AvgS and AvgD were estimated to be 1.73 years, 1.85 years, 6.35 million acre-feet (MAF) and 8.25 MAF respectively. The corresponding historical values were respectively, 2.78 years, 3.13 years, 9.75 MAF and 12.42 MAF. These results indicate that paleo-conditioned historical simulations show reduced surplus lengths and volumes. Results also show droughts of reduced length and deficit, demonstrating that just by changing the ordering of flows over the historical period can presente both reduced droughts and surpluses. Furthermore, the surplus volumes could be quite a bit lower from what has been historically available according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than what is shown in the recent instrumental record. These average statistics for each case, along with estimates of maximum length and volume of surplus and deficit, are presented in tables B-2 and B-3, respectively, along with corresponding projections of future drought and surplus statistics.

Table B-2.—Median Drought Statistics – *Average* Length and Volume of Surplus and Deficit for the klamath Basin Conditioned on Paleo-Hydrologic Data

Count	Scenario	Period	BCSD Projection	Average Length of Surplus (year)	Average Length of Drought (year)	Average Surplus (MAF)	Average Deficit (MAF)
1	Simulated Historical	1950-1999	-	2.78	3.13	9.75	12.42
2	Paleo-Conditioned Historical	-	-	1.73	1.85	6.35	8.25
3	Hot Dry	2020-2049	CMIP-3	1.38	2.21	5.04	10.20
4	Hot Dry	2060-2089	CMIP-3	1.21	3.17	4.35	14.53
5	Hot Dry	2020-2049	CMIP-5	1.31	2.36	4.68	10.22
6	Hot Dry	2060-2089	CMIP-5	1.27	2.85	5.23	12.46
7	Hot Wet	2020-2049	CMIP-3	2.46	1.38	11.72	5.82
8	Hot Wet	2060-2089	CMIP-3	2.25	1.55	12.74	6.12
9	Hot Wet	2020-2049	CMIP-5	2.15	1.47	11.94	5.68
10	Hot Wet	2060-2089	CMIP-5	2.36	1.40	13.39	5.70
11	Central Tendency	2020-2049	CMIP-3	1.79	1.75	7.80	7.93
12	Central Tendency	2060-2089	CMIP-3	1.81	1.73	9.04	6.94
13	Central Tendency	2020-2049	CMIP-5	1.77	1.71	8.16	7.39
14	Central Tendency	2060-2089	CMIP-5	1.75	1.77	8.56	6.75
15	Warm Dry	2020-2049	CMIP-3	1.53	1.92	4.88	9.01
16	Warm Dry	2060-2089	CMIP-3	1.46	2.29	4.96	11.29
17	Warm Dry	2020-2049	CMIP-5	1.54	2.20	5.34	9.79
18	Warm Dry	2060-2089	CMIP-5	1.57	2.14	4.89	9.78
19	Warm Wet	2020-2049	CMIP-3	2.50	1.53	14.40	6.43
20	Warm Wet	2060-2089	CMIP-3	3.09	1.36	18.48	5.43
21	Warm Wet	2020-2049	CMIP-5	2.21	1.43	11.48	5.70
22	Warm Wet	2060-2089	CMIP-5	2.21	1.42	12.43	5.44

Table B-3.—Median Drought Statistics – *Maximum* Length and Volume of Surplus and Deficit for the Klamath Basin Conditioned on Paleo-Hydrologic Data

Count	Scenario	Period	BCSD Projection	Maximum Length of Surplus (year)	Maximum Length of Drought (year)	Maximum Surplus (MAF)	Maximum Deficit (MAF)
1	Simulated Historical	1950-1999	-	5.00	6.00	25.26	34.34
2	Paleo-Conditioned Historical	-	-	4.00	4.00	19.21	21.57
3	Hot Dry	2020-2049	CMIP-3	3.00	6.00	16.04	28.71
4	Hot Dry	2060-2089	CMIP-3	2.00	8.00	14.19	41.24
5	Hot Dry	2020-2049	CMIP-5	3.00	6.00	15.22	29.47
6	Hot Dry	2060-2089	CMIP-5	2.00	7.00	15.09	34.16
7	Hot Wet	2020-2049	CMIP-3	6.00	3.00	34.35	14.13
8	Hot Wet	2060-2089	CMIP-3	6.00	3.00	35.78	14.91
9	Hot Wet	2020-2049	CMIP-5	6.00	3.00	33.13	14.39
10	Hot Wet	2060-2089	CMIP-5	6.00	3.00	36.73	13.37
11	Central Tendency	2020-2049	CMIP-3	4.00	4.00	23.17	20.55
12	Central Tendency	2060-2089	CMIP-3	4.00	4.00	25.66	18.41
13	Central Tendency	2020-2049	CMIP-5	4.00	4.00	24.39	19.80
14	Central Tendency	2060-2089	CMIP-5	4.00	4.00	24.22	17.69
15	Warm Dry	2020-2049	CMIP-3	3.00	5.00	17.41	24.08
16	Warm Dry	2060-2089	CMIP-3	3.00	6.00	16.26	31.67
17	Warm Dry	2020-2049	CMIP-5	3.00	6.00	16.17	26.95
18	Warm Dry	2060-2089	CMIP-5	4.00	5.00	17.50	25.84
19	Warm Wet	2020-2049	CMIP-3	7.00	3.00	39.09	14.67
20	Warm Wet	2060-2089	CMIP-3	8.00	3.00	51.28	12.33
21	Warm Wet	2020-2049	CMIP-5	6.00	3.00	32.65	14.04
22	Warm Wet	2060-2089	CMIP-5	6.00	3.00	34.56	13.39

With this approachtransition probabilities were applied from the paleo-climate analysis to the future periods, generating 1,000 sequences of paleo-conditioned streamflow for each of the 5 quadrant HDe scenarios for the 2030s and 2070s. These were based both on CMIP3 and CMIP5, for a total of 20,000, or 1,000 multiplied by 20 HDe scenarios. Evaluate projected changes in drought and surplus characteristics at select locations throughout the Klamath River Basin could be evaluate based on these traces.

Paleo-conditioned streamflow projections are not carried throughout the 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 suggest 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.

B.3 Surface Water Hydrology

B.3.1 VIC Hydrologic Model Overview

The VIC surface water hydrologic model provides estimates of historical and projected water balance variables that are an integral part of the Basin Study. 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 km on a side). An overview schematic of the VIC model is given in figure B-6.

The VIC model contains a subgrid-scale parameterization of the infiltration process (based on the Nanjing model), which impacts the vertical distribution of soil moisture in, typically, a three-layer model grid cell (Liang et al. 1994). The VIC model also represents subgrid-scale vegetation variability using multiple vegetation types and properties per grid cell. Potential evapotranspiration (ET) is calculated using a Penman Monteith approach (Maidment, 1993). VIC also contains a subdaily (1-hour time step) snow energy balance model, illustrated by figure B-6b (Cherkauer and Lettenmaier, 2003;Wigmosta et al., 1994; Andreadis et al., 2009).

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind speed magnitude (at a minimum) as input to simulate gridded daily state variables such as snow water equivalent (SWE) and runoff (both surface and subsurface runoff). The Basin Study utilizes historical gridded observations developed by Maurer et al. (2002) for the period January 1949 to July 2000. The dataset is primarily based on observation stations that are part of the Co-op Station Network, interpolated to a grid using the SYMAP algorithm

(Shepard, 1984). The Maurer dataset only includes stations with more than 20 years of data from 1949-2000. 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.

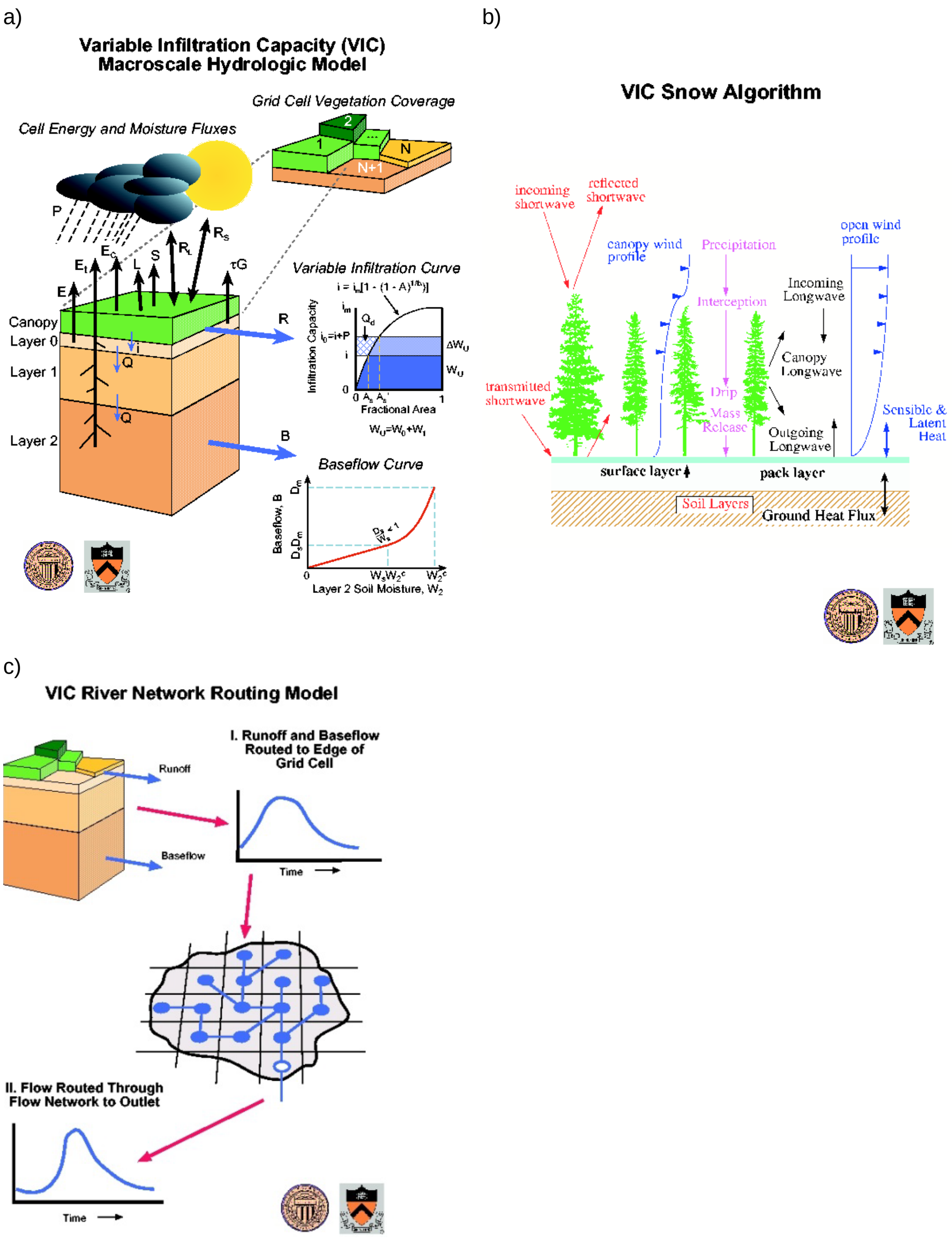


Figure B-6.—Variable Infiltration Capacity Model schematics, including a) spatial discretization and overview, b) snow model algorithm, and c) routing model.

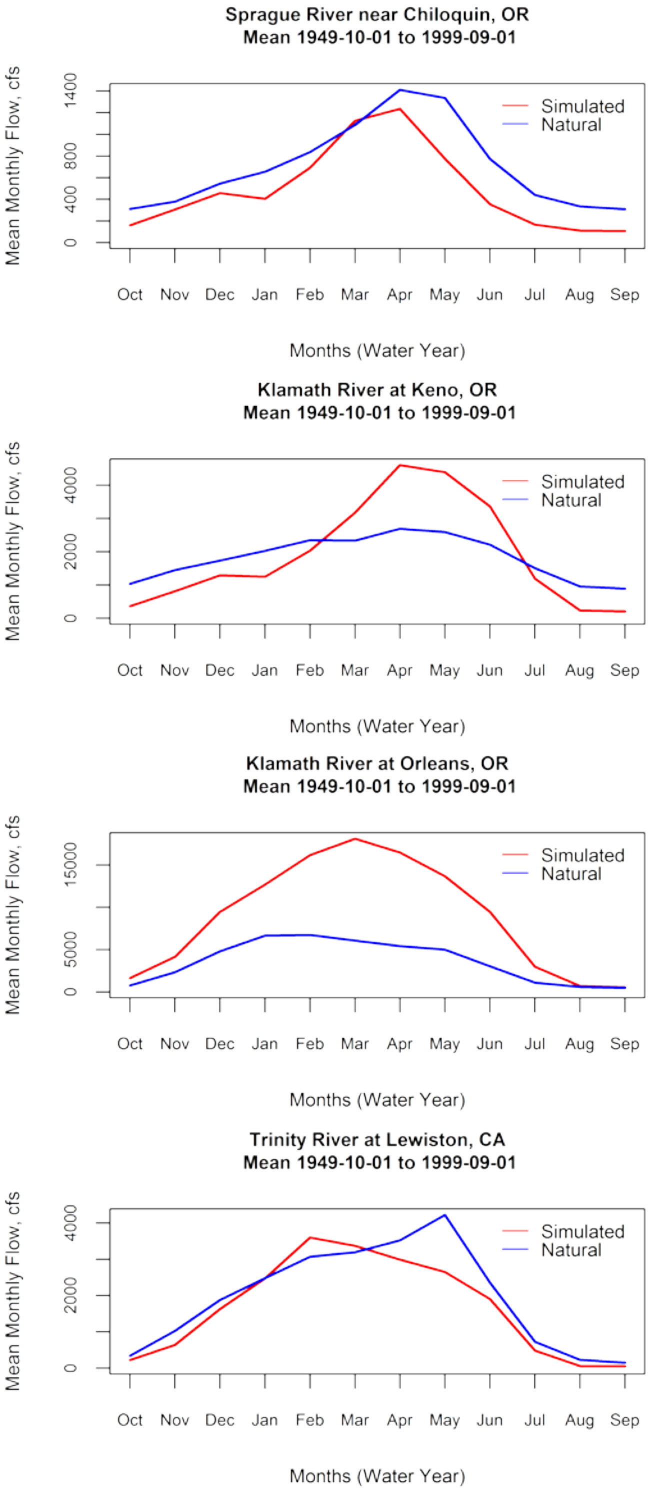
The VIC outputs may be defined by the user, but typically include grid cell moisture and energy states through time (i.e., soil moisture, snow water content, snowpack cold content) and water leaving the basin either as ET, baseflow, sublimation, or runoff, where the latter represents the combination of faster-response surface runoff and slower-response baseflow. 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). A schematic of the VIC routing model is shown in figure B-6c. This setup requires specifying the coordinates of each streamflow location within the basin grid, identifying tributary grid cells and flow directions through these grid cells, and ultimately fraction-area contribution from tributary grid cells to streamflow at the location of interest. Routed streamflow using this approach represents natural streamflow, that is, streamflow that would occur in the absence of water management (diversions, return flows, and storage as examples).

The VIC model has a number of favorable attributes for the Basin Study, but VIC's three most significant advantages are that it has a reliable, physically based model of ET, it has a physically based model of snow dynamics, and it has been used for numerous studies of climate change impacts and hydrologic variability (e.g., Christensen et al., 2004; Christensen et al., 2007; Elsner et al., 2010; Van Rheenen et al., 2004). For climate change impact studies, VIC is commonly run in water balance mode, due to its comparatively higher computational efficiency to the alternative energy balance mode and because it facilitates numerous projected climate simulations.

B.3.2 VIC Model Validation

Simulated natural streamflow from the VIC model is often compared with reconstructed observed natural streamflow as a way of evaluating the integrated performance of the model, and as a means for model calibration. Observed natural streamflow may consist of gaged streamflows in rivers or streams that are in fact natural, in that they do not have signification diversions or storage, or they may consist of reconstructed natural flows, which are equivalent to gaged flows that have management effects removed. Some rivers within the Klamath River Basin have significant agricultural diversions, making it necessary to compare VIC simulated streamflows with reconstructed natural flows.

Figure B-7 illustrates mean monthly historical natural streamflow at four sites within the Klamath River basin, including simulated natural flow by the VIC model (red lines) and reconstructed natural flow from available sources (blue lines). Mean hydrographs were computed over water years 1950-1999 (i.e., October 1949 – September 1999) to allow for spin up of the VIC model between January 1949 and September 1949. Hydrographs were also computed over the water years 1951-1999 (not shown), and there was no noticeable difference in the hydrographs, indicating that the chosen spin up period is appropriate for this analysis. Reconstructed natural streamflow for Sprague River near Chiloquin, OR,



Sprague River near Chiloquin, OR
Mean 1949-10-01 to 1999-09-01

Klamath River at Keno, OR
Mean 1949-10-01 to 1999-09-01

Klamath River at Orleans, OR
Mean 1949-10-01 to 1999-09-01

Trinity River at Lewiston, CA
Mean 1949-10-01 to 1999-09-01

Figure B-7.—Mean monthly historical simulated streamflow (averaging period water years 1950-1999) compared with observed naturalized flows for sites within the Klamath River Basin. Naturalized flows at Sprague River near Chiloquin and Klamath River at Keno originated from Reclamation (2005); naturalized flows at Klamath River at Orleans and Trinity River at Lewiston originated from CD WR Data Exchange.

and Klamath River at Keno, OR, originated from Reclamation (2005), while reconstructed natural flows for Klamath River at Orleans, CA, and Trinity River at Lewiston, CA, originated from CDWR’s Data Exchange. Figure B-7 shows that the VIC model generally underestimates natural streamflow in the Sprague River, while it overestimates natural streamflow, particularly during the peak flow season, at two mainstem Klamath River sites, Keno OR, and Orleans, CA. For the Trinity River site, the VIC model generally underestimates natural streamflow and mischaracterizes the seasonal peak flow.

The discrepancies between VIC simulated natural flow and available reconstructed natural flow may be due to one or more of the following reasons:

1. the VIC model does not have the capability to represent the interaction of surface water and deep groundwater. Due to the geology and soils in the Klamath River Basin, particularly in the Upper Klamath Basin, deep groundwater is an important component of the water balance.

2. the VIC model may not properly capture other physical processes that may be important in the watershed – for example, glacier dynamics at Mount Shasta

3. biases may exist in the datasets used for model simulation and comparison, including meteorological inputs and reconstructed natural flows

Due to the limitations of VIC to accurately simulate natural streamflow at several points in the watershed (described above), as well as identified complexities in reconstructing observed natural streamflow in the watershed (NRC, 2004), the VIC model was not calibrated for the Klamath River Basin Study. Because the Basin Study is a long-term planning study with a goal to evaluate the impacts of climate change on water supply, modeling results in the study are discussed in terms of change in water balance parameters (as opposed to projections of absolute values). Previous studies (e.g., Elsner et al., 2010) have utilized uncalibrated hydrologic models to evaluate the projected changes in water balance parameters as a result of climate change. It may be assumed that potential biases in the VIC model and associated datasets are stationary, meaning any systematic biases in the historical period are the same in the future.

B.4 Groundwater Hydrology

B.4.1 Upper Klamath Basin MODFLOW Groundwater Model

The effects of projected climate on groundwater in the Upper Klamath Basin were analyzed using the existing USGS 3-D Finite-Difference Groundwater Model, MODFLOW (2012). For this Basin 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 Chapter III section –

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 quadrant HDe scenarios, where maximum ET is represented as potential evapotranspiration (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 quadrant HDe scenarios

The methodology for developing each type of projected MODFLOW input is described in detail below.

B.4.1.1 Maximum Evapotranspiration Rate

ET is modeled in the Upper Klamath Basin MODFLOW model (Gannett et al., 2012) using the EVT, or e ET, 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 Precipitation-Runoff Modeling System (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 using PRMS, due to the fact that 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 quadrant HDe 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 reasoning for using change factors and not directly applying projected maximum ET from the VIC model is to not introduce bias due to the differing model constructs (i.e., PRMS generated historical maximum ET, compared with VIC generated projected maximum ET).

B.4.1.2 Groundwater Recharge

The Gannett et al. (2012) historical groundwater simulation uses as input historical groundwater recharge computed by the PRMS model, adjusted by unique factors in the calibration process for each recharge zone. Recharge zone 1, which covers the western basin boundary (see Chapter 3 – Water Supply Assessment of the Basin Study, figure10), has an adjustment factor of 0.7. Recharge zone 2, which covers the northeastern portion of the model domain, has an adjustment factor of 0.5. Recharge zone 3, which covers the central and southern portion of the model domain, has an adjustment factor of 1.5.

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) used in development of surface water hydrology for this study as well as future climate scenarios) and historical annual recharge. A previous study by Crosbie et al. (2013) evaluated the relationship of precipitation and groundwater recharge in the High Plains of the United States and proposed a general power relationship in the form:

$$\text{Recharge} = a^{*}\ \text{Precipitation}^{\,b}$$

Although the above relationship was 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. Figure B-8 illustrates this relationship for MODFLOW model recharge zone 1 (relationships for other zones are similar, but not shown). The linear regression resulted in an R^2 value of 0.70 for zone 1, while the R^2 for zone 2 was 0.59, and 0.60 for zone 3.

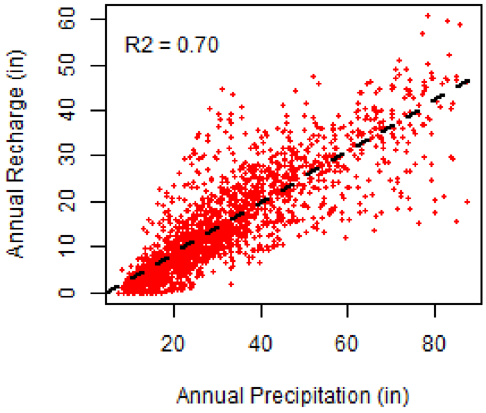


Figure B-8.—Relationship between historical annual recharge (inches) and historical annual precipitation (inches) for MODFLOW model recharge zone 1 (Cascades).

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 quadrant HDe 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.

It should be noted that the same calibration factors used as part of the historical MODFLOW simulation (described above) were applied to resulting recharge (by recharge zone). Therefore, although it may appear in figure B-8 that recharge consists of approximately 50 percent of annual precipitation, the actual recharge amount is adjusted through the development of recharge projections and by application of the calibration factors.

B.4.1.3 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.

B.4.2 GW Screening Tools for Scott and Shasta Valleys

The groundwater models developed as part of the Basin Study assessment of groundwater supply in the Scott and Shasta Valleys follow the same approach as the Santa Ana River Watershed Basin Study (Reclamation, 2013). 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 B-9 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. This section describes in detail the approach for development of model inputs.

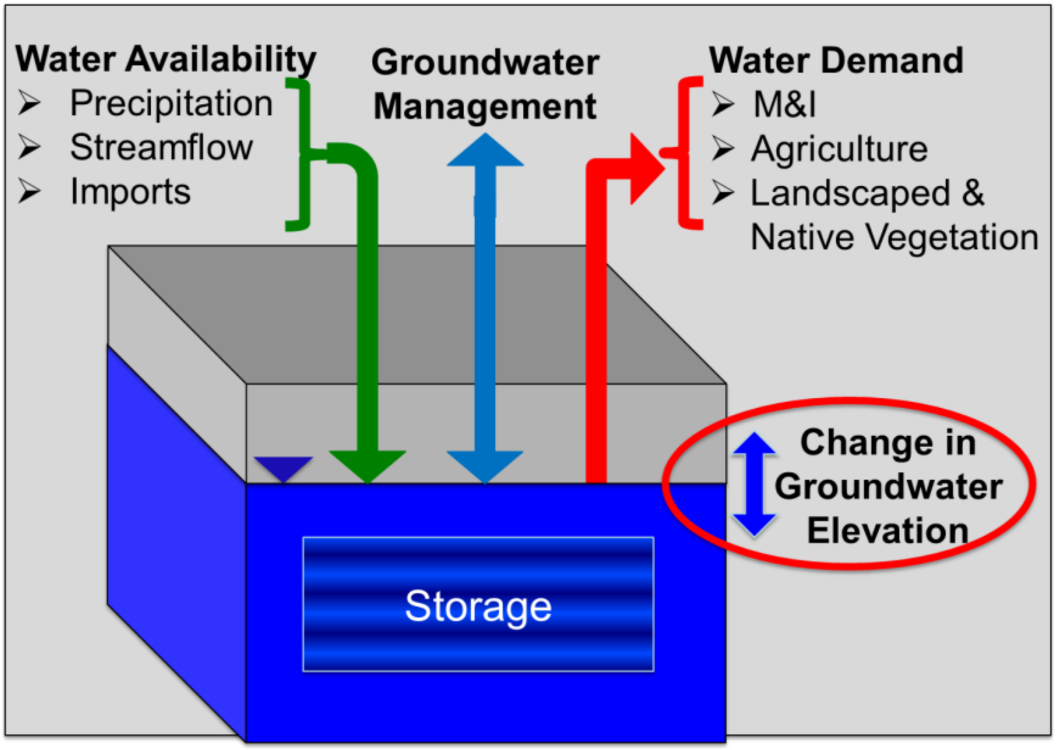


Figure B-9.—Conceptual model of basin-scale groundwater fluctuations used in developing the groundwater screening tool.

The functional relationship of the diagram illustrated in figure 3-A9 is implemented in the form of a multi-variate linear regression equation (Equation 1):

$$\frac{\Delta h}{\Delta t} = (C_1 \cdot P_t) + (C_2 \cdot E_t) + (C_3 \cdot Q_t) + (C_4 \cdot M_t) + (C_5 \cdot A_t) + (C_6 \cdot I_t) + (C_7 \cdot X_t)$$

Where:

$\frac{\Delta h}{\Delta t}$ is the change in basin-averaged groundwater elevation (t is in months)

P_t is total precipitation over the groundwater basin
Q_t is streamflow at a representative location that reflects surface water availability in the basin
I_t is the volume of trans-basin water imports to the groundwater basin
M_t is municipal and industrial demand within the basin
E_t is evaporative demand from native and landscaped (non-agricultural) vegetation

A_t is agricultural water demand (applied water demand)
X_t is a timeseries of values representing the effect of a specific large-scale water management practice on groundwater levels within the basin
C_i are linear regression coefficients

This regression-based groundwater screening tool provides broad flexibility in the development of inputs to the groundwater screening tool. However, accurate and comprehensive data for many of the inflow and outflow terms in the conceptual model are often unavailable for most groundwater basins. The regression-based approach used in the groundwater screening tool allows substitution of related datasets where accurate data for one or more model input is not available.

B.4.2.1 Development of Groundwater Model Inputs

The following sections describe the development of the screening tool inputs (supplies and demands) for the Scott and Shasta Valley models. As mentioned in the body of Chapter 3 –Assessment of Current and Future Water Supply, the model domains for the Scott and Shasta Valleys correspond with groundwater basins defined by CDWR’s Bulletin 118 (CDWR, 2003). Bulletin 118 defines the model domain for the groundwater screening tools for the Scott and Shasta Valleys. These groundwater basins are illustrated in figure B-10 (figure also included within Chapter 3).

B.4.2.2 Historical Input Data (1980-1999)

Historical data were used to fit the regression coefficients in Equation 1 and to evaluate model performance over the historical period (1980-1999). Fitting the regression model and evaluating the results over the historical period are in effect calibration and verification steps. For each groundwater basin (one each for the Scott and Shasta Valleys), historical inputs are required for the six primary input variables to Equation 1. Additional inputs may be provided for the optional exogenous variable (X_t) if desired. No exogenous inputs were developed for the Scott and Shasta groundwater basins.

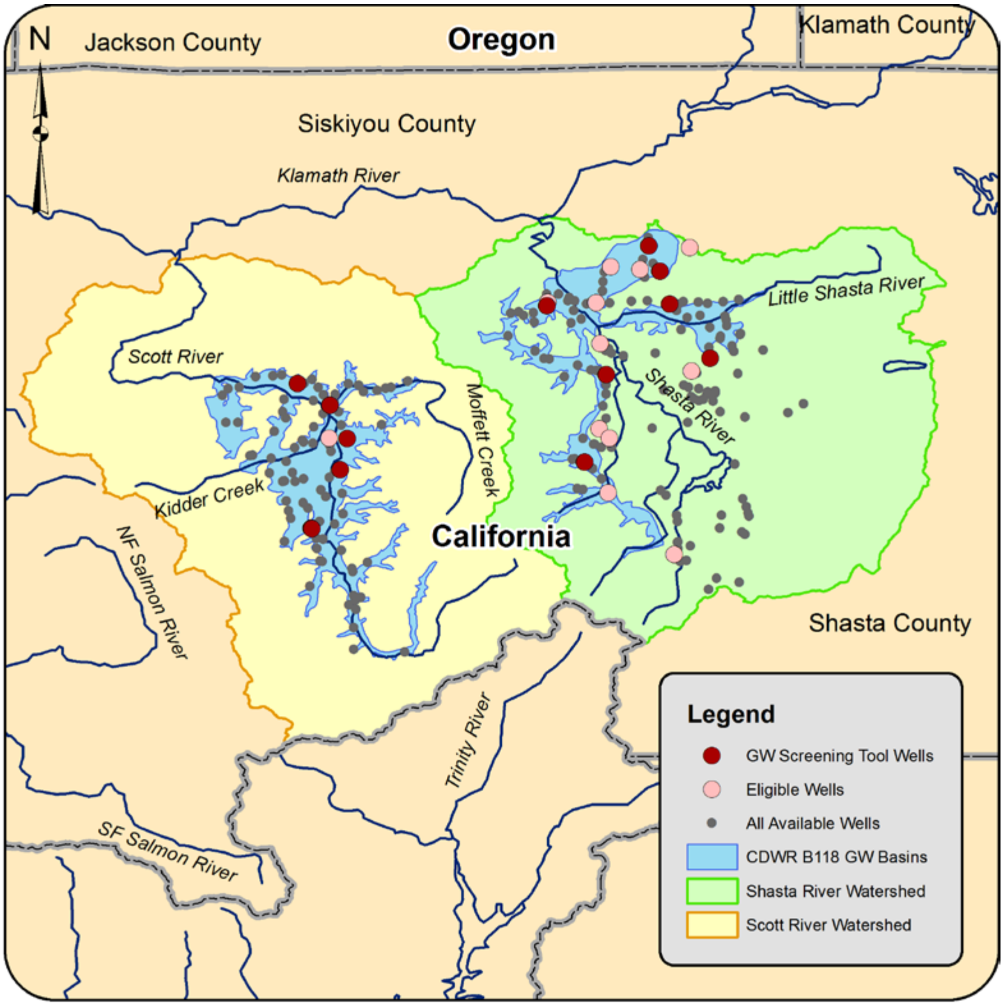


Figure B-10.—Map of CDWR Bulletin 118 – Groundwater Basins for the Scott and Shasta River Basins, as well as all available wells (grey), eligible wells[4] (pink) and wells used in development of the groundwater screening tools for both watersheds (red).

B.4.2.3 Historical Groundwater Elevations (h_t)

The groundwater screening tool requires an input timeseries representative of historical monthly groundwater elevations within the basin for the period 1980-1999. For this study, historical groundwater elevation data primarily came from two sources, including the USGS and CDWR. 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 the groundwater basin. Outliers likely reflect measurement errors, data transcription errors, or measurements affected by nearby pumping. For the CDWR monitored wells, data

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[4] Eligible wells consist of those wells that contain water level data between 1/1/1980 and 12/31/1999, which is the historical period of model simulation. Eligible wells also met criteria for being within 3 km of the groundwater basin boundaries. Individual data point outliers were removed from analyzed eligible wells data.

points that were associated with a "Questionable Measurement Code" were removed. For the USGS monitored wells, data points that were associated with an "R" flag (indicating recently pumped) were removed. The complete list of available wells in the Scott and Shasta Valleys are illustrated in figure B-10 and summarized by tables B-4 and B-5. Available wells were deemed eligible for use in the study if they meet the following criteria:

- Well period of record overlaps the historical model period of record, which is January 1980 through December 1999.
- Wells are located within 3 kilometers (km) of the groundwater basin boundaries of the Scott and Shasta Valleys. The buffer distance (3 km) was chosen such that a reasonable number of wells could be analyzed for developing mean behavior across the groundwater basins.

For each well identified for use in the study, monthly mean groundwater elevations were calculated from the available instantaneous measurements. For months containing more than one measurement, the monthly average was computed as the un-weighted arithmetic average of the available measurements. For months with a single measurement, the single measurement was assumed to reflect average conditions during that month. Lastly, monthly averages were linearly interpolated to develop a complete timeseries of monthly mean groundwater elevations over the period of record. It should be noted that for the Scott and Shasta Valleys, well measurements typically occurred once in the spring and once in the autumn, and interpolated monthly timeseries were computed from these measurements.

Monthly timeseries of basin-averaged groundwater elevations were then developed for each groundwater basin (one for Scott Valley and one for Shasta Valley). Steps were required to avoid two sources of bias in calculating basin-average groundwater elevations: variations in the period of record between wells, and outlier wells that are not representative of large-scale groundwater fluctuations within a basin. The steps taken to account for these biases are briefly described below; however, Reclamation (2013) provides additional details.

To minimize biases associated with varying record lengths, averaging was carried out based on monthly deviations (anomalies) rather than monthly groundwater elevations, where monthly deviations for each well were calculated as the difference between the monthly mean value and the long-term average value for that month.

In addition to differences in record length, potential biases may occur in cases where individual well records reflect unique local conditions that are not broadly representative of groundwater fluctuations within the basin. In basins such as the Scott and Shasta groundwater basins, where a small number of samples are available, individual outliers can disproportionately impact the basin average, resulting in potentially significant bias. A correlation-based clustering procedure was used to group wells into sub-sets exhibiting similar behavior. For the purposes of this analysis, the largest cluster was assumed to reflect basin-average conditions, and basin-average groundwater elevations were calculated based on wells in this cluster. A sensitivity analysis was performed to test model fit using alternative well data clusters, as well as individual wells; however, model fit did not improve through use of alternate clusters or individual wells.

Table B-4.—Summary of Well Data Considered for Use in the Scott Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.41	-122.81	041N008W07J001M	USGS	10/1/1953	10/1/1953	1		
41.37	-122.82	041N008W30L001M	USGS	10/1/1953	10/1/1953	1		
41.43	-122.84	041N009W02J001M	USGS	10/1/1953	10/1/1953	1		
41.43	-122.87	041N009W03L001M	USGS	5/1/1953	5/1/1953	1		
41.42	-122.86	041N009W10J001M	USGS	4/1/1954	4/1/1954	1		
41.42	-122.86	041N009W10J002M	USGS	4/1/1954	4/1/1954	1		
41.41	-122.83	041N009W13B001M	USGS	10/1/1953	10/1/1953	1		
41.40	-122.83	041N009W13G001M	USGS	7/1/1953	7/1/1953	1		
41.38	-122.82	041N009W25H001M	USGS	10/1/1953	10/1/1953	1		
41.37	-122.82	041N009W25R001M	USGS	10/1/1953	10/1/1953	1		
41.36	-122.83	041N009W36B001M	USGS	10/1/1953	10/1/1953	1		
41.36	-122.82	041N009W36J001M	USGS	10/1/1953	10/1/1953	1		
41.52	-122.84	042N009W02A002M	USGS	8/1/1953	8/1/1953	1		
41.52	-122.85	042N009W02G001M	USGS	7/1/1953	7/1/1953	1		
41.52	-122.85	042N009W02N001M	USGS	4/1/1953	4/1/1953	1		
41.52	-122.88	042N009W04Q001M	USGS	10/1/1953	10/1/1953	1		
41.52	-122.90	042N009W05H001M	USGS	10/1/1953	10/1/1953	1		
41.52	-122.92	042N009W06F002M	USGS	10/1/1953	10/1/1953	1		
41.51	-122.91	042N009W08C001M	USGS	10/1/1953	10/1/1953	1		
41.51	-122.91	042N009W08C003M	USGS	4/1/1960	4/1/1960	1		
41.51	-122.89	042N009W09D001M	USGS	10/1/1953	10/1/1953	1		
41.50	-122.86	042N009W10Q001M	USGS	10/1/1953	10/1/1953	1		
41.50	-122.84	042N009W13D001M	USGS	4/1/1954	4/1/1954	1		
41.49	-122.86	042N009W14E001M	USGS	10/1/1953	10/1/1953	1		
41.49	-122.88	042N009W16Q001M	USGS	10/1/1953	10/1/1953	1		
41.48	-122.88	042N009W21A001M	USGS	10/1/1953	10/1/1953	1		
41.47	-122.84	042N009W24M001M	USGS	10/1/1953	10/1/1953	1		
41.46	-122.85	042N009W26K001M	USGS	10/1/1953	10/1/1953	1		
41.46	-122.86	042N009W27G001M	USGS	4/1/1954	4/1/1954	1		
41.46	-122.87	042N009W27N001M	USGS	7/1/1953	7/1/1953	1		
			CDWR	11/2/1965	10/6/2003	78	Yes	Yes
41.44	-122.87	042N009W34L001M	USGS	10/1/1953	10/1/1953	1		
41.44	-122.86	042N009W35Q001M	USGS	10/1/1953	10/1/1953	1		

Table B-4.—Summary of Well Data Considered for Use in the Scott Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.61	-122.87	043N009W03F001M	USGS	4/1/1954	4/1/1954	1		
41.61	-122.91	043N009W05F001M	USGS	5/1/1953	5/1/1953	1		
41.59	-122.86	043N009W10J002M	USGS	10/1/1953	10/1/1953	1		
41.58	-122.84	043N009W13E001M	USGS	4/1/1954	4/1/1954	1		
41.58	-122.87	043N009W15L001M	USGS	10/1/1953	10/1/1953	1		
41.56	-122.89	043N009W21K001M	USGS	10/1/1953	10/1/1953	1		
41.56	-122.88	043N009W21Q001M	USGS	5/1/1953	5/1/1953	1		
41.56	-122.87	043N009W22P001M	USGS	4/1/1954	4/1/1954	1		
41.56	-122.85	043N009W23F001M	USGS	10/1/1953	10/1/1953	1		
			CDWR	5/7/1953	10/19/2011	107	Yes	
41.56	-122.83	043N009W24F001M	USGS	3/20/1953	4/11/1983	25		
			CDWR	11/2/1965	10/19/2011	98	Yes	Yes
41.57	-122.83	043N009W24F002M	USGS	10/1/1953	10/1/1953	1		
41.55	-122.85	043N009W26C002M	USGS	10/1/1953	10/1/1953	1		
41.55	-122.85	043N009W26L001M	USGS	10/1/1953	10/1/1953	1		
41.55	-122.89	043N009W28E001M	USGS	10/1/1953	10/1/1953	1		
41.54	-122.90	043N009W32G001M	USGS	4/1/1954	4/1/1954	1		
41.58	-122.96	043N010W14B001M	USGS	4/1/1954	4/1/1954	1		
41.58	-122.98	043N010W15A001M	USGS	4/1/1954	4/1/1954	1		
41.63	-122.89	044N009W28P001M	USGS	10/1/1953	10/1/1953	1		
			CDWR	11/2/1965	4/22/2011	96	Yes	Yes
41.63	-122.88	044N009W28Q001M	USGS	7/1/1953	7/1/1953	1		
41.62	-122.87	044N009W34G001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.86	044N009W34R002M	USGS	7/1/1953	7/1/1953	1		
41.46	-122.87	42N09W27N002M	CDWR	10/27/1994	10/19/2011	45	Yes	Yes
41.53	-122.84	42N09W02A002M	CDWR	11/2/1965	8/11/2004	84	Yes	Yes
41.60	-122.85	43N09W02P002M	CDWR	3/29/2004	10/19/2011	18	Yes	Yes
41.31	-122.76	040N008W14N001M	USGS	10/1/1953	10/1/1953	1		
41.34	-122.82	040N009W12A001M	USGS	10/1/1953	10/1/1953	1		
41.31	-122.82	040N009W13R001M	USGS	10/1/1953	10/1/1953	1		
41.39	-122.88	041N009W22M001M	USGS	10/1/1953	10/1/1953	1		
41.49	-122.90	042N009W17K001M	USGS	10/1/1953	10/1/1953	1		
41.48	-122.90	042N009W20G001M	USGS	11/1/1953	11/1/1953	1		
41.47	-122.90	042N009W29A001M	USGS	10/1/1953	10/1/1953	1		
41.44	-122.91	042N009W32P001M	USGS	5/1/1953	5/1/1953	1		
41.58	-122.79	043N008W17F001M	USGS	4/1/1954	4/1/1954	1		
41.61	-122.85	043N009W02K001M	USGS	10/1/1953	10/1/1953	1		
41.61	-122.85	043N009W02K002M	USGS	4/1/1954	4/1/1954	1		
41.60	-122.91	043N009W08F001M	USGS	10/1/1953	10/1/1953	1		

Table B-4.—Summary of Well Data Considered for Use in the Scott Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.59	-122.91	043N009W08Q001M	USGS	10/1/1953	10/1/1953	1		
41.60	-122.84	043N009W11H002M	USGS	10/1/1953	10/1/1953	1		
41.57	-122.92	043N009W18R001M	USGS	10/1/1953	10/1/1953	1		
41.54	-122.92	043N009W31B001M	USGS	10/1/1953	10/1/1953	1		
41.54	-122.95	043N010W25P001M	USGS	4/1/1954	4/1/1954	1		
41.54	-122.95	043N010W25P002M	USGS	4/1/1954	4/1/1954	1		
41.63	-122.76	044N008W27L001M	USGS	10/1/1953	10/1/1953	1		
41.63	-122.82	044N008W30P001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.81	044N008W31G001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.80	044N008W32F001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.78	044N008W33C001M	USGS	9/1/1953	9/1/1953	1		
41.62	-122.79	044N008W33D001M	USGS	7/1/1953	7/1/1953	1		
41.63	-122.83	44N09W25R001M	CDWR	7/16/2002	10/19/2011	28		
41.63	-122.87	044N009W27M001M	USGS	10/1/1953	10/1/1953	1		
41.64	-122.91	044N009W29F001M	USGS	7/1/1953	7/1/1953	1		
41.64	-122.92	044N009W30G001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.85	044N009W35Q001M	USGS	10/1/1953	10/1/1953	1		
41.64	-122.94	044N010W25H002M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.97	044N010W34H001M	USGS	10/1/1953	10/1/1953	1		
41.61	-122.98	044N010W34Q001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.96	044N010W35G001M	USGS	7/1/1953	7/1/1953	1		

Table B-5.—Summary of Well Data Considered for Use in the Shasta Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.39	-122.36	041N004W18N001M	USGS	6/20/1980	8/2/1983	13		
41.43	-122.42	041N005W04A001M	USGS	7/17/1981	9/2/1982	10		
41.43	-122.44	041N005W04D001M	USGS	4/1/1953	4/1/1953	1		
41.42	-122.44	041N005W04N001M	USGS	10/1/1955	10/1/1955	1		
41.42	-122.44	041N005W05J001M	USGS	9/12/1979	5/4/1982	4	Yes	
41.42	-122.43	041N005W09E001M	USGS	7/15/1981	7/7/1982	6		
41.42	-122.43	041N005W09F003M	USGS	10/1/1953	10/1/1953	1		
41.40	-122.39	041N005W14L001M	USGS	7/28/1979	8/2/1983	12		
41.38	-122.40	041N005W23M001M	USGS	8/23/1980	8/2/1983	15		
41.49	-122.36	042N004W18D001M	USGS	1/3/1980	1/3/1980	1		
41.48	-122.35	042N004W18P001M	USGS	11/8/1979	7/8/1981	2		
			CDWR	9/4/1990	4/21/2011	44		
41.47	-122.35	042N004W19G001M	USGS	11/24/1979	6/1/1982	7		
41.47	-122.35	042N004W19K001M	USGS	5/27/1979	8/5/1983	13		
41.45	-122.36	042N004W30N001M	USGS	8/18/1979	8/2/1983	14		
41.45	-122.36	042N004W31C001M	USGS	5/15/1976	8/2/1983	12		
41.50	-122.46	042N005W08E001M	USGS	5/1/1954	5/1/1954	1		
			CDWR	5/20/1954	10/20/2011	44		
41.50	-122.45	042N005W08P001M	USGS	5/1/1954	5/1/1954	1		
41.47	-122.44	042N005W20J001M	USGS	4/2/1953	4/11/1983	129		
			CDWR	4/2/1953	10/20/2011	189		
41.47	-122.38	042N005W23J001M	USGS	6/1/1954	6/1/1954	1		
41.46	-122.44	042N005W26A001M	USGS	6/1/1954	6/1/1954	1		
41.46	-122.39	042N005W26R001M	USGS	6/1/1954	6/1/1954	1		
41.44	-122.44	042N005W33M001M	USGS	7/1/1953	7/1/1953	1		
41.44	-122.44	042N005W33M002M	USGS	4/1/1953	4/1/1953	1		
41.51	-122.53	042N006W03L001M	USGS	10/1/1953	10/1/1953	1		
41.50	-122.56	042N006W08H001M	USGS	10/1/1953	10/1/1953	1		
41.50	-122.55	042N006W09F001M	USGS	7/1/1953	7/1/1953	1		
41.50	-122.52	042N006W10J001M	USGS	7/1/1953	7/1/1953	1	Yes	
			CDWR	4/6/1953	10/20/2011	202		
41.60	-122.29	043N004W03A002M	USGS	7/1/1954	7/1/1954	1		
41.59	-122.30	043N004W04R001M	USGS	9/1/1954	9/1/1954	1		
41.59	-122.36	43N04W07M001M	CDWR	8/1/1990	10/23/2007	36		
41.61	-122.39	43N05W02C002M	CDWR	8/9/1990	10/20/2011	42		
41.61	-122.41	043N005W03C001M	USGS	4/1/1953	4/1/1953	1		
41.58	-122.42	043N005W08R001M	USGS	5/1/1954	5/1/1954	1		
			CDWR	5/14/1954	3/22/2000	20		
41.60	-122.38	43N05W11A001M	CDWR	10/28/1971	10/20/2011	84		

Table B-5.—Summary of Well Data Considered for Use in the Shasta Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.58	-122.47	43N05W18G001M	CDWR	9/4/1990	10/20/2011	44		
41.53	-122.37	43N05W36G001M	CDWR	9/4/1990	4/21/2011	43		
41.60	-122.53	043N006W03L001M	USGS	4/1/1953	4/1/1953	1		
41.59	-122.52	043N006W10K001M	USGS	4/1/1953	4/1/1953	1		
41.57	-122.53	43N06W15F003M	CDWR	10/26/1971	10/20/2011	83	Yes	
41.56	-122.55	043N006W21E001M	USGS	4/1/1953	4/1/1953	1		
41.56	-122.54	043N006W21J001M	USGS	7/1/1953	7/1/1953	1		
41.56	-122.54	043N006W21J002M	USGS	7/1/1953	7/1/1953	1		
41.56	-122.52	43N06W22A001M	CDWR	12/11/1952	10/20/2011	187	Yes	
41.55	-122.53	043N006W22P001M	USGS	7/1/1953	7/1/1953	1		
41.55	-122.53	043N006W22P002M	USGS	5/1/1953	5/1/1953	1		
41.55	-122.52	043N006W23N001M	USGS	5/1/1954	5/1/1954	1		
41.55	-122.52	043N006W23N002M	USGS	5/1/1954	5/1/1954	1		
41.54	-122.56	043N006W29Q001M	USGS	5/1/1954	5/1/1954	1		
41.54	-122.56	043N006W29Q002M	USGS	4/1/1953	4/1/1953	1		
41.54	-122.55	43N06W33C001M	CDWR	4/20/1973	10/20/2011	80	Yes	Yes
41.53	-122.54	043N006W33J001M	USGS	10/1/1953	10/1/1953	1		
41.67	-122.33	044N004W08P001M	USGS	7/1/1954	7/1/1954	1		
41.69	-122.36	044N005W01J001M	USGS	5/1/1954	5/1/1954	1		
41.69	-122.36	044N005W01J003M	USGS	5/1/1954	5/1/1954	1		
41.69	-122.38	044N005W02K001M	USGS	4/1/1953	4/1/1953	1		
41.68	-122.38	044N005W02Q001M	USGS	5/1/1954	5/1/1954	1		
41.69	-122.43	044N005W04C001M	USGS	5/1/1954	5/1/1954	1		
41.67	-122.40	044N005W11M001M	USGS	5/1/1954	5/1/1954	1		
41.67	-122.37	044N005W12L001M	USGS	5/1/1954	5/1/1954	1		
41.67	-122.37	044N005W12Q001M	USGS	6/1/1954	6/1/1954	1		
41.66	-122.40	044N005W14M001M	USGS	5/1/1954	5/1/1954	1		
41.66	-122.40	44N05W14M002M	CDWR	9/4/1990	10/20/2011	43	Yes	Yes
41.67	-122.46	044N005W18B001M	USGS	5/1/1954	5/1/1954	1		
41.64	-122.42	044N005W21H001M	USGS	5/1/1954	5/1/1954	1		
			CDWR	5/12/1954	10/20/2011	45	Yes	
41.64	-122.41	044N005W22P001M	USGS	5/1/1954	5/1/1954	1		
41.64	-122.36	044N005W24R001M	USGS	5/1/1954	5/1/1954	1		
41.63	-122.43	044N005W28K001M	USGS	7/1/1953	7/1/1953	1		
41.62	-122.42	044N005W28R001M	USGS	7/1/1953	7/1/1953	1		
41.62	-122.45	044N005W32C002M	USGS	5/1/1954	5/1/1954	1		
			CDWR	5/13/1954	10/20/2011	44		
41.61	-122.42	044N005W33J001M	USGS	4/1/1953	4/1/1953	1		
41.62	-122.41	044N005W34C001M	USGS	7/1/1953	7/1/1953	1		

Table B-5.—Summary of Well Data Considered for Use in the Shasta Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.62	-122.40	044N005W34H001M	USGS	7/1/1953	7/1/1953	1		
			CDWR	11/2/1952	10/20/2011	121		
41.62	-122.40	044N005W34J001M	USGS	10/1/1953	10/1/1953	1		
41.61	-122.42	044N005W34N001M	USGS	10/1/1953	10/1/1953	1		
41.61	-122.41	044N005W34Q001M	USGS	4/1/1953	4/1/1953	1		
41.62	-122.39	044N005W35C001M	USGS	10/1/1953	10/1/1953	1		
41.62	-122.39	044N005W35F001M	USGS	5/1/1954	5/1/1954	1		
41.62	-122.40	044N005W35L001M	USGS	9/1/1953	9/1/1953	1		
41.68	-122.53	044N006W10F001M	USGS	10/1/1953	10/1/1953	1		
			CDWR	4/6/1953	10/20/2011	98	Yes	
41.68	-122.53	044N006W10F003M	USGS	1/1/1951	1/1/1951	1		
41.67	-122.52	044N006W10R001M	USGS	10/1/1953	10/1/1953	1		
41.66	-122.50	044N006W14H001M	USGS	4/1/1953	4/1/1953	1		
41.67	-122.52	044N006W15C001M	USGS	2/12/1968	2/12/1968	1		
41.67	-122.52	044N006W15H001M	USGS	10/1/1953	10/1/1953	1		
41.66	-122.59	044N006W18M004M	USGS	5/1/1954	5/1/1954	1		
41.65	-122.56	044N006W20A001M	USGS	5/1/1954	5/1/1954	1		
41.65	-122.54	044N006W21K001M	USGS	7/1/1953	7/1/1953	1		
41.64	-122.53	044N006W22M001M	USGS	10/1/1953	10/1/1953	1		
41.64	-122.53	044N006W22M002M	USGS	7/1/1953	7/1/1953	1		
41.64	-122.52	044N006W27B001M	USGS	11/4/1975	4/11/1983	16		
			CDWR	11/4/1975	10/20/2011	74	Yes	Yes
41.63	-122.52	044N006W27Q001M	USGS	10/1/1953	10/1/1953	1		
41.64	-122.57	044N006W29D001M	USGS	5/1/1954	5/1/1954	1		
41.62	-122.52	044N006W34K001M	USGS	4/1/1953	4/1/1953	1		
41.69	-122.64	044N007W03Q002M	USGS	5/1/1953	5/1/1953	1		
41.67	-122.61	044N007W13C002M	USGS	10/1/1953	10/1/1953	1		
41.66	-122.60	044N007W13J001M	USGS	7/1/1953	7/1/1953	1		
41.77	-122.47	045N005W06Q001M	USGS	4/1/1965	4/1/1965	1		
41.76	-122.46	045N005W07H001M	USGS	1/1/1949	1/1/1949	1		
41.76	-122.46	45N05W07H002M	CDWR	7/20/1990	10/19/2011	44	Yes	Yes
41.76	-122.48	045N005W07N001M	USGS	4/1/1953	4/1/1953	1		
41.73	-122.47	045N005W19P001M	USGS	7/1/1953	7/1/1953	1		
41.73	-122.43	045N005W21P001M	USGS	7/1/1953	7/1/1953	1		
41.73	-122.41	045N005W22P001M	USGS	4/1/1953	4/1/1953	1		
41.73	-122.38	045N005W23R001M	USGS	7/1/1953	7/1/1953	1		
41.73	-122.36	045N005W24R001M	USGS	7/1/1953	7/1/1953	1		
41.72	-122.40	045N005W27A001M	USGS	7/1/1953	7/1/1953	1		
41.72	-122.44	045N005W28D001M	USGS	11/1/1953	11/1/1953	1		

Table B-5.—Summary of Well Data Considered for Use in the Shasta Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.72	-122.44	045N005W28M002M	USGS	5/1/1954	5/1/1954	1		
41.72	-122.45	045N005W29B001M	USGS	10/1/1953	10/1/1953	1		
			CDWR	4/8/1953	4/7/1969	115		
41.72	-122.45	45N05W29B003M	CDWR	9/4/1990	3/29/2004	28	Yes	Yes
41.71	-122.42	045N005W33B001M	USGS	4/1/1953	4/1/1953	1		
41.71	-122.41	045N005W34C001M	USGS	5/1/1954	5/1/1954	1		
41.70	-122.40	045N005W35N001M	USGS	7/1/1953	7/1/1953	1		
41.71	-122.38	045N005W36D001M	USGS	6/1/1954	6/1/1954	1		
41.70	-122.38	045N005W36E001M	USGS	6/1/1954	6/1/1954	1		
41.70	-122.38	045N005W36N001M	USGS	5/1/1954	5/1/1954	1		
41.78	-122.48	045N006W01H001M	USGS	7/1/1953	7/1/1953	1		
41.77	-122.52	045N006W10A001M	USGS	5/1/1954	5/1/1954	1		
			CDWR	4/7/1953	4/21/2011	47	Yes	
41.76	-122.52	045N006W10G001M	USGS	10/1/1953	10/1/1953	1		
41.77	-122.48	45N06W12G001M	CDWR	7/20/1990	4/27/2011	38	Yes	
41.75	-122.53	045N006W15F001M	USGS	10/1/1953	10/1/1953	1		
41.74	-122.59	045N006W19E001M	USGS	7/1/1953	7/1/1953	1		
41.74	-122.58	045N006W19H001M	USGS	4/1/1953	4/1/1953	1		
41.73	-122.57	045N006W20L001M	USGS	5/1/1954	5/1/1954	1		
41.73	-122.57	045N006W20P001M	USGS	5/1/1954	5/1/1954	1		
41.73	-122.56	045N006W20Q001M	USGS	7/1/1953	7/1/1953	1		
41.74	-122.53	045N006W22C001M	USGS	10/1/1953	10/1/1953	1		
41.73	-122.49	045N006W24N001M	USGS	7/1/1953	7/1/1953	1		
41.73	-122.52	045N006W27A002M	USGS	7/1/1953	7/1/1953	1		
41.73	-122.53	45N06W27D002M	CDWR	7/20/1990	4/21/2011	43	Yes	
41.72	-122.53	045N006W27E001M	USGS	7/1/1953	7/1/1953	1		
41.73	-122.54	045N006W28A001M	USGS	6/1/1954	6/1/1954	1		
41.72	-122.55	045N006W28B001M	USGS	6/1/1954	6/1/1954	1		
41.72	-122.56	045N006W29K001M	USGS	10/1/1953	10/1/1953	1		
41.73	-122.59	045N006W30D001M	USGS	5/1/1954	5/1/1954	1		
41.73	-122.59	45N06W30D004M	CDWR	9/21/2000	4/21/2011	23	Yes	
41.72	-122.59	45N06W30E001M	CDWR	7/20/1990	10/20/2011	44	Yes	Yes
41.70	-122.56	045N006W32K001M	USGS	5/1/1954	5/1/1954	1		
41.71	-122.55	045N006W33E001M	USGS	10/1/1953	10/1/1953	1		
41.73	-122.60	045N007W24R001M	USGS	5/1/1954	5/1/1954	1		
			CDWR	4/7/1953	10/16/1993	20		
41.71	-122.61	045N007W25N002M	USGS	5/1/1954	5/1/1954	1		
41.71	-122.63	045N007W26P001M	USGS	6/1/1954	6/1/1954	1		
41.71	-122.64	045N007W27R001M	USGS	8/1/1954	8/1/1954	1		

Table B-5.—Summary of Well Data Considered for Use in the Shasta Valley Groundwater Screening Tool

Lat	Lon	WellID	Agency	Begin Record	End Record	No. Records	Eligible Well	Used Well
41.71	-122.62	045N007W35B001M	USGS	6/1/1954	6/1/1954	1		
41.70	-122.61	045N007W36L001M	USGS	4/1/1953	4/1/1953	1		
41.80	-122.47	046N005W30P001M	USGS	10/1/1954	10/1/1954	1		
41.79	-122.47	046N005W31F001M	USGS	5/1/1953	5/1/1953	1		
			CDWR	9/5/1990	10/19/2011	43	Yes	Yes
41.79	-122.42	46N05W33J001M	CDWR	9/5/1990	10/20/2011	45	Yes	

B.4.2.4 Precipitation (P_t)

The groundwater screening tool requires an input timeseries that is representative of historical monthly precipitation over the groundwater basin for the period 1980-1999. For this study, basin-average monthly precipitation was calculated for each groundwater basin based on the historical gridded daily meteorological dataset developed by Maurer et al. (2002), the same dataset used to derive the climate scenarios for the water supply assessment. Area-weighted monthly total precipitation was computed for Scott and Shasta groundwater basins.

B.4.2.5 Evaporative Demand (E_t)

The groundwater screening tool requires an input timeseries that is representative of historical monthly evaporative demand from native and landscaped (non-agricultural) vegetation over the groundwater basin for the period 1980-1999. For this study, basin-average monthly mean temperature was used as a surrogate for evaporative demand, given their close correlation. Similar to precipitation, the historical gridded daily meteorological dataset developed by Maurer et al. (2002) was used to compute area-weighted monthly mean temperature for Scott and Shasta groundwater basins. A sensitivity analysis was performed to test model fit using basin mean annual PET in place of basin-average monthly mean temperature; however, results did not improve though use of PET.

B.4.2.6 Streamflow (S_t)

The groundwater screening tool requires an input timeseries that is representative of historical monthly streamflow that contributed to water supply in the groundwater basin for the period 1980-1999. For this study, historical gridded daily runoff, developed through the surface water hydrology analysis portion of this study, was used to compute area-weighted monthly runoff for Scott and Shasta groundwater basins. Due to the relatively small size of the Scott and Shasta Valleys, it is assumed that the time of concentration of flow (i.e., the time it takes a drop of water to flow from the top of the basin to the mouth) is close to one day, therefore, routing of runoff through the basin does not substantially impact the timing of streamflow in either basin.

B.4.2.7 Municipal, Domestic, and Industrial Demand (M_t)

The groundwater screening tool requires an input timeseries that is representative of historical monthly municipal, domestic, and industrial water demand within the groundwater basin for the period 1980-1999. Where demand data are not directly available, demand may be estimated from available population and per capita water use data, interpolated as needed to obtain monthly data for the period 1980-1999. For this study, population within each groundwater basin was calculated from decadal gridded Census data available at 1 km resolution over the period 1930-2000 (https://www.census.gov/programs-surveys/decennial-census/data/datasets.html). Data were interpolated to obtain monthly values. Mean per capita water use was determined based on reported groundwater withdrawals for domestic use of 0.25 acre-feet/year/household (assuming one well per household) from the S.S. Papadopulous (2012) Scott Valley groundwater modeling study. The Siskiyou Census Factsheet (https://www.census.gov/quickfacts/fact/table/siskiyoucountycalifornia, US/PST045218) provided mean persons per household (for 2010) as 2.2. Mean per capita water use was computed as 101 gal/capita/day, and was assumed to be constant over the historical simulation period 1980-1999. Municipal, domestic, and industrial demand was then estimated as the product of population and per capita use.

B.4.2.8 Agricultural Demand (A_t)

The groundwater screening tool requires an input timeseries that is representative of historical monthly agricultural water demand within the groundwater basin for the period 1980-1999. For this study, mean agricultural water use was derived using irrigated acreage and reported rates of water use by crop type. Total agricultural acreages for both Scott and Shasta Valleys were obtained from the 2009 USDA Cropland Data Layer (Johnson and Mueller, 2010). This dataset was used as the basis for Reclamation’s West Wide Climate Risk Assessment for water demands (Reclamation, in preparation). Land use data are also available from the CDWR Land Use Survey. Data from the most recent Siskiyou County survey, which was completed in 2010, were used for this study.

Groundwater use data for irrigation from the S.S. Papadopulos & Associates, Inc. (2012) groundwater study for the Scott Valley (which originated from CDWR 2000 Land Use Survey) was adjusted to account for the difference in acreage of irrigated lands between the CDWR Land Use Survey and the 2009 USDA Cropland Data Layer (both for Scott and Shasta groundwater basins). The same seasonal proportions were used, per the S.S. Papadopulos & Associates, Inc. (2012) study to generate feet of groundwater used per season. Tables B-6 and B-7 summarize seasonal groundwater use for irrigation in the Scott and Shasta groundwater basins, respectively. The values in bold are those groundwater use values used by the Scott and Shasta groundwater screening tools.

Table B-6.—Summary of Groundwater Use for Irrigation in Scott Groundwater Basin

	Alfalfa	Corn	Grain	Pasture	GW Basin
GW Use (ft/acre/season)					
May-Jun**	0.87	0.26	0.55	1.07	
Jul-Sep**	1.96	1.7	0.98	1.83	
Oct-Apr	0	0	0	0	
Acreage (based on USDA, 2009)	9,895	0	1,651	13,115	25,118
GW Use (ft/season)					
May-Jun	8,606	0	908	14,033	5,887
Jul-Sep	19,393	0	1,618	24,001	11,253
Oct-Apr	0	0	0	0	0

**reported by S.S.Papadopulos & Associates (2012) table 4.3a.

Table B-7.—Summary of Groundwater Use for Irrigation in Shasta Groundwater Basin

	Alfalfa	Corn	Grain	Pasture	GW Basin
GW Use (ft/acre/season)					
May-Jun**	0.87	0.26	0.55	1.07	
Jul-Sep**	1.96	1.7	0.98	1.83	
Oct-Apr	0	0	0	0	
Acreage (based on USDA, 2009)	4,857	26	9,137	20,379	34,657
Mean GW Use (ft/season)					
May-Jun	4,226	7	5,025	21,806	7,766
Jul-Sep	9,520	44	8,954	37,294	13,953
Oct-Apr	0	0	0	0	0

**reported by S.S.Papadopulos & Associates (2012) table 4.3a.

B.4.2.9 Other Inputs

Other possible inputs to the groundwater screening tool are trans-basin imported water and an exogenous variable. The Scott and Shasta groundwater basins do not have imported water, so this term is not further discussed here. The exogenous variable allows for the modeler to incorporate additional processes that may not be represented through the other variables. Exogenous variables were not used in development of the groundwater screening tools for the Scott or Shasta Valleys.

B.5 Supporting Information

Appendix B provides complementary analyses to those summarized in Chapter 3– Water Supply Assessment of the Basin Study. Primarily, this appendix contains summaries of projected surface water parameters using CMIP3-based scenarios. CMIP5-based scenarios were summarized within Chapter 3. This appendix also contains supplemental analyses on projected changes in runoff timing.

Figure B-11 illustrates historical and projected April 1 SWE, and mean annual runoff, and mean spring runoff based on the CMIP3 CT HDe scenarios. This figure is similar in format to figure 3-31 in the body of Chapter 3– Water Supply Assessment of the Basin Study. The left panel summarizes historical values over the period 1950-1999, while the middle and right columns illustrate projected changes for the 2030s and 2070s, respectively. Mean percent change in April 1 SWE across the Klamath River Basin is -34 percent for the 2030s and -58 percent for the 2070s. Mean percent change in annual runoff is +7.3 percent for the 2030s and +13.9 percent for the 2070s. Mean percent change in irrigation season runoff is -23.3 percent for the 2030s and -41.4 percent for the 2070s. These projected changes are generally smaller than those projected based on CMIP5.

Figure B-12 illustrates historical and projected June 1 soil moisture and mean annual ET based on the CMIP3 central tendency HDe scenarios. This figure is similar in format to figure 3-32 in the body of Chapter 3 – Assessment of Current and Future Water Supply. The left panel summarizes historical values over the period 1950-1999, while the middle and right columns illustrate projected changes for the 2030s and 2070s, respectively. Mean percent change in July 1 soil moisture across the Klamath River Basin is -4.6 percent for the 2030s and -7.7 percent for the 2070s. Mean percent change in annual ET is +0.7 percent for the 2030s and +2.1 percent for the 2070s.

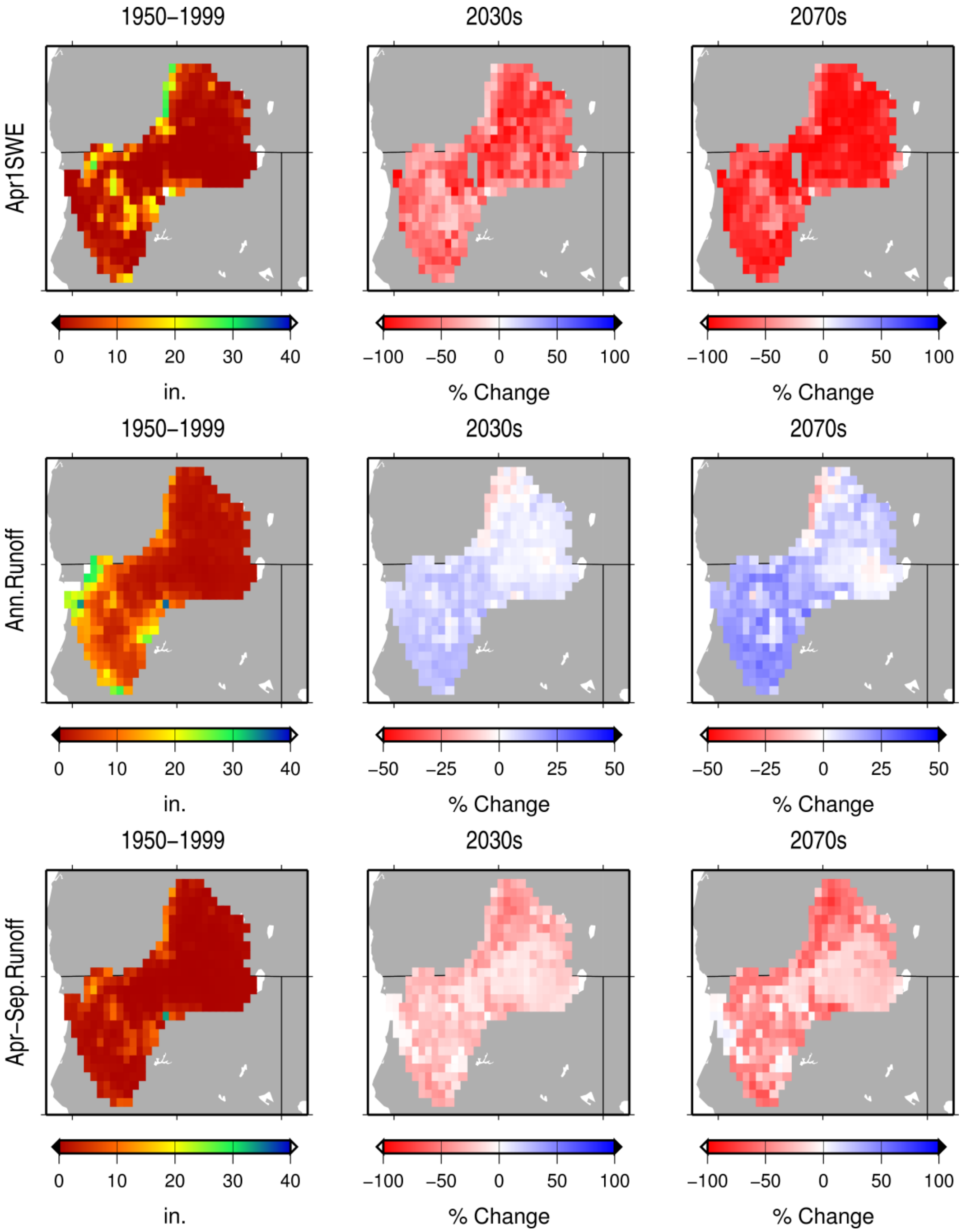

Figure B-11.—Comparison of percent change in mean April 1 SWE (Apr1SWE, top row), mean annual runoff (Runoff, middle row), and mean April-September runoff for the central tendency climate projection, using groupings of GCMs from CMIP3. The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from historical values to the 2030s and 2070s, respectively.

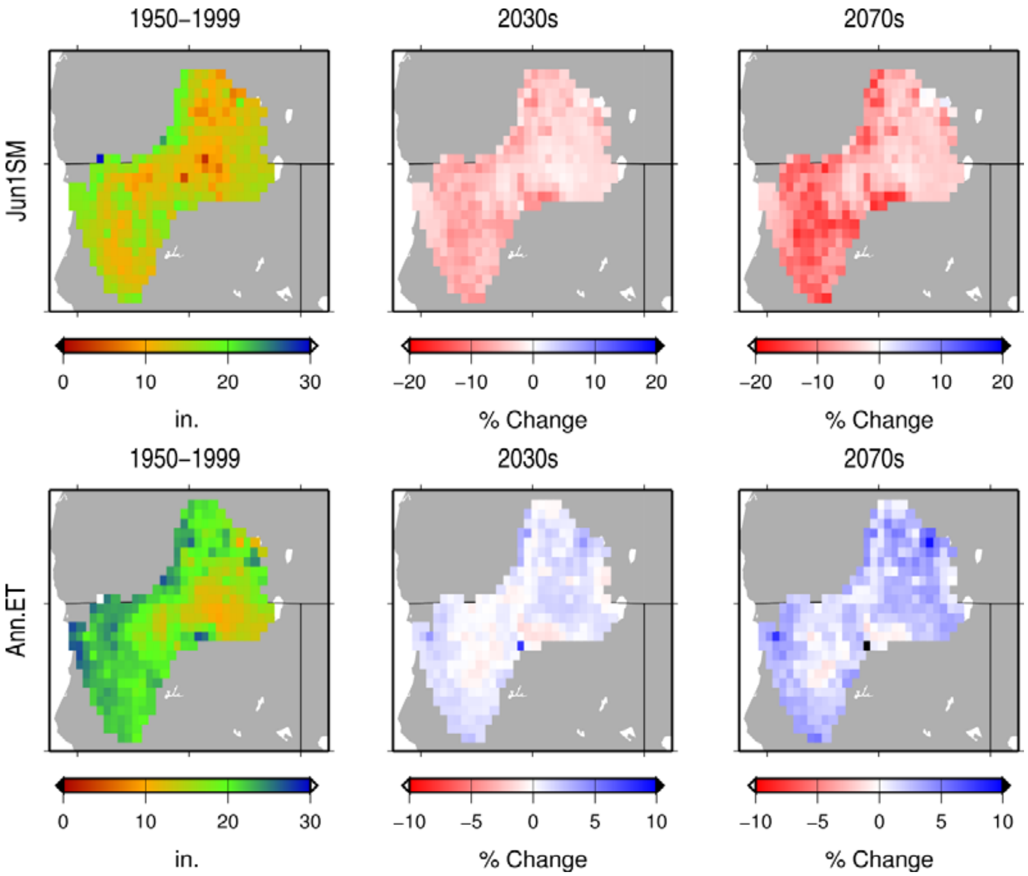

Figure B-12.—Comparison of percent change in mean June 1 soil moisture (Jun1SM, top row), mean annual ET (Ann.ET, bottom row) for the central tendency climate projection, using groupings of GCMs from CMIP3. The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from 1990s values to the 2030s and 2070s, respectively.

Projected shifts (in days) of annual runoff volume (computed based on water year) are summarized in figure B-13 and table B-7 for CMIP3 and figure B-14 and table B-8 for CMIP5. In table B-7 and table B-8, the column "Base Julian Day (or Date)" represents the approximate Julian Day (starting from October 1) of the centroid of the mean annual hydrograph. The approximate centroid date (Julian Day) represents the moment-arm of the mean annual hydrograph, which is computed as the moment of flow for each month divided by the total area under the annual hydrograph (i.e., the total annual flow volume). A similar calculation was performed for each of the 5 quadrant scenarios and for two future time periods (2030s and 2070s), based on CMIP3 and CMIP5 (20 total scenarios). Shifts were computed as the difference of projected centroid dates and the centroid date of the base case mean annual hydrograph (computed over 1950-1999 calendar years). A negative shift indicates that more of runoff is projected to occur earlier compared to the historical baseline because the centroid has shifted to an earlier date. A positive shift indicates that more of the runoff is projected to occur later than the historical baseline.

To gain an understanding of the shifts in runoff timing across the entire Klamath River Basin for the five quadrant HDe scenarios for each future time period, data in tables B-8 and B-9 are illustrated as histograms in figure B-13 and figure B-14, respectively.

Figure B-7 shows that all scenarios show a shift toward earlier runoff regime. Based on CMIP3 HDe scenarios, the projected shifts range from 2 days earlier at the Trinity River at Lewiston, CA (Site ID 00021), which results from the WD quadrant scenario to 26 days earlier at the Klamath River below Iron Gate Dam, CA and Trinity River above Coffee Creek, CA (Site IDs 00026 and 00039, respectively), which result from the HW quadrant scenario. The average shift in runoff timing for the CT quadrant scenario (central tendency) for the 2030s is 13 days earlier in the water year. For the 2070s, the projected shifts range from 2 days earlier to 42 days earlier (at the same sites as projected for the 2030s). The average shift in runoff timing for the CT quadrant scenario for the 2070s is 23 days earlier in the water year.

Figure B-8 shows that all scenarios show a shift toward earlier runoff regime. Based on CMIP5 HDe scenarios, the projected shifts range from 2 days earlier at the South Fork Trinity River below Hyampom, CA (Site ID 00040), which results from the WD quadrant scenario to 27 days earlier at the Klamath River at Keno, OR and Klamath River at the California-Oregon State line (Site IDs 00023 and 00038, respectively), which result from the HW quadrant scenario. The average shift in runoff timing for the CT quadrant scenario (central tendency) for the 2030s is 15 days earlier in the water year. For the 2070s, the projected shifts range from 8 days earlier to 45 days earlier (at the same sites as projected for the 2030s). The average shift in runoff timing for the CT quadrant scenario for the 2070s is 23 days earlier in the water year.

A comparison of results of CMIP5-based scenarios and CMIP3-based scenarios shows that these types of scenarios indicate similar shifts in runoff timing, within no greater than 6 days difference between them. CMIP5-based scenarios indicate greater shifts toward earlier runoff timing than CMIP3 for all quadrants and time horizons, with the exception of WD and WW scenarios for the 2070s. For these scenarios, CMIP3-based projections generally showed greater shifts toward earlier runoff timing. The difference between types of scenarios likely corresponds with projections of greater precipitation increase by CMIP5-based scenarios, compared with CMIP3. This analysis supports a consistent picture of future conditions, where subbasins are likely to experience shifts in seasonal flow volumes earlier than experienced historically.

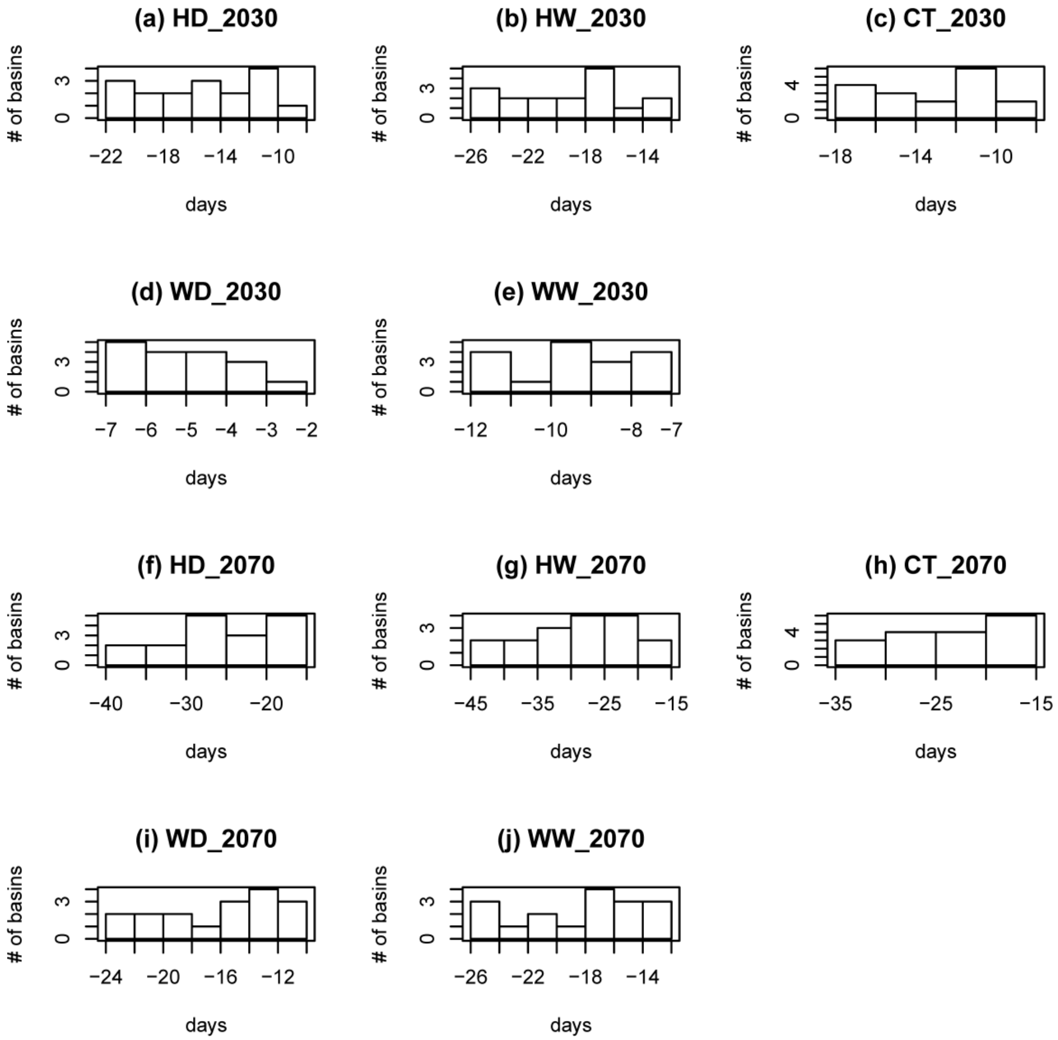

Figure B-13.—Histograms of approximate shift in timing (days) of annual runoff volumes from 17 subbasins of the Klamath River Basin for five HDe scenarios (hot wet=HW, hot dry=HD, central tendency=CT, warm wet=WW, warm dry=WD) for two future periods, 2030s (a-e) and 2070s (f-j) using CMIP3 climate projections. The vertical dashed red line represents no shift in timing. Negative values (days) represent earlier runoff, and positive values (days) represent later runoff from the historical period (1950-1999).

Table B-8.—Summary of Outlet Locations for Subbasins Included in Analysis of Projected Shifts in Annual Runoff Volumes Based on CMIP3 (Corresponds with figure B-13)

Basin ID	Site Name	Base Julian Day	Base Date	HD 2030	HW 2030	CT 2030	WD 2030	WW 2030	HD 2070	HW 2070	CT 2070	WD 2070	WW 2070
00004	Klamath R at Orleans, CA	Base Julian Day	Base Date	HD_2030	HW_2030	CT_2030	WD_2030	WW_2030	HD_2070	HW_2070	CT_2070	WD_2070	WW_2070
00020	Sprague R near Chiloquin, OR	183	1-Apr	-15	-18	-12	-4	-9	-24	-28	-22	-15	-17
00021	Trinity R at Lewiston ,CA	191	9-Apr	-11	-16	-10	-2	-8	-18	-23	-17	-12	-14
00022	Salmon R at Somes Bar, CA	183	1-Apr	-14	-17	-11	-5	-7	-25	-26	-22	-15	-16
00023	Klamath R at Keno, OR	185	3-Apr	-15	-18	-12	-5	-8	-25	-28	-23	-15	-17
00026	Klamath R blw Iron Gate Dam, CA	208	26-Apr	-21	-26	-18	-7	-12	-36	-42	-32	-23	-26
00027	Klamath R nr Seiad Valley, CA	203	21-Apr	-20	-25	-18	-6	-12	-33	-39	-31	-21	-25
00029	Klamath R near Klamath, CA	193	11-Apr	-16	-21	-14	-5	-10	-27	-32	-25	-17	-20
00031	Shasta R near Yreka, CA	173	22-Mar	-11	-14	-10	-3	-7	-19	-22	-18	-12	-13
00032	Scott R near Ft Jones, CA	186	4-Apr	-11	-16	-11	-4	-8	-19	-23	-19	-11	-15
00033	Indian Ck near Happy Camp, CA	180	29-Mar	-13	-17	-11	-4	-9	-22	-25	-21	-13	-16
00034	Trinity R at Hoopa, CA	173	22-Mar	-17	-20	-14	-6	-9	-27	-30	-25	-18	-19
00037	Williamson R below Sprague R near Chiloquin, OR	166	15-Mar	-10	-13	-9	-3	-7	-16	-19	-16	-10	-12
00038	Klamath River at the CA-OR State line	203	21-Apr	-18	-23	-16	-5	-11	-29	-35	-27	-19	-22
00039	Trinity R above Coffee Ck near Trinity Center, CA	207	25-Apr	-21	-26	-18	-7	-12	-36	-42	-32	-23	-26
00040	S Fork Trinity R below Hyampom, CA	190	8-Apr	-19	-22	-15	-7	-9	-32	-34	-28	-20	-21
00041	Shasta R near Montague, CA	159	8-Mar	-9	-13	-8	-3	-7	-15	-17	-15	-10	-12

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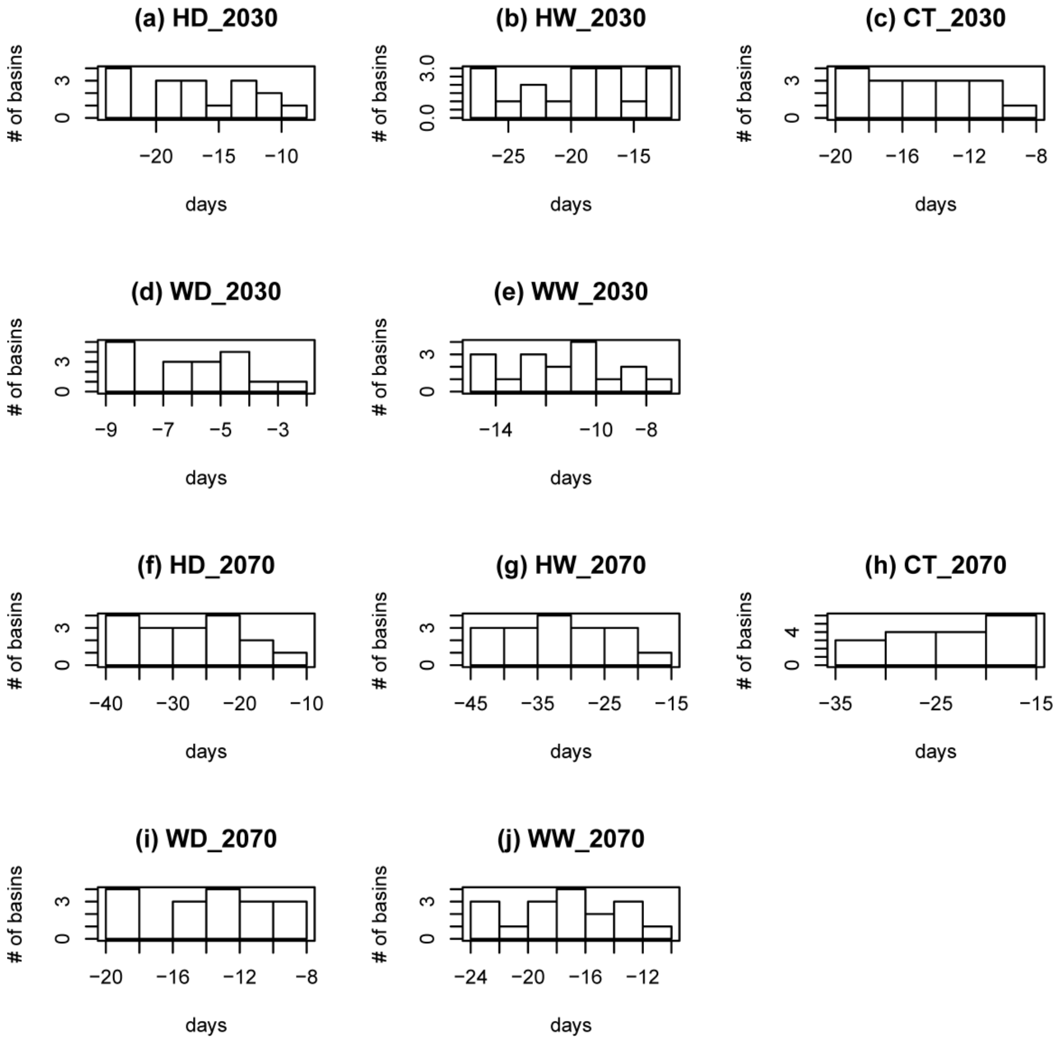

Figure B-14.—Histograms of approximate shift in timing (days) of the date of centroid of runoff from 17 subbasins of the Klamath River Basin for five HDe scenarios (hot wet=HW, hot dry=HD, central tendency=CT, warm wet=WW, warm dry=WD) for two future periods, 2030s (a-e) and 2070s (f-j) using CMIP5 climate scenarios. The vertical dashed red line represents no shift in timing. Negative values (days) represent earlier runoff, and positive values (days) represent later runoff from the historical period (1950-1999).

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Table B-9.—Summary of Outlet Locations for Subbasins Included in Analysis of Projected Shifts (in days) in Annual Runoff Volumes Based on CMIP5 (corresponds with figure B-14)

Basin ID	Site Name	Base Julian Day	Base Date	HD 2030	HW 2030	CT 2030	WD 2030	WW 2030	HD 2070	HW 2070	CT 2070	WD 2070	WW 2070
00004	Klamath R at Orleans, CA	183	1-Apr	-16	-19	-14	-5	-11	-26	-30	-23	-13	-16
00020	Sprague R near Chiloquin, OR	191	9-Apr	-10	-13	-11	-4	-8	-18	-21	-16	-8	-11
00021	Trinity R at Lewiston ,CA	183	1-Apr	-16	-18	-14	-6	-10	-27	-31	-23	-13	-16
00022	Salmon R at Somes Bar, CA	185	3-Apr	-16	-19	-14	-5	-11	-27	-32	-23	-13	-16
00023	Klamath R at Keno, OR	208	26-Apr	-24	-27	-20	-9	-15	-40	-45	-32	-19	-23
00026	Klamath R blw Iron Gate Dam, CA	203	21-Apr	-22	-26	-19	-8	-15	-37	-42	-30	-18	-22
00027	Klamath R near Seiad Valley, CA	193	11-Apr	-18	-21	-16	-6	-12	-30	-35	-25	-14	-18
00029	Klamath R near Klamath, CA	173	22-Mar	-12	-15	-11	-4	-9	-20	-23	-18	-10	-13
00031	Shasta R near Yreka, CA	186	4-Apr	-12	-16	-12	-4	-10	-21	-26	-18	-10	-14
00032	Scott R near Ft Jones, CA	180	29-Mar	-14	-17	-13	-5	-10	-24	-29	-21	-12	-16
00033	Indian Ck near Happy Camp, CA	173	22-Mar	-19	-22	-16	-6	-12	-30	-33	-26	-15	-19
00034	Trinity R at Hoopa, CA	166	15-Mar	-10	-13	-10	-3	-8	-17	-20	-16	-9	-12
00037	Williamson R below Sprague R near Chiloquin, OR	203	21-Apr	-19	-22	-17	-8	-12	-31	-36	-26	-15	-18
00038	Klamath River at the CA-OR State Line	207	25-Apr	-24	-27	-20	-9	-15	-40	-45	-32	-19	-23
00039	Trinity R above Coffee Ck near Trinity Center, CA	190	8-Apr	-22	-24	-18	-9	-13	-35	-39	-29	-18	-21
00040	S Fork Trinity R below Hyampom, CA	159	8-Mar	-9	-12	-9	-2	-7	-14	-17	-15	-8	-12
00041	Shasta R near Montague, CA	188	6-Apr	-12	-16	-13	-4	-10	-22	-27	-19	-10	-14

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Appendix C - Supplemental Information for Assessment of Water Demand

C.1 Figures and Summary Tables for ET Demands Model Results

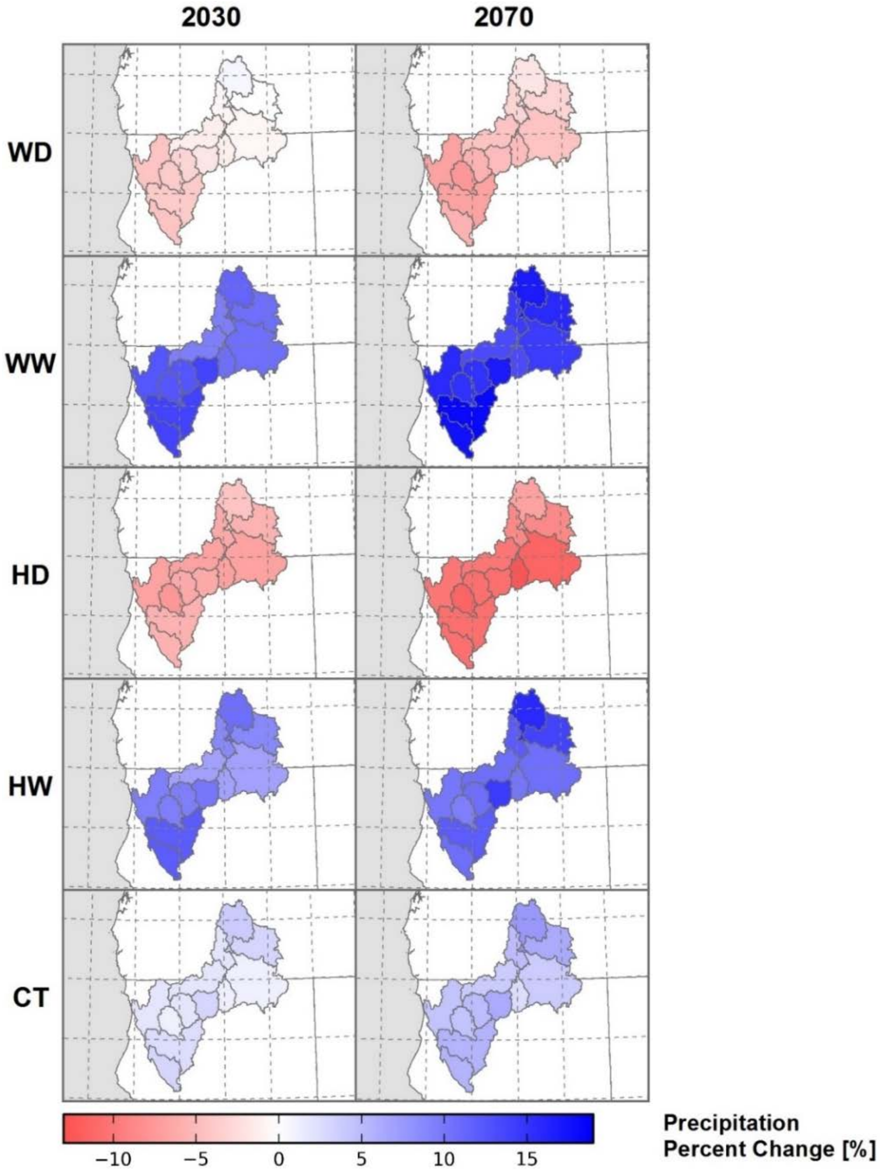

Figure C-1.—Klamath River Basin – Spatial distribution of projected precipitation change (in percent) for different climate scenarios and time periods (CMIP3 climate scenarios).

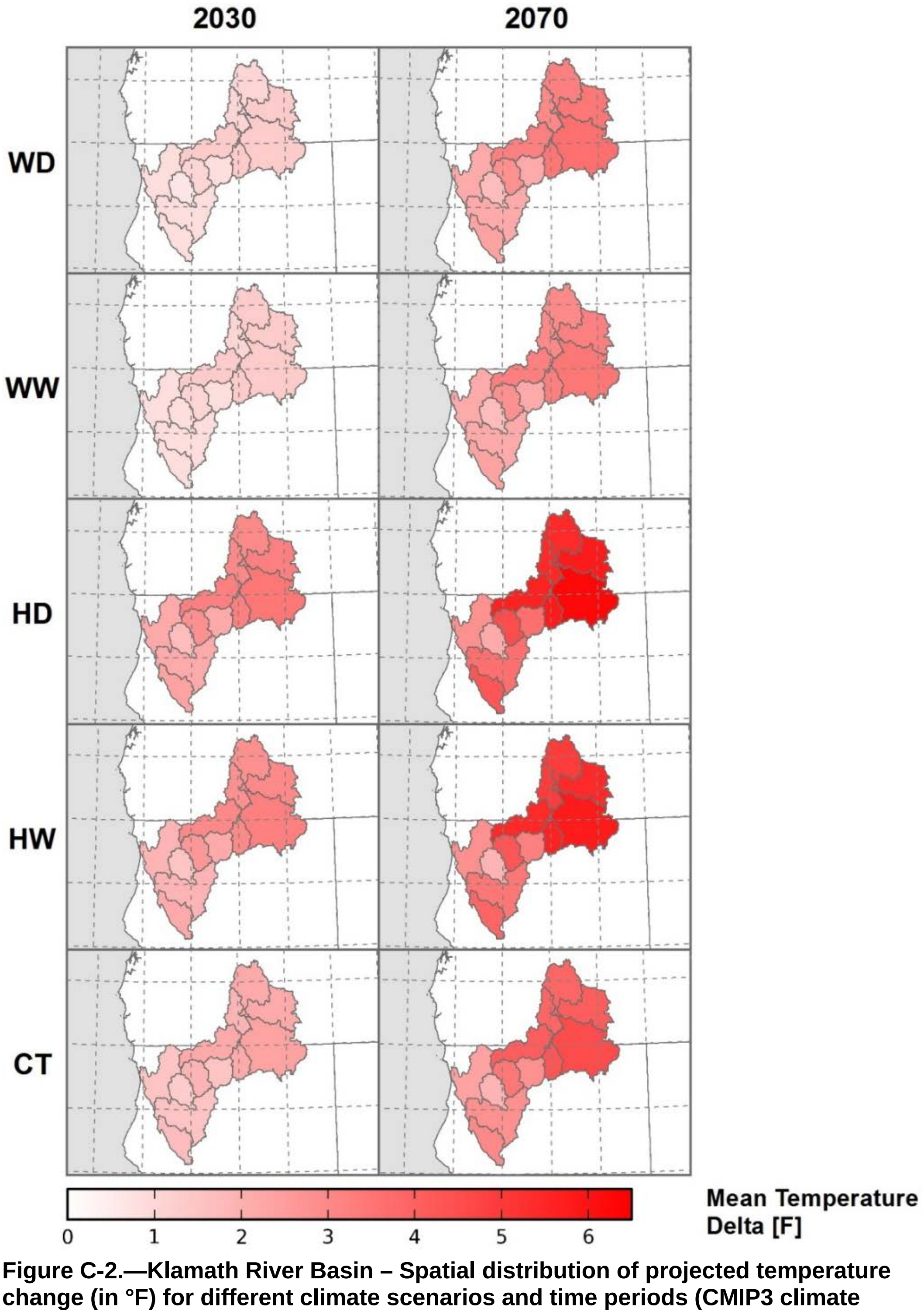

Figure C-2.—Klamath River Basin – Spatial distribution of projected temperature change (in °F) for different climate scenarios and time periods (CMIP3 climate scenarios).

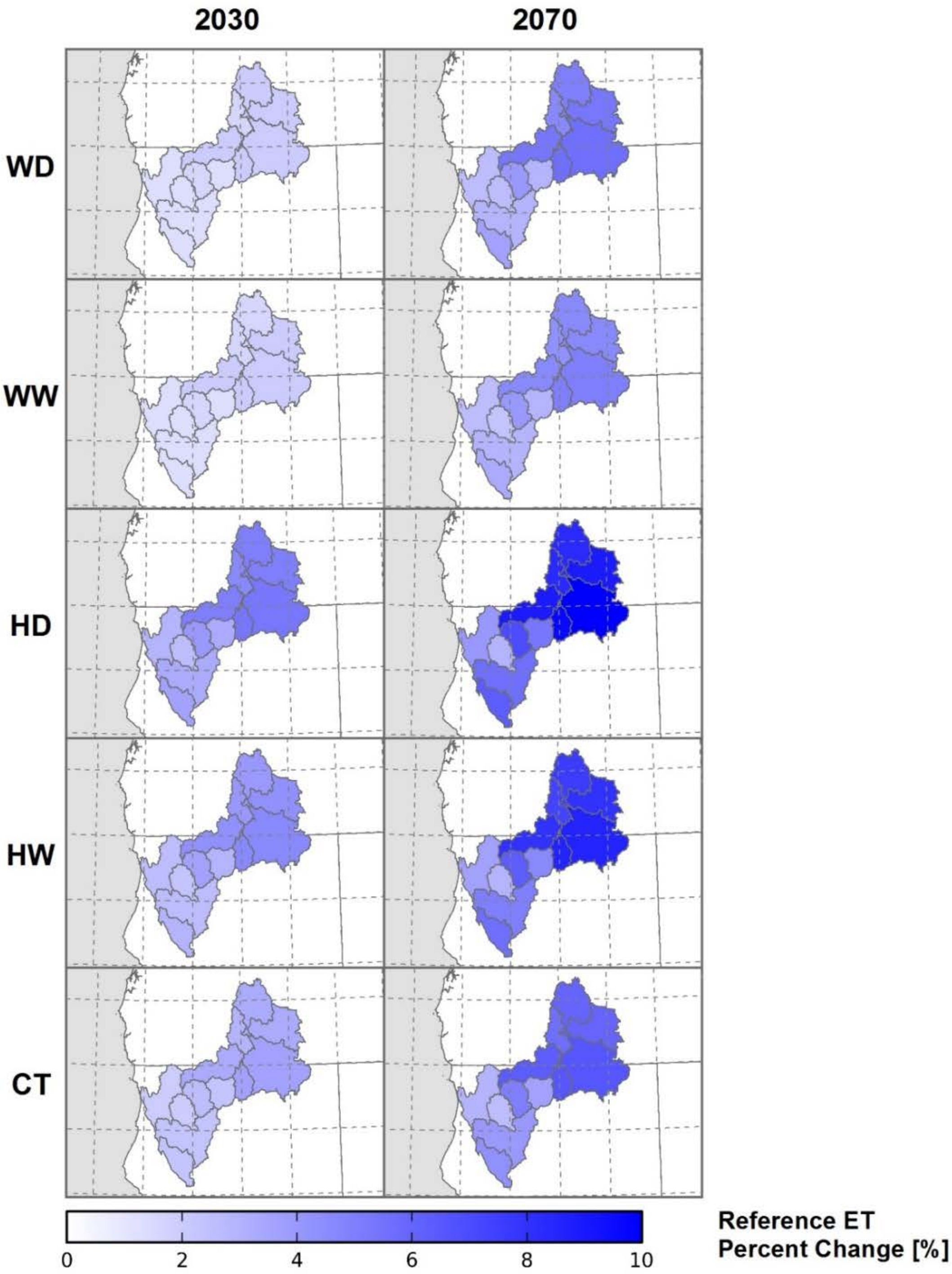

Figure C-3.—Klamath River Basin – Spatial distribution of projected reference ET percent change for different climate scenarios and time periods (CMIP3 climate scenarios).

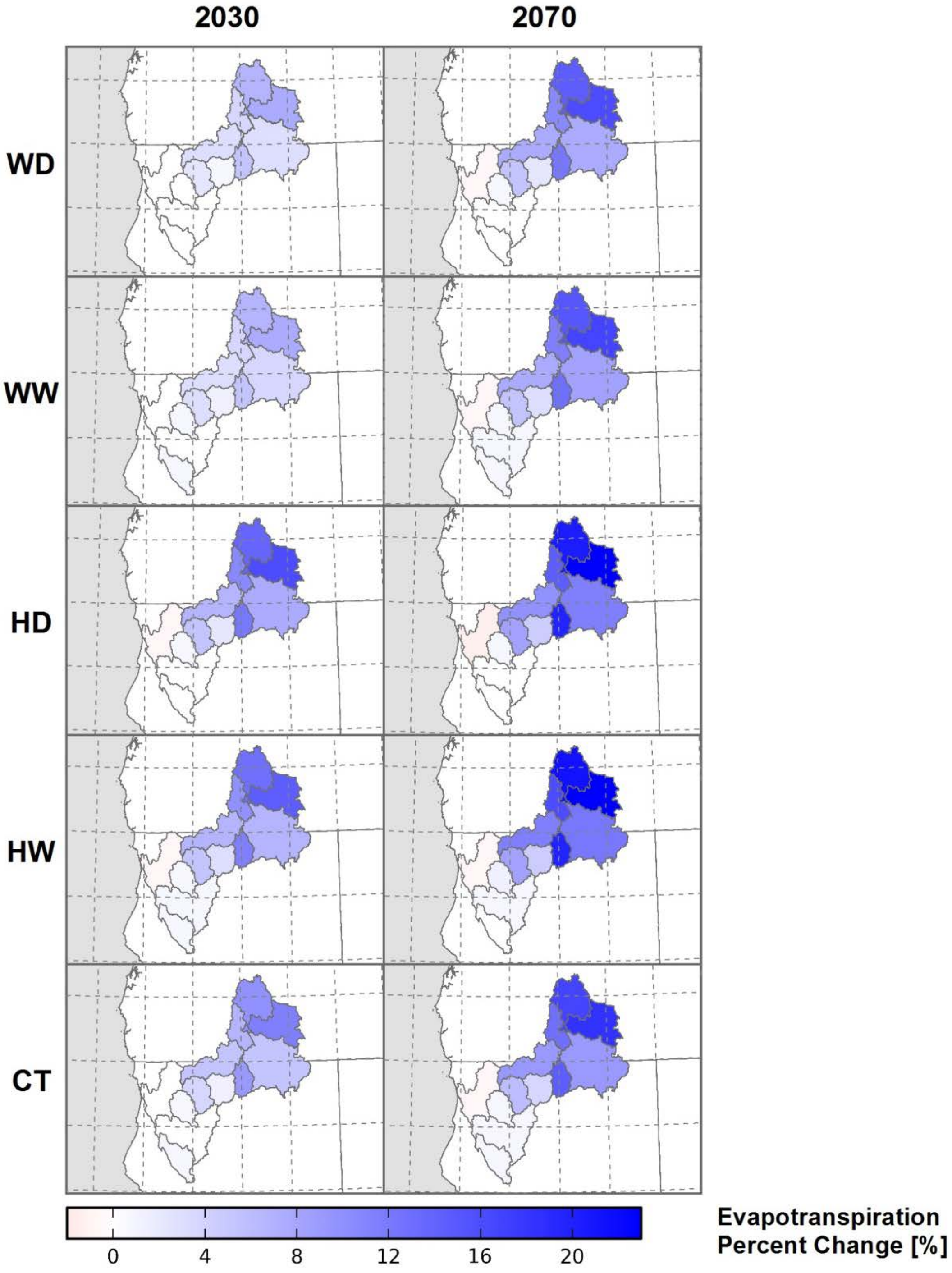

Figure C-4.—Klamath River Basin – Spatial distribution of projected crop ET percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP3 climate scenarios).

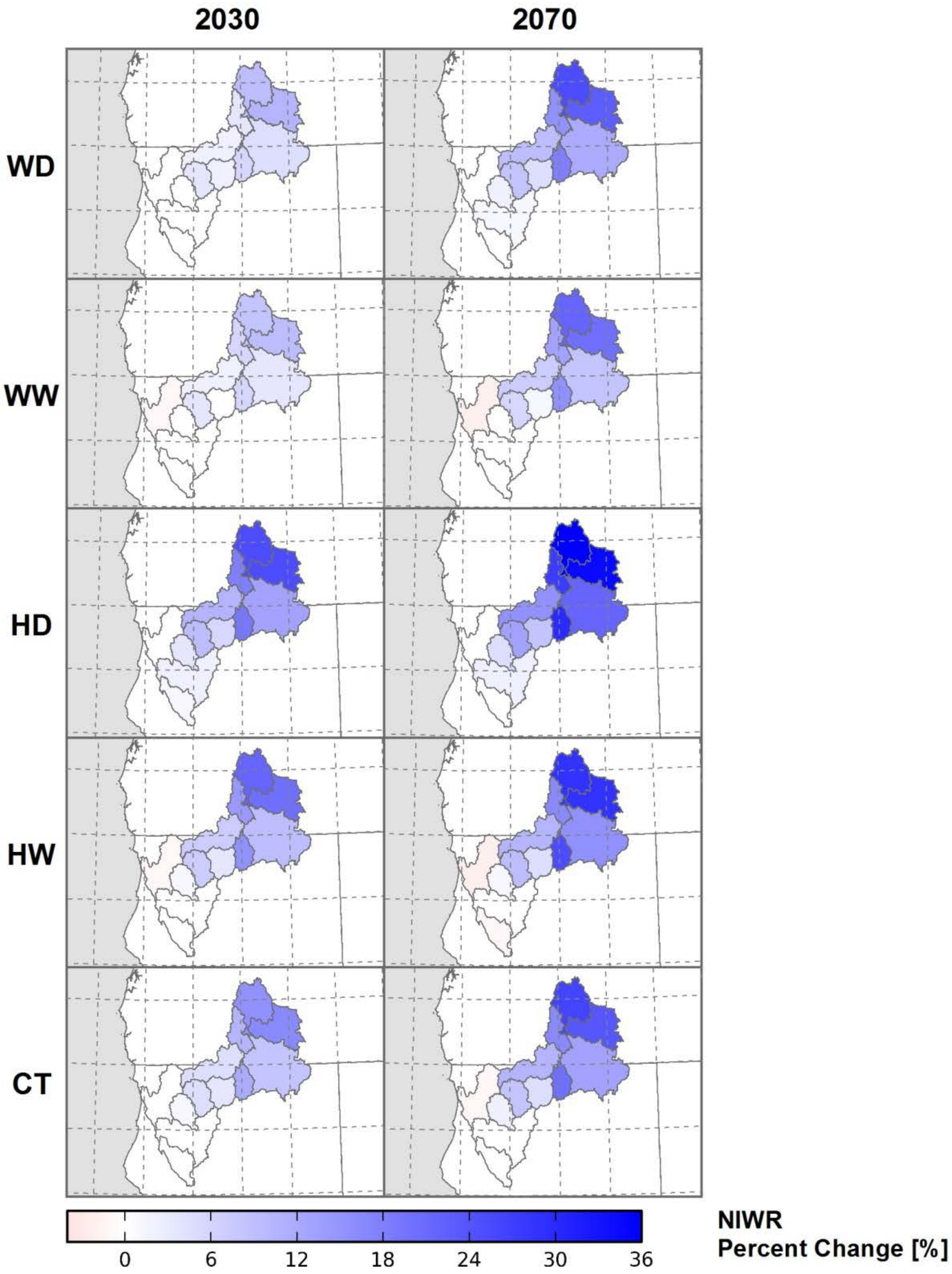

Figure C-5.—Klamath River Basin – Spatial distribution of projected net irrigation water requirements (NIWR) percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP3 climate scenarios).

Table C-1.—Comparison of Projected Annual Average Precipitation (inches/year) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Klamath River Basin and Hydrologic Unit Code (HUC)8 Sub-Basins

Scenario	Period	BCSD Projection	1	2	3	4	5	6	7	8	9	10	11	12	Basin
Historical	Historical	-	20.2	16.3	25.0	12.0	12.7	14.1	19.9	22.4	53.9	43.6	35.6	37.6	15.8
Warm Dry	2030	CMIP-3	20.3	16.3	24.8	11.8	12.5	13.9	19.5	21.6	51.5	41.8	34.1	35.8	15.6
Warm Dry	2030	CMIP-5	19.6	16.0	23.8	11.6	12.0	13.6	19.1	21.4	51.2	41.1	33.7	35.6	15.3
Warm Wet	2030	CMIP-3	22.5	18.0	27.3	13.3	14.1	15.5	22.6	25.2	60.6	49.2	40.6	42.7	17.6
Warm Wet	2030	CMIP-5	22.2	17.8	27.2	13.1	13.9	15.4	22.3	24.8	59.6	48.2	39.9	42.3	17.4
Hot Dry	2030	CMIP-3	19.2	15.3	23.4	11.1	11.8	13.1	18.7	21.0	50.2	40.3	33.6	35.4	14.8
Hot Dry	2030	CMIP-5	19.3	15.6	23.7	11.5	12.0	13.5	19.1	21.4	50.9	41.1	33.5	36.0	15.1
Hot Wet	2030	CMIP-3	22.4	17.8	27.2	12.8	13.6	15.1	21.9	24.5	59.0	47.8	39.8	42.1	17.1
Hot Wet	2030	CMIP-5	22.5	18.0	27.1	13.0	13.7	15.3	22.2	24.7	59.2	47.7	40.1	42.4	17.3
Central Tendency	2030	CMIP-3	21.0	16.8	25.6	12.2	12.9	14.4	20.6	22.9	55.1	44.4	36.6	38.9	16.2
Central Tendency	2030	CMIP-5	21.7	17.5	26.2	12.7	13.3	14.9	21.3	23.6	55.2	44.7	36.7	38.6	16.8
Warm Dry	2070	CMIP-3	19.7	15.8	24.1	11.4	12.0	13.5	18.9	21.0	50.2	40.4	33.1	35.3	15.2
Warm Dry	2070	CMIP-5	20.2	16.3	24.5	11.9	12.5	14.0	19.5	21.8	51.6	41.6	34.3	36.0	15.7
Warm Wet	2070	CMIP-3	23.6	18.8	28.6	13.7	14.3	16.0	23.3	25.7	62.3	50.1	42.1	44.1	18.2
Warm Wet	2070	CMIP-5	23.6	19.0	28.3	13.9	14.7	16.3	23.6	25.9	60.8	49.5	40.9	43.0	18.4
Hot Dry	2070	CMIP-3	18.7	14.8	22.8	10.6	11.1	12.7	17.7	20.0	48.3	38.6	31.8	33.7	14.2
Hot Dry	2070	CMIP-5	19.7	15.7	23.9	11.4	11.7	13.3	19.0	21.3	50.9	40.7	33.3	35.6	15.1
Hot Wet	2070	CMIP-3	23.3	18.5	28.0	13.3	14.0	15.6	22.7	24.8	59.5	47.7	39.8	41.7	17.7
Hot Wet	2070	CMIP-5	24.3	19.7	29.0	14.2	14.6	16.5	23.9	26.0	60.9	49.3	41.4	43.2	18.7
Central Tendency	2070	CMIP-3	21.7	17.3	26.4	12.4	13.0	14.7	21.3	23.5	56.5	45.6	37.7	39.7	16.6
Central Tendency	2070	CMIP-5	21.7	17.5	26.2	12.7	13.3	14.9	21.7	24.0	57.1	46.2	38.1	40.5	16.9

Notes:

1	HUC_18010201	Williamson
2	HUC_18010202	Sprague
3	HUC_18010203	Upper Klamath Lake
4	HUC_18010204	Lost
5	HUC_18010205	Butte
6	HUC_18010206	Upper Klamath
7	HUC_18010207	Shasta
8	HUC_18010208	Scott
9	HUC_18010209	Lower Klamath
10	HUC_18010210	Salmon
11	HUC_18010211	Trinity
12	HUC_18010212	South Fork Trinity

Table C-2.—Comparison of Projected Annual Average Temperature (°F) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Klamath River Basin and HUC8 Sub-Basins

Scenario	Period	BCSD Projection	1	2	3	4	5	6	7	8	9	10	11	12	Basin
Historical	Historical	-	44.0	44.6	44.4	46.7	45.1	48.2	51.8	50.5	57.5	53.0	54.5	52.1	46.7
Warm Dry	2030	CMIP-3	45.2	45.9	45.6	48.1	46.4	49.5	52.8	51.6	58.4	53.9	55.5	53.1	48.0
Warm Dry	2030	CMIP-5	45.7	46.4	46.0	48.7	46.9	50.1	53.1	52.1	58.7	54.2	55.8	53.5	48.5
Warm Wet	2030	CMIP-3	45.2	45.9	45.6	48.1	46.4	49.5	52.8	51.7	58.4	53.9	55.5	53.1	48.0
Warm Wet	2030	CMIP-5	45.7	46.3	45.9	48.6	46.9	50.0	53.1	52.1	58.7	54.2	55.8	53.5	48.5
Hot Dry	2030	CMIP-3	47.0	47.8	47.3	50.1	48.4	51.4	54.1	53.3	59.6	54.9	56.8	54.5	49.9
Hot Dry	2030	CMIP-5	47.5	48.3	47.8	50.7	48.8	51.9	54.2	53.6	59.7	55.0	57.0	54.8	50.4
Hot Wet	2030	CMIP-3	46.8	47.6	47.1	49.9	48.1	51.2	53.9	53.1	59.5	54.7	56.6	54.4	49.7
Hot Wet	2030	CMIP-5	47.5	48.3	47.8	50.7	48.8	51.9	54.3	53.7	59.7	54.9	57.0	54.8	50.4
Central Tendency	2030	CMIP-3	46.1	46.8	46.4	49.1	47.3	50.4	53.4	52.4	59.0	54.4	56.1	53.8	48.9
Central Tendency	2030	CMIP-5	46.5	47.3	46.8	49.6	47.8	50.9	53.7	52.9	59.3	54.6	56.4	54.2	49.4
Warm Dry	2070	CMIP-3	47.1	47.9	47.4	50.3	48.5	51.5	54.1	53.4	59.6	54.8	56.8	54.6	50.0
Warm Dry	2070	CMIP-5	46.5	47.2	46.8	49.6	47.8	50.9	53.7	52.9	59.3	54.6	56.5	54.2	49.4
Warm Wet	2070	CMIP-3	47.1	47.9	47.4	50.2	48.4	51.4	54.1	53.3	59.6	54.8	56.7	54.6	49.9
Warm Wet	2070	CMIP-5	46.5	47.3	46.9	49.6	47.9	50.9	53.7	52.9	59.3	54.7	56.5	54.2	49.4
Hot Dry	2070	CMIP-3	49.3	50.3	49.6	53.0	50.9	53.8	55.4	55.1	60.4	55.2	58.3	56.3	52.4
Hot Dry	2070	CMIP-5	50.7	51.8	51.1	54.7	52.4	55.4	56.2	56.4	60.9	55.6	59.3	57.4	53.9
Hot Wet	2070	CMIP-3	49.0	50.0	49.3	52.6	50.6	53.5	55.1	54.9	60.3	55.1	58.0	56.1	52.0
Hot Wet	2070	CMIP-5	51.1	52.2	51.6	55.2	52.9	55.8	56.5	56.8	61.2	55.8	59.6	57.8	54.3
Central Tendency	2070	CMIP-3	47.9	48.7	48.2	51.2	49.3	52.3	54.5	54.0	59.9	55.0	57.3	55.2	50.8
Central Tendency	2070	CMIP-5	48.2	49.1	48.5	51.6	49.7	52.7	54.8	54.3	60.0	55.0	57.6	55.4	51.2

Notes:

1	HUC_18010201	Williamson	7	HUC_18010207	Shasta
2	HUC_18010202	Sprague	8	HUC_18010208	Scott
3	HUC_18010203	Upper Klamath Lake	9	HUC_18010209	Lower Klamath
4	HUC_18010204	Lost	10	HUC_18010210	Salmon
5	HUC_18010205	Butte	11	HUC_18010211	Trinity
6	HUC_18010206	Upper Klamath	12	HUC_18010212	South Fork Trinity

Table C-3.—Comparison of Projected Annual Reference ET (inches/year) for the Five Quadrant Climate Scenarios, Compared with the historical baseline (1950-1999) for the Klamath River Basin and HUC8 Sub-Basins

Scenario	Period	BCSD Projection	1	2	3	4	5	6	7	8	9	10	11	12	Basin
Historical	Historical	-	40.8	42.3	39.9	43.3	46.9	45.4	50.5	52.3	52.2	52.0	52.3	51.8	44.3
Warm Dry	2030	CMIP-3	41.6	43.2	40.6	44.2	48.0	46.4	51.2	53.2	52.9	52.7	53.0	52.6	45.2
Warm Dry	2030	CMIP-5	42.0	43.6	41.0	44.7	48.4	46.8	51.4	53.6	53.2	52.9	53.3	52.9	45.6
Warm Wet	2030	CMIP-3	41.5	43.1	40.6	44.1	47.9	46.3	51.2	53.2	52.9	52.7	53.0	52.6	45.1
Warm Wet	2030	CMIP-5	41.8	43.4	40.8	44.4	48.2	46.6	51.4	53.5	53.1	52.9	53.2	52.8	45.4
Hot Dry	2030	CMIP-3	42.7	44.5	41.7	45.6	49.5	47.7	52.1	54.5	53.7	53.4	54.0	53.7	46.5
Hot Dry	2030	CMIP-5	43.0	44.7	42.0	45.9	49.7	48.0	52.2	54.7	53.8	53.4	54.1	53.9	46.7
Hot Wet	2030	CMIP-3	42.4	44.1	41.5	45.2	49.1	47.4	51.9	54.2	53.6	53.2	53.8	53.5	46.2
Hot Wet	2030	CMIP-5	42.9	44.6	41.9	45.8	49.7	48.0	52.2	54.7	53.8	53.4	54.1	53.8	46.7
Central Tendency	2030	CMIP-3	42.1	43.8	41.1	44.8	48.7	47.0	51.6	53.8	53.3	53.0	53.5	53.2	45.8
Central Tendency	2030	CMIP-5	42.3	44.0	41.3	45.1	49.0	47.3	51.8	54.1	53.5	53.2	53.7	53.4	46.0
Warm Dry	2070	CMIP-3	42.8	44.5	41.8	45.6	49.5	47.8	52.1	54.5	53.7	53.4	54.0	53.7	46.5
Warm Dry	2070	CMIP-5	42.3	44.0	41.4	45.1	49.0	47.3	51.8	54.1	53.5	53.2	53.7	53.4	46.0
Warm Wet	2070	CMIP-3	42.6	44.3	41.6	45.4	49.3	47.6	52.0	54.4	53.6	53.3	53.9	53.6	46.3
Warm Wet	2070	CMIP-5	42.3	43.9	41.3	45.0	48.9	47.2	51.8	54.1	53.5	53.2	53.6	53.4	46.0
Hot Dry	2070	CMIP-3	44.2	46.0	43.2	47.5	51.4	49.4	53.1	55.9	54.3	53.6	55.2	55.1	48.1
Hot Dry	2070	CMIP-5	45.0	46.9	44.0	48.5	52.4	50.4	53.7	56.9	54.6	53.9	55.8	55.9	49.1
Hot Wet	2070	CMIP-3	43.8	45.6	42.8	47.0	50.9	49.0	52.8	55.6	54.2	53.6	54.9	54.8	47.7
Hot Wet	2070	CMIP-5	45.2	47.1	44.3	48.8	52.8	50.7	53.9	57.1	55.0	54.1	56.1	56.2	49.4
Central Tendency	2070	CMIP-3	43.2	44.9	42.2	46.1	50.0	48.2	52.3	54.9	53.8	53.4	54.3	54.1	47.0
Central Tendency	2070	CMIP-5	43.4	45.1	42.4	46.5	50.4	48.5	52.6	55.2	54.0	53.5	54.5	54.3	47.3

Notes:

1	HUC_18010201	Williamson
2	HUC_18010202	Sprague
3	HUC_18010203	Upper Klamath Lake
4	HUC_18010204	Lost
5	HUC_18010205	Butte
6	HUC_18010206	Upper Klamath
7	HUC_18010207	Shasta
8	HUC_18010208	Scott
9	HUC_18010209	Lower Klamath
10	HUC_18010210	Salmon
11	HUC_18010211	Trinity
12	HUC_18010212	South Fork Trinity

Table C-4.—Comparison of Projected Annual Crop ET (inches/year) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Klamath River Basin and HUC8 Sub-Basins

Scenario	Period	BCSD Projection	1	2	3	4	5	6	7	8	9	10	11	12	Basin
Historical	Historical	-	29.4	29.5	30.3	33.7	36.5	40.9	47.9	49.0	44.6	50.6	48.6	49.6	35.4
Warm Dry	2030	CMIP-3	31.5	31.8	31.6	34.9	38.4	42.2	48.4	50.3	44.4	50.8	48.8	49.9	36.7
Warm Dry	2030	CMIP-5	32.0	32.5	32.2	35.3	39.0	42.6	48.5	50.6	44.3	50.9	48.8	49.9	37.2
Warm Wet	2030	CMIP-3	31.4	31.8	31.6	35.0	38.5	42.3	48.6	50.5	44.5	51.0	48.9	50.0	36.8
Warm Wet	2030	CMIP-5	32.2	32.5	32.2	35.4	39.3	42.8	48.8	50.8	44.4	51.1	48.9	50.1	37.3
Hot Dry	2030	CMIP-3	33.5	34.2	33.5	36.2	40.9	43.9	49.2	51.5	44.1	51.1	48.8	49.9	38.3
Hot Dry	2030	CMIP-5	34.1	34.9	34.0	36.6	41.5	44.4	49.5	51.9	44.1	51.2	48.9	49.9	38.8
Hot Wet	2030	CMIP-3	33.3	33.9	33.4	36.1	40.8	43.8	49.3	51.5	44.2	51.1	48.9	50.0	38.2
Hot Wet	2030	CMIP-5	34.2	34.7	34.0	36.7	41.6	44.4	49.6	52.0	44.2	51.3	49.0	50.0	38.8
Central Tendency	2030	CMIP-3	32.3	32.9	32.4	35.6	39.8	43.1	48.9	51.0	44.3	51.1	48.9	50.0	37.6
Central Tendency	2030	CMIP-5	32.9	33.6	33.3	36.0	40.4	43.6	49.1	51.4	44.3	51.1	49.0	50.1	38.1
Warm Dry	2070	CMIP-3	33.6	34.3	33.6	36.3	41.0	44.0	49.3	51.6	44.2	51.1	48.9	49.9	38.4
Warm Dry	2070	CMIP-5	33.0	33.5	33.2	35.9	40.4	43.6	49.1	51.3	44.3	51.1	48.9	50.0	38.0
Warm Wet	2070	CMIP-3	33.9	34.4	33.9	36.6	41.3	44.2	49.5	51.8	44.3	51.3	49.0	50.1	38.6
Warm Wet	2070	CMIP-5	33.3	33.9	33.6	36.3	40.7	43.8	49.4	51.6	44.4	51.4	49.1	50.2	38.4
Hot Dry	2070	CMIP-3	35.4	36.3	34.8	37.6	43.5	45.2	50.0	53.1	43.9	51.0	48.8	49.5	39.8
Hot Dry	2070	CMIP-5	36.7	37.4	35.9	38.5	45.1	46.1	50.7	54.1	43.9	51.4	49.1	49.3	40.8
Hot Wet	2070	CMIP-3	35.5	36.3	35.1	37.8	43.5	45.5	50.3	53.1	44.1	51.3	49.0	49.8	40.0
Hot Wet	2070	CMIP-5	37.1	37.9	36.3	39.0	45.9	46.6	51.1	54.5	43.9	51.6	49.3	49.3	41.3
Central Tendency	2070	CMIP-3	34.3	35.0	34.2	36.9	41.9	44.6	49.7	52.2	44.1	51.2	49.0	50.0	39.0
Central Tendency	2070	CMIP-5	34.8	35.5	34.6	37.3	42.4	44.9	50.0	52.7	44.1	51.3	49.0	49.9	39.4

Notes:

1	HUC_18010201	Williamson	7	HUC_18010207	Shasta
2	HUC_18010202	Sprague	8	HUC_18010208	Scott
3	HUC_18010203	Upper Klamath Lake	9	HUC_18010209	Lower Klamath
4	HUC_18010204	Lost	10	HUC_18010210	Salmon
5	HUC_18010205	Butte	11	HUC_18010211	Trinity
6	HUC_18010206	Upper Klamath	12	HUC_18010212	South Fork Trinity

Table C-5.—Comparison of Projected Annual Net Irrigation Water Requirements (NIWR) (inches/year) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Klamath River Basin and HUC8 Sub-Basins

Scenario	Period	BCSD Projection	1	2	3	4	5	6	7	8	9	10	11	12	Basin
Historical	Historical	-	18.0	20.4	18.7	20.8	27.2	30.7	35.1	36.8	29.5	35.0	35.9	37.4	23.5
Warm Dry	2030	CMIP-3	19.8	22.7	19.6	21.9	29.1	31.7	36.0	38.5	29.2	35.3	36.3	37.8	24.7
Warm Dry	2030	CMIP-5	20.8	23.7	20.7	22.5	30.1	32.4	36.3	38.8	29.2	35.6	36.3	37.9	25.4
Warm Wet	2030	CMIP-3	19.5	22.4	19.9	21.6	28.9	31.4	35.5	38.1	29.1	35.0	35.8	37.5	24.5
Warm Wet	2030	CMIP-5	19.7	23.0	20.0	21.9	29.5	31.6	35.6	38.2	28.8	34.9	35.6	37.2	24.8
Hot Dry	2030	CMIP-3	22.5	25.4	22.0	23.6	32.5	34.0	37.2	40.4	29.5	36.4	36.7	38.0	26.8
Hot Dry	2030	CMIP-5	22.2	25.5	21.9	23.6	32.4	33.8	36.8	39.8	29.0	36.0	36.1	37.5	26.7
Hot Wet	2030	CMIP-3	21.9	24.6	21.5	22.8	31.4	33.2	36.6	39.8	29.0	35.8	36.2	37.7	26.1
Hot Wet	2030	CMIP-5	22.3	24.9	21.6	23.2	32.2	33.5	36.5	39.7	28.8	35.7	36.0	37.4	26.4
Central Tendency	2030	CMIP-3	20.9	23.8	20.7	22.5	30.7	32.4	36.4	38.9	29.2	35.5	36.2	37.8	25.6
Central Tendency	2030	CMIP-5	21.4	24.2	21.0	22.7	31.0	32.5	36.1	39.2	28.9	35.5	36.2	37.5	25.8
Warm Dry	2070	CMIP-3	22.4	25.1	21.7	23.4	32.2	33.7	36.8	40.2	29.2	36.0	36.4	37.7	26.6
Warm Dry	2070	CMIP-5	21.3	23.9	20.9	22.7	31.1	32.5	36.1	39.1	28.8	35.7	35.9	37.6	25.7
Warm Wet	2070	CMIP-3	21.9	24.5	21.2	22.7	31.5	32.9	35.9	39.1	28.5	35.2	35.7	37.2	25.8
Warm Wet	2070	CMIP-5	20.5	23.4	20.0	22.1	30.4	32.0	35.2	38.2	28.4	34.3	35.1	36.7	25.0
Hot Dry	2070	CMIP-3	24.5	27.5	23.7	25.2	35.2	35.3	38.4	41.8	29.6	36.8	36.9	37.8	28.5
Hot Dry	2070	CMIP-5	24.9	27.5	23.5	25.3	36.0	35.5	38.2	41.8	29.0	36.5	36.4	37.0	28.6
Hot Wet	2070	CMIP-3	23.1	26.2	21.8	24.0	33.8	34.2	36.9	40.4	28.6	35.6	35.8	36.9	27.1
Hot Wet	2070	CMIP-5	23.5	26.9	22.3	24.5	35.4	34.7	37.4	41.2	28.4	35.5	35.6	36.2	27.8
Central Tendency	2070	CMIP-3	22.7	25.3	21.9	23.6	32.8	34.0	36.8	40.0	29.1	35.9	36.3	37.8	26.8
Central Tendency	2070	CMIP-5	22.7	25.5	22.0	23.7	32.7	33.9	36.7	40.2	28.6	35.7	36.2	37.3	26.8

Notes:

1	HUC_18010201	Williamson	7	HUC_18010207	Shasta
2	HUC_18010202	Sprague	8	HUC_18010208	Scott
3	HUC_18010203	Upper Klamath Lake	9	HUC_18010209	Lower Klamath
4	HUC_18010204	Lost	10	HUC_18010210	Salmon
5	HUC_18010205	Butte	11	HUC_18010211	Trinity
6	HUC_18010206	Upper Klamath	12	HUC_18010212	South Fork Trinity

Table C-6.—Comparison of Projected Annual Net Irrigation Water Requirement (NIWR) Volume (acre-feet/year) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Klamath River Basin and HUC8 Sub-Basins
CT: Central Tendency

Scenario	Period	BCSD Projection	1	2	3	4	5	6	7	8	9	10	11	12	Basin
Historical	Historical	-	17,513	55,216	79,101	329,469	83,976	9,255	101,460	77,114	887	197	628	917	755,734
Hot Dry	2030	CMIP-3	21,889	68,710	93,066	374,662	100,471	10,251	107,568	84,580	887	205	643	932	863,864
Hot Dry	2030	CMIP-5	21,608	68,896	92,541	373,696	100,087	10,187	106,399	83,400	874	203	632	918	859,442
Hot Wet	2030	CMIP-3	21,276	66,493	90,716	362,327	97,073	9,998	105,639	83,251	874	202	634	923	839,404
Hot Wet	2030	CMIP-5	21,684	67,311	91,456	368,065	99,295	10,104	105,505	83,067	866	201	630	917	849,101
CT	2030	CMIP-3	20,338	64,445	87,446	357,684	94,652	9,783	105,059	81,335	878	200	633	926	823,379
CT	2030	CMIP-5	20,847	65,357	88,578	360,468	95,619	9,787	104,303	82,140	871	200	633	918	829,721
Warm Dry	2030	CMIP-3	19,217	61,336	82,694	347,180	89,813	9,555	103,866	80,614	880	199	634	926	796,915
Warm Dry	2030	CMIP-5	20,220	63,988	87,300	356,600	93,074	9,771	104,949	81,240	879	201	635	929	819,786
Warm Wet	2030	CMIP-3	18,978	60,698	84,095	342,050	89,233	9,479	102,497	79,820	875	197	627	918	789,468
Warm Wet	2030	CMIP-5	19,198	62,241	84,450	348,031	91,064	9,534	102,864	80,024	866	197	623	912	800,003
Hot Dry	2070	CMIP-3	23,789	74,376	100,241	400,164	108,606	10,659	110,839	87,554	893	207	646	926	918,901
Hot Dry	2070	CMIP-5	24,212	74,289	99,513	401,165	111,001	10,695	110,426	87,416	874	206	638	906	921,340
Hot Wet	2070	CMIP-3	22,412	70,951	92,132	380,264	104,498	10,300	106,445	84,541	862	200	626	905	874,135
Hot Wet	2070	CMIP-5	22,804	72,669	94,245	388,377	109,292	10,462	107,896	86,264	856	200	623	887	894,575
CT	2070	CMIP-3	22,089	68,547	92,714	375,062	101,202	10,249	106,302	83,819	875	202	635	925	862,622
CT	2070	CMIP-5	22,087	69,034	92,940	376,169	101,104	10,216	105,928	84,094	862	201	634	915	864,184
Warm Dry	2070	CMIP-3	21,809	67,843	91,827	371,550	99,548	10,171	106,390	84,097	881	203	637	923	855,880
Warm Dry	2070	CMIP-5	20,734	64,647	88,369	360,100	95,932	9,788	104,239	81,760	867	201	629	921	828,187
Warm Wet	2070	CMIP-3	21,243	66,257	89,766	359,745	97,095	9,922	103,636	81,899	858	198	624	911	832,154
Warm Wet	2070	CMIP-5	19,947	63,235	84,690	350,724	93,881	9,651	101,759	79,963	855	193	613	900	806,411

Notes:

1	HUC_18010201	Williamson
2	HUC_18010202	Sprague
3	HUC_18010203	Upper Klamath Lake
4	HUC_18010204	Lost
5	HUC_18010205	Butte
6	HUC_18010206	Upper Klamath
7	HUC_18010207	Shasta
8	HUC_18010208	Scott
9	HUC_18010209	Lower Klamath
10	HUC_18010210	Salmon
11	HUC_18010211	Trinity
12	HUC_18010212	South Fork Trinity

C.2 Weather Stations Used for Wind Speed and Dewpoint Depression Estimates

Table C-7.—Summary of Weather Stations Used for Removing Biases in Gridded Meteorological Dataset

Node ID	Node Name	State	Latitude	Longitude	Elevation (feet)	Reporting Node	Network*	Description	Corresponding Stations Measuring Dewpoint and Wind
OR1571	Chiloquin	OR	42.58	-121.87	4193	HUC_18010201	NWS COOP	Williamson	-
OR8007	Sprague River 2 SE	OR	42.43	-121.49	4483	HUC_18010202	NWS COOP	Sprague	-
OR1574	Chiloquin 12 NW	OR	42.70	-122.00	4180	HUC_18010203	NWS COOP	Upper Klamath Lake	-
OR4511	Klamath Falls Ag Stn	OR	42.16	-121.75	4092	HUC_18010204	NWS COOP	Lost River	Klamath Falls
CA9053	Tulelake	CA	41.96	-121.47	4035	HUC_18010204	NWS COOP	Lost River	TuleLakeFS
CA5941	Mt Hebron Rng Stn	CA	41.78	-122.04	4250	HUC_18010205	NWS COOP	Butte	-
OR4506	Klamath Falls 2 SSW	OR	42.20	-121.78	4098	HUC_18010206	NWS COOP	Upper Klamath	-
CA9866	Yreka	CA	41.70	-122.64	2625	HUC_18010207	NWS COOP	Shasta	-
CA3182	Ft Jones Rng Stn	CA	41.60	-122.85	2725	HUC_18010208	NWS COOP	Scott	-
CA6508	Orleans	CA	41.31	-123.53	403	HUC_18010209	NWS COOP	Lower Klamath	-
CA8025	Sawyers Bar Rs	CA	41.30	-123.13	2169	HUC_18010210	NWS COOP	Salmon	-
CA9026	Trinity River Hatchery	CA	40.73	-122.79	1861	HUC_18010211	NWS COOP	Trinity	-
CA3791	Harrison Gulch Rs	CA	40.36	-122.97	2750	HUC_18010212	NWS COOP	South Fork Trinity	-

* NWS COOP: NOAA NWS Cooperative Observer Network (http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/cooperative-observer-network-coop).

Table C-8.—Summary of Weather Stations Used for Removing Biases in Gridded Meteorological Dataset

Node ID	Station Name	State	Latitude	Longitude	Elevation (feet)	Reporting Node	Network*	Description	Corresponding Stations for Bias Correction
-	Agency Lake	OR	42.57	-121.98	4150	-	AgriMet	-	-
-	Beatty	OR	42.48	-121.27	4320	-	AgriMet	-	-
-	Brookings	OR	42.03	-124.24	80	-	AgriMet	-	-
-	Klamath Falls	OR	42.16	-121.76	4100	-	AgriMet	-	OR4511
-	Lorella	OR	42.08	-121.22	4160	-	AgriMet	-	-
-	McArther	CA	41.05	-121.45	3307	-	CIMIS	-	-
-	Medford	OR	42.33	-122.94	1340	-	AgriMet	-	-
-	TuleLakeFS	CA	41.96	-121.47	4035	-	CIMIS	-	CA9053
-	Worden	OR	42.01	-121.79	4080	-	AgriMet	-	-

*AgriMet: Reclamation Cooperative Agricultural Weather Network (http://www.usbr.gov/pn/agrimet/) CIMIS: California Irrigation Management Information System (http://www.cimis.water.ca.gov/)

C.3 Summary Tables of Crop Acreage

Table C-9.—Estimated Crop Acreage by HUC8 Sub-Basin and Percent (%) of Acreage by Crop Type within Each HUC8 Sub-Basin

HUC_8 Sub-Basin	1801 0201	1801 0202	1801 0203	1801 0204	1801 0205	1801 0206	1801 0207	1801 0208	1801 0209	1801 0210	1801 0211	1801 0212	Basin Total
Crop Acres	11,665	32,451	50,720	190,405	37,047	3,619	34,659	25,118	361	68	210	294	386,616
Alfalfa	9.2	8.7	2.4	32.3	72.2	55.1	73.8	74.3	30.5	58.9	52.9	33.5	36.2
Pasture	85.4	83.3	86.6	23.4	0.0	11.7	0.0	0.0	0.0	0.0	0.0	0.0	32.6
Winter Wheat	0.0	0.0	0.0	16.7	0.0	3.9	5.0	2.7	2.0	5.6	2.3	0.9	8.9
Hay (Other)	0.8	6.6	2.3	8.4	0.2	22.8	13.7	18.2	56.2	31.9	37.9	63.2	7.8
Barley	1.2	0.5	5.1	6.3	3.2	1.3	1.7	0.2	0.2	0.0	0.5	0.2	4.3
Potatoes	1.4	0.0	2.0	6.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	3.6
Rye	0.0	0.0	0.0	0.4	13.9	2.3	0.5	0.1	0.0	0.0	0.5	0.0	1.6
Oats	1.8	0.1	1.6	1.5	0.6	0.1	1.7	0.3	1.2	0.3	0.1	0.1	1.2
Strawberry	0.0	0.0	0.0	0.3	8.9	0.0	0.0	0.0	0.0	0.0	0.2	0.0	1.0
Onions	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Mint	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Spring Wheat	0.0	0.0	0.0	0.0	0.9	0.1	1.7	4.2	9.0	3.3	1.7	1.7	0.5
Triticale	0.0	0.6	0.0	0.0	0.0	2.4	2.1	0.0	0.6	0.0	0.6	0.3	0.3
Total Other	0.0	0.0	0.0	0.6	0.0	0.0	0.1	0.1	0.3	0.0	3.2	0.0	0.3

C.4 Summary Tables for Projected Municipal and Industrial and Rural Domestic Demands

Table C-10.—Summary of Future Municipal and Industrial Consumptive Use Estimates (AFY)

Future Period and Scenario	Del Norte County	Humboldt County	Klamath County	Modoc County	Siskiyou County	Trinity County	Totals
2030 Base Demand	72	665	4,186	81	3,174	1,401	9,579
2030 Warm-Dry CMIP3	73	674	4,276	82	3,232	1,421	9,759
2030 Warm-Dry CMIP5	73	677	4,324	83	3,257	1,429	9,843
2030 Warm-Wet CMIP3	73	674	4,270	82	3,228	1,421	9,748
2030 Warm-Wet CMIP5	73	676	4,299	83	3,245	1,426	9,801
2030 Hot-Dry CMIP3	74	685	4,412	85	3,312	1,448	10,015
2030 Hot-Dry CMIP5	74	685	4,444	86	3,325	1,451	10,065
2030 Hot-Wet CMIP3	73	683	4,377	84	3,293	1,442	9,952
2030 Hot-Wet CMIP5	74	685	4,440	86	3,325	1,450	10,059
2030 Central CMIP3	73	679	4,340	84	3,268	1,434	9,877
2030 Central CMIP5	73	681	4,365	84	3,284	1,439	9,926
2070 Base Demand	75	670	4,493	77	3,452	1,865	10,632
2070 Warm-Dry CMIP3	77	689	4,745	81	3,604	1,925	11,121
2070 Warm-Dry CMIP5	76	687	4,687	80	3,573	1,916	11,019
2070 Warm-Wet CMIP3	77	689	4,722	81	3,592	1,922	11,082
2070 Warm-Wet CMIP5	76	686	4,679	80	3,567	1,914	11,003
2070 Hot-Dry CMIP3	78	697	4,938	85	3,712	1,968	11,477
2070 Hot-Dry CMIP5	78	701	5,049	87	3,775	1,992	11,682
2070 Hot-Wet CMIP3	76	680	4,885	80	3,681	1,957	11,358
2070 Hot-Wet CMIP5	79	706	5,079	87	3,794	2,003	11,747
2070 Central CMIP3	77	691	4,796	82	3,632	1,938	11,217
2070 Central CMIP5	77	693	4,831	83	3,653	1,945	11,282

Table C-11.—Summary of Future Municipal and Industrial Consumptive Use Estimates (percent change)

Future Period and Scenario	Del Norte County	Humboldt County	Klamath County	Modoc County	Siskiyou County	Trinity County	Totals
2030 Base Demand	8%	8%	7%	7%	8%	12%	8%
2030 Warm-Dry CMIP3	9%	9%	9%	9%	10%	13%	10%
2030 Warm-Dry CMIP5	9%	9%	10%	10%	11%	13%	11%
2030 Warm-Wet CMIP3	9%	9%	9%	9%	10%	13%	10%
2030 Warm-Wet CMIP5	9%	9%	9%	9%	10%	13%	10%
2030 Hot-Dry CMIP3	10%	10%	12%	12%	12%	15%	12%
2030 Hot-Dry CMIP5	10%	10%	12%	12%	12%	15%	13%
2030 Hot-Wet CMIP3	10%	10%	11%	11%	11%	14%	12%
2030 Hot-Wet CMIP5	10%	10%	12%	12%	12%	15%	12%
2030 Central CMIP3	9%	9%	10%	10%	11%	14%	11%
2030 Central CMIP5	10%	10%	11%	11%	11%	14%	11%
2070 Base Demand	11%	8%	13%	2%	16%	34%	17%
2070 Warm-Dry CMIP3	14%	11%	18%	7%	19%	36%	21%
2070 Warm-Dry CMIP5	13%	11%	17%	6%	18%	35%	20%
2070 Warm-Wet CMIP3	14%	11%	18%	7%	19%	36%	21%
2070 Warm-Wet CMIP5	13%	10%	17%	6%	18%	35%	20%
2070 Hot-Dry CMIP3	15%	12%	21%	11%	21%	37%	23%
2070 Hot-Dry CMIP5	15%	12%	23%	13%	23%	38%	25%
2070 Hot-Wet CMIP3	13%	10%	20%	6%	21%	37%	22%
2070 Hot-Wet CMIP5	16%	13%	23%	14%	23%	38%	25%
2070 Central CMIP3	14%	11%	19%	8%	20%	36%	22%
2070 Central CMIP5	14%	11%	19%	9%	20%	36%	22%

Table C-12.—Summary of Future Rural Domestic Consumptive Water Use Estimates (AFY)

Future Period and Scenario	Klamath County, OR	Modoc County, CA	Siskiyou County, CA	Trinity County, CA	Totals
2030 Base Demand	1,496	86	2,884	471	4,938
2030 Warm-Dry CMIP3	1,509	88	2,937	478	5,013
2030 Warm-Dry CMIP5	1,546	89	2,960	481	5,075
2030 Warm-Wet CMIP3	1,527	88	2,934	478	5,026
2030 Warm-Wet CMIP5	1,537	89	2,948	480	5,053
2030 Hot-Dry CMIP3	1,577	91	3,009	487	5,164
2030 Hot-Dry CMIP5	1,589	92	3,022	488	5,190
2030 Hot-Wet CMIP3	1,565	90	2,992	485	5,132
2030 Hot-Wet CMIP5	1,587	91	3,021	488	5,187
2030 Central CMIP3	1,551	89	2,970	482	5,093
2030 Central CMIP5	1,560	90	2,984	484	5,118
2070 Base Demand	1,606	82	3,137	627	5,452
2070 Warm-Dry CMIP3	1,696	87	3,275	647	5,705
2070 Warm-Dry CMIP5	1,676	86	3,246	644	5,652
2070 Warm-Wet CMIP3	1,688	86	3,264	646	5,685
2070 Warm-Wet CMIP5	1,673	86	3,242	644	5,644
2070 Hot-Dry CMIP3	1,765	86	3,373	662	5,887
2070 Hot-Dry CMIP5	1,805	86	3,430	670	5,991
2070 Hot-Wet CMIP3	1,746	90	3,345	658	5,840
2070 Hot-Wet CMIP5	1,816	92	3,448	674	6,030
2070 Central CMIP3	1,715	88	3,301	652	5,755
2070 Central CMIP5	1,727	88	3,320	654	5,790

Table C-13.—Summary of Future Rural Domestic Consumptive Water Use Estimates (percent change)

Future Period and Scenario	Klamath County, OR	Modoc County, CA	Siskiyou County, CA	Trinity County, CA	Totals
2030 Base Demand	7%	7%	9%	13%	9%
2030 Warm-Dry CMIP3	8%	10%	11%	15%	10%
2030 Warm-Dry CMIP5	11%	11%	12%	15%	12%
2030 Warm-Wet CMIP3	10%	9%	11%	15%	11%
2030 Warm-Wet CMIP5	10%	10%	11%	15%	11%
2030 Hot-Dry CMIP3	13%	13%	14%	17%	14%
2030 Hot-Dry CMIP5	14%	14%	14%	17%	14%
2030 Hot-Wet CMIP3	12%	12%	13%	17%	13%
2030 Hot-Wet CMIP5	14%	14%	14%	17%	14%
2030 Central CMIP3	11%	11%	12%	16%	12%
2030 Central CMIP5	12%	12%	13%	16%	13%
2070 Base Demand	15%	2%	18%	51%	20%
2070 Warm-Dry CMIP3	22%	8%	24%	56%	26%
2070 Warm-Dry CMIP5	20%	7%	23%	55%	25%
2070 Warm-Wet CMIP3	21%	8%	23%	55%	25%
2070 Warm-Wet CMIP5	20%	7%	22%	55%	24%
2070 Hot-Dry CMIP3	27%	8%	27%	59%	30%
2070 Hot-Dry CMIP5	30%	7%	30%	61%	32%
2070 Hot-Wet CMIP3	25%	12%	26%	58%	29%
2070 Hot-Wet CMIP5	30%	15%	30%	62%	33%
2070 Central CMIP3	23%	9%	25%	57%	27%
2070 Central CMIP5	24%	10%	25%	57%	28%

C.5 Summary Tables for Reservoir Evaporation Model Results

Table C-14.—Comparison of Projected Annual Reservoir Evaporation (inches) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Primary Reservoirs in the Klamath River Basin
CT: Central Tendency. Trinity Lake: Clair Engle Lake

Scenario	Period	BCSD Projection	Upper Klamath Lake	Clear Lake	Gerber Reservoir	Tule Lake	JC Boyle Reservoir	Copco No.1 Reservoir	Iron Gate Reservoir	Trinity Lake
Historical	Historical	-	44.0	45.6	44.4	45.2	44.2	43.9	44.8	45.0
Warm Dry	2030	CMIP-3	44.8	46.4	45.2	46.0	44.9	44.5	45.5	45.7
Warm Dry	2030	CMIP-5	45.1	46.7	45.5	46.3	45.2	44.9	45.8	46.0
Warm Wet	2030	CMIP-3	44.7	46.3	45.1	45.9	44.9	44.5	45.5	45.7
Warm Wet	2030	CMIP-5	45.0	46.6	45.4	46.2	45.1	44.7	45.7	45.9
Hot Dry	2030	CMIP-3	45.8	47.4	46.2	47.1	45.9	45.4	46.5	46.7
Hot Dry	2030	CMIP-5	46.0	47.6	46.4	47.3	46.1	45.6	46.7	46.9
Hot Wet	2030	CMIP-3	45.6	47.2	46.0	46.8	45.7	45.2	46.3	46.5
Hot Wet	2030	CMIP-5	46.0	47.6	46.4	47.3	46.2	45.7	46.8	47.0
Central Tendency	2030	CMIP-3	45.3	46.9	45.6	46.5	45.4	45.0	46.0	46.2
Central Tendency	2030	CMIP-5	45.5	47.1	45.8	46.7	45.6	45.1	46.2	46.5
Warm Dry	2070	CMIP-3	45.9	47.5	46.3	47.1	46.0	45.5	46.6	46.8
Warm Dry	2070	CMIP-5	45.4	47.0	45.8	46.7	45.6	45.1	46.2	46.4
Warm Wet	2070	CMIP-3	45.7	47.3	46.1	47.0	45.9	45.4	46.5	46.8
Warm Wet	2070	CMIP-5	45.5	47.0	45.8	46.6	45.6	45.1	46.2	46.5
Hot Dry	2070	CMIP-3	47.2	49.0	47.7	48.6	47.4	46.8	48.1	48.3
Hot Dry	2070	CMIP-5	48.1	49.8	48.5	49.4	48.2	47.7	49.0	49.3
Hot Wet	2070	CMIP-3	46.9	48.5	47.3	48.1	47.0	46.5	47.8	48.0
Hot Wet	2070	CMIP-5	48.3	50.0	48.6	49.6	48.5	48.0	49.3	49.6
Central Tendency	2070	CMIP-3	46.3	47.9	46.7	47.5	46.4	45.9	47.1	47.3
Central Tendency	2070	CMIP-5	46.5	48.1	46.9	47.8	46.6	46.1	47.3	47.5

Table C-15.—Comparison of Projected Annual Reservoir Net Evaporation (evaporation – precipitation, in inches) for the Five Quadrant Climate Scenarios, Compared with the Historical Baseline (1950-1999) for the Primary Reservoirs in the Klamath River Basin
CT: Central Tendency. Trinity Lake: Clair Engle Lake

Scenario	Period	BCSD Projection	Upper Klamath Lake	Clear Lake	Gerber Reservoir	Tule Lake	JC Boyle Reservoir	Copco No.1 Reservoir	Iron Gate Reservoir	Trinity Lake
Historical	Historical	-	21.1	32.0	24.1	33.3	22.5	20.8	27.2	-26.0
Warm Dry	2030	CMIP-3	21.9	33.0	25.0	34.2	23.5	22.0	28.3	-22.5
Warm Dry	2030	CMIP-5	22.8	33.6	25.8	34.9	24.3	22.8	29.0	-22.2
Warm Wet	2030	CMIP-3	19.4	31.1	22.8	32.8	20.9	18.7	25.8	-35.3
Warm Wet	2030	CMIP-5	19.8	31.7	23.1	33.2	21.3	19.2	26.2	-33.5
Hot Dry	2030	CMIP-3	24.1	35.0	27.2	36.1	25.6	24.1	30.3	-20.6
Hot Dry	2030	CMIP-5	24.2	34.5	26.9	35.9	25.5	23.9	30.1	-20.4
Hot Wet	2030	CMIP-3	20.5	32.8	23.9	34.1	22.1	20.2	27.2	-32.9
Hot Wet	2030	CMIP-5	20.9	33.0	24.2	34.4	22.5	20.5	27.5	-33.5
Central Tendency	2030	CMIP-3	21.6	33.0	24.9	34.4	23.2	21.3	28.0	-26.8
Central Tendency	2030	CMIP-5	21.1	32.9	24.3	34.3	22.7	21.0	27.8	-27.0
Warm Dry	2070	CMIP-3	23.7	34.7	26.6	35.9	25.2	23.7	29.9	-19.6
Warm Dry	2070	CMIP-5	22.8	33.5	25.6	34.9	24.3	22.7	29.1	-21.9
Warm Wet	2070	CMIP-3	19.3	32.0	22.8	33.5	21.0	19.0	26.3	-37.3
Warm Wet	2070	CMIP-5	19.2	31.3	22.5	32.9	20.8	18.7	26.0	-34.5
Hot Dry	2070	CMIP-3	26.1	37.3	29.3	38.2	27.7	26.3	32.4	-15.6
Hot Dry	2070	CMIP-5	26.1	37.1	29.1	38.3	27.7	26.2	32.5	-17.7
Hot Wet	2070	CMIP-3	21.0	33.7	24.4	35.1	22.8	20.9	28.2	-31.7
Hot Wet	2070	CMIP-5	21.5	34.1	24.2	35.7	23.3	21.4	29.0	-33.6
Central Tendency	2070	CMIP-3	21.9	34.0	25.3	35.3	23.6	21.7	28.6	-27.6
Central Tendency	2070	CMIP-5	22.2	34.0	25.4	35.4	23.7	21.9	28.7	-28.3

C.6 Summary Tables for Wetlands ET

Table C-16.—Summary of Projected Changes in Mean Basin-Wide Wetlands ET Rate (ft/yr)

Future Period and Scenario	Mean Annual Wetland ET Rate (ft/yr)	Mean Annual Wetland ET (percent change)
Historical	3.31	-
2030 Warm-Dry CMIP3	3.41	3.0%
2030 Warm-Dry CMIP5	3.45	4.0%
2030 Warm-Wet CMIP3	3.42	3.3%
2030 Warm-Wet CMIP5	3.46	4.6%
2030 Hot-Dry CMIP3	3.55	7.1%
2030 Hot-Dry CMIP5	3.59	8.3%
2030 Hot-Wet CMIP3	3.54	6.9%
2030 Hot-Wet CMIP5	3.59	8.4%
2030 Central CMIP3	3.49	5.2%
2030 Central CMIP5	3.52	6.3%
2070 Warm-Dry CMIP3	3.56	7.3%
2070 Warm-Dry CMIP5	3.52	6.2%
2070 Warm-Wet CMIP3	3.57	7.8%
2070 Warm-Wet CMIP5	3.54	6.9%
2070 Hot-Dry CMIP3	3.69	11.3%
2070 Hot-Dry CMIP5	3.78	14.1%
2070 Hot-Wet CMIP3	3.70	11.7%
2070 Hot-Wet CMIP5	3.83	15.5%
2070 Central CMIP3	3.61	9.1%
2070 Central CMIP5	3.64	9.9%

Appendix D - Supplemental Information for System Risk and Reliability Analysis

D.1 Summary of System Risk and Reliability Measures

Table D-1.—Description of System Risk and Reliability Measures

Resource Category	Measure Description	Location(s)	Measure Details
Ecological Resources	Salmonid Success	Shasta River; Scott River	Flow thresholds throughout year
	Annual Supply	Lower Klamath National Wildlife Refuge	Mean annual (water year) water supply to LKNWR
	Pool Elevation	Upper Klamath Lake	Elevation thresholds throughout year
	Pool Elevation	Clear Lake; Gerber Reservoir	Minimum elevation thresholds
Hydroelectricl Power Resources	Hydropower production	Sum of JC Boyle power, Copco1 power, Copco2 power, Iron Gate power	Mean annual hydropower production summed over these facilities
	Volume of spill	JC Boyle, Copco1, Iron Gate	Mean annual spill volume based on calendar year
	Frequency of spill	JC Boyle, Copco1, Iron Gate	Mean number of spill days per calendar year at these facilities
	Timing of seasonal peak flow	JC Boyle, Copco1, Iron Gate	Mean date of seasonal peak flow
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
Recreational Resources	Mean fishing days per year	Various 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 Klamath River reaches	Mean number of days per year that flows are within acceptable ranges for select river reaches.
Water Supply	Total Klamath Project irrigation water supply	Klamath Project	Mean annual supply to Klamath Project which may be compared with an assumed full supply of 390,000 acre-feet
	Total Klamath Project irrigation water supply	Upper Klamath Lake	End of February storage plus actual March through September inflow at Upper Klamath Lake
	Klamath Project Deliveries	Klamath Project	Mean annual deliveries to Klamath Project via Upper Klamath Lake
	Mean annual tributary flow	Shasta River; Scott River	Mean annual flow at USGS gages (USGS 11519500 Scott River near Fort Jones; USGS 11517500 Shasta River near Yreka)
Water Quality	Water temperature	Klamath River	Maximum Weekly Average Temperature (MWAT)

D.2 Historical and Projected Basin Wide Response Variables

Table D-2.—Comparison of Historical and Projected Mean Monthly Upper Klamath Lake Storage (units are thousands of acre-feet [KAF])

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	243.1	236.3	296.2	372.5	430.8	442.8	467.4	478.8	452.9	382.0	306.4	271.4
Warm Dry	2030	CMIP-3	204.5	218.9	286.3	357.8	419.8	440.3	459.8	468.1	431.7	345.9	261.6	221.2
Warm Dry	2030	CMIP-5	199.6	213.5	279.6	347.2	407.4	433.0	455.0	463.7	423.7	337.6	253.9	212.2
Warm Wet	2030	CMIP-3	203.0	224.2	296.5	371.3	431.7	444.3	462.1	469.8	433.6	345.4	259.4	216.8
Warm Wet	2030	CMIP-5	199.5	228.1	305.6	381.6	439.1	445.4	460.7	468.4	426.4	336.4	251.9	207.4
Hot Dry	2030	CMIP-3	166.2	190.2	262.9	337.5	403.6	433.1	454.4	452.4	396.6	302.5	219.0	175.6
Hot Dry	2030	CMIP-5	166.1	192.0	267.7	348.4	415.7	438.9	453.8	444.2	382.4	290.0	212.8	173.3
Hot Wet	2030	CMIP-3	159.2	190.2	276.5	368.1	436.6	449.1	458.5	455.5	394.6	297.2	211.4	164.8
Hot Wet	2030	CMIP-5	142.1	180.0	269.9	370.4	444.1	452.8	449.2	417.7	335.3	247.4	180.8	141.3
Central Tendency	2030	CMIP-3	184.2	214.7	290.2	364.2	426.2	442.1	462.6	466.0	413.9	317.5	231.8	189.0
Central Tendency	2030	CMIP-5	152.2	187.7	275.9	363.3	430.9	446.9	457.0	445.7	371.4	274.5	195.0	152.8
Warm Dry	2070	CMIP-3	170.5	194.8	266.8	342.9	409.8	435.3	452.3	448.2	395.3	303.2	220.6	177.8
Warm Dry	2070	CMIP-5	185.0	206.5	277.9	352.8	415.0	436.1	452.7	450.0	398.4	306.6	228.5	191.5
Warm Wet	2070	CMIP-3	165.7	197.2	282.3	373.0	438.7	449.5	456.7	454.2	391.0	292.3	208.0	165.6
Warm Wet	2070	CMIP-5	179.1	210.4	295.0	375.4	437.0	442.7	455.2	453.5	397.7	302.2	219.8	181.4
Hot Dry	2070	CMIP-3	134.0	159.8	242.8	332.8	403.4	431.9	445.2	430.8	358.2	264.3	189.0	144.9
Hot Dry	2070	CMIP-5	133.0	156.5	235.9	328.0	404.8	433.4	439.9	409.2	329.3	246.8	184.1	142.1
Hot Wet	2070	CMIP-3	142.1	180.0	269.9	370.4	444.1	452.8	449.2	417.7	335.3	247.4	180.8	141.3
Hot Wet	2070	CMIP-5	127.1	157.8	245.5	356.9	441.6	449.6	448.8	408.5	321.1	240.8	177.4	134.2
Central Tendency	2070	CMIP-3	152.2	187.7	275.9	363.3	430.9	446.9	457.0	445.7	371.4	274.5	195.0	152.8
Central Tendency	2070	CMIP-5	147.7	177.3	265.4	360.9	432.7	444.8	456.2	443.6	368.7	272.8	193.9	152.3

Table D-3.—Comparison of Historical and Projected Mean Monthly Keno Dam Inflow (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	1,366	1,300	1,188	1,538	2,169	3,643	2,292	1,534	935	609	512	651
WarmDry	2030	CMIP-3	1,081	1,045	1,335	1,700	2,198	3,722	2,291	1,543	1,056	806	665	761
WarmDry	2030	CMIP-5	998	1,012	1,353	1,867	2,085	3,334	2,159	1,405	1,058	754	632	758
WarmWet	2030	CMIP-3	1,049	1,064	1,615	2,509	2,874	4,400	2,652	1,895	1,194	939	770	899
WarmWet	2030	CMIP-5	959	968	1,605	2,447	2,871	4,568	2,512	1,889	1,203	906	742	894
HotDry	2030	CMIP-3	798	839	1,128	1,777	2,147	3,435	1,973	1,456	1,086	792	637	673
HotDry	2030	CMIP-5	787	867	1,125	1,701	2,125	3,408	1,859	1,555	1,110	767	594	638
HotWet	2030	CMIP-3	858	907	1,651	2,835	3,209	4,755	2,514	2,070	1,362	966	805	906
HotWet	2030	CMIP-5	851	963	2,114	3,122	3,861	4,961	2,586	2,623	1,515	866	833	927
CentralTendency	2030	CMIP-3	804	889	1,426	2,179	2,602	3,946	2,275	1,713	1,182	873	690	771
CentralTendency	2030	CMIP-5	766	895	1,545	2,727	3,074	4,436	2,313	2,119	1,372	899	760	770
WarmDry	2070	CMIP-3	798	933	1,291	2,001	2,222	3,456	2,056	1,542	1,111	809	642	707
WarmDry	2070	CMIP-5	880	903	1,257	1,970	2,343	3,613	2,161	1,615	1,123	805	626	690
WarmWet	2070	CMIP-3	891	1,083	1,774	3,064	3,632	5,099	2,908	2,336	1,491	1,058	875	958
WarmWet	2070	CMIP-5	943	957	1,709	2,767	3,229	4,734	2,505	2,268	1,423	1,051	805	908
HotDry	2070	CMIP-3	786	804	1,047	1,888	2,173	3,382	1,715	1,538	1,181	747	648	670
HotDry	2070	CMIP-5	748	843	1,155	2,153	2,243	3,399	1,756	1,875	1,238	688	625	644
HotWet	2070	CMIP-3	851	963	2,114	3,122	3,861	4,961	2,586	2,623	1,515	866	833	927
HotWet	2070	CMIP-5	906	1,045	2,064	3,309	4,085	5,076	2,477	2,934	1,497	825	844	953
CentralTendency	2070	CMIP-3	766	895	1,545	2,727	3,074	4,436	2,313	2,119	1,372	899	760	770
CentralTendency	2070	CMIP-5	816	903	1,343	2,387	2,861	4,374	2,148	2,057	1,333	879	728	751

Table D-4.—Comparison of Historical and Projected Mean Monthly Iron Gate Reservoir Storage (units are KAF)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	57.0	56.4	55.5	55.8	56.2	57.1	55.8	55.2	55.1	55.4	55.5	55.2
WarmDry	2030	CMIP-3	56.5	55.9	55.6	55.7	56.1	57.3	55.9	55.2	55.3	55.8	55.7	55.4
WarmDry	2030	CMIP-5	56.4	56.1	55.7	56.1	56.0	57.0	55.8	55.1	55.4	55.9	55.8	55.5
WarmWet	2030	CMIP-3	56.0	55.9	55.7	56.3	56.8	57.8	55.9	55.2	55.6	56.1	56.0	55.5
WarmWet	2030	CMIP-5	56.0	55.7	55.6	56.3	56.6	58.0	55.9	55.2	55.6	56.1	55.9	55.5
HotDry	2030	CMIP-3	55.7	55.6	55.5	55.9	56.1	57.3	55.5	55.2	55.7	56.1	55.9	55.3
HotDry	2030	CMIP-5	55.6	55.4	55.4	56.0	56.3	57.1	55.4	55.3	55.9	56.1	55.8	55.3
HotWet	2030	CMIP-3	55.5	55.3	55.4	56.6	57.0	58.3	55.8	55.2	56.0	56.2	55.9	55.6
HotWet	2030	CMIP-5	55.5	55.4	55.7	56.9	57.4	58.4	55.8	55.6	56.2	55.8	55.4	55.4
CentralTendency	2030	CMIP-3	55.7	55.5	55.5	56.2	56.5	57.6	55.6	55.2	55.7	56.2	55.8	55.4
CentralTendency	2030	CMIP-5	55.4	55.3	55.4	56.6	57.0	58.0	55.6	55.5	56.1	56.1	55.7	55.3
WarmDry	2070	CMIP-3	55.6	55.6	55.4	56.1	56.3	57.1	55.6	55.2	55.8	56.2	55.9	55.4
WarmDry	2070	CMIP-5	56.0	55.6	55.4	56.2	56.4	57.2	55.7	55.2	55.7	56.1	55.8	55.4
WarmWet	2070	CMIP-3	55.6	55.4	55.5	56.6	57.3	58.6	56.1	55.3	56.0	56.2	56.0	55.5
WarmWet	2070	CMIP-5	55.8	55.6	55.5	56.5	56.8	58.2	55.7	55.2	56.0	56.1	56.0	55.5
HotDry	2070	CMIP-3	55.6	55.4	55.3	56.2	56.5	57.2	55.4	55.4	56.0	56.0	55.5	55.2
HotDry	2070	CMIP-5	55.5	55.3	55.3	56.2	56.4	57.1	55.5	55.8	55.9	55.6	55.1	55.1
HotWet	2070	CMIP-3	55.5	55.4	55.7	56.9	57.4	58.4	55.8	55.6	56.2	55.8	55.4	55.4
HotWet	2070	CMIP-5	55.6	55.6	55.5	56.8	57.6	58.5	55.5	55.7	55.9	55.5	55.4	55.3
CentralTendency	2070	CMIP-3	55.4	55.3	55.4	56.6	57.0	58.0	55.6	55.5	56.1	56.1	55.7	55.3
CentralTendency	2070	CMIP-5	55.4	55.4	55.3	56.4	56.7	57.8	55.5	55.5	56.1	56.1	55.7	55.3

Table D-5.—Comparison of Historical and Projected Mean Monthly Iron Gate Dam Outflow (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	1,841	1,891	1,382	2,131	2,707	4,576	3,013	2,191	1,372	1,108	1,081	1,237
WarmDry	2030	CMIP-3	1,427	1,558	1,420	2,217	2,767	4,866	2,837	1,883	1,267	1,062	1,025	1,239
WarmDry	2030	CMIP-5	1,362	1,617	1,533	2,475	2,720	4,271	2,724	1,799	1,259	999	990	1,332
WarmWet	2030	CMIP-3	1,356	1,520	1,671	3,258	3,688	5,921	3,090	2,038	1,332	1,130	1,132	1,199
WarmWet	2030	CMIP-5	1,268	1,457	1,711	3,275	3,643	6,204	2,970	1,905	1,302	1,101	1,025	1,171
HotDry	2030	CMIP-3	1,184	1,478	1,403	2,550	3,056	4,749	2,498	1,580	1,135	979	967	1,080
HotDry	2030	CMIP-5	1,180	1,390	1,384	2,583	3,061	4,525	2,283	1,505	1,166	973	969	1,114
HotWet	2030	CMIP-3	1,121	1,510	1,737	3,854	4,250	6,726	2,858	1,821	1,306	1,065	1,000	1,117
HotWet	2030	CMIP-5	1,093	1,591	2,089	4,436	5,232	7,045	2,708	1,801	1,262	862	928	1,169
CentralTendency	2030	CMIP-3	1,173	1,473	1,601	2,997	3,485	5,410	2,724	1,787	1,252	1,062	1,000	1,177
CentralTendency	2030	CMIP-5	1,082	1,546	1,759	3,849	4,213	6,241	2,614	1,743	1,270	984	953	1,113
WarmDry	2070	CMIP-3	1,163	1,525	1,543	2,797	3,103	4,563	2,493	1,587	1,173	992	972	1,102
WarmDry	2070	CMIP-5	1,251	1,446	1,445	2,750	3,077	4,646	2,638	1,686	1,183	1,012	996	1,209
WarmWet	2070	CMIP-3	1,139	1,449	1,725	4,031	4,771	7,435	3,165	1,917	1,365	1,081	1,029	1,333
WarmWet	2070	CMIP-5	1,199	1,546	1,763	3,714	4,101	6,563	2,772	1,913	1,363	1,125	1,022	1,217
HotDry	2070	CMIP-3	1,159	1,434	1,515	2,869	3,213	4,718	2,090	1,341	1,136	917	935	1,033
HotDry	2070	CMIP-5	1,102	1,409	1,484	3,219	3,340	4,633	1,997	1,380	1,095	847	917	1,116
HotWet	2070	CMIP-3	1,093	1,591	2,089	4,436	5,232	7,045	2,708	1,801	1,262	862	928	1,169
HotWet	2070	CMIP-5	1,054	1,587	2,011	4,661	5,502	7,272	2,461	1,800	1,165	748	947	1,089
CentralTendency	2070	CMIP-3	1,082	1,546	1,759	3,849	4,213	6,241	2,614	1,743	1,270	984	953	1,113
CentralTendency	2070	CMIP-5	1,107	1,468	1,562	3,549	3,878	6,034	2,482	1,667	1,261	953	995	1,181

Table D-6.—Comparison of Historical and Projected Mean Monthly Shasta River Flow (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	137.8	211.6	239.1	346.3	302.7	369.6	195.6	174.4	125.1	42.5	35.3	77.9
WarmDry	2030	CMIP-3	143.6	220.7	264.2	339.5	292.1	364.0	158.8	137.9	100.5	37.8	35.2	68.9
WarmDry	2030	CMIP-5	146.5	224.2	248.6	343.4	296.3	340.5	154.0	136.0	91.3	34.9	32.8	66.2
WarmWet	2030	CMIP-3	153.5	218.5	312.7	468.2	362.3	407.0	193.6	185.5	129.5	57.3	51.6	78.6
WarmWet	2030	CMIP-5	148.7	213.8	323.7	447.8	340.8	417.4	195.0	165.0	121.5	57.6	45.4	74.4
HotDry	2030	CMIP-3	156.9	220.1	266.4	376.4	305.7	324.8	122.2	106.0	59.5	39.4	41.4	62.8
HotDry	2030	CMIP-5	156.5	211.7	251.0	396.7	296.1	309.7	105.7	111.7	64.5	51.7	54.7	70.5
HotWet	2030	CMIP-3	151.7	232.0	334.2	453.2	359.0	397.4	151.8	127.5	86.6	57.4	55.6	72.1
HotWet	2030	CMIP-5	165.5	212.0	366.7	514.5	364.9	358.6	128.5	122.2	62.7	60.2	70.9	81.7
CentralTendency	2030	CMIP-3	153.6	215.4	268.4	407.1	325.4	361.5	147.7	142.3	92.0	44.2	44.6	70.2
CentralTendency	2030	CMIP-5	166.5	215.0	302.5	466.4	341.4	353.0	127.1	120.0	72.0	59.2	63.4	75.5
WarmDry	2070	CMIP-3	157.9	220.5	272.7	359.7	301.8	309.8	108.6	112.2	68.7	46.1	49.3	66.9
WarmDry	2070	CMIP-5	154.7	212.8	255.6	364.5	292.3	327.2	138.8	127.3	77.4	51.1	51.8	74.7
WarmWet	2070	CMIP-3	161.9	216.9	333.6	499.1	386.2	416.7	179.2	159.2	103.3	71.1	70.5	83.6
WarmWet	2070	CMIP-5	159.7	233.0	332.0	493.6	355.2	406.1	183.7	163.9	120.6	78.7	76.3	92.6
HotDry	2070	CMIP-3	148.7	200.8	274.8	365.3	278.1	285.9	79.6	92.2	39.6	36.2	50.0	65.1
HotDry	2070	CMIP-5	144.1	191.4	256.2	393.8	292.8	299.2	78.9	102.7	35.6	40.7	61.9	77.0
HotWet	2070	CMIP-3	165.5	212.0	366.7	514.5	364.9	358.6	128.5	122.2	62.7	60.2	70.9	81.7
HotWet	2070	CMIP-5	144.7	209.0	356.9	569.2	387.7	381.2	125.2	130.5	53.5	52.1	72.9	89.8
CentralTendency	2070	CMIP-3	166.5	215.0	302.5	466.4	341.4	353.0	127.1	120.0	72.0	59.2	63.4	75.5
CentralTendency	2070	CMIP-5	161.1	219.4	322.4	479.7	327.9	349.0	127.7	123.5	66.1	59.9	67.7	76.5

Table D-7.—Comparison of Historical and projected Mean Monthly Scott River Flow (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	67	440	800	1,191	1,117	1,273	1,006	1,163	700	165	61	67
WarmDry	2030	CMIP-3	47	481	835	1,160	1,107	1,285	916	972	539	97	46	92
WarmDry	2030	CMIP-5	45	536	869	1,202	1,130	1,222	917	992	493	78	35	100
WarmWet	2030	CMIP-3	75	561	1,289	1,747	1,561	1,539	1,094	1,254	721	159	67	77
WarmWet	2030	CMIP-5	66	560	1,372	1,801	1,460	1,586	1,106	1,110	631	143	53	66
HotDry	2030	CMIP-3	49	530	955	1,309	1,246	1,247	828	768	299	58	38	62
HotDry	2030	CMIP-5	45	416	827	1,425	1,247	1,233	763	698	251	63	56	70
HotWet	2030	CMIP-3	57	746	1,493	1,878	1,636	1,611	995	959	469	95	44	68
HotWet	2030	CMIP-5	71	646	1,724	2,173	1,827	1,538	840	667	218	63	64	90
CentralTendency	2030	CMIP-3	70	496	1,115	1,510	1,363	1,390	924	997	498	89	50	75
CentralTendency	2030	CMIP-5	74	601	1,381	1,881	1,565	1,455	861	773	293	68	56	95
WarmDry	2070	CMIP-3	47	540	944	1,296	1,205	1,176	749	733	297	59	42	65
WarmDry	2070	CMIP-5	51	450	932	1,348	1,170	1,239	860	818	354	77	54	96
WarmWet	2070	CMIP-3	68	593	1,497	2,050	1,811	1,694	1,065	1,036	500	104	59	133
WarmWet	2070	CMIP-5	74	717	1,478	2,007	1,590	1,615	1,045	1,007	509	117	73	116
HotDry	2070	CMIP-3	39	442	1,017	1,335	1,234	1,152	650	468	131	39	42	53
HotDry	2070	CMIP-5	38	398	935	1,561	1,385	1,232	604	381	94	42	58	77
HotWet	2070	CMIP-3	71	646	1,724	2,173	1,827	1,538	840	667	218	63	64	90
HotWet	2070	CMIP-5	50	658	1,750	2,511	1,938	1,614	793	473	124	45	71	95
CentralTendency	2070	CMIP-3	74	601	1,381	1,881	1,565	1,455	861	773	293	68	56	95
CentralTendency	2070	CMIP-5	60	678	1,396	1,982	1,516	1,476	875	764	246	68	68	95

Table D-8.—Comparison of Historical and Projected Mean Monthly Klamath River near Orleans Flow (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	2,628	6,036	9,539	15,225	14,679	18,565	13,042	11,151	7,069	2,913	2,102	2,198
WarmDry	2030	CMIP-3	2,188	6,180	10,036	14,931	15,029	19,124	12,353	9,521	5,625	2,472	2,192	2,722
WarmDry	2030	CMIP-5	2,098	6,433	9,810	15,324	15,106	17,928	12,147	9,260	5,177	2,270	1,846	2,857
WarmWet	2030	CMIP-3	2,347	7,231	13,655	21,198	21,767	22,670	14,051	11,080	6,860	2,865	2,352	2,410
WarmWet	2030	CMIP-5	2,161	6,881	13,975	21,319	19,944	23,443	14,121	10,018	6,036	2,677	2,032	2,112
HotDry	2030	CMIP-3	1,937	6,596	10,672	16,704	17,029	18,693	11,319	7,028	3,536	1,976	1,813	2,107
HotDry	2030	CMIP-5	1,855	5,021	9,882	18,135	17,107	18,352	10,310	6,205	3,139	1,955	2,018	2,267
HotWet	2030	CMIP-3	2,002	8,498	14,761	23,187	24,222	24,731	13,333	8,516	4,774	2,403	1,942	2,095
HotWet	2030	CMIP-5	2,133	8,189	17,238	26,460	27,572	24,747	11,972	6,317	3,059	1,892	1,928	2,532
CentralTendency	2030	CMIP-3	2,180	6,572	11,971	18,761	19,103	20,641	12,160	8,859	4,919	2,360	1,945	2,271
CentralTendency	2030	CMIP-5	2,129	7,717	14,448	23,074	23,028	22,161	11,707	7,112	3,600	2,051	1,896	2,409
WarmDry	2070	CMIP-3	1,899	6,447	11,093	16,877	16,945	17,980	10,598	7,030	3,690	2,022	1,840	2,179
WarmDry	2070	CMIP-5	2,036	5,754	10,644	17,281	16,261	18,569	11,646	7,766	3,997	2,164	1,985	2,579
WarmWet	2070	CMIP-3	2,200	7,431	15,158	24,883	26,933	27,195	14,565	9,372	5,023	2,462	2,081	3,134
WarmWet	2070	CMIP-5	2,256	8,667	15,240	23,826	22,400	24,116	13,582	9,224	5,221	2,555	2,326	2,895
HotDry	2070	CMIP-3	1,840	5,741	12,094	17,328	17,533	17,731	9,368	4,693	2,238	1,711	1,710	2,011
HotDry	2070	CMIP-5	1,841	5,412	11,345	19,935	20,078	18,557	8,712	4,256	2,037	1,648	1,942	2,630
HotWet	2070	CMIP-3	2,133	8,189	17,238	26,460	27,572	24,747	11,972	6,317	3,059	1,892	1,928	2,532
HotWet	2070	CMIP-5	1,916	7,965	17,017	29,655	29,042	25,663	11,413	5,290	2,408	1,641	2,041	2,403
CentralTendency	2070	CMIP-3	2,129	7,717	14,448	23,074	23,028	22,161	11,707	7,112	3,600	2,051	1,896	2,409
CentralTendency	2070	CMIP-5	2,005	7,840	14,272	23,467	21,334	21,876	11,657	6,721	3,259	1,975	2,114	2,627

Table D-9.—Comparison of Historical and Projected Mean Monthly Klamath River at Klamath Flow (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	3,886	13,448	22,753	34,068	32,173	36,119	23,585	17,935	10,923	4,835	3,643	3,710
WarmDry	2030	CMIP-3	3,383	13,930	22,543	32,137	31,173	35,830	21,979	15,460	8,986	4,273	3,985	4,869
WarmDry	2030	CMIP-5	3,254	13,814	21,567	32,786	32,223	34,015	21,860	15,278	8,689	3,980	3,244	4,753
WarmWet	2030	CMIP-3	3,919	16,350	30,572	46,171	43,326	42,022	25,591	17,838	10,576	4,820	4,236	4,316
WarmWet	2030	CMIP-5	3,580	15,399	30,715	45,725	39,645	43,337	26,166	16,544	9,744	4,578	3,529	3,645
HotDry	2030	CMIP-3	3,107	14,519	23,275	35,711	34,510	34,341	20,190	12,105	6,331	3,540	3,174	3,722
HotDry	2030	CMIP-5	2,904	11,197	21,591	38,484	34,120	33,877	18,236	11,014	5,970	3,540	3,657	4,081
HotWet	2030	CMIP-3	3,332	19,683	30,888	47,931	45,791	44,528	23,746	14,030	8,102	4,179	3,381	3,676
HotWet	2030	CMIP-5	3,617	17,187	33,357	52,587	48,902	41,859	21,424	11,245	5,645	3,476	3,427	4,501
CentralTendency	2030	CMIP-3	3,711	14,445	26,197	40,088	38,209	38,264	21,756	14,574	8,206	4,091	3,447	4,020
CentralTendency	2030	CMIP-5	3,717	16,331	29,899	47,450	42,300	39,550	20,614	12,166	6,497	3,687	3,408	4,678
WarmDry	2070	CMIP-3	3,004	14,053	23,169	34,990	33,851	32,726	18,046	12,078	6,562	3,603	3,236	3,799
WarmDry	2070	CMIP-5	3,264	12,447	23,080	36,654	32,953	34,325	20,739	13,237	7,251	3,828	3,604	4,924
WarmWet	2070	CMIP-3	3,782	16,640	31,962	51,846	50,008	46,606	26,257	15,447	8,346	4,244	3,682	5,818
WarmWet	2070	CMIP-5	3,842	18,882	32,132	49,654	42,561	43,167	24,547	15,376	8,718	4,382	4,220	5,093
HotDry	2070	CMIP-3	2,789	12,083	24,912	34,998	33,357	31,462	16,235	8,878	4,646	3,137	3,005	3,638
HotDry	2070	CMIP-5	2,890	10,985	23,040	40,347	36,694	32,965	15,669	8,625	4,393	3,105	3,463	4,489
HotWet	2070	CMIP-3	3,617	17,187	33,357	52,587	48,902	41,859	21,424	11,245	5,645	3,476	3,427	4,501
HotWet	2070	CMIP-5	3,163	16,542	32,451	57,942	51,238	43,556	20,864	10,037	4,813	3,208	3,808	4,695
CentralTendency	2070	CMIP-3	3,717	16,331	29,899	47,450	42,300	39,550	20,614	12,166	6,497	3,687	3,408	4,678
CentralTendency	2070	CMIP-5	3,337	17,298	29,931	48,078	40,234	39,207	21,095	11,939	6,120	3,573	3,837	4,821

Table D-10.—Comparison of Historical and Projected Mean Monthly Water Temperature in the Klamath River (units are °F)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	60.3	49.0	43.6	42.9	44.9	47.4	51.1	57.3	64.0	70.1	73.5	69.2
WarmDry	2030	CMIP-3	62.3	49.8	43.7	42.6	44.7	47.4	51.5	58.0	65.0	72.2	76.5	72.0
WarmDry	2030	CMIP-5	63.0	50.3	43.7	42.4	44.8	47.7	51.8	58.6	65.5	72.2	77.2	72.6
WarmWet	2030	CMIP-3	62.3	49.8	44.0	42.7	44.7	47.2	50.9	57.8	64.8	72.1	76.1	72.2
WarmWet	2030	CMIP-5	62.6	50.3	44.6	43.1	45.2	47.5	51.6	57.9	64.8	72.1	76.7	72.6
HotDry	2030	CMIP-3	63.9	51.2	44.6	43.3	46.2	48.9	53.1	60.0	66.7	73.8	78.2	73.8
HotDry	2030	CMIP-5	63.9	51.6	44.9	44.3	46.8	49.3	53.4	60.7	67.3	74.0	78.2	74.1
HotWet	2030	CMIP-3	63.6	50.9	45.2	44.2	46.2	48.1	52.3	59.7	66.4	73.4	77.8	73.4
HotWet	2030	CMIP-5	65.3	53.1	46.6	46.1	48.0	49.8	53.9	61.2	68.3	75.6	79.9	75.6
Central Tendency	2030	CMIP-3	62.9	50.5	44.3	43.0	45.2	47.7	51.6	59.0	66.0	73.0	77.5	73.3
Central Tendency	2030	CMIP-5	64.3	52.0	46.0	44.4	46.7	48.8	53.1	60.4	67.6	74.4	78.9	74.7
WarmDry	2070	CMIP-3	63.9	51.5	44.9	43.6	46.2	48.7	53.2	59.9	66.8	73.7	78.1	74.0
WarmDry	2070	CMIP-5	63.4	50.9	44.7	43.5	45.7	48.6	52.8	59.4	66.2	73.0	77.5	73.1
WarmWet	2070	CMIP-3	63.5	51.3	45.4	44.1	46.2	48.2	52.1	59.3	66.6	73.8	77.9	73.7
WarmWet	2070	CMIP-5	63.3	50.9	45.1	43.9	45.7	48.2	52.4	59.0	66.2	72.9	77.1	73.2
HotDry	2070	CMIP-3	66.0	53.3	46.2	45.3	48.0	50.3	55.1	62.2	68.6	75.7	80.4	76.0
HotDry	2070	CMIP-5	67.3	55.2	48.0	46.3	49.6	52.0	56.1	63.4	69.8	76.2	80.8	77.0
HotWet	2070	CMIP-3	65.3	53.1	46.6	46.1	48.0	49.8	53.9	61.2	68.3	75.6	79.9	75.6
HotWet	2070	CMIP-5	67.8	55.1	48.4	47.2	49.9	51.8	56.2	63.4	69.9	77.0	81.4	77.5
Central Tendency	2070	CMIP-3	64.3	52.0	46.0	44.4	46.7	48.8	53.1	60.4	67.6	74.4	78.9	74.7
Central Tendency	2070	CMIP-5	64.7	52.4	46.1	44.8	46.8	49.4	53.6	61.2	67.6	74.2	78.5	74.6

D.3 Historical and Projected System Reliability Measures

Table D-11.—Comparison of Projected Ecological Resources Measures

Scenario	Period	BCSD Projection	Frequency of Meeting Dry Year Fish Targets - Scott River[1]	Frequency of Meeting Dry Year Fish Targets - Shasta River[1]	Mean Annual Water Delivery to LKNWR (KAF)[2]
Historical	Historical	-	71	57	25
Warm Dry	2030	CMIP-3	66	53	16
Warm Dry	2030	CMIP-5	65	51	16
Warm Wet	2030	CMIP-3	74	61	18
Warm Wet	2030	CMIP-5	74	60	19
Hot Dry	2030	CMIP-3	63	51	10
Hot Dry	2030	CMIP-5	65	52	12
Hot Wet	2030	CMIP-3	71	59	13
Hot Wet	2030	CMIP-5	71	60	13
Central Tendency	2030	CMIP-3	69	55	17
Central Tendency	2030	CMIP-5	70	56	14
Warm Dry	2070	CMIP-3	64	52	12
Warm Dry	2070	CMIP-5	67	54	16
Warm Wet	2070	CMIP-3	73	63	15
Warm Wet	2070	CMIP-5	76	66	16
Hot Dry	2070	CMIP-3	59	47	8
Hot Dry	2070	CMIP-5	58	47	11
Hot Wet	2070	CMIP-3	69	58	15
Hot Wet	2070	CMIP-5	67	57	12
Central Tendency	2070	CMIP-3	69	57	12
Central Tendency	2070	CMIP-5	70	58	14

Notes:

[1] Dry year targets as reported by McBain and Trush (2014) for Shasta River

Table D-12.—Comparison of Projected Hydropower Resources Measures

Scenario	Period	BCSD Projection	Boyle Mean Spill Days per Year[1]	Boyle Mean Spill Volume per Year (KAF)[2]	Copco1 Mean Spill Days per Year[1]	Copco1 Mean Spill Volume per Year (KAF)[2]	IronGate Mean Spill Days per Year[1]	Iron Gate Mean Spill Volume per Year (KAF)[2]	Mean Annual Hydropower Generated (MW)[3]
Historical	Historical	-	106	163	43	186	170	534	26,741
Warm Dry	2030	CMIP-3	155	196	44	212	132	513	25,395
Warm Dry	2030	CMIP-5	144	176	43	193	131	489	24,901
Warm Wet	2030	CMIP-3	196	314	57	342	156	712	27,715
Warm Wet	2030	CMIP-5	188	319	56	347	145	710	27,030
Hot Dry	2030	CMIP-3	151	195	39	224	111	493	23,372
Hot Dry	2030	CMIP-5	157	183	37	203	115	457	23,340
Hot Wet	2030	CMIP-3	217	414	59	455	140	807	26,527
Hot Wet	2030	CMIP-5	223	394	57	428	142	782	26,525
Central Tendency	2030	CMIP-3	176	256	50	288	132	613	25,595
Central Tendency	2030	CMIP-5	193	321	52	351	136	686	25,992
Warm Dry	2070	CMIP-3	164	207	42	229	118	506	24,133
Warm Dry	2070	CMIP-5	167	219	44	234	123	518	24,451
Warm Wet	2070	CMIP-3	237	493	65	529	157	913	27,828
Warm Wet	2070	CMIP-5	230	399	59	416	150	784	27,375
Hot Dry	2070	CMIP-3	157	217	38	243	110	486	22,662
Hot Dry	2070	CMIP-5	176	252	38	258	121	506	22,715
Hot Wet	2070	CMIP-3	239	544	62	566	150	929	26,511
Hot Wet	2070	CMIP-5	253	583	62	584	152	952	26,284
Central Tendency	2070	CMIP-3	206	378	54	419	141	754	25,923
Central Tendency	2070	CMIP-5	204	342	51	375	135	688	25,148

Notes:

[1] Computed as mean number of spill days per calendar year.
[2] Computed as mean annual spill volume per calendar year.
[3] Computed as mean annual hydropower generated by a combination of the following facilities: J.C.Boyle, Copco1, Copoc2, Iron Gate.

Table D-13.—Comparison of Projected Flood Control Measures

Scenario	Period	BCSD Projection	Frequency of Upper Klamath Lake Flood Control Release (percent of days)	Mean Annual Upper Klamath Lake Flood Control Release Volume (KAF)	Change in Mean Date of Seasonal Peak Flow at JC Boyle (days)	Change in Mean Date of Seasonal Peak Flow at Copco1 (Days)	Change in Mean Date of Seasonal Peak Flow at Iron Gate (days)
Historical	Historical	-	44	224	April 9	April 17	April 15
Warm Dry	2030	CMIP-3	41	218	4	1	1
Warm Dry	2030	CMIP-5	40	221	4	0	0
Warm Wet	2030	CMIP-3	46	318	2	-4	-4
Warm Wet	2030	CMIP-5	46	334	2	-5	-5
Hot Dry	2030	CMIP-3	38	232	4	-4	-4
Hot Dry	2030	CMIP-5	38	215	4	-3	-3
Hot Wet	2030	CMIP-3	44	379	1	-9	-9
Hot Wet	2030	CMIP-5	44	366	2	-8	-8
Central Tendency	2030	CMIP-3	44	291	3	-3	-4
Central Tendency	2030	CMIP-5	42	299	2	-6	-6
Warm Dry	2070	CMIP-3	38	243	2	-5	-5
Warm Dry	2070	CMIP-5	41	254	3	-2	-2
Warm Wet	2070	CMIP-3	45	419	2	-7	-7
Warm Wet	2070	CMIP-5	46	367	2	-7	-7
Hot Dry	2070	CMIP-3	34	226	3	-8	-7
Hot Dry	2070	CMIP-5	36	249	1	-8	-8
Hot Wet	2070	CMIP-3	44	448	-2	-15	-14
Hot Wet	2070	CMIP-5	44	448	-4	-17	-16
Central Tendency	2070	CMIP-3	42	359	0	-10	-10
Central Tendency	2070	CMIP-5	41	311	2	-7	-7

Table D-14.—Comparison of Mean Annual Boating Days in Various Reaches of the Klamath River (units are days per calendar year[1])

Scenario	Period	BCSD Projection	Keno Reach	Boyle Reach	Hells Corner Reach	Iron Gate to Scott River Reach	Scott River to Salmon River Reach	Salmon River to Trinity River Reach	Trinity River to Ocean Reach
Historical	Historical	-	172	59	256	275	249	214	253
Warm Dry	2030	CMIP-3	178	53	211	282	257	232	262
Warm Dry	2030	CMIP-5	169	53	209	278	255	234	263
Warm Wet	2030	CMIP-3	205	67	224	269	232	200	233
Warm Wet	2030	CMIP-5	190	57	210	274	234	206	237
Hot Dry	2030	CMIP-3	151	42	180	285	261	244	273
Hot Dry	2030	CMIP-5	152	47	181	288	260	242	274
Hot Wet	2030	CMIP-3	181	55	181	266	236	211	241
Hot Wet	2030	CMIP-5	189	53	181	270	237	215	242
Central Tendency	2030	CMIP-3	177	52	201	280	249	221	255
Central Tendency	2030	CMIP-5	183	56	199	275	250	222	256
Warm Dry	2070	CMIP-3	161	48	188	285	262	243	272
Warm Dry	2070	CMIP-5	159	51	189	284	255	238	266
Warm Wet	2070	CMIP-3	202	60	193	263	230	207	235
Warm Wet	2070	CMIP-5	198	62	204	269	231	206	234
Hot Dry	2070	CMIP-3	142	51	168	285	262	250	282
Hot Dry	2070	CMIP-5	141	45	164	280	258	246	280
Hot Wet	2070	CMIP-3	183	54	169	261	241	222	252
Hot Wet	2070	CMIP-5	183	51	166	247	232	220	247
Central Tendency	2070	CMIP-3	174	51	177	271	244	224	253
Central Tendency	2070	CMIP-5	167	51	173	277	243	220	252

Notes:

[1] Interior, Department to Commerce, NMFS.2012.

Table D-15.—Comparison of Mean Annual Fishing Days in Various Reaches of the Klamath River (units are days per calendar year[1])

Scenario	Period	BCSD Projection	Keno Reach	Boyle Reach	Hells Corner Reach	Iron Gate to Scott River Reach	Scott River to Salmon River Reach	Salmon River to Trinity River Reach	Trinity River to Ocean Reach
Historical	Historical	-	248	155	220	275	184	214	253
Warm Dry	2030	CMIP-3	257	158	258	282	197	232	262
Warm Dry	2030	CMIP-5	263	166	258	278	200	234	263
Warm Wet	2030	CMIP-3	228	125	236	269	174	200	233
Warm Wet	2030	CMIP-5	234	137	243	274	179	206	237
Hot Dry	2030	CMIP-3	273	192	275	285	212	244	273
Hot Dry	2030	CMIP-5	267	194	272	288	210	242	274
Hot Wet	2030	CMIP-3	225	146	244	266	184	211	241
Hot Wet	2030	CMIP-5	227	144	244	270	185	215	242
Central Tendency	2030	CMIP-3	252	156	256	280	189	221	255
Central Tendency	2030	CMIP-5	239	144	249	275	192	222	256
Warm Dry	2070	CMIP-3	261	176	267	285	211	243	272
Warm Dry	2070	CMIP-5	257	176	266	284	201	238	266
Warm Wet	2070	CMIP-3	207	120	229	263	176	207	235
Warm Wet	2070	CMIP-5	213	126	234	269	175	206	234
Hot Dry	2070	CMIP-3	265	198	276	285	216	250	282
Hot Dry	2070	CMIP-5	254	195	264	280	211	246	280
Hot Wet	2070	CMIP-3	214	138	234	261	195	222	252
Hot Wet	2070	CMIP-5	208	138	229	247	190	220	247
Central Tendency	2070	CMIP-3	234	153	245	271	193	224	253
Central Tendency	2070	CMIP-5	241	163	253	277	192	220	252

Notes:

[1] Interior, Department to Commerce, NMFS.2012.

Table D-16.—Comparison of Projected Water Supply Measures

Scenario	Period	BCSD Projection	Mean Annual Upper Klamath Lake Storage and Inflow (KAF)[1]	Mean Klamath Project Supply (Apr-Sep) (KAF)[2]	Mean Annual Scott Streamflow (cfs)	Mean Annual Shasta Streamflow (cfs)
Historical	Historical	-	1,378	361	669	188
Warm Dry	2030	CMIP-3	1,367	357	629	180
Warm Dry	2030	CMIP-5	1,299	344	633	176
Warm Wet	2030	CMIP-3	1,478	369	842	218
Warm Wet	2030	CMIP-5	1,464	371	827	212
Hot Dry	2030	CMIP-3	1,256	330	613	173
Hot Dry	2030	CMIP-5	1,248	339	588	173
Hot Wet	2030	CMIP-3	1,468	365	835	206
Hot Wet	2030	CMIP-5	1,462	369	806	210
Central Tendency	2030	CMIP-3	1,372	358	712	189
Central Tendency	2030	CMIP-5	1,408	359	739	196
Warm Dry	2070	CMIP-3	1,275	339	594	172
Warm Dry	2070	CMIP-5	1,312	349	619	177
Warm Wet	2070	CMIP-3	1,544	374	881	223
Warm Wet	2070	CMIP-5	1,515	372	860	224
Hot Dry	2070	CMIP-3	1,196	318	547	159
Hot Dry	2070	CMIP-5	1,215	321	564	164
Hot Wet	2070	CMIP-3	1,474	366	823	209
Hot Wet	2070	CMIP-5	1,496	368	840	214
Central Tendency	2070	CMIP-3	1,398	360	756	197
Central Tendency	2070	CMIP-5	1,381	362	766	198

Notes:

[1] Defined as mean annual end of February storage plus actual March-September inflow to Upper Klamath Lake.

[2] Full irrigation supply to Klamath Project is 390,000 AF.

Table D-17.—Comparison of Projected Water Quality Measures Relating to the Maximum Weekly Average Temperature (MWAT) (source: SONCC ESU Recovery Plan, NMFS[2012]) (units are degrees F)

Scenario	Period	BCSD Projection	Mean Annual MWAT	Mean Exceedance of MWAT - Poor
Historical	Historical	-	76	12
Warm Dry	2030	CMIP-3	79	15
Warm Dry	2030	CMIP-5	79	16
Warm Wet	2030	CMIP-3	78	15
Warm Wet	2030	CMIP-5	79	15
Hot Dry	2030	CMIP-3	81	17
Hot Dry	2030	CMIP-5	81	17
Hot Wet	2030	CMIP-3	80	16
Hot Wet	2030	CMIP-5	81	17
Central Tendency	2030	CMIP-3	80	16
Central Tendency	2030	CMIP-5	80	16
Warm Dry	2070	CMIP-3	80	17
Warm Dry	2070	CMIP-5	80	16
Warm Wet	2070	CMIP-3	80	17
Warm Wet	2070	CMIP-5	79	16
Hot Dry	2070	CMIP-3	83	19
Hot Dry	2070	CMIP-5	83	20
Hot Wet	2070	CMIP-3	82	19
Hot Wet	2070	CMIP-5	84	20
Central Tendency	2070	CMIP-3	81	18
Central Tendency	2070	CMIP-5	81	17

Notes:

[1] Poor	Greater than 17.6 degrees Celsius (greater than 63.68°F)
Fair	Between 16 and 17.6 degrees Celsius (between 60.8 and 63.68°F)
Good	Between 15 and 16 degrees Celsius (between 59 and 60.8°F)
Very Good	Less than 15 degrees Celsius (less than 59°F)

Appendix E - Supplemental Information for Evaluation of Adaptation Strategy Concepts

E.1 Complete List of Proposed Adaptation Strategies

The following tables present the adaptation strategies identified through the literature review and stakeholder outreach efforts described in Chapter 6 along with the results of the initial screening effort to determine which strategies could be evaluated in the Basin Study models. Strategies were rated using a non-numeric scale of green, yellow, orange and red with strategies that could be modeled given scores of green and yellow.

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
Increase Supply	Alternative Supplies (4)	Increase water supply through increased precipitation enhancement.	Yellow
		Increase water supply through increased desalination.	Yellow
		Implement alternative supplies such as fog capture and waterbag transport.	Yellow
		Expand stormwater capture and reuse	Orange
	GW recharge (3)	Store surplus high flows in GW aquifers.	Yellow
		Augment GW recharge with surface water in areas with high infiltration rates	Orange
		Improving groundwater infiltration and soil retention/capture.	Orange
	Increased surface storage (3)	Provide operational flexibility and short-term storage capacity with on-farm ponds and increased soil moisture storage.	Red
		Increase water stored in Clear Lake by diverting water during wet years from Upper Klamath Lake.	Orange
		Employ new surface storage investments to improve flood management and flexibility to environmental water managers	Orange
	Increased natural storage (1)	Restore meadows, wetlands, marshes.	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
	Recycled water use (1)		Orange
	Conjunctive GW and SW management (1)	Expand water storage and conjunctive management of surface and groundwater resources	Orange
	Increase GW use (1)	Drill new wells within On-Project Plan area.	Yellow
	Vegetation management (6)	Reduce forest density where needed via mechanical or hand thinning and/or prescribed burning.	Red
		Promote ranch land and forest management practices that reduce erosion.	Red
		Invest in restoration forest management by restoring resilient, adaptive, native forest types, and promoting restoration to maintain complex, diverse natural habitats	Red
		Keep continuous forest by reducing fragmentation and maintaining canopy cover	Red
		Restoring historical forest densities (reduction)	Red
		Modify high-elevation forest management practices to allow the snowpack to melt more slowly.	Red
	Other (1)	Support regional groundwater management for drought resiliency	Red
Decrease Demand	Water conservation (domestic) (2)	Expand water conservation strategies discussed in California's 20x2020 Water Conservation Plan to conserve urban water use.	Red
		Reduce per-capita urban water-use consumption statewide by 20 percent by 2020, and require agricultural entities to apply efficient water management practices to reduce water demand.	Green
	Water conservation (agricultural) (4)	Canal lining and pump operation optimization.	Orange
		Crop idling, irrigated land retirement, and rain-fed agriculture (i.e., dry farming).	Green
		Shift agriculture to more drought-tolerant crops to reduce agricultural water use.	Green
		Converting irrigation systems to reduce energy use, increasing use of pressurized irrigation systems, and cover cropping and organic material build-up in soil.	Orange

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
	Improve energy efficiency (6)	Educate homeowners on energy conservation strategies and assist with implementation (e.g., sufficient insulation, proper hot water heater settings).	Red
		Evaluate the future water needs of different types of energy production to identify potential conflicts between energy production and water availability specifically in California.	Red
		Implement algal biodiesel: Algal biodiesel is a type of biodiesel fuel processed from oil produced by farmed algae.	Red
		Implement biomass plants: Biomass plants process raw plant and waste materials into useable biofuels like wood or paper pellets.	Red
		Implement Cellulosic Bioethanol.	Red
		Implement other alternative energy programs.	Red
	Reduce environmental demand (5)	Protect cool water refugia.	Red
		Keep higher quality water in-stream to protect species and river ecosystems by using lower quality water for agricultural purposes.	Orange
		Purchase water from water-rights holders and keep that flow in-stream to reduce demand on a short-term basis.	Yellow
		Ensure adequate flows for fish and wildlife habitat.	Yellow
		Curb demand with ecosystem restoration/improvements, water use effectiveness, and environmental water scarcity programs	Yellow
	Other (1)	Improve and implement recreational water use efficiency programs, and water conservation and water scarcity programs	Orange
Modify Operations	Improve infrastructure (5)	Reinforce or relocate vulnerable conveyance infrastructure.	Red
		Use green infrastructure to filter stormwater runoff.	Red
		Seek to reestablish natural hydrologic connectivity between rivers and their historic floodplains.	Red
		Reassess operating rules for water supply storage in an integrated manner	Yellow

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Expand storm drain system capacity and increase low impact development to combine on-site catchment and filtration technologies to limit runoff from new construction	Red
	Reduce erosion (1)	Restore and manage watersheds to reduce erosion.	Red
	Improve water quality (1)	Siskiyou County Septage Pond Closure - The Siskiyou County Septage Pond Closure project will excavate septage waste and impacted soil from the affected site and relocate it to an impermeable surface on the adjacent airport property where it will be allowed to air dry. Goals are to protect ground and surface water quality, ensure access to safe drinking water, and protect special-status fish species and habitat.	Red
	Improve extreme event preparedness (3)	Modify and manage the system of reservoirs, canals, floodplains, and levees for greater flexibility during exacerbated droughts and floods.	Yellow
		Improve real-time flood operations such as levee and flood wall monitoring, sandbagging levees and flood walls, flood door closures, reservoir operations, and warning and evacuation decisions and emergency mobilization	Red
		Develop injection wells to prevent salt water intrusion in coastal areas and protect water quality.	Red
	Reduce reservoir/lake evaporation (1)	Evaporative suppressant, WaterSavr by Flexible Solutions. WaterSavr is a safe and effective monolayer that reduces water evaporation by 30% that is used in lakes and reservoirs, in both evaporation pan Class A and bucket style trials.	Green
	Minimize out of basin water transfers (1)		Green
	Facilitate intra-regional water transfers (2)	KWAPA could pursue or facilitate transfers of water rights from other upstream consumptive uses to use in the OPPA.	Yellow
		Remove regulatory restrictions or provide incentives to encourage water markets and water transfers	Orange
	Improve operational flexibility (2)	Develop more interconnections between conveyance systems for future operational flexibility and redundancy.	Yellow

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Revise flood-control rules, reservoir storage rules, and reservoir operating plans, and drought contingency plans	Yellow
	Implement settlement agreements (1)	Strategy would include: KBRA, KHSA, UKB Comprehensive Agreement	Yellow
	Other (1)	Utilize low-impact development and other methods in State and regional stormwater permits to restore the natural hydrograph	Orange
	Improve infrastructure (1)	Raise maximum operating level of Upper Klamath Lake and Link River levee raise	Yellow
Governance and Implementation	Improve public education (2)	Implement public education programs to increase the public's understanding of the value of intact ecosystems in providing services that improve the quality of life.	Red
		Provide information to the agricultural community to enable growers to modify farm management practices and adapt to new pests and diseases.	Red
	Develop and/or improve partnerships, including agencies and community (5)	Develop new partnerships across federal and state agencies, tribes, and landowners to encourage landscape-scale planning and climate change planning across jurisdictional boundaries, and coordinate grants and programs to leverage funding and increase broad-scale thinking.	Red
		Promote policies that ensure tribal rights for subsistence practices.	Red
		Strengthen integrated regional water management planning and implementation.	Red
		Develop a DWR climate change approach using a multi-step process: (1) Formation of a workgroup of DWR experts to develop the approach; (2) Development of a suite of probable approaches for climate change characterization based on project purpose, planning horizon, and spatial coverage of projects; (3) Transparent development of a draft methodology document including a standard framework and a set of consistent approaches for review by DWR management as well as peer review by experts from within and outside of DWR.	Red
	Improve research (10)	Support research into management strategies that assist grower adaptation to increased pest and disease pressures.	Red
		Support research on practices to promote soil water-holding capacity.	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	**Examples** (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Develop new technologies for field-level monitoring of climate impacts, including pests	Red
		Use innovative sustainable farm operation systems that integrate energy, water, and natural resource conservation	Yellow
		Assess adequacy of surge and response capacity in light of climate projections for more frequent and more severe weather events	Yellow
		Enhance energy-related climate change research and protect existing energy facilities and consumers from impacts of climate change by conducting vulnerability and adaptation studies for the energy sector, promoting use of sustainable woody biomass materials for power generation, inserting smart grid and microgrid technology, evaluating hydropower adaptation, investigating strategic uses of high temperature, low sag conductors, etc.	Red
		Increase understanding of climate impacts on ocean and coastal ecosystems and resources by furthering vulnerability assessments and cost analyses, continuing modeling, and continuing support and investment in monitoring efforts	Orange
		Improve maps and tools and provide training to incorporate best-available climate science into planning and operation and management decisions for assets at risk from sea-level rise	Red
		Increase research regarding the relationship between snow pack, rainfall, and groundwater recharge and quality; land-cover and ecosystems responses to changing precipitation and runoff conditions; how water quality in rivers, lakes and aquifers will be affected by changes in precipitation, timing of flow, and temperatures; etc.	Yellow
		Develop a better quantitative understanding of the links between climate change, ecosystems, and economic activity	Yellow
	Modify or develop new policies, programs, or regulations (16)	Develop small-scale biomass programs in forest areas.	Red
		Modify Clean Air Act regulations, if necessary, to accommodate more prescribed fires.	Red

Table E-1.—Summary of Representative Strategies and Examples

		Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	
		Assess development of fishing regulations to ensure that they are designed to provide adult salmon and Pacific lamprey returns well above "replacement" levels.	Red
		Develop new standards for land use and development to assist in reducing the amount of pollution in populated areas.	Red
		Develop a Climate Adaptation Advisory Panel (CAAP) to recommend improved opportunities for adaptation.	Red
		Establish a system of sustainable habitat reserves.	Red
		Develop a new $200 million instream flow restoration program (Proposition 1).	Orange
		Encourage local governments to adopt or amend local ordinances that enhance local water supply reliability and conservation.	Red
		Streamline water transfer processes to address both extreme situations and normal system operations.	Red
		Convene a task force of federal, state, and local permitting and flood management agencies.	Red
		Adopt policies and develop facility plans that promote the use of recycled water for all appropriate, cost-effective uses while protecting public health (targeted at water and wastewater agencies)	Orange
		Adopt ordinances that protect the natural functioning of groundwater recharge areas	Orange
		Improve management practices for coastal and ocean ecosystems and resources and increase capacity to withstand and recover from climate impacts, including hazard avoidance for new development	Red
		Address climate impacts in local coastal programs and general plan guidelines	Red
		Revise quantification of environmental water demands, in particular those identified through the listing of Coho and Suckers under ESA	Red
		Support reform of federal flood insurance program	Red
	Planning process and managed development (11)	Incorporate anticipated climate change impacts and vulnerabilities into road management plans and policies.	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	**Examples** (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Implement the blueprint planning process to help identify areas vulnerable to climate change.	Red
		Develop general plan amendments for future land use decisions.	Red
		Improve information systems and develop planning tools.	Red
		Develop a California Climate Vulnerability Assessment (CCVA).	Red
		Develop the “CalAdapt” web-based portal to show state supported research.	Red
		Complete a statewide sea-level rise vulnerability assessment every five years.	Red
		Support expansion and development of voluntary district-level water conservation plans for all agricultural water districts.	Red
		Update Bulletin 118 information.	Red
		Develop conjunctive use management plans that integrate floodplain management, groundwater banking and surface storage	Red
		Integrate the IRWM with land policies that help restore natural processes in watersheds to increase infiltration, slow runoff, improve water quality and augment the natural storage of water, and that encourage low impact development	Orange
	Develop decision support tools (5)	Develop hydropower decision-support tools to better assess and manage climate change variability.	Yellow
		Implement and enforce an accurate monitoring system that records who is diverting water, in what quantities, and when.	Red
		Use modern hydrological forecasting tools such as the Integrated Forecast and Reservoir Management (INFORM) project.	Orange
		Promote the implementation of the Climate Adaptation Planning Guide and inclusion of Climate Risk Reduction in Hazard Mitigation Planning Efforts	Red
		Continue to support the integration of climate risks in state and local government emergency planning efforts and enhance capacity to respond and recover from climate risk	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
	Habitat protection (8)	Encourage the Natural Resources Conservation Service and Conservation Reserve Enhancement Program to facilitate increased restoration work on private lands along waterways and riparian areas.	Red
		Protect and reestablish contiguous habitat and migration and movement corridors in riparian ecosystems.	Red
		Protect habitats by identifying priority conservation areas.	Red
		Implement a statewide habitat restoration grant program (Proposition 1).	Red
		Develop management practices to help safeguard species and ecosystems from climate risks	Red
		Protect and restore water resources for important ecosystems, including key wetlands	Red
		Develop a lamprey hatchery at Fourth Creek Reservoir	Red
		Develop cool-water refugia in the Trinity River	Orange
	Seek funding and/or provide monetary incentives (22)	Develop incentive program to encourage private landowners to create and protect connections between areas that allow for species to migrate.	Red
		Increase funding for full implementation of existing conservations plans.	Red
		Provide a tax incentive for conservation easements for rural landowners.	Red
		Provide tax incentives for forest thinning and other fire-prevention measures.	Red
		Offer incentives to encourage private landowners to cultivate culturally-important species, restore and conserve habitat, and allow harvest by tribes.	Red
		Provide incentives that encourage habitat restoration activities to support the fishing industry.	Red
		Seek resources and expertise that will help them expand capacity to reduce environmental stressors, improve watershed conditions and restore ecosystem services on priority lands.	Red
		Develop sustainable funding mechanisms to support climate change planning efforts that focus on biodiversity conservation.	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Sponsor science-based pilot projects for watershed adaptation research to address climate change adaptation for water management and ecosystems.	Red
		Invest in the prevention, detection and eradication of noxious invaders due to climate change.	Red
		Complement federal financial and technical assistance for farmers to collaboratively encourage improved farm management practices involving tillage, rotations, manure management, fallowing, use of cover crops, inter-cropping, multi-cropping, and fertilizer-use efficiency.	Red
		Develop or expand technical and financial assistance programs for the state's urban and agricultural communities using $100 million provided by Proposition 1 and additional funding from AB 32 Cap and Trade revenues.	Red
		Provide sustainable funding for statewide and integrated regional water management	Red
		Authorize and fund new incentive-based programs to promote the widespread and mainstream adoption of aggressive water conservation by urban and agricultural water systems and their users	Red
		Develop incentive programs for sustainable, science-based practices that create resilience to climate impacts, including pilot-projects	Red
		Promote energy demand side measures that facilitate climate adaptation	Red
		Encourage innovative design of new structures/ infrastructure in areas vulnerable to sea-level rise	Red
		Support pilot projects for innovative shoreline management techniques	Red
		Continue to study and support investment in cost-effective green infrastructure to reduce flood risk and stormwater runoff and to maximize associated co-benefits	Red
		Fund, or assist with access to funding, to help isolated communities develop infrastructure to improve water access and adaptive capacity	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	**Representative Strategy**	**Examples** (provided examples are not exhaustive and may not include all identified strategies under each representative category)	**Ability to Model and Quantitatively Evaluate Strategy**
		Create State-sponsored innovation incentives to tap local deep knowledge of climate variability and previously implemented adaptation measures.	Red
		Dedicate a percentage of annual funding from state and federal water projects to watershed conservation and restoration (or from fed and state renewable energy and fuel subsidies to Woody Biomass Energy/Fuel Facilities)	Red
	Watershed management (6)	Implement land use practices that promote water retention on-site and reduce forest fuels.	Orange
		Implement management practices that enhance groundwater recharge and quantify conveyance efficiency.	Orange
		Implement an effective watershed management strategy that provides multiple benefits.	Red
		Reestablish natural hydrologic connectivity between rivers and their historic floodplain.	Red
		Identify strategies that can improve the coordination of local groundwater storage and banking with local surface storage along with other water supplies including recycled municipal water, surface runoff, flood flows, urban runoff, storm water, imported water, water transfers and desalinated groundwater and seawater.	Red
		Continue development of state sediment master plan and sediment management activities	Red
	Improve land use practices (7)	Implement land use practices that promote water retention on-site and reduce forest fuels.	Orange
		Develop inter-cropping and soil enhancing practices.	Orange
		Support land conservation programs and smart growth.	Red
		Develop and employ methods to update existing soil classification maps based on climate change scenarios.	Red
		Continue purchase of wetland easements on marginal, flood-prone, agricultural lands to diversify grower income and buffer productive lands from flood events and improve the environmental services.	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Require closer collaboration and coordination of land use and water planning activities to ensure that each reinforces sustainable development that is resilient to climate changes	Red
		Limit development in vulnerable regions through land-use planning and zoning regulations	Red
	Other (6)	Diversify energy supply to reduce vulnerability to extreme weather-related events and climate change	Red
		Increase understanding of impacts and opportunities associated with offshore renewable energy development	Red
		Consider, employ, and protect sources of natural carbon storage to increase the global atmospheric concentration of carbon dioxide	Red
		Enhance carbon capture through a carbon dioxide "fertilization effect" (maintain carbon uptake under a moderate level of drought stress)	Red
		Develop and implement an early warning system for heat waves	Red
		Implement AB 3030 Groundwater Management Plans as a fundamental component of IRWM plans	Red
Miscellaneous	Habitat restoration (8)	Restore and enhance existing floodplain and wetland habitat.	Red
		Protect upland habitat and transition zones to allow for wetland migration.	Red
		Restore and manage habitat to promote native species.	Red
		Restore habitat to remove barriers to fish migration.	Orange
		Restore connections between streams and rivers and their side channels and floodplains so that fish and other aquatic animals can avoid impacts from unusually high or unusually frequent winter storm flows and allow water to flow freely between these features.	Orange
		Fence stream bank and lakeside areas to provide better grazing control as protection against erosion.	Red
		Identify and conserve key connections across the Klamath-Cascade to ensure that there is a flow of diverse habitats across the landscape.	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Work with dam owners and operators, federal resource management agencies, and other stakeholders to evaluate opportunities to introduce or reintroduce anadromous fish to upper watersheds	Red
	Improve infrastructure (1)	Build infrastructure (i.e., levees, sea walls) to protect sacred sites; Consider implementing "coastal-armoring," "planned retreat," or integrating natural ecosystems as buffers against sea-level rise and storms (“ecosystem-based adaptation”)	Orange
	Improve extreme event preparedness (5)	Decommission nonessential roads to reduce the overall impact of erosion and sedimentation during severe storm events.	Red
		Assess road/stream crossing culverts to ensure they can accommodate increased storm frequency and runoff and replace improperly-sized culverts.	Red
		Improve level of preparedness, emergency response capacity, and ability to facilitate rapid and climate-cognizant recovery.	Red
		Practice and promote integrated flood management, including upgrading and managing flood systems to accommodate the higher variability of flood flow, to protect public safety, the economy, and ecosystems	Orange
		Implement land use policies that decrease flood risk	Red
	Protect cultural areas (2)	Restore habitat to buffer sacred sites.	Red
		Create fire breaks to protect sacred sites.	Red
	Watershed management (16)	Manage sediment to maintain/enhance wetland elevations.	Red
		Integrate ecosystem resilience with disadvantaged community resilience - recognize the connection between ecosystem function and economic vitality and promote strategies that benefit from this connection.	Red
		Identify other still vulnerable areas using more advanced elevation data and mapping and modeling techniques to reduce flood risk from sea level rise.	Red
		Enhance watershed function to reduce fire intensity, yield older forests that are more fire resistant, and restore and maintain essential habitat in more natural, carbon-rich forests	Red

Table E-1.—Summary of Representative Strategies and Examples

Category	Representative Strategy	Examples (provided examples are not exhaustive and may not include all identified strategies under each representative category)	Ability to Model and Quantitatively Evaluate Strategy
		Conduct an assessment of the carbon footprints of large water and wastewater utilities and consider implementation of strategies in the draft AB 32 Scoping Plan to reduce GHG emissions	Red
		Incorporate corridor connectivity and restoration of native aquatic and terrestrial habitats to support increased biodiversity and resilience for adapting to a changing climate into the IRWM and regional flood management plans	Red
		Develop new and/or adapt existing best management practices that reduce climate risks, such as soil conservation practices and practices that support pollinator health	Red
		Support efforts to systematically collect and preserve agricultural genetic material in recognition of the risk of agricultural biodiversity loss from climate change	Red
		Improve habitat connectivity and protect climate refugia	Orange
		Support environmental stewardship across sectors	Red
		Create and maintain partnerships that support biodiversity conservation in a changing climate	Red
		Continue and enhance coordinated efforts to reduce wildfire risks and promote fire safe communities	Red
		Provide funding to support, maintain and expand seed banks and revive state tree nurseries	Red
		Utilize sustainability modeling tools for fishery managers	Red
		Maintain future biodiversity by mapping and protecting ecosystem services, speciation processes, potential future refugia, and corridor networks to facilitate dispersal.	Red
		Develop and implement a plan to address the impact of climate change on sporting and recreational activities	Red
	Other (2)	Promote public education and outreach on climate change impacts to biodiversity	Red
		Provide support for the continuation of the CDFW Climate College and educational outreach efforts and link those efforts to broader state climate literacy programs	Red

E.2 Summary Tables of Measures with Strategies

Table E-2.—Comparison of Historical and Projected Mean Monthly Upper Klamath Lake Storage under Strategy “Reduce ET 30%” (units are KAF)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	255.0	239.7	296.1	372.2	430.6	441.4	465.2	476.4	452.4	388.6	319.2	288.0
Warm Dry	2030	CMIP-3	203.4	217.8	285.4	357.1	419.1	440.1	460.7	469.1	432.1	345.9	261.1	220.4
Warm Dry	2030	CMIP-5	199.1	213.1	279.2	346.4	406.8	432.9	456.1	465.2	424.6	337.6	253.9	211.9
Warm Wet	2030	CMIP-3	202.1	223.4	295.9	370.8	431.4	444.3	462.6	470.4	434.1	345.6	259.1	216.2
Warm Wet	2030	CMIP-5	198.6	227.3	305.0	381.1	438.6	445.2	461.9	470.0	427.4	336.7	251.6	206.9
Hot Dry	2030	CMIP-3	166.0	190.0	262.8	336.9	403.0	433.1	456.6	455.8	398.8	303.5	219.3	175.8
Hot Dry	2030	CMIP-5	165.6	191.7	267.7	348.3	415.7	439.5	456.4	447.6	384.7	290.9	213.1	173.3
Hot Wet	2030	CMIP-3	159.4	190.4	276.9	368.7	436.6	449.2	460.2	458.1	396.7	298.3	211.7	164.9
Hot Wet	2030	CMIP-5	155.9	188.6	278.9	368.4	439.2	451.6	459.8	453.5	384.8	285.5	203.1	159.9
Central Tendency	2030	CMIP-3	184.2	214.6	290.1	364.1	426.0	442.2	463.9	467.6	415.1	318.0	231.9	188.9
Central Tendency	2030	CMIP-5	179.7	206.4	283.9	363.7	425.3	435.7	451.9	457.9	404.9	308.7	225.1	185.1
Warm Dry	2070	CMIP-3	170.2	194.9	267.0	343.0	409.8	435.7	454.7	451.2	397.3	304.0	220.7	177.6
Warm Dry	2070	CMIP-5	184.7	206.4	277.9	352.6	414.9	436.1	454.5	452.6	400.0	307.1	228.2	191.0
Warm Wet	2070	CMIP-3	165.4	197.4	282.7	373.1	438.9	449.9	457.8	455.9	392.6	293.3	207.9	165.0
Warm Wet	2070	CMIP-5	178.3	209.9	294.8	375.3	437.0	443.1	456.4	454.9	398.7	302.4	219.4	180.5
Hot Dry	2070	CMIP-3	134.2	161.2	244.2	332.6	403.9	433.3	448.5	434.4	360.8	265.8	189.2	143.9
Hot Dry	2070	CMIP-5	133.4	158.1	237.9	329.8	406.3	434.9	443.6	412.3	331.1	247.1	183.8	141.5
Hot Wet	2070	CMIP-3	142.7	181.4	270.9	369.9	443.5	453.3	451.8	421.2	336.9	247.7	180.7	141.2
Hot Wet	2070	CMIP-5	127.8	159.5	247.6	358.5	442.5	450.5	451.0	411.0	321.6	240.5	177.4	134.2
Central Tendency	2070	CMIP-3	152.6	188.6	277.2	364.4	431.3	447.2	458.8	448.2	372.9	275.4	195.1	152.8
Central Tendency	2070	CMIP-5	147.7	177.9	266.2	361.6	433.0	445.0	458.1	446.2	370.2	273.7	194.1	152.2

Table E-3.—Comparison of Historical and Projected Mean Monthly Keno Dam Inflow under Strategy "Reduce ET 30%" (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	1,508	1,431	1,193	1,544	2,163	3,696	2,328	1,632	974	653	550	659
WarmDry	2030	CMIP-3	1,084	1,046	1,334	1,698	2,197	3,728	2,307	1,551	1,062	808	666	762
WarmDry	2030	CMIP-5	1,005	1,017	1,366	1,862	2,082	3,345	2,177	1,410	1,064	758	634	761
WarmWet	2030	CMIP-3	1,051	1,062	1,614	2,508	2,869	4,418	2,664	1,902	1,193	943	773	900
WarmWet	2030	CMIP-5	962	968	1,606	2,445	2,875	4,575	2,530	1,896	1,203	909	744	899
HotDry	2030	CMIP-3	809	841	1,137	1,782	2,152	3,449	2,002	1,464	1,103	801	639	672
HotDry	2030	CMIP-5	796	866	1,124	1,708	2,129	3,434	1,880	1,573	1,120	773	595	640
HotWet	2030	CMIP-3	865	907	1,651	2,842	3,218	4,777	2,538	2,080	1,365	977	810	908
HotWet	2030	CMIP-5	870	919	1,579	2,650	3,146	4,817	2,540	2,112	1,420	994	776	855
CentralTendency	2030	CMIP-3	812	893	1,428	2,181	2,604	3,960	2,302	1,723	1,184	879	693	774
CentralTendency	2030	CMIP-5	907	931	1,560	2,424	2,861	4,297	2,398	1,805	1,261	927	733	810
WarmDry	2070	CMIP-3	802	935	1,294	2,005	2,225	3,476	2,078	1,554	1,124	817	646	708
WarmDry	2070	CMIP-5	886	905	1,262	1,973	2,339	3,638	2,182	1,628	1,132	810	628	692
WarmWet	2070	CMIP-3	894	1,082	1,773	3,075	3,629	5,139	2,935	2,346	1,494	1,069	880	964
WarmWet	2070	CMIP-5	947	956	1,706	2,773	3,231	4,763	2,524	2,272	1,426	1,056	808	912
HotDry	2070	CMIP-3	781	804	1,080	1,878	2,189	3,416	1,763	1,560	1,195	768	651	679
HotDry	2070	CMIP-5	750	848	1,157	2,167	2,271	3,451	1,785	1,916	1,271	703	627	648
HotWet	2070	CMIP-3	854	963	2,153	3,122	3,867	5,006	2,612	2,654	1,532	878	837	937
HotWet	2070	CMIP-5	911	1,043	2,070	3,336	4,104	5,149	2,499	2,973	1,524	829	846	965
CentralTendency	2070	CMIP-3	770	895	1,545	2,743	3,084	4,471	2,340	2,133	1,383	910	762	773
CentralTendency	2070	CMIP-5	820	903	1,345	2,396	2,881	4,402	2,183	2,077	1,344	888	730	757

Table E-4.—Comparison of Historical and Projected Mean Monthly Iron Gate Reservoir Storage under Strategy "Reduce ET 30%" (units are KAF)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	57.0	56.6	55.6	55.8	56.2	57.1	55.9	55.3	55.1	55.3	55.4	55.2
WarmDry	2030	CMIP-3	56.5	56.0	55.6	55.7	56.1	57.3	55.9	55.2	55.3	55.8	55.7	55.4
WarmDry	2030	CMIP-5	56.4	56.1	55.7	56.1	56.0	57.0	55.8	55.1	55.4	55.9	55.8	55.5
WarmWet	2030	CMIP-3	56.1	55.9	55.7	56.3	56.7	57.9	55.9	55.2	55.6	56.0	56.0	55.5
WarmWet	2030	CMIP-5	55.9	55.7	55.6	56.3	56.6	58.0	55.9	55.2	55.6	56.1	55.9	55.5
HotDry	2030	CMIP-3	55.8	55.6	55.5	55.9	56.2	57.3	55.6	55.2	55.8	56.2	55.9	55.3
HotDry	2030	CMIP-5	55.6	55.4	55.5	56.0	56.3	57.1	55.4	55.3	55.9	56.1	55.8	55.3
HotWet	2030	CMIP-3	55.6	55.4	55.4	56.6	57.0	58.4	55.8	55.2	55.9	56.2	56.0	55.6
HotWet	2030	CMIP-5	55.5	55.2	55.4	56.5	57.0	58.4	55.8	55.3	56.2	56.2	55.9	55.4
CentralTendency	2030	CMIP-3	55.7	55.5	55.5	56.2	56.6	57.6	55.6	55.2	55.7	56.2	55.9	55.5
CentralTendency	2030	CMIP-5	55.9	55.5	55.5	56.4	56.8	57.9	55.7	55.2	55.8	56.1	55.9	55.4
WarmDry	2070	CMIP-3	55.6	55.6	55.4	56.1	56.2	57.1	55.6	55.2	55.7	56.2	55.9	55.4
WarmDry	2070	CMIP-5	56.0	55.6	55.5	56.2	56.4	57.3	55.7	55.2	55.7	56.1	55.8	55.4
WarmWet	2070	CMIP-3	55.6	55.4	55.5	56.6	57.3	58.6	56.1	55.3	56.0	56.2	56.0	55.5
WarmWet	2070	CMIP-5	55.8	55.6	55.5	56.5	56.8	58.2	55.7	55.2	56.0	56.2	56.0	55.5
HotDry	2070	CMIP-3	55.5	55.3	55.3	56.2	56.5	57.2	55.4	55.4	56.0	56.0	55.5	55.2
HotDry	2070	CMIP-5	55.4	55.3	55.3	56.2	56.5	57.1	55.5	55.9	55.9	55.6	55.1	55.1
HotWet	2070	CMIP-3	55.5	55.4	55.7	56.9	57.4	58.4	55.8	55.6	56.2	55.8	55.5	55.4
HotWet	2070	CMIP-5	55.6	55.6	55.5	56.8	57.6	58.5	55.5	55.8	56.0	55.5	55.4	55.3
CentralTendency	2070	CMIP-3	55.4	55.3	55.3	56.6	57.0	58.0	55.6	55.4	56.1	56.1	55.7	55.3
CentralTendency	2070	CMIP-5	55.4	55.4	55.3	56.4	56.7	57.8	55.5	55.5	56.1	56.1	55.8	55.3

Table E-5.—Comparison of Historical and Projected Mean Monthly Iron Gate Dam Outflow under Strategy "Reduce ET 30%" (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	1,979	2,017	1,395	2,137	2,701	4,628	3,050	2,287	1,413	1,150	1,121	1,243
WarmDry	2030	CMIP-3	1,432	1,558	1,419	2,216	2,767	4,872	2,853	1,890	1,273	1,063	1,026	1,240
WarmDry	2030	CMIP-5	1,370	1,622	1,546	2,470	2,717	4,282	2,743	1,805	1,264	1,004	992	1,335
WarmWet	2030	CMIP-3	1,358	1,519	1,669	3,258	3,684	5,938	3,102	2,046	1,332	1,135	1,135	1,199
WarmWet	2030	CMIP-5	1,271	1,457	1,711	3,273	3,648	6,211	2,988	1,912	1,302	1,104	1,027	1,175
HotDry	2030	CMIP-3	1,194	1,481	1,411	2,555	3,060	4,764	2,523	1,590	1,147	991	970	1,080
HotDry	2030	CMIP-5	1,190	1,390	1,382	2,589	3,065	4,550	2,301	1,522	1,174	981	971	1,116
HotWet	2030	CMIP-3	1,126	1,511	1,737	3,860	4,259	6,747	2,884	1,829	1,308	1,075	1,006	1,121
HotWet	2030	CMIP-5	1,115	1,383	1,720	3,601	4,254	6,890	2,860	1,794	1,322	1,057	998	1,107
CentralTendency	2030	CMIP-3	1,184	1,475	1,604	2,998	3,488	5,424	2,750	1,800	1,251	1,069	1,004	1,180
CentralTendency	2030	CMIP-5	1,196	1,470	1,673	3,369	3,632	6,057	2,789	1,725	1,261	1,068	992	1,230
WarmDry	2070	CMIP-3	1,166	1,527	1,545	2,802	3,103	4,583	2,514	1,600	1,184	1,002	974	1,105
WarmDry	2070	CMIP-5	1,258	1,447	1,450	2,753	3,071	4,671	2,658	1,697	1,193	1,016	998	1,211
WarmWet	2070	CMIP-3	1,142	1,448	1,723	4,044	4,769	7,474	3,193	1,927	1,366	1,092	1,033	1,339
WarmWet	2070	CMIP-5	1,205	1,544	1,761	3,719	4,102	6,591	2,791	1,919	1,362	1,132	1,025	1,220
HotDry	2070	CMIP-3	1,155	1,433	1,541	2,868	3,227	4,753	2,132	1,359	1,149	933	939	1,042
HotDry	2070	CMIP-5	1,105	1,412	1,488	3,234	3,366	4,685	2,025	1,414	1,125	863	920	1,120
HotWet	2070	CMIP-3	1,096	1,591	2,125	4,439	5,238	7,090	2,736	1,826	1,282	874	931	1,179
HotWet	2070	CMIP-5	1,060	1,584	2,018	4,684	5,525	7,344	2,488	1,833	1,188	754	945	1,102
CentralTendency	2070	CMIP-3	1,084	1,548	1,757	3,865	4,223	6,277	2,641	1,755	1,282	991	955	1,118
CentralTendency	2070	CMIP-5	1,111	1,469	1,565	3,558	3,896	6,062	2,518	1,682	1,272	962	999	1,188

Table E-6.—Comparison of Historical and Projected Mean Monthly Shasta River Flow under Strategy “Reduce ET 30%” (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	191.8	225.4	242.3	348.8	315.0	411.2	290.3	320.2	280.9	209.4	176.6	170.4
WarmDry	2030	CMIP-3	141.7	220.1	265.0	340.5	293.8	367.7	162.8	138.1	102.0	36.2	32.9	69.8
WarmDry	2030	CMIP-5	144.3	224.2	250.3	344.9	298.7	344.8	158.9	137.5	94.2	33.0	30.4	67.7
WarmWet	2030	CMIP-3	151.8	219.0	314.1	469.9	365.4	411.5	195.7	183.7	129.4	52.9	47.1	78.0
WarmWet	2030	CMIP-5	146.3	215.9	326.8	449.8	344.1	423.1	198.1	161.9	120.8	52.6	41.5	74.1
HotDry	2030	CMIP-3	151.7	221.4	270.0	379.1	311.4	334.7	130.8	107.3	62.1	34.8	35.4	63.4
HotDry	2030	CMIP-5	150.1	213.1	254.9	400.6	304.2	320.8	114.0	109.9	65.2	43.2	45.2	69.0
HotWet	2030	CMIP-3	146.9	234.1	338.8	458.3	367.7	408.1	159.0	126.5	89.0	50.4	46.7	70.6
HotWet	2030	CMIP-5	149.8	213.3	334.1	475.5	386.0	413.0	161.5	136.7	86.4	51.3	54.0	72.9
CentralTendency	2030	CMIP-3	150.9	217.0	271.8	409.5	330.1	369.2	153.1	142.7	94.2	40.3	39.1	70.4
CentralTendency	2030	CMIP-5	145.5	218.9	296.3	460.3	312.9	384.0	159.0	128.4	86.8	45.6	43.6	74.2
WarmDry	2070	CMIP-3	152.0	221.8	276.9	364.3	308.6	319.3	116.5	111.2	70.2	39.9	40.8	66.4
WarmDry	2070	CMIP-5	150.5	213.9	259.2	367.3	297.7	335.2	144.9	124.8	78.0	44.0	44.0	73.7
WarmWet	2070	CMIP-3	155.6	218.5	337.9	504.4	394.9	427.6	183.3	152.4	103.1	60.8	58.4	80.3
WarmWet	2070	CMIP-5	154.4	235.1	336.0	498.4	361.5	413.9	185.4	155.4	117.6	66.4	63.8	88.6
HotDry	2070	CMIP-3	144.5	206.5	281.0	370.7	289.7	299.8	89.7	90.7	40.0	30.1	39.7	62.7
HotDry	2070	CMIP-5	141.2	197.2	263.3	400.1	305.8	314.5	88.4	97.7	35.7	32.7	49.1	72.9
HotWet	2070	CMIP-3	157.9	217.6	373.8	521.0	378.5	372.9	135.6	115.3	63.0	50.0	56.3	77.6
HotWet	2070	CMIP-5	140.8	214.7	365.2	577.6	403.0	396.7	133.7	120.7	53.4	42.3	57.6	83.0
CentralTendency	2070	CMIP-3	159.6	218.7	308.9	472.1	350.8	364.8	134.1	116.6	72.2	49.5	51.1	73.5
CentralTendency	2070	CMIP-5	153.4	223.6	328.8	485.6	337.9	362.2	135.7	119.2	66.4	49.3	54.3	73.6

Table E-7.—Comparison of Historical and Projected Mean Monthly Scott River Flow under Strategy "Reduce ET 30%" (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	89	443	801	1,192	1,122	1,295	1,058	1,248	788	260	141	122
WarmDry	2030	CMIP-3	50	482	835	1,161	1,108	1,288	919	973	539	98	48	91
WarmDry	2030	CMIP-5	47	537	870	1,203	1,132	1,226	921	993	494	79	37	98
WarmWet	2030	CMIP-3	78	563	1,289	1,748	1,562	1,542	1,096	1,253	720	159	69	75
WarmWet	2030	CMIP-5	68	561	1,373	1,802	1,463	1,591	1,109	1,108	629	142	53	63
HotDry	2030	CMIP-3	50	533	957	1,310	1,250	1,255	835	769	302	57	37	60
HotDry	2030	CMIP-5	45	418	829	1,428	1,252	1,242	770	696	252	58	54	67
HotWet	2030	CMIP-3	59	749	1,494	1,880	1,641	1,620	1,002	959	470	93	43	65
HotWet	2030	CMIP-5	59	536	1,397	1,913	1,724	1,637	975	918	373	80	54	70
CentralTendency	2030	CMIP-3	73	498	1,116	1,511	1,365	1,395	928	997	499	88	50	73
CentralTendency	2030	CMIP-5	55	568	1,197	1,714	1,330	1,498	967	918	430	89	49	93
WarmDry	2070	CMIP-3	48	542	946	1,297	1,210	1,184	756	733	299	57	41	63
WarmDry	2070	CMIP-5	53	452	933	1,350	1,173	1,246	866	816	354	75	53	93
WarmWet	2070	CMIP-3	70	596	1,499	2,053	1,816	1,703	1,070	1,033	500	100	57	129
WarmWet	2070	CMIP-5	75	720	1,480	2,009	1,594	1,621	1,049	1,003	506	111	71	112
HotDry	2070	CMIP-3	41	447	1,019	1,338	1,242	1,164	660	465	134	35	39	53
HotDry	2070	CMIP-5	40	404	939	1,565	1,394	1,246	614	374	96	39	55	75
HotWet	2070	CMIP-3	72	650	1,727	2,177	1,836	1,550	847	662	218	57	59	88
HotWet	2070	CMIP-5	53	664	1,754	2,516	1,949	1,628	802	464	127	42	66	91
CentralTendency	2070	CMIP-3	76	604	1,383	1,884	1,571	1,464	868	771	294	64	53	93
CentralTendency	2070	CMIP-5	62	682	1,399	1,986	1,522	1,486	883	760	246	63	64	93

Table E-8.—Comparison of Historical and Projected Mean Monthly Klamath River near Orleans Flow under Strategy "Reduce ET 30%" (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	2,842	6,186	9,561	15,234	14,689	18,676	13,228	11,483	7,362	3,226	2,375	2,362
WarmDry	2030	CMIP-3	2,194	6,180	10,035	14,931	15,031	19,137	12,377	9,532	5,632	2,474	2,194	2,723
WarmDry	2030	CMIP-5	2,106	6,438	9,824	15,323	15,107	17,946	12,175	9,269	5,184	2,275	1,849	2,859
WarmWet	2030	CMIP-3	2,350	7,232	13,655	21,200	21,768	22,694	14,067	11,086	6,859	2,866	2,352	2,408
WarmWet	2030	CMIP-5	2,165	6,884	13,980	21,320	19,954	23,461	14,146	10,022	6,032	2,673	2,031	2,112
HotDry	2030	CMIP-3	1,942	6,602	10,683	16,715	17,042	18,727	11,361	7,042	3,552	1,983	1,810	2,105
HotDry	2030	CMIP-5	1,858	5,024	9,886	18,147	17,123	18,399	10,345	6,219	3,149	1,951	2,008	2,264
HotWet	2030	CMIP-3	2,004	8,503	14,768	23,200	24,244	24,772	13,375	8,524	4,778	2,404	1,939	2,093
HotWet	2030	CMIP-5	1,969	6,641	15,000	23,171	24,432	25,019	13,078	8,228	4,244	2,232	1,917	2,150
CentralTendency	2030	CMIP-3	2,189	6,577	11,978	18,766	19,112	20,667	12,195	8,873	4,923	2,363	1,944	2,272
CentralTendency	2030	CMIP-5	2,035	6,922	12,760	21,305	18,628	22,441	12,876	8,292	4,616	2,358	1,944	2,635
WarmDry	2070	CMIP-3	1,896	6,452	11,102	16,888	16,956	18,018	10,635	7,044	3,703	2,026	1,834	2,179
WarmDry	2070	CMIP-5	2,041	5,758	10,653	17,289	16,261	18,612	11,678	7,774	4,007	2,159	1,980	2,576
WarmWet	2070	CMIP-3	2,198	7,434	15,160	24,904	26,945	27,253	14,601	9,375	5,022	2,459	2,072	3,133
WarmWet	2070	CMIP-5	2,257	8,670	15,244	23,837	22,412	24,158	13,607	9,219	5,213	2,544	2,314	2,889
HotDry	2070	CMIP-3	1,831	5,751	12,120	17,343	17,565	17,791	9,432	4,711	2,254	1,719	1,702	2,017
HotDry	2070	CMIP-5	1,842	5,425	11,360	19,957	20,124	18,639	8,762	4,283	2,065	1,656	1,931	2,628
HotWet	2070	CMIP-3	2,130	8,198	17,275	26,482	27,600	24,817	12,018	6,329	3,081	1,890	1,914	2,535
HotWet	2070	CMIP-5	1,918	7,975	17,035	29,690	29,092	25,763	11,463	5,300	2,438	1,637	2,020	2,405
CentralTendency	2070	CMIP-3	2,126	7,725	14,454	23,098	23,057	22,216	11,750	7,118	3,614	2,046	1,886	2,409
CentralTendency	2070	CMIP-5	2,003	7,848	14,284	23,484	21,365	21,928	11,710	6,730	3,273	1,968	2,102	2,628

Table E-9.—Comparison of Historical and Projected Mean Monthly Klamath River at Klamath Flow under Strategy "Reduce ET 30%" (units are cfs)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	4,100	13,599	22,775	34,077	32,184	36,230	23,772	18,268	11,219	5,150	3,918	3,875
WarmDry	2030	CMIP-3	3,388	13,930	22,543	32,136	31,176	35,842	22,002	15,472	8,992	4,275	3,986	4,869
WarmDry	2030	CMIP-5	3,262	13,819	21,580	32,786	32,225	34,032	21,888	15,287	8,696	3,985	3,246	4,755
WarmWet	2030	CMIP-3	3,922	16,351	30,572	46,173	43,327	42,047	25,608	17,844	10,574	4,820	4,236	4,314
WarmWet	2030	CMIP-5	3,584	15,402	30,720	45,726	39,655	43,354	26,191	16,548	9,740	4,574	3,528	3,645
HotDry	2030	CMIP-3	3,113	14,525	23,286	35,722	34,522	34,375	20,231	12,119	6,347	3,547	3,172	3,719
HotDry	2030	CMIP-5	2,908	11,200	21,595	38,496	34,137	33,924	18,272	11,027	5,980	3,537	3,648	4,077
HotWet	2030	CMIP-3	3,335	19,689	30,896	47,944	45,812	44,568	23,788	14,039	8,105	4,179	3,378	3,674
HotWet	2030	CMIP-5	3,294	14,713	32,151	48,704	46,366	43,804	23,614	13,942	7,525	3,959	3,452	3,932
CentralTendency	2030	CMIP-3	3,721	14,450	26,204	40,093	38,219	38,291	21,791	14,588	8,209	4,095	3,445	4,021
CentralTendency	2030	CMIP-5	3,263	15,134	27,345	44,236	36,546	40,292	23,032	14,038	7,796	4,086	3,423	4,391
WarmDry	2070	CMIP-3	3,001	14,058	23,177	35,001	33,863	32,764	18,083	12,093	6,574	3,607	3,231	3,798
WarmDry	2070	CMIP-5	3,268	12,451	23,089	36,663	32,952	34,367	20,772	13,245	7,262	3,823	3,598	4,921
WarmWet	2070	CMIP-3	3,780	16,643	31,964	51,867	50,020	46,664	26,293	15,451	8,345	4,241	3,673	5,816
WarmWet	2070	CMIP-5	3,843	18,885	32,136	49,665	42,572	43,209	24,573	15,371	8,709	4,371	4,208	5,086
HotDry	2070	CMIP-3	2,780	12,093	24,937	35,015	33,389	31,522	16,299	8,897	4,663	3,145	2,998	3,644
HotDry	2070	CMIP-5	2,891	10,999	23,055	40,368	36,740	33,048	15,719	8,651	4,420	3,113	3,451	4,486
HotWet	2070	CMIP-3	3,614	17,196	33,392	52,610	48,930	41,928	21,470	11,256	5,666	3,474	3,413	4,503
HotWet	2070	CMIP-5	3,165	16,552	32,470	57,976	51,288	43,656	20,914	10,046	4,844	3,203	3,786	4,696
CentralTendency	2070	CMIP-3	3,714	16,340	29,904	47,474	42,329	39,605	20,657	12,173	6,511	3,681	3,398	4,676
CentralTendency	2070	CMIP-5	3,335	17,305	29,943	48,095	40,265	39,259	21,148	11,948	6,133	3,566	3,825	4,822

Table E-10.—Comparison of Historical and Projected Mean Monthly Water Temperature in the Klamath River under Strategy "Reduce ET 30%" (units are °F)

Scenario	Period	BCSD Projection	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Historical	Historical	-	60.27	48.94	43.60	42.93	44.91	47.38	51.09	57.31	64.07	70.22	73.52	69.20
WarmDry	2030	CMIP-3	62.31	49.82	43.67	42.55	44.67	47.36	51.53	58.03	65.05	72.20	76.53	72.04
WarmDry	2030	CMIP-5	62.98	50.30	43.72	42.37	44.76	47.73	51.77	58.56	65.47	72.24	77.18	72.60
WarmWet	2030	CMIP-3	62.30	49.82	44.04	42.70	44.70	47.16	50.92	57.80	64.85	72.10	76.13	72.25
WarmWet	2030	CMIP-5	62.61	50.27	44.63	43.06	45.24	47.49	51.57	57.93	64.85	72.10	76.72	72.62
HotDry	2030	CMIP-3	63.87	51.18	44.58	43.30	46.25	48.85	53.08	60.00	66.70	73.79	78.18	73.81
HotDry	2030	CMIP-5	63.93	51.57	44.91	44.27	46.75	49.28	53.39	60.66	67.28	73.96	78.18	74.16
HotWet	2030	CMIP-3	63.58	50.94	45.23	44.23	46.19	48.07	52.29	59.70	66.40	73.42	77.79	73.45
HotWet	2030	CMIP-5	64.09	51.64	45.58	44.21	46.52	48.82	52.84	60.23	67.07	73.87	78.21	74.15
CentralTendency	2030	CMIP-3	62.87	50.49	44.34	43.03	45.24	47.68	51.64	58.98	65.96	73.02	77.47	73.31
CentralTendency	2030	CMIP-5	63.50	50.90	44.71	43.39	45.50	48.35	52.38	59.15	66.12	73.12	77.46	73.07
WarmDry	2070	CMIP-3	63.93	51.54	44.89	43.58	46.22	48.64	53.15	59.88	66.81	73.72	78.11	74.06
WarmDry	2070	CMIP-5	63.42	50.89	44.68	43.53	45.66	48.64	52.80	59.45	66.20	72.97	77.51	73.08
WarmWet	2070	CMIP-3	63.48	51.27	45.40	44.09	46.24	48.17	52.12	59.32	66.63	73.82	77.90	73.72
WarmWet	2070	CMIP-5	63.32	50.92	45.12	43.86	45.67	48.16	52.36	59.04	66.20	72.92	77.13	73.22
HotDry	2070	CMIP-3	66.00	53.32	46.21	45.33	48.01	50.24	55.12	62.23	68.66	75.73	80.40	76.04
HotDry	2070	CMIP-5	67.35	55.16	47.97	46.27	49.59	51.93	56.11	63.43	69.88	76.26	80.85	77.03
HotWet	2070	CMIP-3	65.27	53.13	46.62	46.10	47.99	49.81	53.91	61.25	68.36	75.57	79.89	75.61
HotWet	2070	CMIP-5	67.84	55.13	48.40	47.21	49.91	51.75	56.19	63.36	69.90	77.03	81.40	77.49
CentralTendency	2070	CMIP-3	64.34	52.05	45.97	44.41	46.71	48.80	53.10	60.41	67.62	74.40	78.87	74.66
CentralTendency	2070	CMIP-5	64.66	52.35	46.12	44.83	46.77	49.35	53.63	61.16	67.64	74.15	78.53	74.66

Appendix F - Klamath River Basin Study Peer Review Summary Report

F.1 Introduction

The Klamath River Basin Study (Basin Study) was conducted in cooperation with Reclamation’s Mid-Pacific Regional Office, the Oregon Water Resources Department (OWRD), and the California Department of Water Resources (CDWR). OWRD and CDWR are non-federal study partners. These groups comprise the Basin Study Technical Working Group (TWG). Interested organizations and individuals also provided input to the Basin Study.

This Basin Study provides a comprehensive assessment to define current and future imbalances in water supply and demand, evaluate the effects of climate change on water supply and demand, and develop and analyze adaptation strategies to alleviate those imbalances.

This Basin Study underwent peer review that was designed to ensure that assumptions, findings, and conclusions of the Basin Study were clearly stated and supported; oversights, omissions, and inconsistencies were identified; and limitations and uncertainties were disclosed.

This peer review summary report describes the approach for the peer review process for the Basin Study. It also identifies the individuals who performed reviews. Finally, comments by external peer reviewers and descriptions of how comments were addressed are provided as a way of ensuring a transparent external peer review process.

F.2 Review Process Approach

The final report underwent a three-step review process, which is detailed in table 1-1. In general, reviewers were asked to ensure that assumptions, findings, and conclusions were clearly stated and supported; identifies oversights, omissions, and inconsistencies; and encourages authors to fully acknowledge limitations and uncertainties. Reviewers were also asked to ensure that scientific uncertainties were clearly identified and characterized.

The final report consists of six individual chapters. Each report chapter underwent a technical sufficiency review process as the first step. The technical sufficiency review was performed by members of the TWG. Because the technical aspects of the study were largely performed by Reclamation's Technical Service Center (TSC) in Denver, Colorado. TSC staff also performed technical sufficiency review of each report chapter. Under the TSC technical sufficiency review process, selected reviewers were not associated directly or indirectly with the study, but their scientific and technical background and expertise are relevant to the study component subject matter.

Chapters three through six of the final report involved technical work including modeling and data analysis. These chapters underwent a second step of review by external peer reviewers. Peer reviewers consisted of stakeholders and/or experts in the fields discussed in each of these chapters. Like the technical sufficiency review process, peer reviewers were not associated with the study.

In the third step of the review process, the final report underwent a programmatic review that was conducted by Reclamation's Policy and Administration Office.

Table F-1.—Summary of Review Components

Type of Review	Description
Technical Sufficiency Review	Review performed by Reclamation Technical Service Center as well as the Basin Study TWG
External Peer Review	Review performed by individuals who were identified as experts in the subject matter and who were not involved with the Klamath River Basin Study
Programmatic Review	Review performed by Reclamation's Policy and Administration Office

Reviewers of the final report were asked a series of general guiding questions in addition to being asked to provide specific comments. These guiding questions were as follows:

1. Is purpose of the report chapter clear?
2. Is the approach well-designed and executed?
3. Is the approach to quantifying water demand projections clearly explained?
4. Has the assessment met the report goals?
5. Are the data and information appropriately cited?
6. Are assumptions and limitations explicit and justified?
7. Is the documentation accurate, understandable, clearly structured, and temperate in tone?

8. Are the reports compelling, useful, and relevant to stakeholders and decision makers?

General comments pertaining to these guiding questions helped to ensure that content was not only scientifically robust, but also well-presented.

F.3 Identified Reviewers

This section identifies individual reviewers for each chapter of the Klamath River Basin Study (Basin Study) final report.

F.3.1 Chapter 1 Introduction

Technical Sufficiency Review

- Tom Perry – Hydrologist (now retired), TSC
- Mark Spears – Civil Engineer, TSC
- TWG

External Peer Review

External peer review was not performed for Chapter 1 because the chapter does not contain modeling results or data analysis.

F.3.2 Chapter 2 Interrelated Activities and Literature Review

Technical Sufficiency Review

- Kristine Blickenstaff – Civil Engineer, TSC (now with U.S. Geological Survey [USGS])
- Tom Perry – Hydrologist (now retired), TSC
- TWG

External Peer Review

External peer review was not performed for Chapter 2 because the chapter does not contain modeling results or data analysis.

F.3.3 Chapter 3 Water Supply Assessment

Technical Sufficiency Review

- Levi Brekke – Chief, Research and Development at Reclamation
- TWG

External Peer Review

- Jeff Arnold – Senior Climate Scientist, U.S. Army Corps of Engineers (USACE)
- Marshal Gannett – Hydrologist, USGS
- Kathie Dello – Associate Director of Oregon Climate Change Research Institute

F.3.4 Chapter 4 Water Demand Assessment

Technical Sufficiency Review

- Levi Brekke – Chief, Research and Development at Reclamation
- Marci Early – Intern, TSC
- TWG

External Peer Review

- Clayton Creager – Environmental Program Manager, North Coast Regional Water Quality Control Board
- Tim Hemstreet – Klamath Program Manager, PacifiCorp – Hydro Resources
- Tim Mayer – Hydrologist, U.S. Fish and Wildlife Service (USFWS)
- John Risley – Research Hydrologist, USGS

F.3.5 Chapter 5 System Reliability Analysis

Technical Sufficiency Review

- Nancy Parker – Civil Engineer, TSC
- TWG

External Peer Review

- Tim Hemstreet – Klamath Program Manager, PacifiCorp – Hydro Resources

- Edward Jones – Fishery Biologist, Western Fisheries Research Center, Columbia River Research Laboratory, USGS

F.3.6 Chapter 6 System Reliability Analysis with Adaptation Strategy Concepts

Technical Sufficiency Review

- Nancy Parker – Civil Engineer, TSC
- TWG

External Peer Review

- Tim Hemstreet – Klamath Program Manager, PacifiCorp – Hydro Resources
- Edward Jones – Fishery Biologist, Western Fisheries Research Center, Columbia River Research Laboratory, USGS

F.4 Responses to External Peer Review Comments

F.4.1 Comments – Chapter 3 Water Supply Assessment

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
Jeff Arnold	cover	CDWR and OWRD logos switched on cover page	Fixed
Jeff Arnold	17	I think a quick exe summ of the chp would be very helpful: there's a lot of information here in several sub domains and it's easy for the reader to lose track of the overall direction and endpoint. Also: summaries at the end of every major section would be helpful to round-up the important 3 or 4 points there from the mass of detail and to ready the reader for how those key points will be used in the succeeding chpt. And I think the narrative flow of the chp would be helped by taking out some of the detail that remains in the body of the text and appears in the appendices, too – this may be a simple case of not deleting sections that were previously in the text and were then moved to an appendix.	
Jeff Arnold	18	Why are they different? Referring to geographic extents of surface and groundwater analyses.	The difference in approach is due to the extents of existing surface and groundwater modeling tools that may be applied in the study.
Jeff Arnold	19	Maybe include a little more of an executive summary here saying where and how this fits into the larger project, and using some of the section headers of this chapter to indicate how this chapter will unfold, as in an introduction. This could include a figure of the numerical model input-output cascade	
Jeff Arnold	21	Nice to have this in a table so the reader could refer to it all quickly	Table added as recommended
Jeff Arnold	23	Discuss this together w/Fig 3-2; here it breaks the narrative	This section has been revised.
Jeff Arnold	30	I don't know what this means and cant see how these are shown here to be linear	The term linear was removed from the caption description. The term relative, when describing the trends, is maintained to distinguish this from a presentation of absolute trends. Relative trends are presented as a ratio

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
			change, whereas absolute trends are presented as a difference.
Jeff Arnold	30	Also because Furniss is 4y later than Mote	Modified text
Jeff Arnold	31	This wouldn't seem to be true everywhere	The authors have modified this section for greater accuracy to previous publications.
Jeff Arnold	33	It'd be useful to show these domains on the sub basin maps together	Given the time available, this is not a high priority.
Jeff Arnold	34	Maybe suggest how common this lack of clarity is over the wider West - and give reference	Added reference to Hoerling et al (2010)
Jeff Arnold	36	As above, maybe a table of these values here	There is a table summarizing historical trends in climate and water balance variables (formerly Table 3-2).
Jeff Arnold	45	But that would have to be more important and prevalent here than in other locations – is that so?	This statement reiterates one by Gannett et al (2012) for the Lower Klamath Subbasin. The sentence was revised to the following: 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 subbasin (Gannet et al., 2012).
Jeff Arnold	45	Can you quantify majority of groundwater use?	We don't have specific numbers, but this was inferred in part from CDWR Groundwater Bulletin 118 (update 2003).
Jeff Arnold	47	Was it confidence in the model or in the application (where there might be insufficient data to initialize appropriately, e.g.)?	This bullet statement was modifed as suggested by the reviewer. The lack of confidence is with the model results and lack of available data for such a model. Changed to: 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 .
Jeff Arnold	50	1) Report the value and whether the difference is reasonable or significant. 2) Hard to imagine this matters at all for differences btwn 0.11 and 0.12 and when so little of the difference is explained.	This section was modified for clarity and indicate that the linear fit of both models is limited, but there is some ability of the model to explain some part of the variance in groundwater elevation.
Jeff Arnold	55	A little more detail on the BCSD method used to generate the projections would help	Detail added on BCSD downscaling approach.
Jeff Arnold	57	This unhelpfully confuses anthropogenic change and natural variability which are better left separate as you set out above.	This sentence was removed.
Jeff Arnold	60	That's true globally; but for a region like the Klamath there're good wind data going bk 30-50y in places. And the regional models are capable of	This sentence was removed.

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
		simulating winds w/some accuracy. And you use local wx data for ET below.	
Jeff Arnold	61	This is a little repetitive internally here and repeats things already written abv so could the section could be consolidated	This paragraph was consolidated as suggested.
Jeff Arnold	63	But there's no indication fr the paleo data what the temporality of the transitions could have been, so it's not clear why the remark abt ENSO and PDO, which have defined temporalities, is here.	We feel the explanation is clear. However, we did move the detailed discussion to the Chapter 3 appendix and provide a much higher level overview in the body of Chapter 3.
Jeff Arnold	67	It's perfectly fine to present only CMIP3 here and CMIP5 in the supplement. But since you've used CMIP5 to start the scenario process, you might write a sentence or two (or create a table) that shows the comparison of the two.	We have done extensive comparison between CMIP3 and CMIP5 projections.
Jeff Arnold	105	A little more detail on glacial rebound and why that makes relative local SL fall when eustatic SL is rising would help	This section was modified to improve clarity.
Jeff Arnold	106	But isnt this a common problem already? There's the standard occurrence and any change in that fr climate variability and then any possible change fr climate change	Once sentence was added stating rising landmasses may exacerbate the issue of coastal flooding and erosion.
Jeff Arnold	109	This is a little confused since many of the processes listed here have rather good representations at the global scale of the GCMs but not at sub-grid scales important to vulnerability and effects analyses like this one	These examples were removed.
Jeff Arnold	117	It's not truly "observed" natural, right? It has to be modeled back to a simulated natural state -	Changed to reconstructed observed natural streamflow .
Jeff Arnold	118	Just abv you say it can not (referring to VIC capturing complex interactions of surface and groundwater	Removed the sentence saying VIC may not capture complex interactions…
Jeff Arnold	118	Relative to other basins? To other time periods? Other stresses than Climate Change?	This section was modified to improve clarity.
Marshall Gannett	cover	This title seems a bit generic. Something more descriptive might be helpful to those doing research in the future.	The title for the overall report will be similar to "Klamath River Basin Study," but the chapter titles will be more descriptive.
Marshall Gannett	20	It might be helpful to discuss precip and other climate variables in the context of the actual physiographic regions (for example the Cascade range or the interior basins). This can be done by looking at individual weather stations. The climate divisions tend to average out a lot of these important differences.	Due to the level of effort involved in changing the geographic regions for analysis, we will maintain the Climate Division analysis. This still provides some understanding of how hydro-climatology varies throughout the watershed.

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
Marshall Gannett	22	What you describe here is supplemental use of groundwater. There are many parts of the upper basin where irrigators depend solely on groundwater; it is their primary and only source. Primary groundwater use is probably double the supplemental use.	Added a statement saying many more irrigators rely solely on groundwater to meet their water needs.
Marshall Gannett	22	I am actually embarrassed that the USGS has this map on line. The polygons of this nationwide map have almost no relation to any meaningful geology in the basin at this scale. (If we had our act together, the resolution of the geology would change with the chosen scale.) I suggest either removing this map and the associated table and rely on simple verbal descriptions of the geology throughout the basin, or (my preference) would be to take the 1:500,000 scale digital geologic maps of Oregon and California and generalize them into a dozen or so units. I have done this for the upper basin and would be happy to provide a shape file. I would also be happy to provide guidance in generalizing the 1:500,000 CA geology.	This map has been revised as suggested.
Marshall Gannett	50	It would be helpful to let the reader know that the observed GW elevations are basin-wide averages, and maybe include a sentence or two explaining how this was done. (I realize you explain all this in the appendix, but not all readers will read the appendices.).	Without going into a lot of detail in the chapter, text was added to identify GW elevations and basin-wide averages. Additional references to the appendix were also added.
Marshall Gannett	51	It might be helpful if you described how this observed gw elevation lines in parts a and b were developed. Are these individual wells or some aggregate? I assume it is in the appendix, but many readers will not drill into the appendices.	Additional details regarding development of observed groundwater elevations are now included in this main discussion.
Marshall Gannett	68	Since the stage in all of these reservoirs are artificially controlled and managed for either irrigation supply, refuge use, or a combination of refuge use and return flow management, they probably respond more to warming-related changes in demand than open water evaporation. I'll look for further explanation in the appendix.	No response needed.
Marshall Gannett	69	I'm not sure this is a defensible approach, at least for Upper Klamath Lake. The stage is basically set by Biological Opinions for the suckers, varying from year to year based on water-year type. Changes in ET come out of diversions, since stage and outflow are largely set by BOs. I think a more reasonable approach (at least for UKL) might have been to determine the occurrences of water-year types under your projected future climate and followed the stage patterns in recent-historic water-year types. Unless you think that the BOs are going to go away I think they need to be incorporated.	Reservoir operations will be incorporated into the analysis for the system reliability phase of the study. For now, we simply wanted to get a sense of the relative impact of changes in open water evaporation to projected changes in climate, without effects of management.
Marshall Gannett	71	I think this is a great approach.	No response needed.

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
Marshall Gannett	72	Again, a very reasonable approach in my opinion.	No response needed.
Marshall Gannett	73	I would argue that temperature and precip affect irrigation demand and that climate change related increases (or decreases) in demand might markedly affect groundwater levels. On the other hand a certain amount of demand variation is already built into the historic data used to develop relationships in your screening tools. It might be worthwhile elaborating on this (one way or the other).	Several lines were added to address this issue. We agree that agricultural demand will be affected by projected changes in precipitation and temperature, and this issue will be addressed in Chapter 4 of the Klamath River Basin Study in terms of changing agricultural demands, and in Chapter 5 in terms of how system reliability (as defined by chosen metrics) will change as a result.
Marshall Gannett	76	There are no associated “a” and “b” on the graphic. Also, the scale scales are slightly different on the precip graphs. The upper one goes to about 68 inches while the lower only goes to about 62.	Figure was modified as suggested
Marshall Gannett	Fig 3-28, pg 76	There are no associated “a” and “b” on the graphic. Also, the scale scales are slightly different on the precip graphs. The upper one goes to about 68 inches while the lower only goes to about 62.	Figure was modified as suggested
Marshall Gannett	Fig 3-29, pg 77	This is a nice graphic.	No response needed.
Marshall Gannett	90	Because these values are so different than the measured values in the USGS NWIS data base, I assume the historical values in figure 37 are simulated historical values. For example, your graphs show the annual peak or more than 4000CFS in April when the historical peak (1950-99 means) is about 3000 CFS and occurs in March. This should be made clear to the reader. Addendum… I see you discuss this in the appendix.	Yes, that is right. Added "Simulated historical…" as suggested.
Marshall Gannett	101	I think your point here is a good one, but I would make the case in terms of year-to-year water-level variations since these best reflect changes in mean-annual recharge. Monthly or seasonal variations can be heavily influenced by local anthropogenic stresses.	Referring to Figure 3-15, we actually mean changes in mean annual groundwater levels fluctuate by up to 20ft (not mean monthly), so this was revised in the text.
Marshall Gannett	117	Nice discussion….	No response needed.
Marshall Gannett	120	The scale on the vertical axes on the upper two graphs does not to zero so the red line does not extend the entire year. Also, by extending the axes to zero, the reader can better visually compare the annual volumes of simulated and historic flows. For what it’s worth…I think it is reasonable to invoke groundwater in explaining at least part of the differences between simulated and	Fixed axis limits on figures.

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
		observed values of the Sprague and the Klamath at Keno. The Klamath at Orleans is a different matter….	
Kathie Dello	19	For this reason we really try to stay away from using the divisions and I'm not sure it makes a strong point. Most people won't know what the names refer to, and as the map shows below, the state boundary makes for an artificial division	Climate division analysis will remain in the report, but the limitations are noted and included in the report text.
Kathie Dello	20	A map would be great here	Added a map of mean annual precipitation over 1950-1999 time period.
Kathie Dello	24	Citation? This is USDM drought monitor terminology but it wasn't considered extreme on the USDM	Changed extreme drought to moderate to severe drought
Kathie Dello	30	I can't find a copy of the Furniss study nor am I familiar with it, but I think the Shasta point only needs to be mentioned once and the section could be tightened up a bit	Removed sentence saying The Mote et al. (2008) study does not include measurements from Mount Shasta, and therefore the expanding glaciers (and snowpack by extension) reported by Furniss et al. (2012) are not represented in this study.
Kathie Dello	31	I'd consider a Barnett et al 2008 in citation in this section, up to 60% of the climate related trends in streamflow are human induced	Added reference to Barnett et al (2008)
Kathie Dello	33	I see you based a lot off the climate divisions and that is probably fine. The political boundary nature of the divisions steers me away from them, but you do offer the caveat up front. I don't think it's fatal.	See response in line 70
Kathie Dello	34-35	Consider including figures of seasonal trends also (P and T)	There was not enough time available for this analysis, even though it could be interesting.
Kathie Dello	54	I think you could be a bit bolder here without getting into trouble (too many mays)	Modified text
David Rupp	31	Several comments related to identifying domain of previous studies	Modified text to include definition of spatial domain when summarizing previous studies.
David Rupp	31	Awkward sentence "…to evaluate how historical precipitation… has driven the quantity, timing… of precipitation…" - referring to first sentence of approach section	Modified sentence as suggested
David Rupp	33	Please say why the month with the maximum soil moisture is the most relevant, and/or if it is the one most sensitive to climate change.	Added the following text: Because summer months typically receive low precipitation (see Table 3-X) in the Klamath River Basin, 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 and hence the reporting of trends in June 1 soil moisture, which was found to be the month with maximum soil moisture in the greater watershed.

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
David Rupp	Figure 3-6	Why does the temperature scale go past 60 degrees when the highest report temperature is less than 50 degrees?	The figure was modified to reflect a more reasonable yaxis for historical mean annual temperature
David Rupp	53	Was this 30 year period above/below “average” with respect to temperature and precipitation, compared to the historical record (say, 1900-2010)? If so, by how much?	Added the following text: 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 3-6 illustrates historical trends from 1950-1999.
David Rupp	54	This is not a clear definition of climate. Nor does “climate change” consist of natural variability from ENSO. I suggest reading the definitions of climate, climate variability, and climate change provided by the WMO (http://www.wmo.int/pages/prog/wcp/ccl/faqs.html) or the IPCC.	Text was modified using reference souces suggested.
David Rupp	58	No, it does not “ensure” that the “change signal” is a result of climate change. However, if a sufficiently large number of projections are averaged, it does reduce the “noise” of internal variability.	Changed text to: 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.
David Rupp	58	Is this trend consistent throughout the seasons?	Changed text to: 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.
David Rupp	Figure 3-18	Have these been statistically downscaled? It does not say so, but step 1 in the approach is to statistically downscale. Also, use same scale for (a) and (c) and for (b) and (d) so differences between CMIP3 and CMIP5 are more apparent. Also, do these include all 4 SRES and all 4 RCP scenarios discussed above? RCP2.6, for example, is considered by many to be a pipe dream, so one wonders if it should be included.	"Statistically downscaled" was added in figure caption. Scale was revised for panel figures. Discussion now includes the lists of emissions scenarios used for CMIP3 and CMIP5.
David Rupp	59	Fine, but I had to google this. How many readers of this will know what the Mahalanobis distance is?	Moved to footnote.
David Rupp	59	Seasonal differences in projections have already by noted above as being important. How do these grouping stand up under seasonal analysis? Are the 10 annually WW scenarios all WW during spring, for example? They may not be.	Seasonal differences in projections is not something that was explored as part of this basin study. Although it would be interesting to explore, it would not modify the approach for creating ensemble climate scenarios. This is in part due to desired consistency in approach for the WWCRA and

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
			other basin studies, but also we do not have justification for selecting projections based on one particular season.
David Rupp	60	Though I think it is fine at this stage to assume no change in wind climate within the VIC runs, some mention should be made of how wind climate is projected to change (or not) based on CMIP3 and CMIP5 experiments, and/or regional dynamical downscaling experiments.	One line was added based on existing research. 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.
David Rupp	62	While this is an interesting and informative exercise, I would think that the inclusion of third, “central,” state, would have allowed for better defining periods of stress in the system. With only two states, you will get many transitions of, say, a little dry to a little dry, but of what consequence? It is consecutive very dry (wet) years that carry the most consequences. One could argue for any number of states, but I think there is substantial payoff from going from 2 to 3 states.	We sample a rich variety (several realizations) of a two state system using the non-homogeneous Markov-Chain approach, and what matters in water management is when a system is "truly" wet or dry. Water managers are risk averse and having average water supply conditions does not influence operations. The reviewer may also refer to Prairie et al. (2008) for further discussion.
David Rupp	63	Doubtful whether the AMO has much effect on drought in the Klamath Basin. McCabe et al (2011), for example, show little correlation between drought frequency and AMO in the region. (McCabe, G.J., M.A. Palecki, and J.L. Betancourt (2004), Pacific and Atlantic ocean influences on multidecadal drought frequency in the United States, Proc. Natl. Acad. Sci. U.S.A., 101(12), 4136–4141.)	Removed mentioning of AMO.
David Rupp	Figure 3-22	Acronyms/abbreviations in figure should be defined in caption.	Caption was revised as suggested.
David Rupp	66	To be clear, were the same transition probabilities from the paleo-climate analysis applied to the 2030s and 2070s?	Yes, this text was added to the discussion for clarity.
David Rupp	71	This usage of the term maximum ET may be clear to users of MODFLOW, but not to others. PET – actual ET = unmet evaporative demand. It is not “maximum” ET (PET is the maximum ET). Furthermore, it is confusing to divide the supply to ET demand into precipitation and groundwater. For one, groundwater comes from precipitation. For another, PRMS and VIC meet ET demand mainly from the soil water (with a little from open water bodies). Also, does MODFLOW consider the soil column. If so, it seems some double accounting is being done here.	We have clarified the definition of maximum ET and also tried to make clear that this is a MODFLOW term.
David Rupp	72	Were any other explanatory variables considered? For example, PET or ET, given it is a major term in the water balance, as can be estimated using a variety of methods.	We found PET and ET to be highly correlated with temperature, while recharge is highly correlated with precipitation. We did not further explore relationships between PET (or ET) ad recharge.

Table F-2.—Review Comments for Klamath River Basin Study Final Report Chapter 3 – Water Supply Assessment of the Basin Study

Reviewer	Page	Reviewer Comments	Responses to Comments
David Rupp	76	Is RCP2.6 included? Are there any SRES scenarios which such low forcing by 2100? If RCP2.6 is included, this could explain why CMIP5 shows a lower boundary than CMIP3. If not, then, as suggested, it could be largely due to larger CMIP5 sample size.	Comment refers to figure 3-24. RCP2.6 is included further supporting information was provided in this section. Also, Figure 1 from Knutti et al (2012) was added in the section describing the approach for developing climate scenarios as a way of illustrating the differences in global warming due to the range of CMIP3 and CMIP5 projections.
David Rupp	79	The fact that the patterned is reversed between the 2030s and 2070s suggests to me this is internal variability and, therefore, these CMIP5-CMIP3 spatial patterns should not be over-emphasized to water managers.	This section was modified to "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."
David Rupp	84, Figure 3-33	Might be easier to interpret if the “Dry” scenarios were next to each other, and the “Wet” scenarios were next to each other.	No change was made. The authors feel this is a matter of personal preference. Also, provided the limited schedule, this was seen as an unnecessary change.
David Rupp	88	In-ground water? How about soil water? - in reference to comment about potential usefullness of soil moisture projections. Additional comment on this section, I commented on this above. What is missing is a good rationale for this metric.	We have provided rationale for use of this metric.
David Rupp	95 Figure 3-38	Please define the acronyms/abbreviations in the caption.	Added definitions to caption as suggested.
David Rupp	101	Careful with the wording. Reads as if VIC can generate natural vegetation.	Reworded this sentence for clarity.
David Rupp	107	There is no Mote et al (2013) in references section.	This reference should be Mote et al (2014)
David Rupp	111	True, but an approach consistent with the climate model ensemble used would be to apply a variety of models, not just VIC.	Modified text to include this point

F.4.2 Comments – Chapter 4 Water Demand Assessment

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
Clayton Creager		1) The list of impaired Beneficial Uses in the Klamath River provided on page 46 of the draft chapter does not match the list included in our TMDL Staff report provided below: "As detailed in Section 2.5, 17 of the 23 designated beneficial uses for the Klamath River are 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; Municipal & Domestic Supply; Shellfish Harvesting; Estuary Habitat; Marine Habitat; Aquaculture; Agricultural Supply; Commercial and Sport Fishing; and Wildlife Habitat. Subsistence fishing (FISH) is also listed in the Basin Plan as a beneficial use of the waters in the region. Although the specific areas in which this use exists have not yet been designated in the Basin Plan, this does not alter the need to protect this existing beneficial use."	This list of beneficial uses was added as a footnote to the text discussion of water quality impairments
Clayton Creager		2) Is the estimated total volume of flow by sub-basin and for the Klamath River going to be estimated? Could that volume be expressed as acre feet so some comparison could be made to uses? Can the BO required flows be expressed as a consumptive use (in acre feet)? Not sure that is even possible.	This comment will be considered in the next phase of the Klamath River Basin Study, namely the system risk and reliability evaluation.
Clayton Creager		1) I realize that this is chapter 4 of a larger document but I missed a framing of the use issue relative to the public trust and maintenance of an aquatic environment for fish & wildlife. That is, environmental water should either be recognized explicitly as a use or a baseline should be established that protects public trust resources within the waterway.	Aquatic environment for fish and wildlife, or environmental water, will be evaluated as a set of agreed upon metrics for determining water shortages in the basin. This demands chapter discusses how these will be handled in upcoming phases of the study.
Clayton Creager		2) Environment Canada has developed an indicator for risk to aquatic ecosystems called the use / availability ratio. I have attached a rough example of this indicator that provides status information on the risk to aquatic life from depleted flows.	This suggestion will be considered as we identify metrics for evaluating river system risk and reliability, i.e., quantifying the effects of climate change on water supplies and demand.
Clayton Creager		3) Most of the rivers and tributaries in the Klamath Basin have been listed as impaired under the CWA section 303(d) as impaired relative to temperature. Should the document discuss the relationship between flow and temperature? In addition, uses that divert water and return some portion back to the stream can affect temperature and	The Klamath River Basin Study will evaluate the impacts of climate change on Klamath River temperature, as a surrogate for overall river ecosystem health. This will be done in the next phase of the study, which is the system risk and reliability analysis.

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
		biostimulatory conditions in a negative manner. I believe this should receive some consideration.	
Clayton Creager		4) Hydro power is listed as a non-consumptive use, but reservoirs are listed as a consumptive use. This seems like a contradiction. In addition, controlling levels of water for power supply becomes a defining parameter for timing and amount of use and generates tremendous environmental impact in affected spawning areas. So even though the water remains in the system there are "use effects." Will these be addressed?	This comment is noted. The use effects of hydropower, outside of reservoir evaporation, are not considered by the study and are outside the study scope. Hydropower generation in the Klamath River Basin is largely oportunistic.
Clayton Creager		5) The report is well written and clearly presents an enormous amount of information. It should be required reading for all who are working in the Klamath Basin. I would respond affirmatively to all (8) of the review questions in emailed instructions.	The study team appeciates this feedback.
Tim Hemstreet	42	These edited capacity and surface area values are as described in PacifiCorp's Final License Application, Exhibit A, Table A2.1-1. I've not seen these higher numbers before.	Edits accepted
Tim Hemstreet	43	This value for JC Boyle evaporation seems inconsistent with the other PacifiCorp reservoirs. If 44.2 inches evaporate from 420 acres of reservoir, then this would be 1,547 AF. So this value seems only about 50% of what it should be if there is a direct comparison to the other reservoirs. The Iron Gate and COPCO 1 reservoir evaporation values seem within 7 percent of what I would expect for their actual surface area and estimated evaporation inches/yr.	Evaporation volumes are based on average storage levels not maximum. The average water surface elevation is approximately 3791 ft which corresponds with a surface area of about 195 acres. If 44.2 inches evaporate from 195 acres of reservoir, then this would be about 718 AF, which is pretty close to the reported 729 AF result. A sentence was added to clarify that evaporation volumes are based on an average reservoir depth.
Tim Hemstreet	50	There are other hydro plants in the Klamath basin – the C Drop hydro plant on Reclamation's project, a couple of small hydropower facilities in Siskiyou County, etc. Maybe just add the qualification here. There are also other generating facilities (Klamath Falls co-gen) that are not hydro – so add hydro to power.	Added "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."
Tim Hemstreet	50	I've made some adjustments here. The Project is 2082, not the license specifically. Let me know if you have any questions on these edits.	Edits accepted
Tim Hemstreet	50	The ESA restrictions have actually been on Reclamation's operations, which have then had effects on PacifiCorp. We've adjusted/restricted operations at East Side and West Side for sucker issues, but do not have other ESA restrictions on our operations, though we provide Reclamation's ESA flows below Iron Gate dam.	Edits accepted

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
Tim Hemstreet	50	It would be more accurate to say the ESA requirements superseded Reclamation's water rights. However, aside from impacts at East Side and West Side – very minor facilities at 3.8 MW total – there have been no PacifiCorp water rights impaired by the ESA. One could actually say that the ESA restrictions on Reclamation have increased water availability to PacifiCorp's project since the instream flow requirements have put more water down river (and thus through the hydroelectric project).	Noted
Tim Hemstreet	50	Deleted this text since it is uncertain whether these water rights would be dedicated instream under some other potential settlement involving dam removal. Retirement of hydro water rights is a certainty only under KHSA/KBRA.	Deletion accepted
Tim Mayer	21	What is meant by losses – do you mean canal losses? Seepage losses? You mention below that conveyance losses are usually included – this is a little confusing.	Losses are described in the same paragraph.
Tim Mayer	21	Make it clear that this is the estimate developed below (correct?). General comment: I prefer that you refer the study here consistently rather than two different ways ("this study" or the "Klamath River Basin Study"). Using two different references is a little confusing. It's not always clear that they are one and the same.	Inserted "as described below". Reviewed entire document and replaced "this study" with "Klamath River Basin Study".
Tim Mayer	21	But you didn't include them here? Again, this was confusing when I first read through it.	Inserted "Given the numerous variables associated with conveyance and on-farm losses, loss estimates were not calculated in this study" at the end of the paragraph.
Tim Mayer	22	Doesn't include conveyance losses or application losses (correct?)	Correct (revised text to clarify this)
Tim Mayer	28	Good discussion of the ET modeling	Noted
Tim Mayer	31	I'm a little concerned that your estimate is so much lower than the others – how realistic is it not to include some kind of estimate of losses? Seems like you may be significantly underestimating irrigation demand. Maybe it doesn't matter for your purposes?	See above response to similar comment by TM
Tim Mayer	32	What is the basis for the 40 %?	Basis is discussed in following paragraph.
Tim Mayer	36	Same question here – 40%?	Noted
Tim Mayer	38	17,300 acres – this is really small – it sounds like just the acres of wetlands surrounding UKL. This is much smaller than the area of all wetlands in the basin – Klamath Marsh NWR itself is much larger than this (about a 40,000 ac refuge). Sycan Marsh is maybe 20,000 acres –	The wetlands section was revised to include additional wetland acreage outside of the Upper Klamath Lake area. The National Wetlands Inventory was used as a basis for estimated total emergent and forest/shrub wetlands.

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
		are these wetland areas included in the model? They are both above the lake. Then there are lots of smaller, wetland areas too. It may be a small point, since there is so much more irrigation demand in the basin, but did you have a crop coefficient curve for the wetland vegetation, a soil water evap coeff, and a stress coeff? Where did these values come from? They would seem to be more important since it's likely that much of the wetland acreage in the basin is unmanaged and is likely to be more water-stressed than the wetlands at LKNWR that we studied or the ones at UKL that Stannard studied. I think that Stannard et al studied a wetland that was connected to UKL and was inundated the entire season (not sure though).	
Tim Mayer	38	Good agreement! But is this because you used the same acreage for all three estimates? Provide acreage and ET rate (ft/yr) in table.	Table revised and now includes ET rates and acres
Tim Mayer	42	Should not be considered a lake or reservoir – this is the surface area and capacity if all the management units were filled simultaneously, but they never are. (Actually 40,000 acres seems high to me). Does the amount of storage make a difference in your model – does it matter how much water you put in Lower Klamath Lake in the model? If so, correct his or talk to me or the refuge.	LKL removed
Tim Mayer	43	This is often a point of confusion. Lower Klamath Lake doesn't really exist anymore – this area is part of the refuge wetlands. Are you double-counting? How are you distinguishing a lake from a wetland? (Lakes have a higher rate of ET). There is a remnant of Lower Klamath Lake that is called Unit 2. It is about 2000 acres I believe. It is a permanent wetland, and is not open water, as are most of the wetlands out there. They are shallow and have emergent vegetation growing in them. There is certainly nothing like a lake with half the evaporation demand of UKL out there now. It looks like you used an acreage of about 30,000 ac for Lower Klamath lake – The entire refuge (including lease lands) is about 30,000 acres. Depending on the year, some of this will be farmed, some permanent wetland, and some seasonal wetland. None pf it should be counted as lake.	LKL removed
Tim Mayer	43	Looks way too high for this area. This is just a consumptive use estimate? Again, I think you've overestimated use and acreage for this area.	LKL removed

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
Tim Mayer	50	I'm not sure how important water rights info is but this statement is not quite true or complete. Bear Valley and Clear Lake have no rights at all. The other four refuges have federal reserved rights but they also have other rights. LKNWR and TLNWR have a vested Project water right (just like the irrigators) and KMNWR has several vested (Walton) water rights. The BO only deals with water right availability for LKNWR and TLNWR.	This paragraph was modified to incoroporate information in this comment.
Tim Mayer	50	Actually, much of our use is consumptive. Wetland ET – you just showed that above?	Changed to "Similar to other environmental resource water needsWith the exception of open water evaporation and wetland ET, water used by refuges is generally non-consumptive and recommended targets"
Tim Mayer	55	Looks like the table just includes Wetland ET. Am I missing something?	Table was revised.
John Risley	15	The word "highly" may sound too qualitative here.	Deleted
John Risley	17	They are a loss from the stream system. But, some might say they are still (like ET for example) a part of the water budget.	Replaced "water budget" with "supply system"
John Risley	19	Is this what the authors mean?	Yes, as indicated in text (most current data available)
John Risley	20	"M&I" should be spelled out for the reader.	Noted
John Risley	21	Should indicate in the table the geographic extent of these estimates. Is it for the entire Klamath basin or just the Upper Klamath?	Added "for Klamath River Basin" to caption
John Risley	21	Should spell it out in the table.	Replaced "M&I" with "Municipal and Industrial"
John Risley	21	"Both cases" to mean M&I and Rural Domestic demand? Maybe rephrase the sentence.	Inserted "(M&I and Rural Domsestic)"
John Risley	22	Does "Reservoir Evaporation" include the Upper Klamath Lake? If so I suggest changing the figure label to: "Lake and Reservoir Evaporation"	Revised to "Lake and Reservoir Evaporation"
John Risley	23	Is this true?	Yes (accepted insertion)
John Risley	24	Maybe include a paragraph pointing out how the sum of CA and OR estimates (1,212,504 AF) is greater, though comparable, to the USGS (Table 4-2) estimate for total irrigation: 1,150,318 AF.	Inserted "The sum of CDWR and OWRD estimates (1,212,504 AF) is greater, though comparable, to the USGS estimate for total irrigation (1,150,318 AF) and it is assumed the discrepancies are associated with which loss estimates were included and how they were estimated."
John Risley	25	A reference is needed here for the user to learn about the ET Demands model. I assume this one would be the best?	Insertion accepted
John Risley	27	Some of the weather stations shown in fig. 4-4 are not listed in Appendix 4-B. Also, appendix 4-B says that ALL wind and dewpoint data came	Appendix 4-B was revised to include all meteorological stations used for development of inputs to the ET Demands model. Also, errors in Appendix 4-B were

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
		from just the KF Agrimet and the Tulelake CMIS stations. That would contradict this sentence.	addressed. There are nine meteorological stations with dewpoint and windspeed estimates. The two previously listed are a subset of those which also provide other meteorological inputs for the ET Demands model.
John Risley	27	All weather stations in figures 4-3 and 4-4 should be labeled. How does the reader know which ones they are when they look at Appendix 4-B?	Figure 4-3 was revised to included labeled stations (also dewpoint depression and wind stations). Figure 4-4 was not revised - readers are left to refer back to Figure 4-3 for station references.
John Risley	27	Consider adding the specific soil conditions? I assume these would be soil depth, soil texture, AWC?	Inserted "(including allowable water content and percent clay, silt and sand)"
John Risley	28	Should indicate these are mean annual numbers and should include the period of record in the caption.	Inserted "(1950-1999) mean annual "
John Risley	29	Can some discussion on how the Ke coefficient is determined be provided in this paragraph?	Inserted "Ke 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."
John Risley	30	Some information on the type of crops grown in the HUC8 subbasins would be useful. Maybe a table listing the most dominant 2 or 3 crop types in each of the 12 HUC8 subbasins?	Table with crop type percentage by HUC added to appendix.
John Risley	31	Place NIWR depth first to be consistent with the order of the plots.	Figure revised
John Risley	34	Any reason why the rate for Weed and Yreka (Siskiyou County) is so much higher than the other towns?	No
John Risley	38	Should specify geographically where the Upper Klamath Basin is in relation to the HUC8 subbasins. Is it just UKL, Williamson, and Sprague HUC8 subbasins? If that is the case, then the 70 square km of wetlands would not include the Lower Klamath NWR and Tule Lake since those areas are in the Lost HUC8.	Wetland discussion revised and this suggestion incorporated.
John Risley	39	Should be more specific.	Wetland discussion revised and this suggestion incorporated.
John Risley	39	Table 4-10 says 49,551?	Wetland discussion was revised.
John Risley	39	Text says 50,046?	Wetland discussion was revised.
John Risley	43	Should include reference for the model here.	Done
John Risley	45	Some more discussion would be helpful here. How was the “overall efficiency” estimated? An efficiency greater than 90% sounds unrealistically high. Does that mean that less than 10% was lost to	More discussion added and additional references cited

Table F-3.—Review Comments for Klamath River Basin Study Final Report Chapter 4

Reviewer	Page	Reviewer Comments	Responses to Comments
		canal seepage and on-farm losses? Also, if “return flows are reused,” how is that factored into the estimate of overall efficiency?	
John Risley	48	Is this the Klamath River estuary near the Pacific Ocean? Or, the Williamson River estuary in the Upper Klamath Lake?	Noted…by definition at ocean. Still, added Klamath River estuary for clarity.
John Risley	50	Should explain what “non-jeopardy” means here?	Footnoted definition
John Risley	56	I am having a hard time understanding the difference between this section and the following section “Projected Future Demand Scenario.” Maybe the sections could be renamed better? Is the “Demand Scenarios” section describing a scenario where there is population growth in the future but with NO climate change. If so, please state that in this section.	Changed the heading of this section to "Growth Scenarios" to help distinguish demand based on growth and development from demand based on climate change. Also revised the text in this introductory paragraph for clarity.
John Risley	56	But, the previous section just discussed the future demands?	Noted. Changed the previous heading to "Growth Scenarios" to distinguish it from the current section.
John Risley	57	Contrary to what this sentence is saying, Table 4-15 only shows wetland losses.	Table 4-15 replaced
John Risley	58	Figure 4-6 shows projections for 2030 or 2070?	Added (2030s and 2070s) to table caption.
John Risley	59	2030 or 2070?	2030s. Added this to the figure caption.
John Risley	59	What does “single future demand scenario” mean? What future time horizon? An average of 2030 and 2070? Or, is it no climate change in the future?	Changed to single future growth scenario to be consistent with changes in previous sections.
John Risley	60	But, if this study uses a subset of the WWCRA set, than the WWCRA range would not be less of a representation?	Removed this sentence. Also, added a reference to discussion of approach for climate change scenario development in Chapter 3.
John Risley	60	Do you mean the baseline “No Action” one?	Changed this to single growth scenario for clarity and consistency. Also improved definition of Future No Action scenario earlier in document.
John Risley	62	Please consider providing some examples of these crop types and which ones have larger differences between future and historic?	Crop types and acres by subbasin added to appendix
John Risley	71	Need to list out in this paragraph these five scenarios. The table defining these scenarios must be chapter 3? This reviewer was only provided with chapter 4.	S1, etc., replaced with other convention throughout
John Risley	71	Okay. But, what about S1, S2, and S5?	Noted
John Risley	77	Consider adding the historic baseline curve to these plots.	They are there
John Risley	77	Consider adding the historic baseline curve to these plots.	They are there

F.4.3 Comments – Chapter 5 System Reliability Analysis

Table F-4.—Review Comments for Klamath River Basin Study Final Report Chapter 5

Reviewer	Page	Reviewer Comment	Responses to Comments
Tim Hemstreet	16	Reclamation's Project Supply allocation is set under the 2013 BiOp based, in part, upon the April 1 UKL inflow forecast, so a reduction in April 1 SWE would be expected to reduce the April-September inflow forecast and result in reduced agricultural allocation. But it doesn't seem that this is borne out in the Project Supply predictions. Is this not the case since there is more water coming in from the Lost River (higher Keno dam inflows) – or is there some other explanation?	April 1 Swe has historical decreased throughout the basin due primarily to warming. Historical precipitation, however has changed little or even increased slightly according to VIC model simualtions, so the mean annual inflow to Upper Klamath Lake may not have historically changed much. No change to the document was made based on this comment.
Tim Hemstreet	16	It is unclear in the water supply assessment analysis how these precipitation/ET/SWE trends play out in terms of affecting ag supply. One of the constraints on Klamath basin water supply (or at least Reclamation deliveries) is that much of the UKL inflow is snowmelt driven and there is essentially no carryover storage in Upper Klamath Lake. Over the period 1981-2011 the lake typically peaked in elevation/storage during the first week of May. Thus, a drier summer and less April 1 SWE will likely reduce the amount of inflow to UKL after peak lake storage for the year has been realized. And this chapter indicates there will be greater ag demand in the summer due to increased ET. It isn't clear in this chapter how less summer inflow is mitigated.	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. Also, the simulations indicate more flood control release (any release above Project needs and environmental requirements) in the future as well. Although we don't have a figure illustrating 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. So any reduction in summer UKL inflow does not appear to affect Project Supply by a large amount, on average. This text was added to the summary portion of the chapter.
Tim Hemstreet	17	So is it true that the decrease in April 1 SWE is offset by the projected increases in annual runoff? It seems that is the case based on Figure 5-11, but this is not clearly explained in the text if this is true.	The following language was added to the referenced bullet point. Projected increases in mean annual runoff are offset by projected changes in April 1 SWE primarily due to projected increases in mean annual precipitation,
Tim Hemstreet	17	There does not appear to be any data in the report or the appendix on monthly UKL inflows under the different climate scenarios. Why not, when it is included for the other parameters?	This was an oversite. Give the time constraints, we took out the mention of this measure.
Tim Hemstreet	18	Commented below, but is Keno inflow the same as Keno discharge? May want to adjust the description of this parameter as I would think this meant Keno discharge, as measured at the USGS gage below Keno.	The location is actually the inflow to Keno reservoir. The text has been updated.

Table F-4.—Review Comments for Klamath River Basin Study Final Report Chapter 5

Reviewer	Page	Reviewer Comment	Responses to Comments
Tim Hemstreet	18	Should this be described as Orleans, as below?	The location was changed to Klamath River at Orleans, CA
Tim Hemstreet	18	Should this be described as at Klamath, CA as below?	The location was changed to Klamath River near Klamath, CA
Tim Hemstreet	18	Commented below as well, but how the temperature result for the Klamath River mainstem is determined is not clear. A specific point in the river, the average of all river segments in the RBM-10 model, something else?	The location is Klamath River near Klamath, CA
Tim Hemstreet	19	It might be worth adding here for clarity that supply is calculated under 2013 BiOp formula.	Table was revised as suggested.
Tim Hemstreet	19	This metric for ag supply may mask the storage constraint in the Klamath basin. Its seems a better metric would not just be UKL March-September inflow, but amount of that inflow that is able to be stored.	Metrics were vetter through numerous sources and there is not time to change the metrics at this stage. We may evaluate alternative metrics in future studies.
Tim Hemstreet	19	Annual hydropower production should be expressed as MWh.	Unfortunately, there is not time to make the unit conversion
Tim Hemstreet	21	This measure may mask the potential limitations associated with basin storage capacity in delivering supply when it is needed for agricultural purposes. The shift toward more winter rainfall and less spring/summer snowmelt may max out available storage capacity in UKL earlier such that further inflow is incapable of being stored and put to use for Project supply. This seems to be indicated by the increase in flood release volumes and the decrease in	same as Comment #30
Tim Hemstreet	21	As noted elsewhere, production units should be megawatt-hour rather than megawatts, which measures capacity.	same as Comment #31
Tim Hemstreet	24	The frequency measure is later presented as percent of days with spill. Yet the units are presented here as CFS.	The text has been corrected to reflect that the measure is in fact computed as the mean percent of days per year.
Tim Hemstreet	24	As above – should this be percent of days?	Same as Comment #34
Tim Hemstreet	26	It would be helpful to describe where on river the temperature metric was highest. The temperature model goes the entire 253 mile length of the river, but the coho temperature criteria would arguably only be relevant where coho presently exist, or where they may exist under a dam removal/fish passage scenario. The upstream historical limit of coho is typically accepted to be Spencer Creek at RM227.5.	The location for the stream temperature simulation is Klamath River near Klamath, CA. We did not make any changes to the RBM-10 model version that was sent to us by USGS, so we did not alter the output locations.

Table F-4.—Review Comments for Klamath River Basin Study Final Report Chapter 5

Reviewer	Page	Reviewer Comment	Responses to Comments
Tim Hemstreet	30	Seems worth noting here also that all scenarios experience a deeper drawdown of UKL than historical and show minimum elevations in October as compared to November (historical).	This text was added.
Tim Hemstreet	30	All of these charts seem counterintuitive to what has been described in terms of the expected shift to more winter rainfall, and less April 1 SWE resulting in reduced snowmelt. With Keno Dam inflow (fig. 5-3) showing winter flow increases as compared to historical, and Iron Gate flows (fig. 5-5) also higher in winter, it would seem to point to an earlier fill of the lake. While that earlier peak is apparent, it would seem the peak storage would be higher than historical at least in the wet scenarios, but UKL storage never gets as high as historical. This could use explanation in the report.	The following text was added to discussion: 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 contain no flexibility to respond to different hydrologic conditions, such as changes in Upper Klamath lake inflow timing.
Tim Hemstreet	31	Is this inflow to Keno reservoir (net of withdrawals and returns from ag), or is this really Keno outflow? If this is inflow, what is driving the increase of inflow as compared to historical – greater precipation, greater withdrawals from UKL storage, greater returns from the Lost River Diversion Channel, Klamath Straits Drain, etc.?	The following was added to the discussion in this section: 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.
Tim Hemstreet	33	Shouldn’t this be Iron Gate dishcharge?	Yes - this was updated in the text.
Tim Hemstreet	33	How does one reconcile fig. 5-3 and fig. 5-5? Keno inflow is predicted to increase during the May-Sept period in fig. 5-3, but Iron Gate outflow is predicted to decrease in those same months. Is Keno inflow water being diverted to Project Supply and not going downstream of Keno? Otherwise you would expect the two figures to be similar – Iron Gate should show a similar pattern as Keno.	Text was added to fill out this discussion. New text is not included here.
Tim Hemstreet	39	Where are these temperatures simulated? Are these temperatures all at the same location? Is the data below the highest MWAT at any location in the river for the time periods? Or is there a single model node where temperature is always the maximum. If so, please state.	The simulated location is Klamath River near Klamath, CA. This was included in the text.
Tim Hemstreet	41	For Project Supply, is this just percent change as compared to historical supply of 390,000 AF for Project Supply, or is it compared to predicted future Project Supply needs (assuming increased ET, etc., as discussed in the earlier chapter) for the different scenarios? May want to make it clear.	The following text was added to discussion: Similar results are shown for mean (Klamath) Project supply from April through September. Percent change in Upper Klamath Lake supply and Klamath Project supply (bottom two measures listing in figure 5-11) are computed based on projected and historical simulated values under the 2013 BiOp management criteria.
Tim Hemstreet	43	It seems odd that the Iron Gate mean spill days per year is negative in all scenarios given that Boyle is all positive, and Copco 1 is nearly all	Discussion of this counterintuitive result has been provided in the text.

Table F-4.—Review Comments for Klamath River Basin Study Final Report Chapter 5

Reviewer	Page	Reviewer Comment	Responses to Comments
		positive. What might drive that counterintuitive result? Also, it doesn't seem to make sense that JC Boyle and Copco 1 don't show the same pattern of increases in spill days given they have similar hydraulic capacity.	
Tim Hemstreet	46	Does the Hells Corner reach boating days metric account for the ability to peak flows from JC Boyle such that you don't need average daily flows to be in the suitable boating range, just the peak daily flows?	The following text was added to discussion: It should be noted that the boating recreation measures doe not account for the ability to peak flows from JC Boyle to assure a suitable boating recreation flow range.
Tim Hemstreet	49	Why are the water supply indicators for Project Supply relatively mixed, whereas the indicators for refuge supply are all quite substantially reduced as compared to historical? This could use some further explanation. It could be that the historical period here is slightly misleading as the recent history has been one of very reduced deliveries to the refuge, but that hasn't been captured in the 1950-99 period.	Discussion of this result has been provided in the text.
Tim Hemstreet	50	I think there can be confusion about statements such as this, since what this is really saying (I think), is that under average conditions represented in the WW, WD, HW, HD scenarios these minimum elevations were met or exceeded. I think there can be confusion that HotDry does not mean drought conditions (in which minimum elevations may not be attained), but rather average conditions under the HotDry assumptions (a hotter, dryer climate future).	The following text was added to discussion: These results are not illustrated, as minimum pool elevations are met or exceeded in all climate change scenarios considered by the Basin Study hydrology scenarios.. It should be noted that climate change scenarios represent adjusted historical climate 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.
Tim Hemstreet	50	Meeting these thresholds where? Is this data averaged over the length of the river below IGD – and for what period?	Location was clarified to be Klamath River near Klamath, CA
Tim Hemstreet	51	It would be worth characterizing these temperatures for Fall Chinook salmon as well. The temperature thresholds may not be any different, but could also be informative as to conditions for chinook, which are important for tribal, sport, and commercial harvest, unlike coho, for which there is no harvest.	Provide out time constraints, we were not able to investigate temperature thresholds for Fall Chinook. We may mention this analysis in the "next steps" section of the report.
Tim Hemstreet	51	These two charts look the same, are two charts necessary?	Baesd on comments from other reviewers, this figure was modified to only include the MWAT

Table F-4.—Review Comments for Klamath River Basin Study Final Report Chapter 5

Reviewer	Page	Reviewer Comment	Responses to Comments
Tim Hemstreet	52	It may be worth mentioning if this factor of Lost River basin contributions explains some of the higher Keno Dam inflows in the winter time.	Text was added as suggested.
Tim Hemstreet	53	In figure 5-12, the days of spill at JC Boyle were shown to increase in all scenarios. How is it that JC Boyle spill frequency increases by UKL flood control spill decreases or holds relatively steady? May be worth explaining.	Text was added to fill out this discussion. New text is not included here.
Tim Hemstreet	54	Does this have adverse impacts on water availability for ag, refuge, or wildlife (instream flow) uses?	Text was added to fill out this discussion. New text is not included here.
Edward Jones	17	Is this correct?	Values were revised
Edward Jones	19	No footnote this page	This measure does not belong under hydropower, so it was removed.
Edward Jones	21	Inconsistent spacing before the 1 and 2	Updated references to COPCO 1 and COPCO 2
Edward Jones	22	Seems low	Confirmed this is the report range in the EIS/EIR for dam removal
Edward Jones	23	Capitalize? AFS standard for common fish names is now to capitalize, e.g., “Chinook Salmon”	Changed as suggested
Edward Jones	23	Coho Salmon	Changed as suggested
Edward Jones	25	Coho Salmon for AFS standard, however, the Reclamation publication standard may differ—I’ll stop pointing it out from here forward.	Changed as suggested
Edward Jones	26	Acronym undefined	added definition
Edward Jones	26	Abbreviated earlier as “M&I” without definition	Revised usage and added M&I to acronym list
Edward Jones	27	Length?	Although I am not sure the exact question raised, we removed the reference to the length
Edward Jones	27	Aha, your work-around for negative flows. Good to acknowledge.	No change made based on comment
Edward Jones	34	WD?	Yes, changed from driest to WD
Edward Jones	34	I think there’s a detail missing here… something seems amiss Except for the WD scenarios during the 2030s?	Yes, the suggested change was incorporated.

Table F-4.—Review Comments for Klamath River Basin Study Final Report Chapter 5

Reviewer	Page	Reviewer Comment	Responses to Comments
Edward Jones	39	Where in the Klamath River?	Klamath River near Klamath
Edward Jones	40	Last sentence of the inset text does not match the main body here.	The inset text does appear to match the body text and are consistent with results presented in Figure 5-11.
Edward Jones	44	Appendix Table…	Text was changed based on comment
Edward Jones	48	HD	Text was changed based on comment
Edward Jones	50	Where, more specifically? Klamath R near Klamath? What river mile?	Klamath River near Klamath
Edward Jones	51	The upper and lower panels are identical—consider only presenting the lower panels which have a more intuitive interpretation. Also, I think this might benefit as a presentation of the change in degrees as opposed to the percentage—it's easier to think in terms of X degrees warmer, in contrast to X percent warmer. Also, a percentage change in degrees F will not equate to an equivalent percentage change in degrees C because the temperature scales are different	Changed results reporting to mean annual MWAT only. Also, change is now presented in degrees, not percent change.
Edward Jones	54	Table	

F.4.4 Comments – Chapter 6 System Reliability Analysis with Adaptation Strategy Concepts

Peer review comments were requested, but there were no comments for Chapter 6 that were not already addressed in Chapter 5.