2011 Technical Report for the

Columbia River Basin

Long-Term Water Supply and Demand Forecast

Submitted Pursuant to RCW 90.90.040 by:

DEPARTMENT OF ECOLOGY State of Washington in collaboration with WASHINGTON STATE UNIVERSITY

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The 2011 Columbia River Basin Long-Term Water Supply and Demand Forecast was prepared by Washington State University for the Washington State Department of Ecology.

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1.0 Introduction to the Long-Term Forecast

Every five years the Office of Columbia River (OCR) develops a long-term water supply and demand forecast (Forecast). The first Forecast was created in 2006 and the second Forecast in 2011. To develop the 2011 Forecast, OCR contracted with Washington State University (WSU) and Washington State Department of Fish and Wildlife WDFW). WSU analyzed surface water supplies and agricultural, municipal and hydropower water demands, while WDFW analyzed instream supply and demand for eight fish and low flow critical basins. This report documents the technical aspects of WSU's work.

The Columbia River basin encompasses parts of seven U.S. states and British Columbia over a land mass approximately the size of France. It is a vital part of the environment and economies of the region, providing vital ecosystem services, water supplies and renewable, low-cost hydropower generation. The Columbia River basin, like other semi-western watersheds, is likely to experience increased pressure on water resources and ecosystems, due to population growth, threatened and endangered species, and economic development. Climate change, which is already reducing summer discharges and increasing summer stream temperatures due to changes in snowmelt patterns (Mantua et al. 2005), is adding to these pressures. These pressures have the potential to cause far-reaching social, economic, and ecological impacts related to agricultural production, endangered salmon populations, hydroelectric production, and human activities.

Recognizing that development of new water supplies for eastern Washington is a priority concern, the Legislature passed Chapter 90.90 RCW, directing the Department of Ecology (Ecology) to aggressively develop water supplies for instream and out-of-stream uses. The Office of Columbia River, formed as a result of this legislation, has a mission to develop water supplies for the following purposes:

1. Permitting new water rights
2. Securing water for drought relief
3. Providing water for instream flows to benefit fish
4. Addressing aquifer decline in the Odessa Subarea by replacing groundwater sources with surface water sources.

Water supplies developed under this program are to support both instream and out-of-stream uses. Since 2006, OCR has funded a variety of water supply projects consistent with the four legislative directives. The Office of Columbia River is rapidly improving water supply for eastern Washington with approximately 150,000 acre-feet of water supply already developed (developed water supplies are those that have been constructed or for which Ecology is in the process of permitting new secondary water uses) and another 200,000 acre-feet in near-term development (near-term refers to those projects that OCR is currently constructing or for which OCR is in the process of conducting environmental review and permitting for the water supply). The Office of Columbia River is developing a portfolio of diverse projects including modification of existing storage (e.g. Lake Roosevelt and Sullivan Lake), new storage facilities (e.g. Kennewick, Boise and White Salmon aquifer storage projects), conservation piping and canal lining projects (e.g. Red Mountain American Viticultural Area (AVA), Barker Ranch, Manastash, and Columbia Basin Irrigation District projects), transmission piping projects (e.g. Potholes Supplemental Feed Route and Weber Siphon), and water right acquisitions.

Revised Code of Washington 90.90.040 requires that OCR carry out a long-term water supply and demand forecast for the Columbia River basin every five years, to support the development of new water supplies. The first Forecast was completed in November 2006, and the second in 2011. These forecasts aim to provide information to the public, to water managers and planners, and to policy makers about the availability of water in the Columbia River basin. This information will improve decision-making about water issues, and enhance the state's ability to ensure that future water needs will be met.

The 2011 Forecast was developed by OCR in collaboration with Washington State University (WSU) and the Washington Department of Fish and Wildlife (WDFW). This report is the technical compendium to Ecology's Washington State Legislative Report: Columbia River Basin Long-Term Water Supply and Demand Forecast (Ecology Publication 11-12-011). It contains more detail than the legislative summary as well as expanded explanations of the theories, assumptions, and interpretations used to complete WSU's scope of work. The report focuses on the work carried out by WSU researchers and includes the work on instream flows in Washington State carried out by Ecology and a summary of the instream work carried out by the WDFW. Detailed information on the instream forecasting carried out by the WDFW can be found in the report "Columbia River Instream Atlas" (Atlas) (Ecology Publication 11-12-015).

The Forecast will help OCR strategically fund water supply projects by improving understanding of where additional water supply is most critically needed, now and in the future. The Forecast provides a generalized, system-wide assessment of how future environmental and economic conditions are likely to change water supply and demand by 2030. It also analyzes the impacts likely to occur if additional water is made available to users, though it does not consider the benefit-cost ratio of any individual project.

The 2011 Forecast was developed using state of the science modeling techniques and economic scenarios to evaluate the impacts of climate change, regional and global economic conditions, and state level water management actions on surface water supplies and irrigation demands across the Columbia River basin.

This technical report provides a project overview (Chapter 1), background on the Columbia River basin (Chapter 2), and detailed methodology (Chapter 3). This is followed by a summary of major results (Chapter 4) and detailed results for the Columbia River basin (Chapter 5), watersheds within Washington (Chapter 6), and Washington's Columbia River mainstem (Chapter 7). Finally, the report concludes with a discussion of data gaps and limitations (Chapter 8) and recommended improvements for future work (Chapter 9).

1.1 Project Overview

The 250,000 square mile snowmelt-dominated Columbia River basin provides water for a wide variety of uses. The river and its tributaries irrigate 7.8 million acres of farmland and 55 major hydroelectric projects generate an annual average of over 16,600 megawatts of electricity in the U.S. and Canada (Northwest Power and Conservation Council 2010). It supports a variety of fish and other wildlife important to maintaining cultural, environmental and recreational opportunities, and is home to numerous listed threatened and endangered fish stocks. Future water management decisions involving the complex interactions and trade-offs between sustainable water supplies, economic development, ecosystem functions, energy, food security, societal values, recreation, navigation, laws, and cultural beliefs must be based on sound interdisciplinary and transdisciplinary science communicated to multiple audiences (Max-Neef 2005). In order to facilitate these decisions within the Washington State, this Forecast focused on both instream and out-of-stream uses, forecasting the water supply and demand with regard to four major user groups: agricultural production, municipal (residential/industrial/commercial), hydropower, and instream (fish/salmonid) needs.

The Forecast evaluated surface water supply and demand at three geographic tiers: the entire Columbia River basin, Eastern Washington's watersheds, and Washington's Columbia River mainstem. A general survey was carried out for the entire basin with in-depth analysis for Washington's Water Resource Inventory Areas (WRIAs)[1] and mainstem.

Using a combination of modeling techniques and economic scenarios, WSU evaluated the impacts of climate change, regional and global economic conditions, and state level water management actions on surface water supplies and irrigation demands across the Columbia River basin. To evaluate water supplies for Washington State, the project used 30 years of historical flow data (1977-2006) and projected these conditions forward to the 2030s using data from Global Climate Models. On the demand side, irrigation demands were forecasted for roughly 40 primary Washington crop types over a broad range of alternative scenarios including climate change, economic scenarios, increased water capacity through development of water supply projects, and various cost recovery rates for water supply development. Economic analyses were conducted to

[1] WRIAs are used to define administrative and planning areas for water in Washington State. They were formalized under Washington Administrative Code (WAC) 173-500-040, and authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54. Additional information regarding Washington WRIAs can be found on the Ecology website at http://www.ecy.wa.gov/apps/watersheds/wriapages/index.html.

consider how changes in factors within and outside of Washington are likely to influence cropping decisions. Municipal demand forecasting (including self-supplied domestic use) was forecasted in the Washington portion of the basin using data from county level population estimates from the Washington State Office of Financial Management, combined with data in water treatment plant and water system plans submitted to the Washington State Department of Health. For those municipalities where data allowed, industrial growth was also included. For hydropower demands, this report summarizes and incorporates existing planning efforts. Instream flow work relying on historical data carried out by Ecology is summarized in this report, while the assessment carried out by WDFW can be found in the report "Columbia River Instream Atlas" (Atlas) (Ecology Publication 11-12-015).

Analysis of WRIAs and the mainstem are linked because flows in the WRIAs impact the downstream flows in the Columbia mainstem. However, results of the analyses are provided separately for two reasons: 1) some instream and hydropower demands are unique to the mainstem, and 2) separation makes it possible to highlight which portions of WRIA level demand can be supplied by water in the mainstem. To the extent possible, this report provides sufficient detail in each geographic tier to understand the approaches used without duplicating common information.

Stakeholder input was also essential to the development of the 2011 Forecast. Washington State University researchers presented and discussed initial biophysical and economic modeling methods with the Columbia River Policy Advisory Group (PAG). This group represents a wide range of stakeholder interests and helps OCR identify and evaluate policy issues. Feedback from the PAG and watershed planning unit representatives was used to adapt WSU forecasting methods. To further ensure that comprehensive and scientifically valid methods were utilized, an external peer review panel comprised of four national experts in economics, modeling, and regional water issues periodically reviewed and commented on the proposed methodologies. Preliminary results of the Forecast were presented at three public stakeholder events. A draft report was released with public comment accepted for 30 days. Based on feedback received at workshops, on-line forums, and the draft comment process, economic and biophysical modeling assumptions were fine-tuned and results were finalized.

1.2 Study Objectives

Washington State University's study objectives differed for each of the three geographic tiers (Figure 1) used in the forecasting effort.

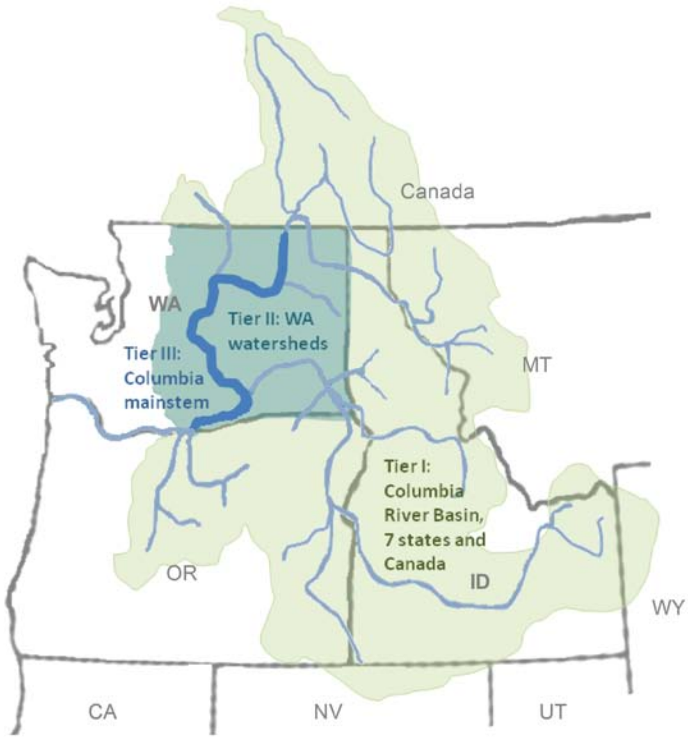

Figure 1. Long-term water supply and demand was forecasted at three tiers. Tier I: the entire basin-wide scale; Tier II: the WRIA scale; and Tier III: the Columbia River mainstem within Washington State upstream of Bonneville Dam.

Tier I, basin-wide, project objectives were to:

- Identify future potential out-of-state water projects or changes in legal, policy and management that could affect water supplies in Washington.
- Report on demand forecasting efforts for U.S. states outside of Washington and Canadian portions of the Columbia River basin.
- Summarize the latest Washington information and studies performed on potential water supply projects in the state, as well as recent changes to the legal, policy and management framework.
- Model water supply and agricultural demand over the Columbia River basin in 2030 at a resolution of $1/16^{th}$ degree and at a daily time step. Incorporate demand forecasts for other sectors, and the ability to model storage and release of water by major dams.

Tier II, more detailed scale within Washington WRIAs, project objectives were to:

- Report supply estimates, including variability in supply with climate change and year-to-year variability.
- Report agricultural, hydropower and municipal demands

- Report the regulatory scheme for WRIAs, including instream flow requirements for fish.

Tier III, the Columbia River mainstem, project objectives were to:

- Report supply estimates for the Columbia River using ground and surface water data available within Ecology and other published documentation. Compare estimates of tributary supplies to mainstem supplies.
- Investigate the sensitivity of mainstem supply (including the contribution from the Snake River) entering Washington as a result of climate-induced changes in upstream watersheds.
- Report on the legal, regulatory and management scheme of the Columbia River supply in Washington. Estimate hydropower and instream demands on the Columbia River mainstem.
- Estimate the portion of WRIA-level demand in 2030 that the Columbia River mainstem could supply.

1.3 Definitions of Water Supply and Demand Used in the 2011 Forecast

It is important to recognize that disciplines use the terms supply and demand differently. In economics, supply and demand refer to the relationship between the quantity consumed or produced and price, whereas in engineering, supply refers to the biophysical availability of water and demand (such as for irrigation) refers to the water needed for irrigation given climatic conditions, crops grown, and irrigation efficiency.

1.3.1 Water Supply Definitions

Surface Water Supplies incorporate the impacts of operations of major reservoirs on the Columbia and Snake Rivers, as well as the major reservoirs in the Yakima. Thus, with the exception of Yakima (WRIAs 37, 38, and 39), water supplies at the watershed (WRIA) level are "natural supplies," without consideration for reservoirs. Supplies reflect supply prior to accounting for demands. They should not be compared to observed flows, which do account for demands through withdrawals for irrigation and other out-of-stream uses.

Groundwater Supplies were not modeled for the 2011 Forecast due to time and resource constraints.

Historical Supplies indicate surface water supplies for 1977-2006. This time period was selected based on the available data as the most appropriate comparison point for the future period.

2030 Forecast Supplies indicate forecasted supplies for the 2030s decade. Major reservoir operations are assumed not to change in response to changes in 2030 forecasted water supply.

While this assumption may not be realistic, it was impractical to predict what management changes might occur.

1.3.2 Water Demand Definitions

Water Demands are derived under the baseline economic scenario unless otherwise noted. The baseline is defined to include medium domestic economic growth, medium growth in international trade, and no changes in water pricing or water supply capacity.

Agricultural Water Demand represents demand for water as applied to crops, often referred to as "top of crop." This includes water that will be used consumptively by crops, as well as water resulting from irrigation application inefficiencies (such as evaporation, drift from sprinklers, or runoff from fields). In comparing these demands to supplies, it is important to include additional water to account for conveyance losses, such as occurs when transporting diverted water in unlined channels.

This is a physical, rather than an economic definition, where the latter would reference the quantity demanded at specific prices. Agricultural water demand is forecasted under a projected crop mix that takes into account changes in domestic economic growth and growth in international trade. The land base in agriculture is assumed to be the same. The Forecast does not incorporate improvements in irrigation efficiency or changes in crop mix that might be adopted by producers in response to limitations in water availability.

Water that is not consumptively used by crops (including irrigation application inefficiencies and conveyance losses) percolates through the soil and returns to the groundwater or surface water system. Non-consumptive return flows may be available to users downstream although the time-lags vary considerably both in time and location. Thus, some of the upstream water demand will be counted towards supply downstream of the original place of use.

Conveyance Losses indicate water that is lost as it travels through conveyance systems (which can range from unlined ditches to fully covered pipes). These losses vary widely and are difficult to estimate, but have been estimated to average about 20% basin-wide. Because of increased uncertainty associated with these estimates, conveyance losses have been treated and shown separately from "top of crop" demands.

Municipal Demand includes estimates of water delivered through municipal systems, as well as water delivered through self-supplied domestic systems. For those municipalities where data allowed, it also includes municipally-supplied industrial water. It does not include self-supplied industrial water use. Municipal demand also has a consumptive portion and a non-consumptive portion, which includes water that is lost within the municipal system through system leakages and water that returns for wastewater treatment. Together, the consumptive and the non-consumptive portions represent municipal diversion demand.

Instream Water Demand was incorporated into water management modeling through state and federal instream flow targets. Within WRIAs, the highest adopted state and federal instream flows for a given month were used to express current minimum flows for fish in both historical and 2030 forecasted instream demands. State and federal instream flows along the mainstem were also compared to historical and future supplies.

1.4 Approach Synopsis

This section provides an overview of the methodologies used to complete the objectives for each tier described in the previous section. Each of the methodologies presented here is also discussed in Chapter 3, Methodology.

1.4.1 Overview of the University of Washington Water Supply Forecast and Relationship to WSU Forecast

This Forecast has leveraged the modeling tools and datasets developed by the University of Washington Climate Impacts Group (UW CIG) as part of the Washington Climate Change Impacts Assessment (WACCIA) which was funded by the Washington State Legislature through House Bill 2860. WACCIA involved the development of historical and future climate datasets and assessment of impacts of projected climate change on agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. For assessing impacts on hydrology and water resources, Elsner et al. (2010) implemented, calibrated, and evaluated the VIC model over the Pacific Northwest (PNW) region at a spatial resolution of 1/16th degree. The Forecast directly applies the Elsner et al. (2010) calibrated hydrology model (VIC) implementation for the water supply portion of this study (http://www.hydro.washington.edu/2860/). It also directly applies the UW CIG historical and future downscaled gridded climate data, the reservoir model (ColSim), and the simulated streamflow bias correction data and processing programs developed by UW CIG, all of which are described in Chapter 3, Methodology.

The Forecast has expanded on the UW CIG efforts by incorporating the water demand forecast and the coupled dynamics between supply and demand. The primary unique additions to the modeling framework include the following: 1) full integration of the VIC land surface hydrology model to a cropping system model (CropSyst), 2) simulation of water curtailment and prorationing using instream flow rules, and 3) integration with economic modeling of both short- and long-run agricultural producer response. Details for each of the unique components are provided below and in Chapter 3, Methodology.

1.4.2 Computer Modeling

Water supply and demand impact each other. Out-of-stream diversions reduce supply downstream, while water that is diverted, but that is not consumptively used (such as water that is lost through leaks in municipal systems), may return to the system and provide water supply downstream. WSU researchers thus simulated surface water supply and out-of-stream demands with an integrated computer model that simulated the relationships between water supply, climate, hydrology, irrigation water demand, crop productivity, economics, municipal water demand and water management at all three geographic tiers.

The Forecast's biophysical modeling component integrated and built upon three existing models (Figure 2):

1. VIC: Variable Infiltration Capacity, a land surface hydrology model (Liang et al. 1994).
2. CropSyst: Cropping Systems Simulation, a cropping system model (Stockle et al. 1994, 2003).
3. ColSim: Columbia Simulator, a reservoir operations model (Hamlet and Lettenmaier 1999).

Each of these models has been used independently many times to simulate conditions in our region (e.g. Hamlet and Lettenmaier 1999; Stockle et al. 2010; Payne et al. 2004; Elsner et al. 2010; Maurer et al. 2002; Markoff and Cullen 2008; Hamlet et al. 2010; Jara and Stockle 1999; Marcos 2000; Pannkuk et al. 1998; Peralta and Stockle 2002; Kemanian 2003). What is novel about WSU's approach is that VIC and CropSyst were integrated to exchange hydrologic and crop production information. For example, VIC informed CropSyst of daily weather and water supply; and CropSyst informed VIC of crop water needs and whether or not a particular crop was water stressed on any given day.

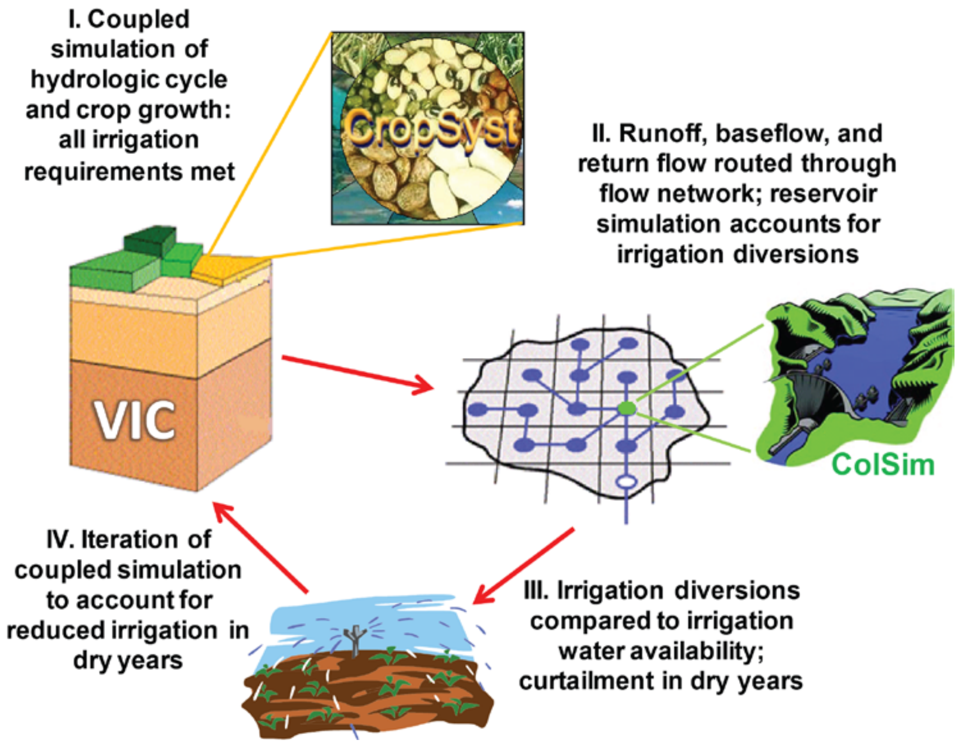

Figure 2. Biophysical modeling framework for forecasting surface water supply and irrigation water demand.

This new model, termed VIC-CropSyst, used daily precipitation and temperature observations from across the basin for 1977-2006 to generate baseline simulations of present conditions for each location. To forecast future conditions, the model used daily weather information for the 2030s decade (referred to in this report as 2030) from five different climate change scenarios, representing a range of future greenhouse gas emissions and adapted for our region by the Climate Impacts Group at the University of Washington (Elsner et al. 2010). The biophysical modeling effort used downscaled climate projections from the A1B and B1 emissions scenarios, developed by the Intergovernmental Panel on Climate Change (IPCC).

1.4.2.1 Modeling Water Supply

For the supply analysis, the Forecast focuses on surface water and shallow subsurface/surface hydrologic interactions, and does not analyze deep groundwater dynamics. It is recognized that deep groundwater supplies play a significant role in many parts of eastern Washington, however, due to time, resource, and data constraints, deep groundwater supplies were not considered in this Forecast. For this report, with the exception of the Odessa, it was assumed that demands met by groundwater supplies would remain groundwater in the future.

Surface water supplies for our region reflect the current management of the existing reservoir system. The integrated VIC-CropSyst model was thus linked to reservoir and water use curtailment models that enabled evaluation of how a changing water supply might impact future reservoir storages and releases, irrigation application amounts, crop yields, and how frequently some groups of water users might be interrupted. The project did not model all dams in the Columbia River basin, as there are more than 400 dams (both storage and run-of-the-river) operated to meet a variety of purposes. Reservoir modeling captured operations of the dams shown in Figure 3, including the major storage dams on the Columbia and Snake Rivers, and the five major reservoirs in the Yakima basin (Keechelus, Kachess, Cle Elum, Tieton and Bumping Lake). Dam management captured within ColSim included operations for power generation, flood control, instream flow targets, water storage, and stream flow regulation.

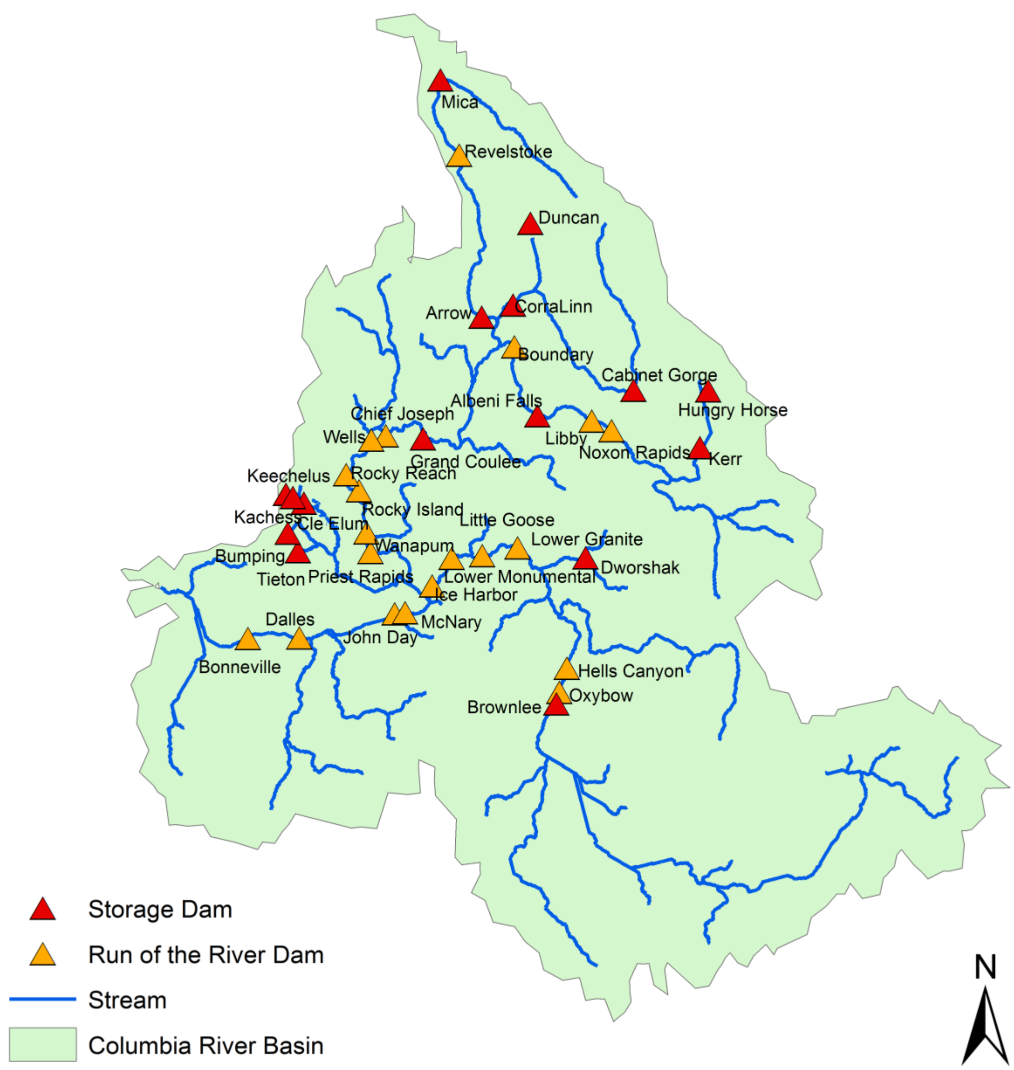

Figure 3. Dams incorporated in reservoir modeling.

The modeling effort assumed that dam management does not change in the future. To better understand how changes in infrastructure and management could change the water supplies entering Washington State in the future, and to help interpret the modeling results, WSU surveyed basin water managers about water supply planning, project development, and water management, using a 29-question survey developed in collaboration with OCR.

1.4.2.2 Modeling Agricultural Water Demand

VIC-CropSyst focused on agricultural irrigation demands because irrigation represents the majority of out-of-stream water use in the Columbia River basin and is a prominent driver of Washington's economy. The U.S. Geological Survey (USGS) estimated that agriculture represented 61% of out-of-stream water use statewide, considering municipal, domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, irrigation represented 82% of all uses except thermoelectric (which could not be separated regionally due to limitations in data presentation). Agricultural water uses other than irrigation, including stock water, were not estimated for this Forecast. While stock water use is important within some WRIAs, the magnitude of this use basin-wide is small relative to consumptive use for crops. In 2005, the U.S. Geological Survey estimated that within eastern Washington, stock water uses represented approximately 0.4% of out-of-stream water use, considering domestic, irrigation, stock water, aquaculture, industrial, and mining (Lane 2009). If stock water represents a significant proportion of water use in the future, it may merit additional attention in future forecasts.

To accurately simulate surface water supply and demand, the combined model needed accurate land use information for the entire Columbia River basin, including upstream areas in other states and British Columbia. The historical simulation (1977-2006) used recent crop mix information from the United States Department of Agriculture (USDA) for areas outside of Washington, and from the Washington State Department of Agriculture (WSDA) for areas inside the state. Each of these datasets is described more fully in Chapter 3, Methodology. The WSDA data were used in Washington because they were slightly more precise for the Washington crop mix when evaluated against the USDA data layer and because they delineated irrigation extent whereas irrigation extent outside of Washington was based on crop type. To capture the diversity of agriculture across Washington, nearly 40 groups of field and pasture crops, tree fruit, and other perennials were simulated. Because of the status of the Odessa groundwater area, all irrigated agriculture in this area that was served by groundwater in the historical period was assumed to need surface water in the 2030 forecast to grow irrigated crops.

Evaluation of the VIC-CropSyst irrigation water demand simulations was primarily based on observed diversion data at Banks Lake, which serves the Columbia Basin Project's irrigated area in central Washington. Based on 2008, 2009 and 2010 data, observed irrigation diversions from Banks Lake were in the range of 2.5 to 2.7 million acre feet (ac-ft) per year. The VIC-CropSyst simulated "top of the crop" demand (for water as applied to crops) for the period 1977 to 2006 for this area was on average about 2.2 million ac-ft. The difference of 14-22% between the simulation results and observed diversions could be attributed to conveyance losses (which are included in the observed data, but not in the VIC-CropSyst values, which measure only "top of the crop" demand). These values are within a reasonable range of expected losses. WSDA's number of irrigated acreage, 730,000, agreed reasonably well with 670,000 irrigated acres that the Columbia Basin Project serves, though it may be a bit on the high side.

Lack of high-quality metered diversion data was an impediment for similar evaluations of modeling results at the watershed scale. Some crop acreage and irrigation demand estimates are indicated in watershed plans of individual WRIAs, but these numbers have large uncertainties and are not appropriate for model result evaluation. Addressing this gap should be considered in the future.

A great deal of uncertainty is inherent in predicting changes in water supply and demand 20 years into the future. For example, water demand from agriculture could change significantly as producers respond to changes in a variety of factors such as domestic demand to input costs, water availability and weather patterns, and foreign trade in markets around the world. However, it is possible to investigate a likely range of possible future water supply and demand by analyzing three broad types of changes that may occur:

- Biophysical factors, including water availability and growing conditions for crops.
- Economic factors, including impacts on agricultural water demand resulting from changes in domestic food demand and international trade.
- State-level changes in water management to increase water availability or recover costs for developing new water storage capacity.

1.4.2.3 Economic Analysis of Changes in Agricultural Production

Economic analysis examined historical changes in production and emerging trends within Washington, allowing for a forecast of how the crop mix is likely to change in response to shifting economic and non-economic factors. Land use changes to predict movement of acreage into and out of agriculture were beyond the scope of this Forecast.

Within Washington, modeling captured the fact that over time, producers respond to changes in the profitability of various crops resulting from changes in domestic economic growth and international trade flows. For example, over the last 20 years, Washington producers have increased hay exports to meet demand resulting from growth in meat and milk production in Asia. To carry out economic analysis, the Forecast used low, medium, and high scenarios for domestic economic growth and international trade. These scenarios were based on statistical projections so that the medium scenario for domestic growth and international trade can be interpreted as the most likely future condition, while the low and high scenarios provide lower and upper bounds on what is likely to happen.

Domestic economic growth captured variation in the growth of the domestic economy and population, which impacts the amount of money households have to spend on goods. International trade captured variation in imports and exports of agricultural goods, which is an important source of demand for many crops in Washington. Approximately one third ($2.6 billion) of Washington's agricultural production is exported internationally. Trade analysis was based primarily on historical trends in international imports and exports at the state level for broad crop categories, including fruits, vegetables, and wheat, using data provided by the USDA. A detailed analysis was performed for specific crops such as alfalfa and wine grapes that were deemed to be particularly sensitive to assumptions made about changes in trade flows.

Due to resource limitations, it was not possible to model all the ways in which producers could adapt to a reduction in water availability. For example, some producers may switch to less water-intensive crops, particularly if curtailment becomes more regular in the future. In the long run, they may also increase irrigation efficiency by investing in more efficient irrigation infrastructure, or by investing in improved irrigation timing.

A simpler approach aims to capture how producers attempt to mitigate water shortages within a growing season by allowing for selective deficit irrigation of less profitable crops. This provides an upper bound on the negative impacts of reduced water availability on production and profitability. A more complex representation of producer decision-making could be considered for the 2016 Forecast.

1.4.2.4 Economic Analysis of Changes in Water Capacity and Cost Recovery for Development Costs of New Water Capacity

A set of water management scenarios was developed to assess how increasing water availability would affect agricultural production and water use. Working from the baseline scenario of no added capacity, the Forecast examined the following possible water management changes:

- Three different scenarios for water capacity enhancement, corresponding to approximately 100,000, 200,000, and 500,000 ac-ft of additional capacity at specific sites (at no cost to users for new water)
- Recovering direct costs of additional water capacity development at $25, $100, or $200 per ac-ft per year.

The consideration of additional water capacity was based on a list of specific conservation and storage projects currently being considered by OCR that would make additional water available for instream and out-of-stream uses. Details of the projects considered are provided in Chapter 3, Methodology. One important constraint relevant to the water capacity analysis was that most of the projects OCR is considering would provide water for drought relief or new permits. WSU assumed that any newly irrigated land would have approximately the same mix of crops as is present on nearby farmland, based on the fact that the extent of irrigated production in the Columbia River basin is primarily constrained by water availability.

In addition to considering the impacts of additional capacity on water demand, WSU analyzed the economic impacts of additional capacity in terms of additional output, employment and tax revenue. The analysis used IMPLAN® data and software, a standard input/output model that captures the interlinkages between industries in the region. This specific package was chosen because it delineates between agriculture sectors by general crop types such as fruits, vegetables, and grains. Out-of-stream water allocated for newly irrigated land was accounted for on a project specific basis at the county level. New water was allocated to new irrigated crops based on the baseline future county-level crop mix for irrigated crops. The calculation of how much land would be allocated to new crops was done based on the amount of water available and the yields under future climate conditions.

The exploration of cost recovery for the direct costs of developing water was structured to provide information about the potential feasibility of cost recovery strategies for supporting development of new water capacity. The analysis thus considered whether increases in prices would decrease water demand by users or impact the total amount of cost recovery that could be expected. Potential changes in the costs of new water were considered on a crop specific basis. The analysis captured the fact that increased costs for water may prompt farmers to adopt new business practices. For example, they may choose to invest in more efficient watering systems, change their crop production choices, or make other changes in order to use less water.

Three possible prices that could be charged for cost recovery were explored. Existing OCR projects in the region that have attempted to recover some development costs have charged about $35 per ac-ft. The lower price of $25 was considered to approximate this price point. The medium price, $100, was chosen to represent the high end of what has been observed in actual market transactions for agriculture in the region, while $200 was meant to represent a possible high price in the future. The total amount of cost recovery funds that could be expected was determined by discounting the stream of payments received over time into a single present value.

Because this Forecast does not consider costs of specific projects it was not necessary (or possible) to directly address whether the prices would allow for complete recovery of costs. Thus, it is possible that a given price charged for water could recover only some of the costs (whether supply costs or economic costs), or that it could fully (or more than fully) recover costs, but this is not possible to determine from our analysis.

1.4.2.5 Forecast of Municipal Water Demand

Municipal use represents a much smaller portion of water use than agriculture in the Columbia River basin, but one that is important for supporting the continued prosperity of the region. The USGS estimated that domestic uses (including public and self-supplied) represents 11% of out-of-stream water use statewide, when considering domestic, agricultural irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, domestic uses represents 13% of these uses except thermoelectric (which could not be separated regionally due to limitations in data presentation) (Lane 2009). For areas of the Columbia River basin outside Washington State, WSU reviewed existing municipal projections. Within Washington, municipal demand, including self-supplied domestic use and municipally-supplied industrial use, was forecasted and then integrated into the modeling.

Municipal forecasting in Washington State relied on data from water system plans submitted to the Washington State Department of Health from the one to three largest public water systems in each WRIA, scaled to a common analytical base year of 2000. This generally captured a majority of residents in a WRIA. For those municipalities where data allowed, municipally-supplied industrial growth was also included. Industrial growth was assumed to occur at the same rate as population growth, due to the difficulty of accurately forecasting industrial use using other methods. However, since not all water supply plans include industrial use information, industrial use could not be included for all WRIAs. Self-supplied industries were outside the scope of this Forecast. Data from water system plans were used to compute an Average Daily Demand (ADD) in terms of gallons per capita per day (gpcd). In some instances, diversions were much higher because of system leaks.

Using county-level population estimates obtained from the Washington State Office of Financial Management, city populations were counted in their primary WRIA, while projected county-level population growth outside of cities was distributed evenly by WRIA. Calculations of total WRIA water demand assumed that all people in the WRIA would use the average demand of nearby municipalities. Growth in rural demand will likely be met by groundwater supplies, but it was assumed that domestic wells would be shallow enough to impact surface water flows. Because municipal systems account for only about 10% of consumptive water use in the Columbia River basin, economic scenario analysis (to explore the impacts of variations in economic growth and trade on water demand) was not carried out for the municipal forecasting.

Consumptive use was estimated by examining the difference between water diversions and discharges at corresponding wastewater treatment plants, while recognizing the potential for significant discrepancies due to municipal inflow and infiltration. Evidence from other locations in the western United States shows that loss or addition of flow due to groundwater exchanges in aging wastewater collection systems can be significant. The rate of loss has been sometimes assumed to be fairly even across systems; for example, the Utah Division of Water Resources has traditionally estimated the fraction between winter (indoor) water diversions and wastewater discharges to be approximately 0.90, while Oregon uses 0.80-0.90, (Cooper 2002). However, a study of 52 municipal systems in Utah found significant variability in this ratio (Hughes 1996). In fact, among the 52 municipal systems 63% suffered from excess infiltration or exfiltration, with 17 ratios greater than 1.0 and 16 ratios less than 0.70. The remaining systems averaged a supply/effluent ratio of 0.83 during the winter. Similar analysis of summer flows revealed a return flow ratio of 0.51 indicating nearly half the flow is used for outside irrigation. In our analysis, 28 of 34 WRIAs produced values where wastewater treatment plant discharges were less than diverted amounts. This produced 28 positive consumptive use values, which were substituted for the six negative values when calculating consumptive uses.

Municipal demands were incorporated into modeled water supply and agricultural water demand. This was done by withdrawing consumptive demands from the surface water system when water system plans or other evidence confirmed that municipal systems were supplied by surface water or by groundwater in close hydraulic continuity with surface water supplies.

1.4.2.6 Model Outputs

An integrated overview of the modeling structure is shown in Figure 4. Instream demands were not determined within modeling, but were represented through the adopted state and federal instream flows which were assumed to be the same in the historical and future periods. Historical and forecast municipal demands were included in the modeling framework by withdrawing the consumptive use portions from surface water availability. The models were able to forecast a variety of potential impacts on a spatially distributed basis, including predicted surface water supply, total irrigation demand, unmet irrigation demand due to curtailment, and decreases in crop yield due to curtailment.

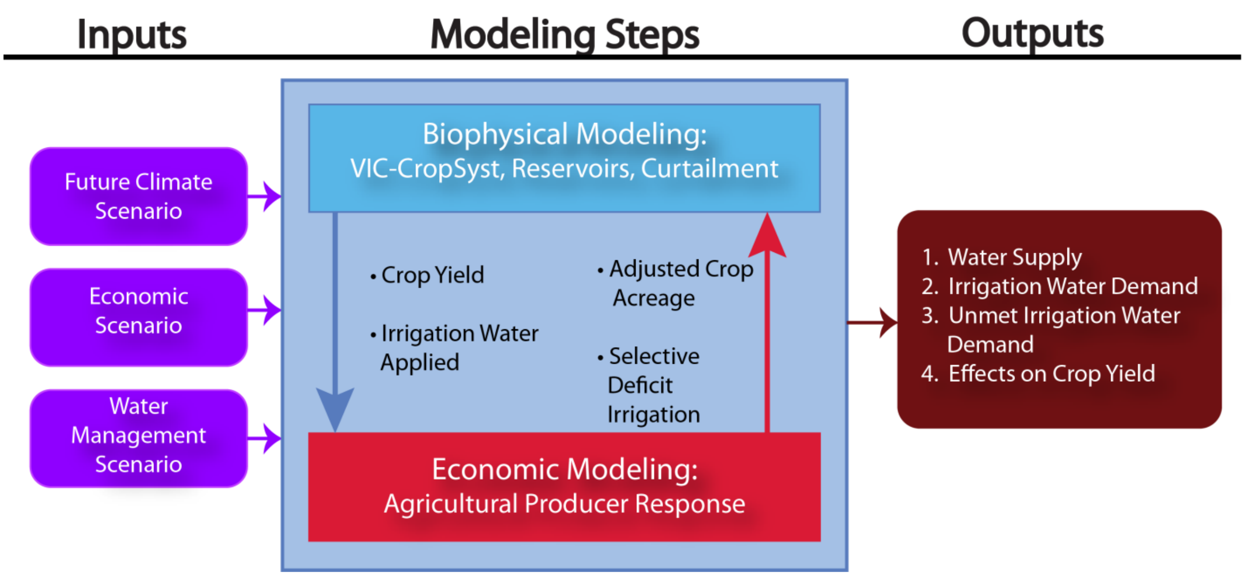

Figure 4. Integration of biophysical modeling (surface water supply, crop dynamics and climate) with economic and policy (human decision-making) modeling.

1.4.3 Incorporation of Instream Flow Rules and Assessment of Current Conditions for ESA-Listed Fish Stocks

The waters of the Columbia River basin support a variety of fish and other wildlife important to maintaining cultural, environmental, and recreational opportunities, including several ESA-listed threatened and endangered fish stocks (Table 1). Wildlife and fish (including both listed and non-listed species) help support a vibrant tourism, recreation, and fishing industry in the Columbia River basin, one that plays a vital role in maintaining the rural economy. While values specifically derived for eastern WA were not available, recreational spending associated with fishing, hunting, and wildlife viewing was estimated to be $3.1 billion statewide in 2006, according to a study by the U.S. Department of Fish and Wildlife (2007).

Table 1. Fish stocks listed under the Endangered Species Act in Washington's Columbia River basin (table provided by the Washington Department of Fish and Wildlife).

ESA Listing Unit by region	Status
Lower Columbia River	
Southwest Washington/Columbia River Coastal Cutthroat	**Candidate**
Columbia River Chum	**Threatened**
Lower Columbia River Bull Trout	**Threatened**
Lower Columbia River Chinook	**Threatened**
Lower Columbia River Coho	**Threatened**
Lower Columbia River Steelhead	**Threatened**
Mid-Columbia River	
Mid-Columbia River Spring Run Chinook	**Not Warranted**
Middle Columbia River Bull Trout	**Threatened**
Middle Columbia Steelhead	**Threatened**
Touchet/Walla Walla (Oregon Recovery Unit) Bull Trout	**Threatened**
Snake Basin	
Snake River Sockeye	**Endangered**
Snake River Basin Steelhead	**Threatened**
Snake River Bull Trout	**Threatened**
Snake River Fall Run Chinook	**Threatened**
Snake River Spring and Summer Run Chinook	**Threatened**
Upper Columbia River	
Upper Columbia River Bull Trout	**Threatened**
Upper Columbia River Spring Run Chinook	**Endangered**
Upper Columbia River Summer and Fall Run Chinook	**Not Warranted**
Upper Columbia Steelhead	**Threatened**
Lake Wenatchee Sockeye	**Not Warranted**
Okanogan River Sockeye	**Not Warranted**
Northeast Washington Bull Trout	**Threatened**

Across the Washington portion of the Columbia River basin, OCR developed a comprehensive database of available historic flow data for each major tributary to the Columbia River. Using this data, OCR compared historic low, average, and high flow water years to state and federal minimum instream flow targets. This work was intended to improve understanding of:

- How often minimum flow targets in fish critical basins are being met
- How often water users subject to minimum flow targets are curtailed
- Whether trends exist in the historic data relative to water availability, the shape of the hydrograph, or drought severity
- Where opportunities exist to improve stream conditions by re-timing or re-locating water.

WSU's modeling also integrated quantitative instream flow requirements in the Washington portion of the Columbia River basin. Within WRIAs, the highest adopted state and federal instream flows for each month were used to express current minimum flows for fish historically and in the 2030 forecast. State and federal instream flows along the mainstem were also compared to historical and future supplies.

In addition, OCR contracted with the WDFW to provide information on instream water demands for eastern Washington's eight fish and low flow critical basins:

- Walla Walla (WRIA 32)
- Middle Snake (WRIA 35)
- Lower Yakima, Naches, and Upper Yakima (WRIAs 37, 38, and 39)
- Wenatchee (WRIA 45)
- Methow (WRIA 48)
- Okanogan (WRIA 49)

The Atlas presents WDFW's analysis of existing data, best professional knowledge, and new data for 189 stream reaches (Ecology Publication 11-12-015). Each reach was scored on three critical components: fish stock status and habitat utilization, fish habitat condition, and stream flow. This allowed for comparisons of stream reaches within each of the WRIAs. WDFW's results were at a finer geographic scale than WSU's modeling analysis, and were qualitative rather than quantitative. Thus they are presented independently in the Atlas. OCR will use the information in the Atlas, and consultations with WDFW staff, to identify and prioritize projects that benefit stream flows.

1.4.4 Forecast of Hydropower Water Demand

According to the Northwest Power and Conservation Council (NWPCC), the more than 55 major federal and nonfederal hydroelectric dams in the Columbia River basin produce upwards of 16,000 annual average megawatts (MWa) of energy (NWPCC 2010). This relatively inexpensive source of power accounts for approximately fifty-five percent of the power generating capacity in the

Pacific Northwest, and on average provides about three quarters of the region's electricity. From a power generation perspective, the most significant dams are on the mainstem. Power entities in the northwest regularly carry out extensive forecasting of electricity demand and power-generating capacity. For this Forecast, WSU reviewed existing projections across the Columbia River basin with two specific objectives in mind:

- Find out whether regional and state level power entities expected to be able to meet anticipated growth in demand over the next 20 years.
- Determine the likelihood of any additional hydroelectric storage capacity being built within the Columbia River basin over the next 20 years

Available reports that were reviewed included those carried out by the Bonneville Power Administration (BPA), Northwest Power and Conservation Council (NWPCC), Avista, Idaho Power, Portland General Electric (PGE), and Grant County PUD (Canadian and U.S. Entities 2010, NWPCC 2010, Idaho Power 2011, Avista 2009, PGE 2009; Grant County PUC 2009). BC Hydro documentation was also reviewed, though long-term planning documents were general in nature. Reviews were supported with conversations with staff at public utility districts in Washington State and Avista Utilities.

2.0 Background

2.1 Study Area

The Columbia River basin is the fourth largest watershed in North America in terms of average annual flow, encompassing all or parts of Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, and British Columbia (BC) (Figure 5). The watershed drains approximately 258,000 square miles including nearly 40,000 square miles in British Columbia. For thousands of years, the 1250 mile long river has shaped the economy and lives of the indigenous people who lived near it. Over the past two hundred years, the basin has been developed extensively for hydropower generation, irrigation, navigation, and flood control. In fact, steamboats began operating on the river as early as 1836 and the first hydroelectric dam in the Pacific Northwest (PNW) was built on the Spokane River in 1885. The river is also managed for the protection of salmonid species listed under the Endangered Species Act, municipal and industrial supplies, maintenance of water supplies in accordance with tribal treaties, and recreation. This creates a myriad of competing demands.

Figure 1. Schematic of Columbia River Basin (Army Corps 2009).

Forecasting future water supply and demand in the Columbia River basin is further complicated by the size, complexity, and multiple jurisdictions of the river system. Nevertheless, because reliable access to water is essential for existing and future regional economic growth and environmental and cultural enhancement, resource managers are tasked with conducting such forecasts. The urgency and importance of forecasting water supply and demand continues to grow particularly as seasonal variations in water supply and demand have resulted in localized shortages with increasing regularity due to population growth, climate variability and change, and increased implementation of regulatory flow requirements. Competing demands on the region's fresh water resources will only increase in the future, particularly in summer months when demand is high. Water supply is also anticipated to decrease during these summer months of peak demand due to long-term shifts in temperature and precipitation, exacerbating summer unmet water demand.

2.2 Existing Conditions within the Columbia River Basin

This section briefly describes the most important features of current water supply and demand in the Columbia River basin. These overviews are designed to broadly characterize existing conditions with the understanding that variation exists between sub-basins.

2.2.1 Climate

Surface water flows in the Columbia River basin are dominated by the temperature-sensitive cycle of snow accumulation and melting (Leung and Ghan 1998). The average annual precipitation is quite variable across the region and ranges from less than 8 inches in central Washington to 20-30 inches near the mountain foothills across the basin and 40 or more inches in some mountain areas. The majority of the precipitation in the basin falls during the period from October through March, while summers are relatively dry. During the winter, when the majority of precipitation occurs, snow accumulates in upper elevations of the basin. This snow melts in the spring and early summer, resulting in peak flows for the year. Nearly 60% of the natural runoff to the Columbia River occurs during May, June, and July (Army Corps 1989). The actual measured USGS gage flow at the Dalles, OR (USGS 14105700) shows that the May-July 1878-2010 average discharges account for 46.5% of the total due to reservoir operations and diversions. This is followed by a characteristic low flow period in the late summer and early fall (17.4% of annual flow at USGS Dalles gage during Aug-Oct), followed by a smaller runoff peak in late fall in response to increased precipitation falling as rain (not evident in some arid regions). During the winter, flow is again low as precipitation falls as snow and accumulates throughout much of the basin.

The headwaters of the river begin in Canada's Selkirk Mountains where the source of the river (Columbia Lake) is at an elevation of 2,650 feet. Significant parts of the Columbia basin are low enough that winter precipitation falls as both rain and snow (Hamlet and Lettenmaier 1999). However, while rain events may cause short-term localized flooding, these parts of the basin have typically received much less water than higher portions of the basin that are dominated by winter snowfall. Thus, flows in the basin as a whole are dominated by the pattern described above. A major concern is that climate change is raising the elevations where winter precipitation falls as rainfall thus altering the historic runoff pattern.

2.2.2 Streamflows and Water Supplies

Water supplies in the Columbia River basin come from both surface water flows and groundwater sources. While surface water and groundwater are often physically linked, the impacts of regulations and timing on these two sources can vary greatly. Streamflows at any given location and time are influenced by the amount of precipitation coming into the system, the speed with which water moves through the system, upstream reservoir operation, diversions, and return flows. Water exits the surface system through consumptive withdrawals, losses to evaporation, and potentially through exchanges with groundwater.

Groundwater consists of water that is below the surface. This water originates as surface water that infiltrates to groundwater areas. Once there, groundwater may move laterally over long distances, including between watersheds. The amount of water available in groundwater sources and the relationships between surface and groundwater resources are not well characterized in many areas. While groundwater investigations have been conducted in several critical regions (Hseih et al. 2007; Vaccaro and Sumioka 2006; Barber et al. 2011) uncertainties even in those areas exist due to the nature and difficulty of characterizing subsurface aquifer properties and recharge zones.

Due to data and time restraints, the 2011 Forecast assessed only surface water supplies and not groundwater supplies.

2.2.2.1 Surface Water

Historically, streamflow in the Columbia River responded strongly to patterns of rain and snowfall in the basin. At the beginning of the 20th century, roughly 75% of the annual flows occurred during the summer months (April-September) as snow melted, and roughly 25% of the annual flows occurred during the winter months (NRC 2004). A look at historic discharge recorded at the USGS gage (14105700 Columbia River at the Dalles, OR) reveals that from water year 1879 through 1910, April-September flows averaged 75.1% while May-July flows averaged 52.4% of the annual total. Streamflow is significantly altered today, because numerous mainstem and tributary impoundments (dams) were built to generate hydroelectricity, store water for irrigation, and provide flood control. Today, flows on the Columbia River mainstem are managed for these needs, as well as the sometimes competing goals of fish migration, habitat protection, navigation, recreation, and municipal and industrial water supply. Management has altered the natural flow regime, smoothing out the sharp peak in flow that occurs as snow melts in late spring, and augmenting flows during the fall and winter (NRC 2004). Meanwhile, water velocity (speed) in rivers has decreased, the shape of the river's plume into the Pacific Ocean has been altered, and the limnology and nutritional pathways of the river's estuary and food web have changed (NRC 2004). Looking at the same USGS gage at the Dalles shows that from water year 1979 through 2010, April-September flows averaged 55.5% while May-July flows averaged 34.2% of the annual total.

The long-term mean average annual flow of the Columbia River at the Dalles, OR is approximately 189,400 cfs. Though historically as high as 313,600 cfs, in recent decades the recorded flows have reached 263,700 cfs in a high water year (1997), and only 117,400 cfs during a low water year (2001) (Department of Ecology 2012). Despite considerable year-to-year variability, there has been a small decrease in the average annual discharges as shown in Figure 6. Perhaps just as important, is the prolonged low flow period from 1923 to 1944 (average discharge 165,000 cfs). Although several years of discharge data may have been influenced by the completion of Grand Coulee Dam in 1942, the overall pattern indicates the system could be subject to consecutive or multiple low flow conditions.

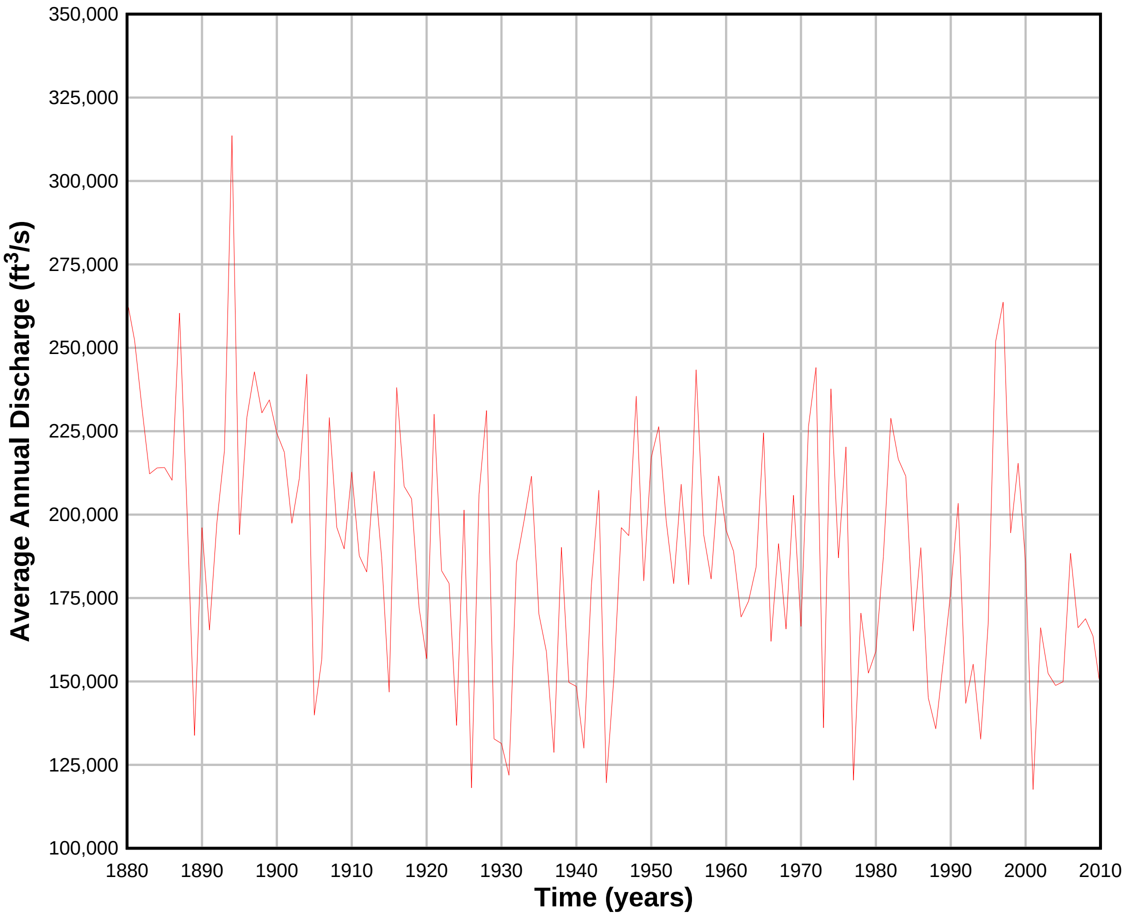

Figure 2. Average annual discharge recorded at the USGS Dalles, OR gage (USGS 2012).

It is important to note that while British Columbia accounts for less than 16% of the drainage area, nearly 40% of mean annual flow originates in Canada. Comparison of the mean annual flow at the USGS gage at the international boundary (USGS 12399500) from 1939 through 2010 indicates that the upstream gage averages about 54.8% of the downstream gage reflecting both upstream Canadian and US (Pend Oreille and Kootenai River) contributions. In other words, the river flow nearly doubles between the point where the Columbia enters Washington State and The Dalles, mainly due to the inflow of the Snake River, which comprises approximately 44% of total mean annual flow. A number of other tributaries are also important, with 30 tributaries having mean annual flows greater than 200 cfs (Golder and Anchor 2006).

Total operational water storage capacity in the entire Columbia River basin represents 42.0 million ac-ft (out of 55.0 MAF total storage), only about 30% of an average year's runoff (Bonneville Power Administration et al. 2001). This is small relative to some other river systems; for example, dams on the Missouri River can hold two to three times the total annual runoff, which gives operators more flexibility to respond to year to year variations in weather (Bonneville Power Administration et al. 2001). It is important to distinguish between operational and total storage volumes when discussing reservoir operations as most reservoirs are not designed to be drained completely. For example, Dworshak Reservoir on the North Fork of the Clearwater (in Idaho) has a total storage capacity of 3.5 MAF but since nearly 1.5 MAF is designated as dead storage, the operating pool has only about 2.0 MAF of useable storage (Army Corps 2011a). Similarly, Grand Coulee has a total storage capacity of 9.6 MAF with an operational storage capacity of 5.2 MAF within its 82 foot operating pool. Much of this type of storage is on the mainstems of the Columbia and the Snake River systems with several notable exceptions such as Libby (~5.0 MAF useable storage, Hungry Horse (~3 MAF useable storage), Dworshak (~2.0 MAF useable storage), and Duncan (1.4 MAF useable storage).

A considerable amount of Columbia River basin storage capacity exists in Canada as a result of the Columbia River Treaty between the U.S. and Canada signed in 1964. The three treaty dams built in BC account for 20.5 MAF (Mica 12.0 MAF, Keenleyside 7.1 MAF, and Duncan 1.4 MAF) with 15.5 MAF of this assigned to the treaty. Another Canadian facility (Revelstoke), not constructed under the Columbia River Treaty, has an additional 1.2 MAF of storage. Conversely, in spite of numerous run of the river hydroelectric facilities, relatively little storage occurs within the State of Washington with Grand Coulee, Lake Chelan, Chief Joe, and Cle Elum representing the most significant storage capacities.

In addition to natural flows and reservoir releases, surface waters can be augmented in locations where groundwater flows to the surface. This is particularly important in areas with extensive agriculture, as return flows can contribute significantly to late-summer stream flows. Quantification of these flows has not been widely attempted across the Columbia River basin.

2.2.2.2 Groundwater

Groundwater resources are used to meet water demand in many parts of the Columbia River basin, and are particularly important for domestic, municipal, commercial, and industrial uses (NRC, 2004). For instance, the City of Spokane receives its entire drinking water supply from a network of groundwater extractions and Yakima basin groundwater withdrawals accounted for approximately 10% of the overall water use in 2000 (Vaccaro and Sumioka 2006). Sources of groundwater vary throughout the region. Much of the basin is underlain by the Columbia Plateau regional aquifer system (Figure 7), which covers about 44,000 square miles of northern Idaho, northeastern Oregon, and southeastern Washington (Burns et al. 2010). The aquifer system comprises three major deep geologic formations: the Grand Ronde Basalt and the overlying Wanapum and Saddle Mountains Basalt. The Grand Ronde Basalt is the oldest (and therefore the deepest), and the thickest of these formations (Whitehead 1994).

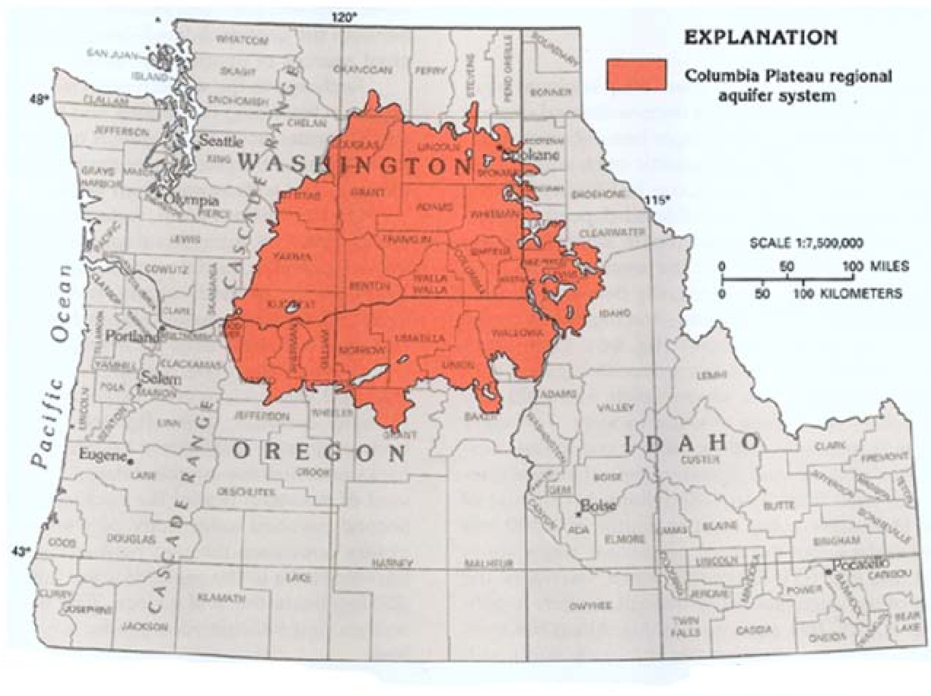

Figure 3**.** Spatial extent of Columbia Plateau aquifer system (Whitehead 1994).

Figure 7 gives the misleading impression that the aquifer behaves as a single system when in fact it has multiple subareas that may react to changes such as increased withdrawals independently (e.g., Odessa Subarea). Water flows through these basalt aquifer systems in complex ways, driven by gravity and the permeability of the geologic formations that are encountered (Burns et al. 2010). These geologic features include lithology, folding, faulting, buried granitic bedrock or vertical basalt dikes, individual interflow zones, and erosional features such as coulees (Porcello et al. 2009). In general, water enters the system from recharge areas near the edges of the plateau, and exits toward regional “drains” including the Columbia and Snake River. However, there are considerable uncertainties with respect to the exact rates and locations of both recharge and discharge. The Cascade Range in Oregon and Washington represents an important recharge area, because permeable volcanic rocks accept large volumes of precipitation, and because groundwater use is relatively light (Whitehead 1994).

Shallower, unconsolidated-deposit aquifers overlie the basalt aquifers in some areas, particularly in lowlands (Figure 8). These aquifers range in thickness, exceeding 200 feet in many areas, and reaching as much as 2,000 feet in some localized areas (Whitehead 1994). In areas where they are thick (and therefore more productive), they may be more important for water supply than the deeper basalt aquifers, providing water for public supply, domestic, commercial, agricultural, and industrial needs. These deposits may be hydraulically interconnected with surface waters, so that water flows back and forth between the ground and surface water systems in complex ways, depending on the seasonal depths of the water.

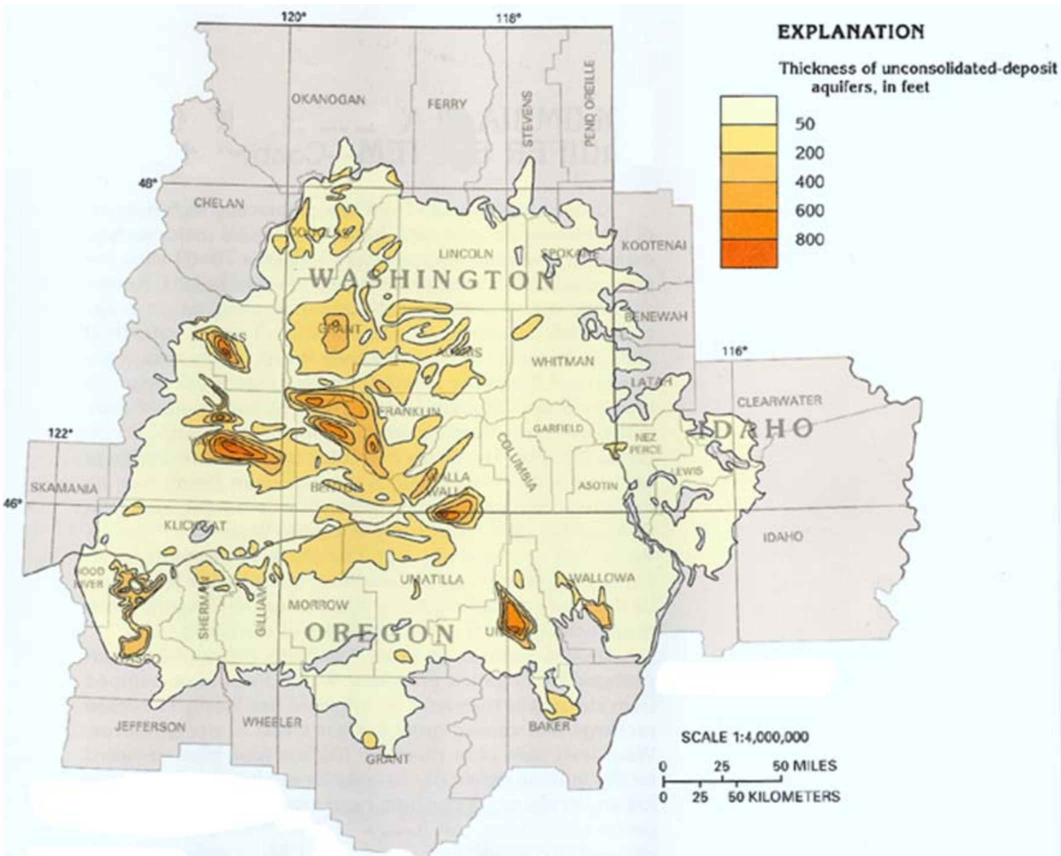

Figure 4**.** Unconsolidated aquifers in the Columbia River plateau (Whitehead 1994).

Groundwater is equally important and complex in other parts of the Columbia River basin such as the Eastern Snake Plain in Idaho. As illustrated in Figure 9, the groundwater resource covers a significant portion (approximately 10,800 square miles) of eastern Idaho. The most productive portion of the aquifer is in the upper 300-500 feet where estimates of storage range from 200 to 300 MAF. However, even with a storage volume approximately the size of Lake Erie, groundwater withdrawals and reductions in groundwater recharge resulting from more efficient irrigation have reduced discharges to springs and the Snake River prompting management concerns. Changes in Snake River flows are a concern for Washington and other downstream users.

Northeast of the City of Spokane, on the Washington-Idaho border, the Spokane Valley-Rathdrum Prairie (SVRP) aquifer is also important. Although this aquifer covers a much smaller area (approximately 370 square miles), the aquifer is designated as a sole source aquifer by the U.S. Environmental Protection Agency (EPA) and serves as the area's primary source for drinking water (both municipal and rural domestic), irrigation, and industrial (Hutson et al. 2004, as cited in Kahle et al. 2005). Concerns include the growing demands on groundwater due to rapid growth and associated development, low streamflow in reaches of the Spokane and Little Spokane Rivers, and water quality problems associated with changing land use activities (Kahle et al. 2005).

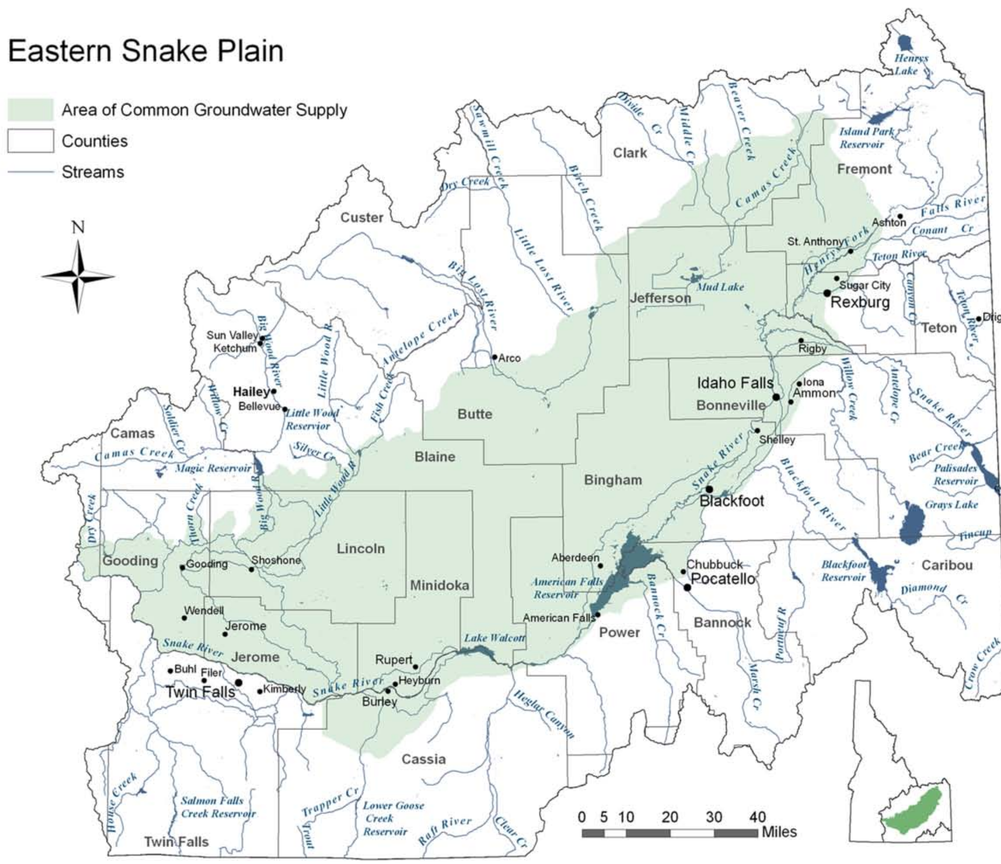

Figure 5. Eastern Snake Plain aquifer (Idaho Department of Water Resources 2009).

Modern water use patterns in eastern Washington have drastically altered the flows of groundwater in the Columbia Plateau regional aquifer system. In many areas, water diverted or pumped from streams or reservoirs and applied to fields has infiltrated through the soil and enhanced natural groundwater levels. Groundwater levels have risen as much as 500 feet or more in some areas of eastern Washington (Drost et al. 1997). Conversely, in other areas with substantial irrigation with groundwater, declines of as much as 180 feet have been recorded by the USGS as withdrawal rates have far exceeded recharge rates. Other groundwater issues relevant to current and future water supply and demand planning include a reduction in base flow to rivers in some areas with associated impact on temperature and water quality, and the current and anticipated effects of climate change on recharge rates, base flow, and groundwater availability (Burns et al. 2010).

2.2.3 Agriculture

Overall, about 6% of the surface water flowing through the Columbia River basin is currently removed for agricultural irrigation (Bonneville Power Administration et al. 2001). This represents the largest out-of-stream water use. Of more than 6.5 million cropped acres in Washington State, roughly 37% is irrigated (NRC 2004). Irrigated cropland currently produces tree fruit, potatoes, sugar beets, hops, fruit, vegetables, mint, wine grapes, hay, grain and many other crops (Washington also has significant non-irrigated production of hay and grain). The USGS estimated that agriculture represented 61% of out-of-stream water use statewide,[1] considering municipal, domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, irrigation represented 82% of all uses except thermoelectric (which could not be separated regionally due to limitations in data presentation) (Lane 2009). Some of this water is used by crops, while some infiltrates through the soil and returns to the river system downstream.

Production of these crops forms a significant portion of the economy of eastern Washington. Together, irrigated and non-irrigated agriculture and related services account for more than 10% of the basin's employment (NRC 2004). Farm owners, tenants, and ranch families represent 19% of households in the basin (Quigley et al. 1997, as cited by NRC 2004).

Agricultural water uses other than irrigation, such as stock water, are important within some WRIAs, but the magnitude of these uses basin-wide is small relative to consumptive use for crops. In 2005, the USGS estimated that within eastern Washington, stock water uses represented approximately 0.4% of out-of-stream water use, considering domestic, irrigation, stock water, aquaculture, industrial, and mining (Lane 2009). If stock water represents a significant proportion of water use in the future, it may merit additional attention in future forecasts.

2.2.4 Municipal

Municipal use represents a much smaller portion of water use than agriculture in the Columbia River basin, but one that is important for supporting the continued prosperity of the region. The USGS estimated that eastern WA's domestic uses (including public and self-supplied) represented 11% of out-of-stream water use statewide, considering domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses (Lane 2009). Within eastern Washington, domestic uses represented 13% of all uses except thermoelectric (which could not be separated regionally due to limitations in data presentation) (Lane 2009).

Of the roughly 9.5 million people who live in Washington, Oregon, Idaho, and Montana (the four northwestern states that comprise the majority of the Columbia River basin), nearly 5 million live in the Columbia River basin (Volkman 1997, as cited by (NRC 2004). Since the 1980's, the basin's interior has experienced population growth in many areas. In Washington State, some of the most significant growth areas are the Tri-Cities (Richland/Pasco/Kennewick), Spokane,

[11] This includes both consumptive and non-consumptive use of water by agriculture.

Wenatchee, and Yakima (NRC, 2004). Many other areas in the Columbia River basin are sparsely populated, although some rural areas are also experiencing significant growth. Population is expected to grow and will likely increase demand for municipal water and hydroelectricity (NRC 2004).

2.2.5 Hydropower

According to the Northwest Power and Conservation Council (2010), the more than 75 major federal and nonfederal hydroelectric dams in the Columbia River basin produce upwards of 15,000 annual average megawatts (MWa) of energy. Figure 10 shows the hydropower generation capacity in the Pacific Northwest in relation to other power sources in the area as of 2010. According to the U.S. Energy Information Administration, Washington alone produced over a quarter of the nation's hydropower in 2009 at an average retail cost of $0.066/kWh, the fourth lowest in the United States.

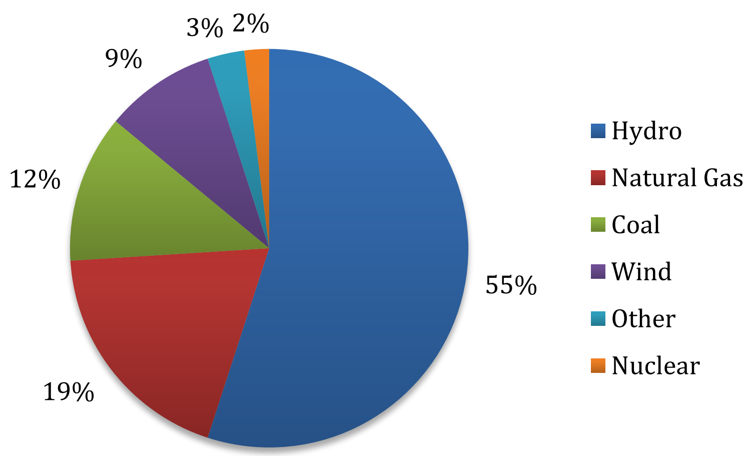

Figure 6**.** Sources of Pacific Northwest power generation by capacity as of 2010.

2.2.6 Ecosystem and Instream Flow Requirements

The waters of the Columbia River basin support a variety of fish and other wildlife important to maintaining cultural, environmental, and recreational opportunities, including both listed and non-listed species. Statewide in Washington, recreational spending associated with fishing, hunting, and wildlife viewing was estimated to be $3.1 billion in 2006 (U.S. Department of the Interior, Fish and Wildlife Service & U.S. Department of Commerce, U.S. Census Bureau, 2007).

Fish are central to the Columbia River basin. Historically, salmon were essential to Native American subsistence, culture, and religion (IEAB 2005). Prior to the building of the Dalles Dam, more than 5,000 people gathered annually near Celilo Falls to trade, fish, feast, and participate in games and religious ceremonies (IEAB, 2005). Today, salmon produced in the Columbia River system are harvested by ocean fisheries from California to Alaska. Commercial landings of salmon and steelhead harvested in the Columbia River have declined from around 20 million pounds annually in the late 1940s, to just over one million pounds in 1993. The Independent Economic Analysis Board estimated that the income generated by harvesting and preparing marketable fish, plus the secondary impacts on other economic activities generated between $40 and $142 million per year to the regional economy, depending on the assumptions made about production and harvest (IEAB, 2005). About 77% of this contribution occurs in the Pacific Northwest, while the rest occurs in Alaska and British Columbia, with a very small portion in California.

Most salmon stocks in the Northwest are at a fraction of their historical levels due to fishing pressures, blockages of fish passage, loss of freshwater and estuary habitats, poor ocean conditions, hydropower facilities, and hatchery practices (NRC 2004; Lower Columbia Fish Recovery Board 2004). Twelve evolutionarily significant populations of four species of Columbia River basin salmon and steelhead, and two resident species (bull trout and Kootenai River white sturgeon) have been listed for protection under the ESA since 1991. Figure 11 shows the distribution of ESA-listed fish in the Columbia River basin.

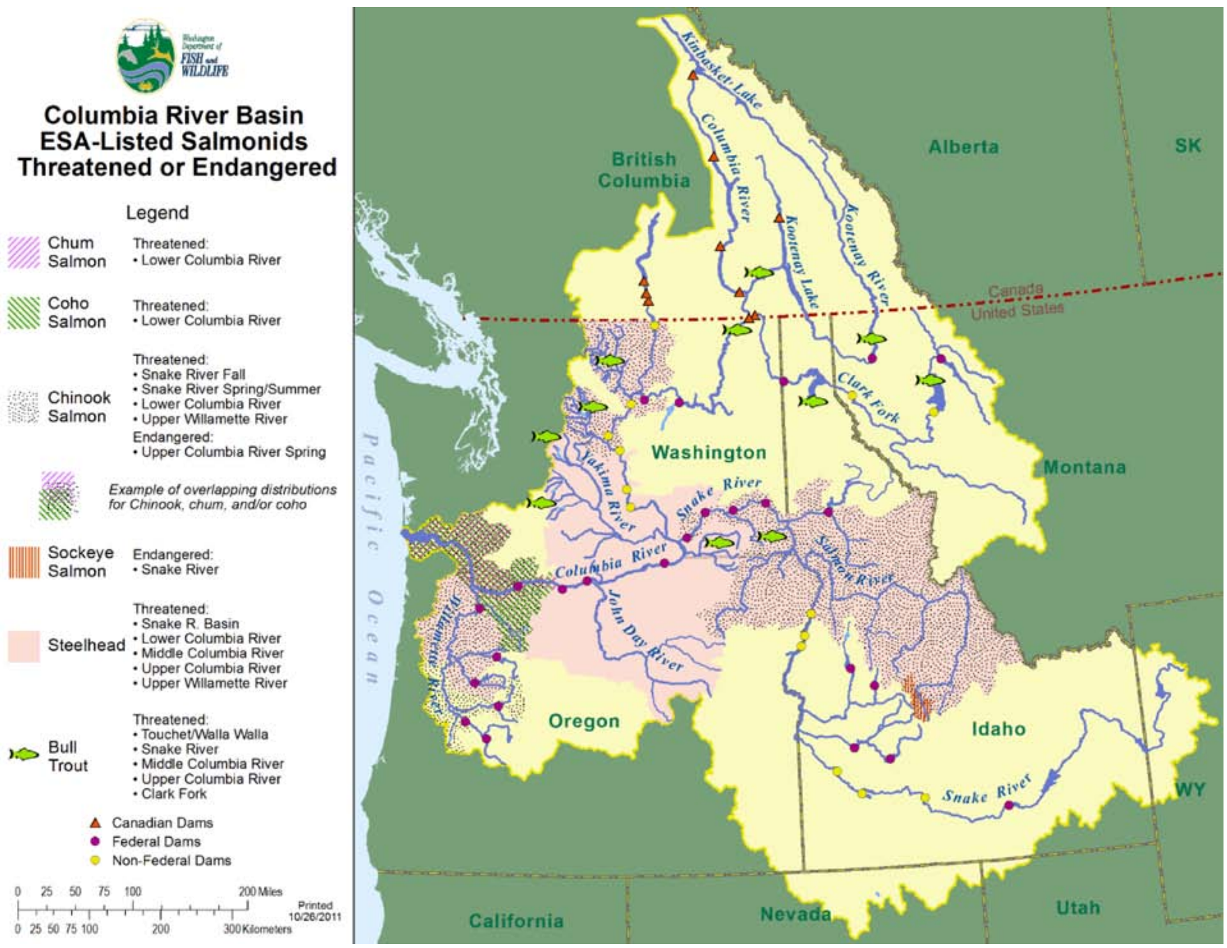

Figure 7. Distribution of fish listed under the Endangered Species Act in the Columbia River basin.

The twelve Columbia River basin salmon and steelhead ESA listings are:

- Snake River Sockeye, November 1991
- Snake River fall Chinook, April 1992
- Snake River combined spring/summer Chinook, April 1992
- Lower Columbia River Chinook, March 1999
- Upper Willamette River Chinook, March 1999
- Upper Columbia River Chinook, March 1999
- Columbia River chum salmon, March 1999
- Upper Columbia River steelhead, August 1997
- Snake River Basin steelhead, August 1997
- Lower Columbia River steelhead, March 1999
- Upper Willamette River steelhead, March 1999
- Middle Columbia River steelhead, March 1999.

As a result of concerns about declining fish populations and ESA listings, state regulatory agencies have adopted minimum instream flows in several watersheds. In eastern Washington, regulatory flows have been adopted on the Columbia River mainstem, and also within certain tributaries to the Columbia River (Walla Walla, Wenatchee, Entiat, Methow, Okanogan, Little Spokane, and Colville). These regulated flows are legal water rights with priority dates and can affect subsequently issued water rights. This means that water rights holders with later priority dates (junior water right holders), may have their water use curtailed in order to protect the regulated flows, (senior water right holders) (Rushton 2000).

The Yakima basin has de-facto federal flows, resulting from the target flows over Sunnyside and Prosser Diversion Dams described in Title XII of Public Law 103-434 (Tri-County Water Resource Agency 2003). In managing the water for the Yakima Project (a federal irrigation project covering much of the basin), the U.S. Bureau of Reclamation (USBR) calculates total water supply available (TWSA), a combined measure of unregulated flow, return flow, and stored water available for use (Tri-County Water Resource Agency 2003). Instream flow needs are met from TWSA prior to determining if pro-rationing is necessary. In water-short years, all pro-ratable users share the shortage equally, and are allotted a portion their full water supplies (Tri-County Water Resource Agency 2003).

In addition to these flows, the Department of Ecology and its predecessor agencies have established administrative low flow restrictions and closures on several surface water sources in the state, known as surface water source limitations (SWSLs). These SWSLs were generally established as a result of letters of recommendation from the Washington Department of Fish and Wildlife or their predecessor agencies (HDR 2005). The majority of these SWSLs occurred in the 1950s and 1960s, with some as early as the 1940s, and some as late as the 1980s (HDR 2005). In most cases, the low flows and closures have been in place since the letters were received by Ecology, and thus have been applied to all subsequent water right applications (HDR 2005).

2.3 Summary of 2006 Forecast

Washington's first long term Forecast was completed in 2006, as mandated by HB 2860, the legislation that created the Columbia River basin Water Supply Development Program (Golder and Anchor 2006). Because the timeline for completing this first Forecast was less than six months, the Forecast relied heavily on reviewing work carried out by others in forecasting water supply and demand. The 2006 long term supply and demand forecast focused on three objectives:

- Document existing and future demand in the basin (20 years).
- Develop an initial inventory of conservation and storage projects that could help meet future demand.
- Lay the foundation for understanding how the Columbia River is managed and what factors affect water supply.

Below is a summarization of the 2006 Forecast's report on existing and future demands for Washington.

2.3.1 Estimates of Existing Demand

2.3.1.1 Analysis of Current Water Rights on the Columbia River Mainstem

Within a one mile corridor around the Columbia River, Golder and Anchor (2006) summarized all the water rights in the Washington State Department of Ecology's Water Rights Tracking System (WRTS) database, as well as relevant data provided by the Oregon Department of Water Resources (ODWR). These databases did not include rights for water use that is federally reserved to the tribes, nor permit-exempt water use in the two states. Water rights with a purpose of "power" or "reservoir" were assumed to be non-consumptive, and were not considered. For records containing no annual quantity (Q_a) of water use, an annual quantity was calculated by assuming continuous use of instantaneous quantity (Q_i). Results are summarized for Washington and Oregon in Table 2 and Table 3 below.

Analysis of interruptible rights in Washington State revealed more than 350 interruptible water rights within 1 mile of the Columbia River mainstem, accounting for 487,104 ac-ft per year. This represents less than 5% of water rights issued by Ecology within this area.

Table 1. Washington's total number of water right documents and total annual water use allowed under claims, permits, and certificates within a one mile corridor of the Columbia River mainstem in Washington State upstream of Bonneville Dam (included in the Ecology WRTS database) (Golder and Anchor 2006).

Use Category	Total number of water documents (claims, permits, and certificates)	Total annual water use represented (ac-ft/yr)
Agricultural (dairy, frost protection, irrigation, and stock watering)	2,365	6,508,773
Commercial and Industrial (industrial cooling, commercial and industrial manufacturing, highway, mining, power, and railway)	152	623,119
Domestic (domestic, municipal, and recreation)	4,378	572,143
Environment and Wildlife (environment, fire protection, fish propagation, and wildlife propagation) (non-consumptive)	61	481,994
Undefined (water use not provided or not recognized)	131	8,557
TOTAL	**7,087**	**8,194,586**

Table 2. Oregon's total number of water documents and total annual water use allowed under claims, permits, and certificates within a one mile corridor of the Columbia River mainstem in Oregon State upstream of Bonneville Dam (included in the database of the Oregon Water Resources Department) (Golder and Anchor 2006).

Use Category	Total number of water documents (claims, permits, and certificates)	Total annual water use represented (ac-ft/yr)
Agricultural (agriculture, cranberry, dairy, frost protection, greenhouse, irrigation, livestock, and nursery)	334	561,453[a]
Commercial and Industrial (commercial, manufacturing, laboratory, mint still, log deck sprinkling, sawmill, mining shop, and road construction)	36	46,798
Domestic (aesthetic, recreation, domestic, human consumption, and municipal)	132	327,939
Environment and Wildlife (instream, fire protection, forest management, groundwater recharge, pollution abatement, fisheries, and wildlife) (non consumptive)	49	5,927,321
TOTAL (excluding environmental and wildlife non-consumptive use)	**502**	**936,190**

[a] In addition, 116,726 ac-ft per year of supplemental rights exist for agriculture in Oregon; these supplemental water rights were not included in the table above because they are not used at the same time as primary rights.

2.3.1.2 Analysis of Current Water Use in the Columbia River Basin

The 2006 Forecast also estimated existing demand by reviewing use estimates carried out by other entities: the USGS and the Washington State Department of Health (DOH) (for public water system use only).

USGS Estimate of Current Water Use

Estimated water use for the counties that make up the Columbia River basin was drawn from USGS estimations of water use in 2000 (Lane 2004), and is summarized in Table 4 below.

Table 3**.** Estimates of current water use from Lane (2004) as summarized by Golder and Anchor (2006)**.** The use categories shown here (public and self-supplied domestic, crop irrigation, golf course irrigation, and industrial) historically have accounted for 92% of use.[a]

County	Domestic (public supplied) (ac-ft/yr)	Domestic (self-supplied) (ac-ft/yr)	Crop Irrigation (ac-ft/yr)	Golf Course Irrigation (ac-ft/yr)	Industrial (ac-ft/yr)	County Total (ac-ft/yr)
Adams	2,780	1,468	209,610	123	2,500	216,481
Asotin	4,125	235	224	123	0	4,707
Benton	14,684	3,721	265,656	1,311	84,180	369,552
Chelan	6,580	2,242	56,382	818	16,253	82,275
Columbia	583	247	4,831	56	90	5,807
Douglas	3,497	594	27,462	347	3,744	35,644
Ferry	404	740	5033	45	325	6,547
Franklin	9,079	2,477	489,838	191	1,962	503,547
Garfield	314	168	572	45	11	1,110
Grant	11,075	5,941	1,042,446	2,287	3,598	1,065,347
Kittitas	7,342	1,558	223,061	516	1,580	234,057
Klickitat	2,320	1,054	29,704	146	3,116	36,340
Lincoln	1,334	706	40,241	202	11	42,494
Okanogan	4,551	4,192	81,378	370	4,237	94,728
Pend Oreille	594	785	829	0	1,031	3,239
Skamania	628	460	280	235	12,666	14,269
Spokane	88,552	13,115	10,268	1,580	48,423	161,938
Stevens	2,858	2,074	10,682	146	135	15,895
Walla Walla	6,053	1,188	138,993	258	18,271	164,763
Whitman	3,632	1,009	3,139	90	0	7,870
Yakima	28,807	14,236	637,798	1,424	7,297	689,562
Oregon[b]	52,806	NA	768,204		26,084	847,094
Use Type Totals	**252,598**	**58,210**	**4,056,944**		**235,514**	**4,603,266**

[a] Data from Lane (2004) for Washington counties and USGS (2004) for Oregon were originally reported in million gallons per day (mgd) and converted to ac-ft per year.
[b] Oregon includes water use from seven counties: Multnomah, Hood River, Wasco, Sherman, Gilliam, Morrow, and Umatilla, as reported in USGS (2004).

Estimate of Current Public Water System Use per Washington State Department of Health Data

DOH provided its 2006 water system database for Group A and Group B public water systems.[2] Total public water system use in the counties making up the Columbia River basin was estimated at 594 ac-ft per day or approximately 200,000 ac-ft annually. Average usage ranged from 92 to 300 gallons per capital per day (gpcd), with an average use of 170 gpcd per person (Golder and Anchor 2006).

2.3.2 Forecast of Future Demand

Future (2026) water demand in Washington for the one mile corridor of the Columbia River mainstem was carried out through a review of water rights applications on file with Ecology. For Washington's portion of the Columbia River basin, a projection of future water use by the agricultural and domestic/municipal sectors was conducted.

2.3.2.1 Water Rights Applications for the Columbia River Mainstem

Water right applications in Ecology's WRTS database were reviewed for Washington's 1-mile corridor along the Columbia River mainstem, and are summarized in Table 5 below.

Table 4**.** Summary of new water rights applications (ground and surface water) in WRTS in 2006 within one mile of the Columbia River mainstem upstream of Bonneville, with estimations of the total ac-ft per year associated with these rights (Golder and Anchor 2006).

Water Use	Number of Applications	Total annual ac-ft represented
Agriculture	195	211,323[a]
Domestic	214	86,849[b]
Commercial/Industrial	36	82,237[c]
Environmental	6	12,181[d]
Unidentified	4	2,211
Total	**455**	**394,801**

[a] To fill in Q_a for records that did not have this value, annual irrigation duties were calculated for the set of applications containing both acreage and Q_a. The average annual irrigation duty was 3.41 ac-ft per acre for groundwater applications and 3.83 ac-ft per acre for surface water applications.
[b] Total ac-ft were calculated from a total instantaneous use of 242 cfs, by assuming that annual use would be 50% of continuous use. This converts to a peak factor of 2, consistent with Washington State Department of Health guidance. Based on average per capita water use of 170 gallons per day per person, this is equivalent to a population of just over 450,000 people.
[c] This assumes the same peaking value as domestic water. However, this likely underestimates the amount of annual water use somewhat, because water is often used on a more continuous basis for industrial/commercial operations.
[d] Assumes continuous use of water. If these applications are intended for summer instream flow purposes, annual use would be lower.

[2] Group A water systems include those that regularly serve 15 or more connections or serve 25 or more people per day for 60 days or more (WAC 246-290). Other systems are classified as Group B systems.

Based on this method, the total annual water needed for agriculture, as represented by a combination of water right applications (211,323 ac-ft) and estimated interruptible water rights along the mainstem (163,000 ac-ft), was estimated to be 374,323 ac-ft per year (Golder and Anchor 2006).

2.3.2.2 Projections of Future Water Use for Agriculture and Domestic/Municipal

A second forecast of demand was carried out by making projections of future water use by two sectors: agriculture and municipal/domestic (including commercial and industrial).

Forecast of Future Agricultural Water Use

Changes in agricultural demand were forecasted by researchers at WSU using two contrasting methods: a Vector Autoregression (VAR) model and a survey of expert opinions (Wandschneider et al. 2006). First, a VAR model was used to determine crop production trends on a county-wide and regional basis for the top 25 crops (accounting for over 95% of farm gate revenue in the Columbia River basin), using USDA National Agricultural Statistics Service data on production and acreage from 1981- 2004 for most crops. Past trends were then used to project potential future production in 2025. This type of analysis captures factors that impact crop production that have occurred in the historical period, but will not capture factors that affect crop production that have not occurred in the historical period. Forecasts using this model can only be made if stable relationships exist between variables in the VAR equations. Unfortunately, it was not possible to forecast acreage for wine grapes or alfalfa. Overall, little or no increase in agricultural acreage was expected. However, the expected range for changes in total acreage was also quite large, with changes expected to be between an increase of nearly one million acres and a decrease of 750,000 acres at a 95% confidence level.

This general picture of stable irrigation demand was confirmed by the second analysis, a survey of experts' opinions about future crop production and water use for major crops, which suggested that participants believed that water demand would increase for wine grapes and cattle producers, but would remain stable for potatoes and apples/other tree fruit (Wandschneider et al. 2006).

Together, these estimates of future agricultural water use suggested less agricultural demand for water than the water rights applications (which suggested a growth in irrigation demand of about 211,323 ac-ft per year by 2025, 0.35% per year, or 9% by 2025). However, Golder Associates and Anchor Environmental (2006) pointed out that large projects have the potential to change this generally stable picture. Converting all interruptible rights to uninterruptible rights would require an additional 163,000 ac-ft per year. Converting the Odessa Region acreage surface water from groundwater would convert an additional 170,000 acres to surface water supply, while enlarging the Columbia basin Project to its full capacity would irrigate an additional 400,000 acres (Golder and Anchor 2006).

Forecast of Future Municipal/Domestic Water Use

Municipal/domestic (including commercial and industrial) water use growth was projected using the Washington State Office of Fiscal Management (OFM) population projections. On average, the population of all counties in the Columbia basin was projected to grow approximately 20% (350,000 people) by 2025. At an average per capita water use similar to current use levels (170 gpd), these populations would demand an extra 67,400 ac-ft per year. This is similar to the projected demand calculated by applying the OFM growth rate to the 2004 USGS estimates of current public and self-supplied domestic water use, 52,500 ac-ft per year. Assuming that the commercial/industrial water demand would grow at the same rate as population, an additional demand of 42,000 ac-ft per year is projected for 2025 for the counties within the Columbia River basin.

2.4 Overview of Anticipated Future Climate Conditions and Impacts

2.4.1 Current Evidence of Climate Change

A growing body of evidence, documents that the climate of the Pacific Northwest has changed over the last century. These changes cannot be explained by climate variability alone. The observed changes in the region are consistent with the scientifically accepted projected global and regional climate change impacts.

Average temperatures across the PNW have risen about 1.5 degrees F over the past century, with some areas experiencing increases up to 4 degrees F (Mote 2003) (Figure 12). Warming has occurred in rural and urban areas, with the highest rates of warming during the winter, and at lower elevations (Mote 2003)

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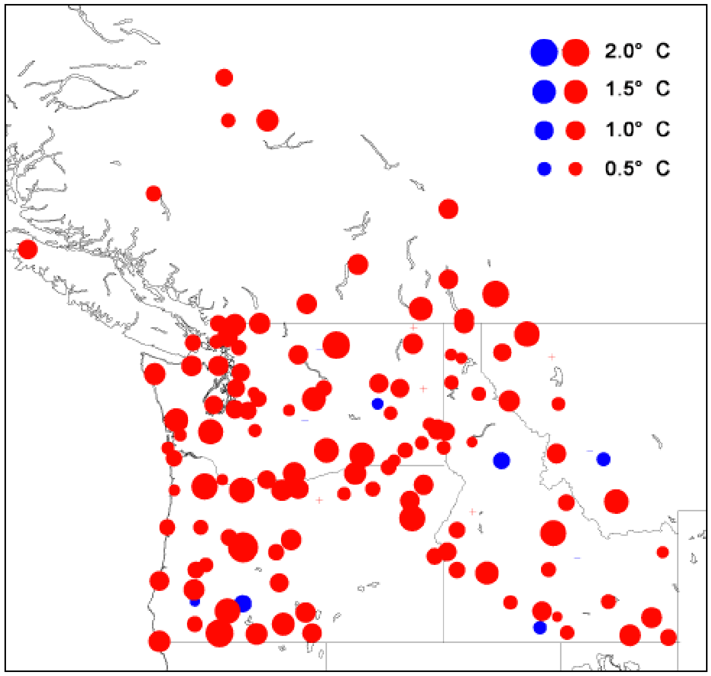

Figure 8. Trends in average annual temperatures across the Pacific Northwest, 1920-2000 (adjusted weather station data from Historical Canadian Climate Database and the U.S. Historical Climate Network) (from UW/NOAA JISAO, CSES 2011a with permission).

A warmer climate has led to changes in the timing of streamflow. In much of the Columbia River basin, a significant amount of precipitation falls during the winter as snow. As the snowpack melts in spring and early summer, this water (which can represent as much as 50-80% of annual streamflow) is released (Stewart et al. 2005). Higher temperatures mean that more precipitation falls as rain during the winter, and that snowmelt occurs earlier in the spring. Over the last 50 years, the peak of spring runoff has shifted from a few days earlier in some places to as much as 25 to 30 days earlier in others (Stewart et al. 2005; Hamlet et al. 2007). As further evidence of this same trend, average snowpack on April 1st (a key indicator of water storage available for the warm season) has already declined substantially. In the Cascade Mountains, April 1 snowpack has declined about 25% over the last 40 to 70 years, with most of this due to the increase in cool season temperatures (Figure 13; Mote 2006). This has direct implications for the availability of water because the snowpack acts as a natural reservoir in much of the Columbia River basin, storing the water for use during the summer when supply is otherwise scarce and demand from agriculture and other uses is high.

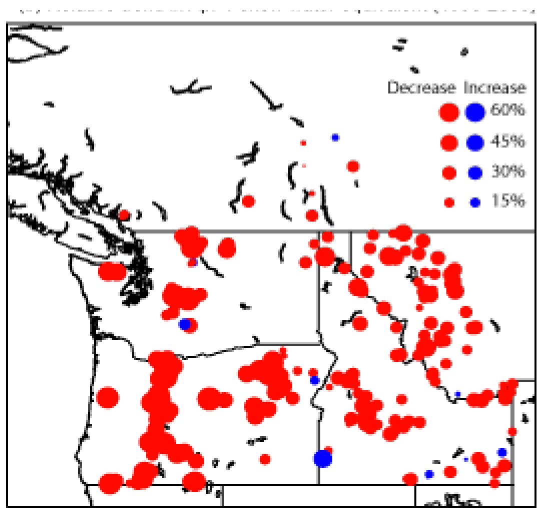

Figure 9. Relative trend in April 1 snow water equivalent (1950-2000) (from UW/NOAA JISAO, CSES 2011b with permission).

Overall precipitation in the PNW has changed over the last century due to regional climatic cycles, but analysis of precipitation patterns across the U.S. suggest that global warming has so far played a relatively minor role in determining precipitation patterns (Hamlet et al. 2007; Mote et al. 2005a). Variability in precipitation during the cool season has increased since about 1973 (Hamlet and Lettenmaier 2007). Although evidence to suggest what has caused this phenomenon is lacking, the effects are seen throughout the West, suggesting a large-scale climatic influence. Overall, however, flooding risks in the Columbia basin do not seem to have increased greatly in the last century, though flooding risk does seem to have increased in some costal drainage basins where winter temperatures favor a combination of rain and transient snow (Hamlet and Lettenmaier 2007).

2.4.2 Anticipated Future Changes Due to Climate Change

Climate models suggest that precipitation and temperature changes will continue and intensify in the next century. Warming is anticipated over at least the next few decades even if emission of greenhouse gasses is stabilized or reduced, due to greenhouse gases that have already been emitted (Mote et al. 2005b). Later in the century, rates of change increasingly will be influenced by whether human actions collectively accelerate or slow emissions of the gases that contribute to warming and associated climatic changes. Temperature changes are projected to be in the range of 1 degree F to 5.0 degrees F over the next 50 years, with a best estimate of about 2.5 degrees F (Mote et al. 2005b).

Although much less certain than temperature projections, precipitation changes are projected to be modest, and are unlikely to be distinguishable from natural variability until late in this century (Mote et al. 2005b). However, changes in precipitation seasonality are anticipated with increasing precipitation during the cool season and decreasing precipitation during the warm season (Mote and Salathe 2010). This change in precipitation seasonality exacerbates warming impacts on streamflow seasonality, reducing warm season flows and increasing cool season flows.

Although annual precipitation is not expected to change much in the mid-term, temperature changes will likely change water availability throughout the Columbia River basin. Specifically, higher temperatures will cause earlier snowmelt. The trend towards earlier peak spring runoff has already occurred and is projected to continue, with runoff shifting 15 to over 35 days earlier within this century (Stewart et al. 2004). April 1 snowpack is projected to decline as much as 40% by the 2040s (Payne et al. 2004). This will reduce the amount of water available during the summer and autumn, when flows are already normally low (Payne et al. 2004; Stewart et al. 2004). The summer dry period will be longer (Stewart et al. 2004) and flows will be lower in the late summer, both due to earlier snowmelt and because higher summer temperatures will lead to increased evaporation and higher water loss from vegetation. Reservoir management can compensate for some timing changes in areas of the basin with storage, but the overall level of storage in the Columbia River basin is lower (as a percentage of annual runoff) than some other major river systems in the U.S.

Simultaneously, higher summer temperatures could change demand for out-of-stream water in complex ways. Irrigated crops and natural vegetation are likely to have higher evapotranspiration (loss of water through evaporation and plant transpiration) rates and thus need more water (Stockle et al. 2010b). Decreases in summer precipitation could also increase irrigation demand because irrigation demand is the crop water requirement beyond what is provided by rainfall. Some harvested crops may be planted earlier and reach maturity earlier, which could increase demand for some crops earlier in the season, but reduce demand later in the season. Meanwhile, higher summer temperatures could also cause an increase in domestic water demand.

Demand in the summer may also be higher for instream water. Summer demand for hydropower is likely to increase due to increased use of air conditioning (Casola et al. 2005). Simultaneously, in many areas, lower summer streamflows and higher summer water temperatures will likely stress salmon, trout, and steelhead that prefer colder water temperatures (Casola et al. 2005).

These temperature-driven changes in water supply and demand have the potential to seriously stress the Columbia River basin water supply system, which was built to reliably deliver water under historical conditions. As temperature projections are more robust than precipitation projections, these highly temperature-driven impacts on surface water availability should be considered in long-term water resource planning (Barnett et al. 2005). Climate change is thus incorporated as an important feature of this Forecast, to provide information that will help legislators, water managers, and agency professionals begin to plan for future conditions that will likely be different than what we have experienced in the past.

3.0 Methodology

This chapter outlines the methodology we have used, and includes the data sources, a description of the various components of the model, as well as a description of the integrated modeling framework.

3.1 Data Sources for Integrated Modeling

3.1.1 Climate

3.1.1.1 Historical Climate Scenario

Climate information is one of the primary drivers of the hydrologic model. The model requires precipitation and temperature data at a daily time step. In addition, surface wind speed data, downward short and long wave radiation and vapor pressure deficit are required. We use the gridded datasets at 1/16 degree spatial resolution created by Elsner et al. (2010). The gridded dataset for temperature and precipitation is based on methods outlined in Maurer et al. (2002) and Hamlet et al. (2005) and accounts for correction for important systematic biases, such as the influence of orography when gridding temperature and precipitation observations. Wind speed values are based on the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis products (Kalnay et al. 1996). Other variables were derived from the daily temperature range or mean temperature as described in Maurer et al. (2002).

3.1.1.2 Future Climate Scenarios

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) archived results for 21 Global Climate Models (GCM) for multiple greenhouse gas emission scenarios (Mote and Salathe 2010). Mote and Salathe (2010) compared the performance of the GCMs over the Pacific Norwest area and concluded that all the GCMs have precipitation and temperature biases and there is no one GCM that is ideal for the area. Therefore we decided to use 5 different GCM/emission scenario combinations based on discussions in Mote and Salathe (2010) such that they captured the entire spread of temperature and precipitation change projections for the area for the 2030s. This includes four GCM/emission scenario combinations that represent the four possible combinations of extremes in projected P and T changes as well as a GCM/emission scenario combination (PCM1 B1, IPSL A1B, CCSM3 B1, CGCM3.1 t47 B1) that represents the central tendency (HADCM B1). The GCM results were downscaled to the $1/16^{th}$ degree resolution and the hybrid-delta change method (see Elsner et al. 2010 for details) was applied to them create gridded data products for the 2030s for the five future climate scenarios. The Elsner et al. (2010) downscaled data were created for the 2030s for this project by the University of Washington Climate Impacts Group.

3.1.2 Land Cover

Land cover and its parameterization are important drivers of evapotranspiration, interception, infiltration and the runoff components of the hydrologic cycle. Elsner et al. (2010) used land cover classification derived from Maurer et al. (2002) for running the Variable Infiltration Capacity (VIC) model (which is described in detail below) over the PNW (Table 6). This dataset was based on the University of Maryland global vegetation classification dataset (Hansen et al. 2000) and is described in Maurer et al. (2002). For each of the 1/16th degree grid cells, proportions of vegetation classes (Table 6) within the grid cell were provided. When the proportions did not add up to one, the remaining fraction was treated within VIC as bare soil. The original land use classification used by VIC (before our coupling of it to CropSyst) has only one class categorized as cropland and is parameterized as corn. For incorporating crops into the modeling framework (described in more detail below), we extended the VIC land use data to include a full range of crop types (Table 7). The complete list of specific crops is given in Table 8**.**

The crop land data layers from a) the Washington State Department of Agriculture (WSDA) [dataset of year 2008] and b) the United States Department of Agriculture (USDA) [dataset of year 2009] were used to identify crop distributions within each VIC grid cell in the US. For the Canadian part of the Columbia River basin, the crop model was not invoked and we retained the Elsner et al. (2010) land cover characterization.

Table 6. Vegetation classes in the original VIC implementation

Class number	Vegetation class
1	Evergreen Needleleaf
2	Evergreen Broadleaf
3	Deciduous Needleleaf
4	Deciduous Broadleaf
5	Mixed Cover
6	Woodland
7	Wooded Grasslands
8	Closed Shrublands
9	Open Shrublands
10	Grasslands
11	Crop land (corn)

Table 7. The crops selected for simulation by VIC-CropSyst

Main crops		**Generic vegetables**	**Lentil/ wheat/ cereal types**	**Berries**	**Other pastures**	**Other fruit trees**
Winter Wheat	Lentil	Onions	Oats	Caneberry	Grass hay	Pear
Spring Wheat	Mint	Asparagus	Bean, green	Blueberry	Bluegrass	Peaches
Alfalfa	Hops	Carrots	Rye	Cranberry	Hay	
Barley	Grape, Juice	Squash	Barley		Rye grass	
Potato	Grape, Wine	Garlic	Bean, dry			
Corn	Pea, Green	Spinach	Bean, green			
Corn, Sweet	Pea, Dry					
Pasture	Sugarbeet					
Apple	Canola					
Cherry						

3.1.2.1 Washington State Department of Agriculture Information

The cropland data layer from the WSDA is the primary source of crop distribution information within Washington state (Figure 14**)**, and is more detailed than the USDA dataset for crop distribution within Washington. This dataset also provides information on irrigation method, crop rotation (if used) and the dates of survey. The information on irrigation methods was used in the new land cover characterization to identify whether or not the crop was irrigated. Information on irrigation efficiencies from other sources (National Agricultural Statistics Service (NASS) and irrigation guide books) was then assigned to these irrigation methods. This allowed us to estimate on-field irrigation water losses within Washington state.

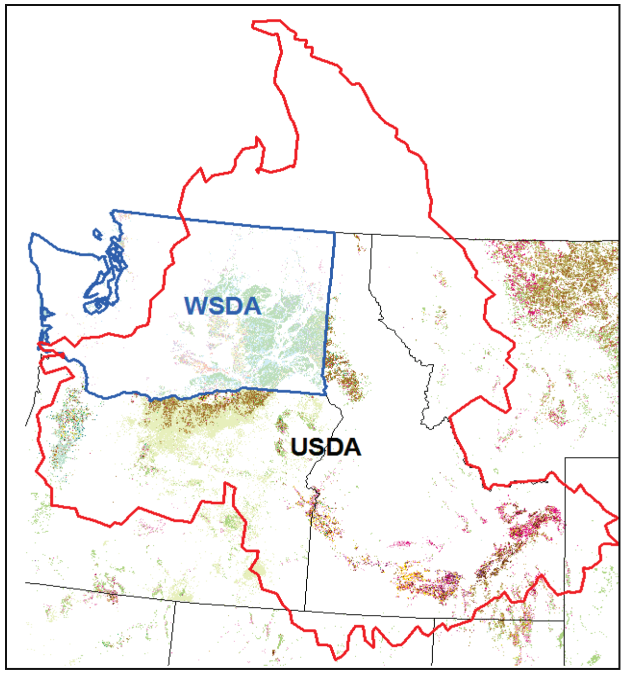

Figure 14. Cropland data layer from WSDA (within Washington state) and USDA (other states). No crops were simulated in the Canadian portion of the Columbia River basin; this portion was simulated using the original VIC land cover parameters (Table 6).

3.1.2.2 United States Department of Agriculture (USDA) Information

The cropland data layer from USDA is a nation-wide dataset based on the National Land Cover Dataset (NLCD) from the US geological Survey (USGS). It is derived by re-classifying the crop class within the NLCD data into more refined crop classes. This dataset was used in this project to derive crop distribution in the US part of the Columbia River basin outside of Washington. This however does not have information on irrigation methods and we used simple rules to irrigate crops outside of Washington state. High value crops such as corn, fruit crops, potato were always irrigated and other crops were never irrigated. The irrigation methods were assigned based on the most dominant type of irrigation for the crop in the WSDA dataset. For example, if sprinkler was the dominant irrigation type for potato in Washington, potato was always irrigated by sprinkler method outside of Washington also.

3.1.2.3 Crop Yield

The National Agricultural Statistics Service (NASS) provides yield statistics by crop and for each county; we used this information to calibrate simulated yields as described in Section 3.4.8.2. We used yield data for the period of 1997 to 2006.

3.1.2.4 CropSyst Parameters for Crops

CropSyst crop parameters describe phenology, canopy growth, transpiration, biomass production and yield. Parameters were provided for a basic set of crops, as shown in Appendix A. These parameters are based on well-known values from model applications in the region and elsewhere in the world for the last 15 years. Other crops were described by approximation to the basic set. Biomass production and yield information for other crops that have small production acreage were not readily available. For these crops, the primary parameterization emphasis was on canopy cover and water use by approximation to crops in the basic set and thus yield outputs for these crops should not be considered definitive.

3.1.3 Soils

3.1.3.1 VIC Soils

For soil characteristics, we used the gridded 1/16th degree resolution soil file developed by Elsner (2010) which is based on Maurer (2002) which in turn is based on gridded datasets developed as part of the Land Data Assimilation System (LDAS; Mitchell et al. 1999) project.

3.1.3.2 CropSyst Soils

The original soil hydraulic properties data (used by the VIC model) were found to be incompatible with crop growth simulation as there was a uniform distribution of a few key soil parameters for each of the three VIC soil moisture layers. Crop growth algorithms are relatively sensitive to this vertical distribution. Therefore, the soil parameter import utility included in the CropSyst Suite software package was used to generate CropSyst soil parameters. The soil properties were taken from the STATSGO2 soil survey database provided by the USDA NRCS. (http://soils.usda.gov/survey/geography/statsgo). The predominate agricultural soil component occurring at the centroid of each cell of the study area grid was selected as the representative soil description for the entire cell. When the centroid fell in water, urban areas, or non-agricultural land, then soil data from the nearest adjacent cell were used.

3.1.4 Water Management

3.1.4.1 Water Rights

This information was available to us for the Washington state portion of the study area only; we used the Washington Department of Ecology water rights database. The database has information related to the water right priority date, purpose of use, appropriated water amount, point of withdrawal/diversions and the place of use of the water right. We used this information primarily to model the curtailment process of water rights. Curtailment or interruption of certain water rights happens when there is insufficient water to meet all demands including instream flow demands. The Department of Ecology provided us a list of interruptible water rights along the Columbia mainstem, Snake River, three Water Resources Inventory Areas (WRIAs) in the central Washington region (Methow, Okanogan, Wenatchee) and three WRIAs in the Eastern

Washington Region (Walla Walla, Little Spokane and Colville). We used this list in conjunction with the water rights database to locate the grid cells that rely on interruptible water rights (Figure 15). The interruptible water rights include both surface and groundwater rights. However, for this study we modeled curtailment of surface water rights only. Figure 15 does not show proratable cells in Yakima. In the absence of reliable information for the Yakima currently, we apply prorationing in Yakima over all grid cells.

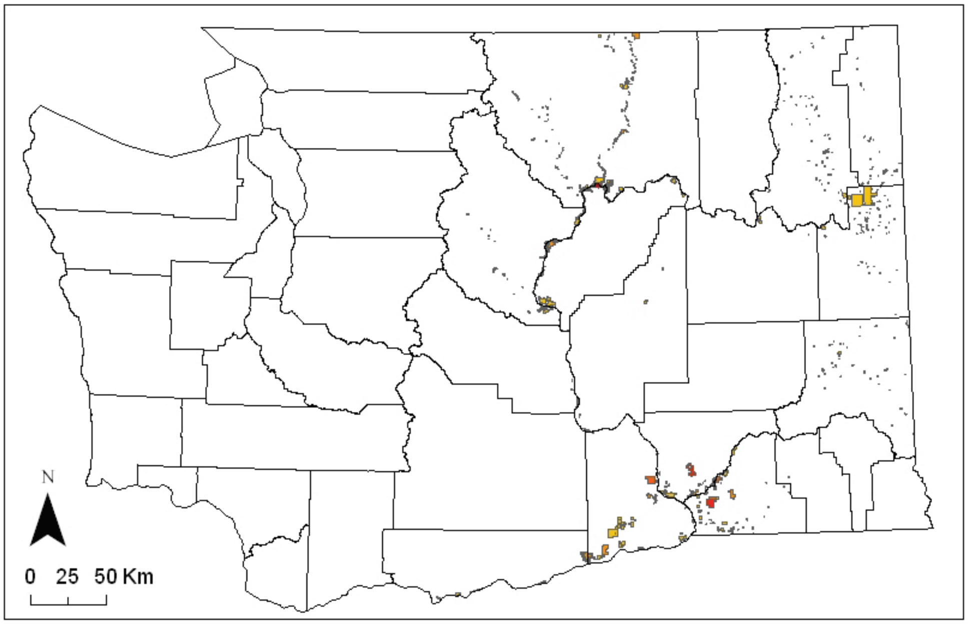

Figure 15. Places of use of interruptible water right holders in Washington.

3.1.4.2 Instream Flow Rules

Instream flow rules at different locations in Washington state were used to determine whether or not there is a need to curtail interruptible water right holders. Interruptible water rights are those that can be curtailed in low flow years. The instream flow targets, on which curtailment decisions are made, may be based on Washington Administrative Codes (WAC) or low flow provisions inserted into individual water rights called Surface Water Source Limitations (SWSL). Tables related to WAC rules for all locations along the Columbia mainstem and tributaries can be found in Appendix B. Because it was not feasible for us to read low flow provisions related to SWSLs from each individual water right, we assumed that they correspond with WAC rules. In the WRIAs belonging to the Yakima region, interruption of rights is based on a different mechanism. Instead of the binary "water on/water off" process in other areas, the Yakima follows a system of prorationing of interruptible water right holders. We followed the details provided in USBR (2002) to account for this. Prorationing is based on the calculation of the Total Water Supply Available (TWSA) every year. This includes streamflow, usable return flows, and reservoir storage. The level of proration is determined by matching the TWSA against demand as detailed in USBR (2002).

3.1.4.3 Reservoir Operations

The reservoir operation rules for the Columbia mainstem are exactly as used by Hamlet et al. (1999). Reservoir operation rules in Yakima are simplified rules based on (USBR 2002) as described in Section 3.4.4.3 below.

3.1.5 Streamflow

3.1.5.1 Naturalized Flows

We follow a methodology of bias correcting simulated stream flow data to adjust for model bias as described in Section 3.4.6.1 below. To bias correct simulated streamflows, we need "naturalized" or "reconstructed" stream flows for which the effects of human intervention have been removed from observed flows. This information was collected from several sources for 148 stations in the Columbia River basin by the University of Washington's Climate Impacts Group (UW CIG) and used by Elsner (2010) and for this study. For locations where this information is not available, it was not possible to perform bias correction.

3.1.6 Diversions

Year 2008, 2009 and 2010 irrigation diversion data for Bank's lake, which supplies water to the Columbia Basin Project area in central Washington, were provided to us by the Washington Department of Ecology. This was used a benchmark to verify VIC-CropSyst simulated irrigated demand and to get an estimate of channel conveyance losses.

3.1.7 Municipal Demand

3.1.7.1 Municipal Data Sources

Municipal forecasting in Washington state relied on data from water system plans submitted to the Washington State Department of Health from the one to three largest public water systems in each WRIA. These plans generally captured a majority of residents in a WRIA. For those municipalities where data allowed, municipally-supplied industrial growth was also included, and was assumed to occur at the same rate as population growth, based on the difficulty of accurately forecasting industrial use using other methods.[1] Self-supplied industries were outside the scope of this Forecast. One challenge was that the water system plans were developed across a variety of years so consistent years of analysis were developed. The year 2000 was used to provide a common base so populations and supplies were scaled. Projecting forward to 2010 caused a small (0.3%) difference between OFM total County level population figures and our population estimates.

1 Not all water supply plans include industrial use information; therefore, this could not be included for all WRIAs.

Using county-level population estimates obtained from the Washington State Office of Financial Management (www.ofm.wa.gov/pop/gma), city populations were counted in their primary WRIA, while projected county-level population growth outside of cities was distributed evenly by WRIA. By subtracting major urban area population from the total population and dividing by the county area, average rural densities for each county could be determined. Many of the 2030 urban area populations were estimates based on OFM county growth projections as specific growth rates for smaller communities were generally unavailable except when specifically discussed in the water system plans. Overlaying and summing the appropriate WRIA areas on top of the contributing county areas in GIS allowed "rural" WRIA populations to be determined. Urban populations were added according to their geographic location so total population could be determined.

3.1.7.2 Per Capita Water Usage

These figures were used to compute an Average Daily Demand (ADD) in terms of gallons per capita per day (gpcd). In some instances, diversions were much higher because of system leaks. Calculations of total WRIA water demand assumed that all people in the WRIA would use the average demand of nearby municipalities.

3.1.7.3 Consumptive Use and Waste Water Treatment Plant Return Flows

Consumptive use was estimated by examining the difference between water diversions and discharges at corresponding wastewater treatment plants (WWTP). This approach has been used by others while recognizing the potential for discrepancies due to municipal inflow and infiltration. Evidence from other western locations shows that loss or addition of flow due to ground water exchanges in aging wastewater collection systems can be significant. The Utah Division of Water Resources has traditionally estimated the fraction between winter (indoor) water diversions and wastewater discharges to be approximately 0.90 (Oregon uses 0.80-0.90) (Cooper 2002). However, a study of 52 municipal systems in Utah found great variability in this ratio (Hughes 1996). Among the 52 municipal systems 63% suffered from excess infiltration or exfiltration, with 17 ratios greater than 1.0 and 16 ratios less than 0.70. The remaining systems averaged a supply/effluent ratio of 0.83 during the winter. Similar analysis of summer flows revealed a return flow ratio of 0.51 indicating nearly half the flow is used for outside irrigation (Hughes 1996).

In our analysis, 28 of 34 WRIA produced values where wastewater treatment plant discharges were less than diverted amounts, producing positive consumptive use values. The average of the 28 positive values was substituted for the six negative values when calculating consumptive uses.

3.1.7.4 Integration with VIC-CropSyst Modeling

Municipal demands were incorporated into modeling of water supply and agricultural water demand by withdrawing consumptive demands from the surface water system when water system plans or other evidence confirmed that municipal systems were supplied by surface water, or by ground water in close hydraulic continuity with surface water supplies.

Growth in rural demand will likely be met by ground water supplies, but it was assumed that domestic wells would be shallow enough to impact surface water flows. Because municipal systems account for only about 10% of consumptive water use in the Columbia River Basin (Lane 2009), economic scenario analysis (to explore the impacts of variations in economic growth and trade on water demand) was not carried out for the municipal forecasting.

3.2 Economic Forecasting

Changes in agricultural production and the demand for water for irrigation in the future will depend on factors internal and external to Washington. A set of economic scenarios were developed to forecast these changes. A range of methodologies grounded in basic economic concepts were used to explore these scenarios. The fundamental economic framework of supply, demand, and market equilibrium serve as the starting point. A market equilibrium consists of market clearing prices and quantities where all goods produced are sold. Supply and demand schedules show the relationship between price, quantity supplied, and quantity demanded of a good by producers and consumers. The concept of an equilibrium means that given current conditions, the market has settled on a particular price and quantity which will not change unless something shifts supply or demand schedules such as income, population, production technologies, or resource constraints.

Putting these relationships into mathematical terms, a market is defined by three relationships: supply, demand, and a market clearing condition.

$$Q^d = D\left(P, \mathbf{Z}\right): \text{ Demand}$$
$$Q^s = S\left(P, \mathbf{W}\right): \text{ Supply}$$
$$Q^d = Q^s = Q: \text{ Market Clearing}$$

Demand is a function of prices and a vector of exogenous demand shifters **Z.** Supply is a function of prices and a vector of exogenous supply shifters **W.** The region is the state of Washington so that state production is equal to state consumption plus exports to other states and countries minus imports. The objective is to identify a new market equilibrium representing future macroeconomic and biophysical conditions circa 2030. Displacement from the current equilibrium condition occurs due to changes in the exogenous factors. Because agriculture is a small part of the total national economy in the U.S., it is safe assume that income for most households does not depend on agriculture. The same is true for population. Factors that affect supply but are exogenous to the regional agriculture economy are primarily related to climate. These relationships can be expressed in the form of equilibrium displacement by transforming the above equations into total log differentials where, for example $P^* = dP/P = d\ln P$ represents the percentage change in price (Davis and Espinoza, 1999).

$$
\begin{aligned}
Q^{d*} &= \eta^d P^* + \boldsymbol{\eta}^{\mathbf{Z}}\mathbf{Z}^* \\
Q^{s*} &= \eta^s P^* + \boldsymbol{\eta}^{\mathbf{W}}\mathbf{W}^* \\
Q^{d*} &= Q^{s*}
\end{aligned}
$$

The parameters η^d and η^s represent own-price demand and supply elasticities while $\boldsymbol{\eta}^{\mathbf{Z}}$ and $\boldsymbol{\eta}^{\mathbf{W}}$ are vectors of elasticities for the exogenous shifters. All together these are the structural parameters. Solving for the reduced form equations makes it possible to calculate percent changes in prices and quantities due to changes in exogenous factors. The reduced form equations are found by writing price and quantity as functions of the exogenous variables.

$$
\begin{aligned}
P^* &= \frac{\boldsymbol{\eta}^{\mathbf{W}}\mathbf{W}^*}{\eta^d - \eta^s} - \frac{\boldsymbol{\eta}^{\mathbf{Z}}\mathbf{Z}^*}{\eta^d - \eta^s} = \boldsymbol{\pi}^{\mathbf{PW}}\mathbf{W}^* + \boldsymbol{\pi}^{\mathbf{PZ}}\mathbf{Z}^* \\
Q^* &= \frac{\eta^d \boldsymbol{\eta}^{\mathbf{W}}\mathbf{W}^*}{\eta^d - \eta^s} - \frac{\eta^s \boldsymbol{\eta}^{\mathbf{Z}}\mathbf{Z}^*}{\eta^d - \eta^s} = \boldsymbol{\pi}^{\mathbf{QW}}\mathbf{W}^* + \boldsymbol{\pi}^{\mathbf{QZ}}\mathbf{Z}^*
\end{aligned}
$$

The parameters π are the reduced form elasticities. Changes in the exogenous variables are constants that are based on forecasts or projections that depend on factors outside of the regional agriculture economy. Price and quantity are both positively related to the magnitude of the elasticities of the exogenous demand shifting factors but are negatively related to the magnitude of the exogenous supply shifting factors. If incomes or population increase then consumption will increase inducing an increase in equilibrium price and quantity. The increase in price stimulates increased production, the magnitude of which depends on the supply elasticity and the price change. Ignoring any shifts in the supply schedule, which makes the first quantity in the equations above zero, helps in deriving a few key relationships. Highly elastic demand and supply schedules result in large changes in quantity relative to price changes while very inelastic demand and supply schedules lead to large changes in price and relatively smaller changes in quantity. Food demand tends to be inelastic. Higher income elasticities and larger changes in income lead to larger changes in equilibrium prices and quantities, all other things equal.

The equilibrium displacement equations can be indexed to explicitly account for trade where good *i* is exported from producing country *j* to importing country *k* (Mutondo et al., 2009)

$$
Q_{ij}^{s*} = \frac{Q_{ijj}^d}{Q_{ij}^s} Q_{ijj}^{d*} + \sum_{k \neq j}^{K} \frac{Q_{ijk}^d}{Q_{ij}^s} Q_{ijk}^{d*}.
$$

This simply shows that the percent change in supply in the exporting country is related to the percentage change in demand in the importing country multiplied by the share of production in country *j* exported to country *k*. It was beyond the scope of this project to explicitly model shifts in exogenous factors in importing countries because of data limitations and the number of good and country combinations. Instead, historical state level total exports by crop type are used to specify reduced form relationships that are used to forecast future changes in exports.

This framework does make restrictive assumptions which are summarized by Harrington and Dubman (2008). It lacks the richness of other economic modeling frameworks such as partial equilibrium and computable general equilibrium models. These other approaches were not feasible for this project because of the time and effort required to integrate with the biophysical modeling and water rights data. The strength of this framework is that it makes it possible to look at the impact of changes in underlying economic factors like income growth on regional agricultural production in a simple and transparent way.

3.2.1 Global vs. Regional Commodities

3.2.1.1 Global Commodities

Figure 16 compares the change in price and quantity from (P1, Q1) when supply is unit elastic (P2, Q2) and inelastic (P2, Q3) in response to an upward shift in demand that is perfectly elastic. The case of perfectly elastic demand applies to goods where any additional supply produced within the region can be absorbed by demand without a change in price. This is the case for the global commodities like wheat where Washington produces only a small portion of the global total and markets clear globally thanks to extensive trade and generally uniform quality. In terms of the original supply equation, $Q^{s*} = \eta^s P^* + \boldsymbol{\eta}^{\mathbf{W}} \mathbf{W}^*$, price can be assumed to be exogenous for these crops. In response to a given price change the response in Washington production is greater if the regional supply curve is relatively more elastic (Q2) than inelastic (Q3). For these crops regional production simply responds to global prices, so two pieces of information are used to forecast future production: forecast of future prices and supply elasticities.

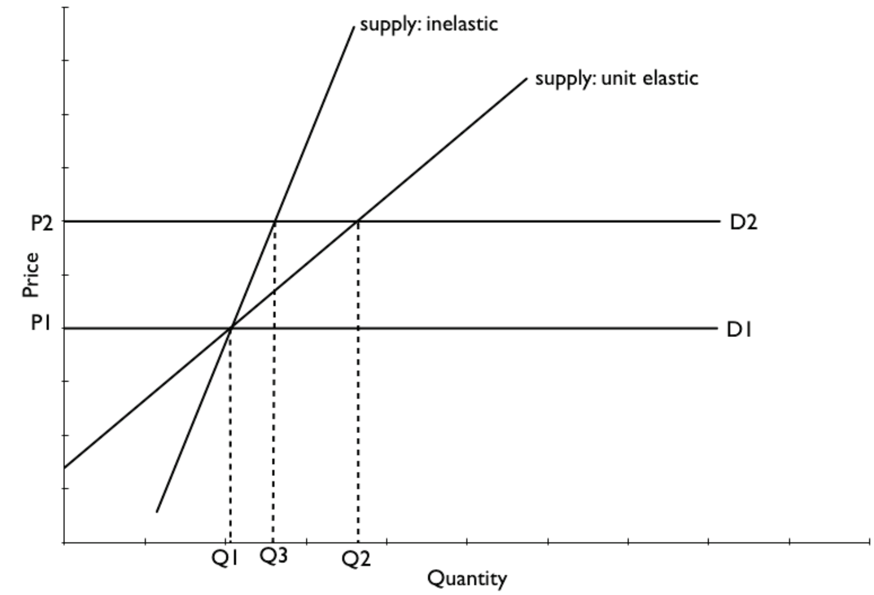

Figure 16. Supply and demand for global commodities.

Global commodity prices are determined by underlying structural relationships that determine supply and demand schedules, however, these are exceedingly complex because of the need to consider macroeconomic conditions, exogenous changes to supply and demand across a large number of countries, and barriers to trade. Considering these factors for each of the global commodities is beyond the scope of this report so we use historical price trends to forecast future prices and consult other forecasts that consider these issues in more detail. A fairly consistent conclusion across long-range forecasts is that major grain prices will fall slightly from current levels but will remain above historical averages (USDA, 2011). This slight reversal from recent price spikes has been conjectured to be the result of a slowing of the growth of crop use for biofuels, less frequent negative weather induced supply shocks to major wheat growing regions, and increased production stimulated by higher prices.

A common assumption within the equilibrium displacement framework in studies of US agriculture is to assume a supply elasticity of 1.0 for crop commodities. Sumner (2006) assumed a supply elasticity of 1.0 for corn, wheat, rice, and soybeans. For the rest of the world values were assumed to be in a range between 0.2 and 0.5. Harrington and Dubner (2010) compare their own model calibration to other studies and find that the assumption of supply response of 1.0 to be reasonable, although they warn that this assumption should be considered carefully. Their estimates of acreage responses cluster around 0.3 with higher values just above 1.0 and lower values near zero.

An econometric model of partial acreage adjustment was estimated for crops in Washington to provide estimates of supply response which were compared against other studies. Changes in plantings are assumed to be a function of the previous year's acreage and previous years' price movements.

$$A_t^* = \alpha + \sum_{i=0}^{n-1} \beta_i P_{t-i} + \gamma A_{t-1} + \varepsilon_t$$

Uncertainty is always involved in these sorts of estimates, although there is general agreement on conceivable ranges. Sensitivity analysis is performed to provide estimates of how much results would change if alternative values were used. As an example, if wheat prices are expected to increase by 5% and the acreage response for wheat in Washington is 0.33, then production from additional land being used for wheat production in the region would be

$$Q^* = \eta^s P^* = 0.3(0.05) = 1.5\%.$$

3.2.1.2 Regional Commodities

For crops like tree fruit, potatoes, vegetables, and other specialty crops, equilibrium price is a function of Washington production. Increased (decreased) production will decrease (increase) price where the magnitude depends on the elasticity of demand and the amount by which production increases (decreases). The market for these crops is shown graphically in Figure 17.

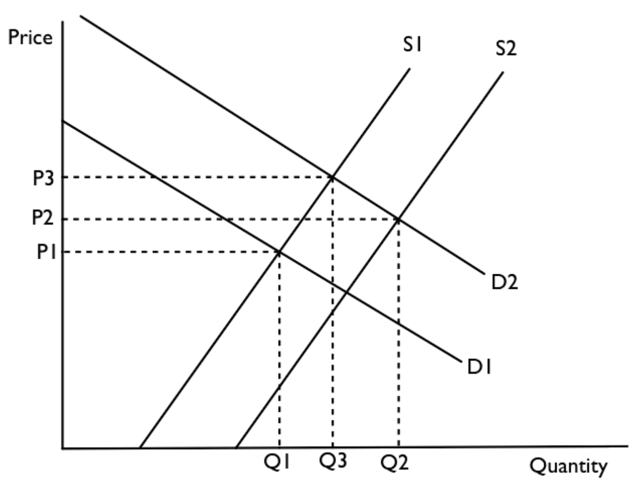

Figure 17. Supply and demand for regional commodities.

The initial market equilibrium (Q1, P1) changes due to a shift in either the supply or demand schedules, or both. If the supply curve shifts outward due to an event like additional water available for irrigation or technological change that increases productivity then the equilibrium quantity increases and price decreases. If the demand schedule shifts outward then quantity will increase. The direction of the price change depends on the relative shift in supply compared to demand and the slope of the curves. In Figure 17 the impact of the shift in demand is enough to result in an increase in price despite the fact that supply also shifted outward. Shifts in the supply schedule are considered in the water capacity scenarios. The economic growth and trade scenarios focus on changes in demand. In terms of Figure 17, this means that the supply schedule remains S1 while demand shifts from D1 to D2. This causes a movement along the supply curve to a new equilibrium price and quantity (Q3, P3) where a higher price stimulated producers to increase production.

Estimates of the change in equilibrium are taken from the relationships described in Equation 3. If there is no shift in the supply curve then the change in demand is given by

$$Q^* = -\frac{\eta^s \boldsymbol{\eta}^{\mathbf{Z}} \mathbf{Z}^*}{\eta^d - \eta^s}$$

The upper bound on the change in quantity occurs when supply is perfectly elastic. Estimating supply elasticities that are generally applicable is difficult so one simplifying assumption that can be made is to assume perfectly elastic supply which provides an upper bound on the change in supply for a given shift in the demand schedule (Howitt et al. 2008; Huppert et al. 2006). In Figure 18 when demand shifts from D1 to D2 the equilibrium quantity changes from Q1 to Q3 while the price remains at P1. If supply is not perfectly elastic then equilibrium is defined by (Q2, P2) where Q2<Q3 and P2>P1.

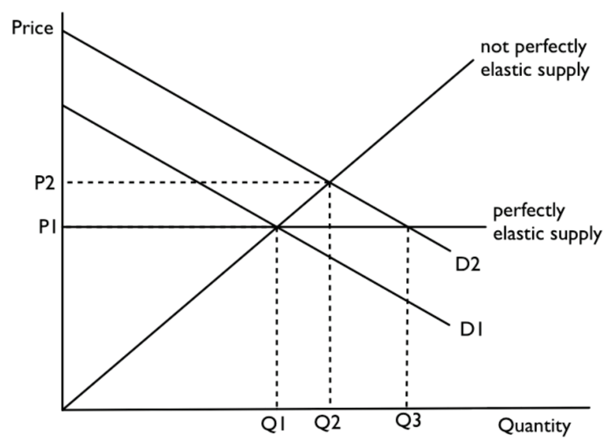

Figure 18. Change in equilibrium price and quantity assuming different supply responses.

In contrast to global commodities it is necessary to account for changes in factors that influence demand for regional commodities because changes in regional and domestic (U.S.) demand have a significant impact on regional prices and quantities. This is the motivation behind the economic growth and trade scenarios. For the economic growth scenario the vector **Z** consists of population and income. Demand price elasticities, η^d, tend to be in the inelastic range between 0 and 1 for most food items. Non-necessity foods like wine and steak tend to have more elastic demand schedules compared to basic staples like cereal grains. Food price elasticities are based on previous empirical demand studies. The USDA Economic Research Service maintains an online database of estimates of own-price, cross-price, and income elasticities.[2] Following Howitt et al. (2008), the impact of population is assumed to be unitary so that a 1% increase in population shifts demand upward by 1%. This assumption is plausible because it simply assumes that an additional person consumes the same quantity and mix of foods as the existing population. Even when there is no shift in supply it is necessary to have an estimate of the supply elasticity to determine the relative change in price and quantity as the equilibrium point moves along the supply schedule in response to a shift in demand.

Percentage change in population and income are based on the forecasts. Both these factors are assumed to be exogenous to (determined outside of) what happens in the regional agriculture economy. Combinations of low, medium, and high values for each are substituted into the equilibrium displacement equations to arrive at a new equilibrium price and quantity. The VIC/CropSyst model provides new estimates of yields that are based on changes in growing conditions. It was not possible to accommodate technological change that increases potential yields for crops.

3.2.2 Population and Income Forecasts

Consumption by Washington residents is calculated by converting US demand to Washington demand by assuming that in-state residents consume at the national average

$$Q^{d,WA} = Q^{d,US}\left(pop^{WA} / pop^{US}\right).$$

Population projections for Washington and the US are taken from the US Census Bureau Population Division for 2030 which are checked against a simple univariate statistical forecast model. The projections based on the 2010 Census are not yet released so the projections created are based on the 2000 Census but have been updated based on more recent trends.

3.2.3 Trade

In the absence of policies that prohibit trade, goods flow between regions depending on differences in comparative advantage, which can change as a result of technology, resource endowments, and transportation costs. Exports are an important source of demand for Washington agriculture. Approximately one-third of production in terms of cash receipts is exported to foreign destinations depending on the year (USDA NASS, 2009).

Figure 19 demonstrates graphically why trade occurs in terms of supply and demand relationships for the case of two countries and one good. In the absence of trade the market

[2] http://www.ers.usda.gov/data/elasticities/query.aspx

equilibrium for the two countries would be (Pnti, Qi) and (Pnte, Qe) for the importing and exporting countries, respectively. If trade is permitted to occur then there is just one price (Pt), ignoring transportation costs and other factors for simplicity, which is higher than the exporting country domestic price and lower than the importing country domestic price without trade. Trade also changes consumer surplus (pink), producer surplus (yellow), and total surplus (color shaded areas). The blue areas represent the gains to trade. The width of the red line, or the difference between quantity supplied and demanded, is the same for both countries because the amount exported has to be equal to the amount imported.

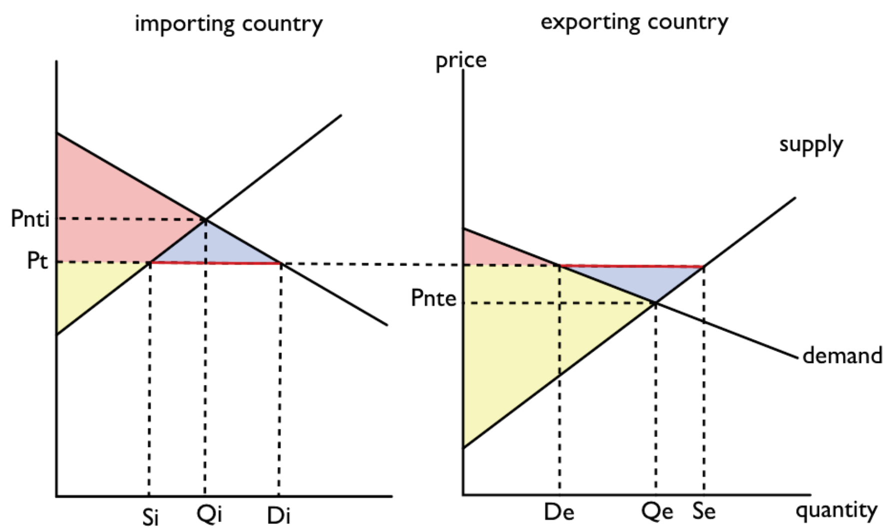

Figure 19. Market equilibrium supply and demand with trade.

The trade scenario is included to consider changes in production in Washington that could conceivably occur if shifts in foreign market supply or demand alter the demand for exports. The quantity exported and total supply increase if there is an upward shift in import country demand. This change in exports occurs without any change in the supply or demand schedules for the exporting country.

Ideally, a trade forecast would consider supply, demand, and trade agreements explicitly. A number of limitations restrict the extent to which this sort of detail can be accounted for in this study. There is a very large number of crops (40+) being modeled. An analysis of just one crop and all its foreign demand centers and relevant trade restrictions is a significant undertaking. For example, export markets and trade agreements for blueberries are very different than alfalfa. There are also a number of data limitations. Export data are provided in values that can be difficult to translate back into field level production quantities and acreage. Value of trade is based on prices at the port which includes margins that are added to the farm gate price. At the same time, physical measures of quantities or volumes can also be problematic to accurately translate back into regional production quantities (Jerardo, 2008) Also, most goods are exported to many countries. Changes in exports to each country depend on a number of importing country specific factors such as population and income growth, as well as income and price elasticities. Estimates of these values are limited in many cases. Agricultural trade flows are also strongly dependent on existing trade agreements, tariffs, and quotas. Changes in these policies can have large impacts on production. However, predicting the political factors that will determine when and if a change is likely to occur in the future is beyond the scope of this study.

For all these reasons a simple forecasting approach is used for the trade scenarios. While simplicity has its limitations there are also advantages. First, reduced form statistical forecasting based on historical trends has been shown to have a favorable level of performance relative to more complex and detailed models. In fact, there is a large literature on economic forecasting demonstrating that reduced form models outperform larger models that try to account explicitly for all the underlying factors (Sims 1980, Dorfman 1993). Kargbo (2007) compared the performance of commonly used reduced form time series models for analyzing agricultural exports and found that single equation models (ARIMA and Engle-Granger single equation) outperform multiple equation forecasts. Second, crops can be classified into a few general categories in terms of trade. Some crops are primarily consumed domestically so production is insensitive to trade fluctuations. Exports of global commodities like rice, corn, soybeans, and wheat are driven by the global price that depend less on specific country to country trade dynamics or agreements and more on aggregate supply and demand fluctuations. The more complicated crops to consider are crops with regional prices that are traded extensively but are often sensitive to specific trade arrangements or agreements, or supply and demand trends in a handful of countries. Examples in Washington are apples and alfalfa. In addition to the reduced form export forecast, additional analysis is provided for apples, alfalfa, and wine grapes because of their importance in terms of economic value, trade, and resource use.

3.2.4 Regional Water Policy Scenarios: Water Capacity Development and Cost Recovery

Modeling scenarios consider changes in the cost and availability of water for irrigation. The scenarios reflect potential changes in water management by the Department of Ecology. Before proceeding to give background on the methodologies used for these scenarios a brief summary is provided on the economics of water use for irrigation.

3.2.4.1 Economics of Water Use for Irrigation

Economists refer to the ***demand side*** and the ***supply side*** of a market where the market price for a good is determined simultaneously by both. The former describes the quantity of a good consumers are willing to buy at a given price, and the latter describes the quantity producers are willing to supply at a given price. In the example below, water is part of the supply side of the market that describes the production of an agricultural commodity. So, why is the term demand used? Economists use the term ***factor demand*** to make it clear that they are talking about the demand for a good that is a factor of production for another good, or something that is used to produce something else, as opposed to a final good that is purchased by consumers.

Consider the production of a single crop, call it **y**, on a tract of land. The only input is water, abbreviated as **w**. Suppose the transformation of water into **y** can be closely approximated by the formula $y=10w-w^2$. Graphically, this production relationship is represented in Figure 20.

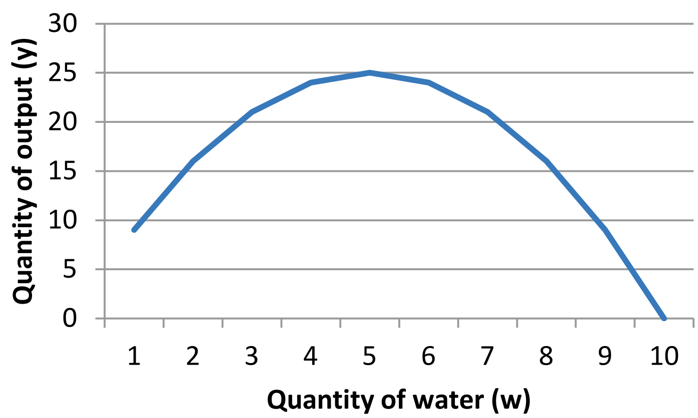

Figure 20. Quantity of output (y) produced for a given of input of water (w).

Initially, an additional unit of water increases output. The rate of increase is largest with the first unit. Each additional unit has an ever smaller positive effect until an additional unit of water reduces production. In this example, this happens at 10 units of water. This makes sense given that too much water can completely wipe out a crop, as can occur after an extreme rainfall event or flood.

Given information available to the producer at the time of planting, such as input costs and expected output prices, the producer chooses the quantity of water that maximizes net revenue, the difference between gross revenue and input costs. We denote input costs and output prices by p_W and p_y, respectively. The producer's objective is to choose the quantity of water that maximizes profit. Written out mathematically this is:

$$\text{Profit} = p_y y - p_W w = p_Y\left(10w - w^2\right) - p_W w$$

The far right side of the equation is derived by substituting for **y** according to the production equation given previously. Assume that the price received for the good produced is $p_y = 1$, and the unit price of water is $p_w = 0$. Identifying the quantity of water that maximizes profit at different values for p_w is what economists mean by *demand*.

The next task is to figure out what quantity of water maximizes profit. This can be done graphically, numerically (plugging in a bunch of numbers), or by using calculus. When water is free it is easy to use a graphical approach to figure out that the optimal quantity is the level that maximizes physical production. In the example given, production is maximized at 25 units when 5 units of water are applied. Putting these values into the net revenue equation shows that the profit earned by the producer in this scenario is $25.

To see how the profit maximizing quantity of water changes as the price of water changes assume that $p_w = 5$. As shown in Table 8, numbers can be plugged into the net revenue equation to see what produces the largest profit.

Table 8. Quantity of water that maximizes net revenue when water costs $5 per unit.

Quantity of Water	**Production**	**Price of Y**	**Price of Water**	**Net Revenue**
1	9	1	5	4
2	16	1	5	6
2.5	**18.75**	**1**	**5**	<u>**6.25**</u>
3	21	1	5	6
4	24	1	5	4
5	25	1	5	0
6	24	1	5	-6
7	21	1	5	-14
8	16	1	5	-24
9	9	1	5	-36
10	0	1	5	-50

It appears that 2.5 units of water maximize net revenue. Additional water above 2.5 units continues to increase production but the cost increase is larger than the increase in revenue.

We now have all the information we need to describe what economists' mean by "demand for water". There are a few things to make clear first. In economics, demand <u>does not</u> refer to a specific quantity. Rather, demand describes the relationship between the quantity of water that maximizes profit and water price. Another way to think of economic demand is as a **schedule** that informs how to fill in the blanks in the following statement:

"If the price of water per unit is <u>*blank,*</u> then I maximize profit by using <u>*blank*</u> units of water."

To refer to the optimal quantity of water for a given price, economists use the term **quantity demanded** to refer to the aggregate, or total, quantity of water demanded by all producers. Using the example described above, **demand** for water for irrigation is shown in Figure 21.

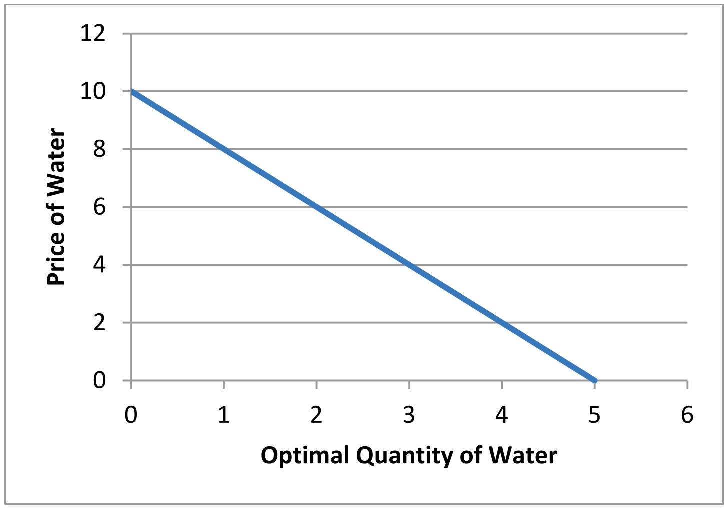

Figure 21**.** A demand curve for water.

When water is free the quantity of water demanded is 5 units. A price greater than zero will decrease the profit maximizing quantity of water. The producer will continue to purchase water at a certain price as long as the additional revenue generated by allocating an additional unit of water for production is greater than the cost. This does not necessarily mean that charging an additional per unit fee for cost recovery will reduce the total amount used because water use is not determined within a market. Many users only pay the transmission costs so they are likely to still use the same amount of water as they currently do even if an additional cost is added in. However, if this becomes large enough then the quantity they purchase will go down.

3.2.4.2 Water Capacity Scenarios

The water capacity scenario is based on specific projects that the Department of Ecology is considering that would increase the amount of water available for both in-stream and out-of-stream uses. Only out-of-stream irrigation uses are considered in this analysis. Each project being considered has an associated water quantity. In most cases this means issuing new permits for the irrigation of land that is currently under dryland production or has some other use. The value of additional production is based on per acre revenue estimates. Price information is not available for many of the crops in the model so enterprise budgets with estimates of costs and returns provide information on per acre revenue for a broad range of crops. A graphical explanation of the change in equilibrium price and quantity from issuing permits to irrigate land that previously was not irrigated is shown in Figure 22. This graph simply shows that production of irrigated crops will increase which will shift the supply curve outward resulting in a lower price and higher production. Water quantities associated with specific projects are shown in Figure 23 and Table 9.

The region wide economic impact of the additional production is translated into job and tax estimates using the input/output (I/O) modeling framework. I/O models track all of the linkages between industries in a regional economy. Change in industry output is followed through all backward linked industries that provide intermediate inputs and through household spending that is generated by income supplied by an industry.

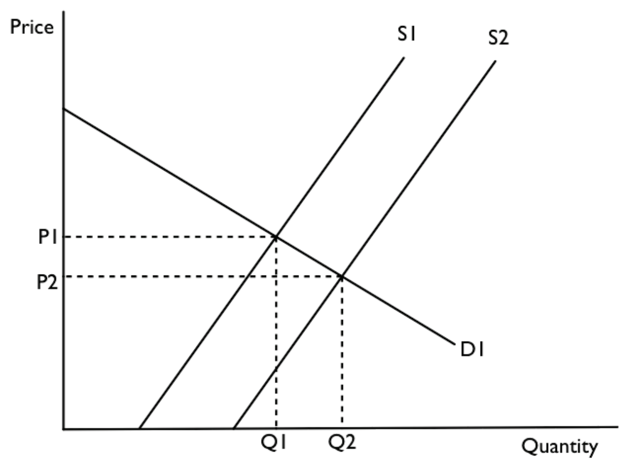

Figure 22. Change in equilibrium price and quantity in water capacity scenario.

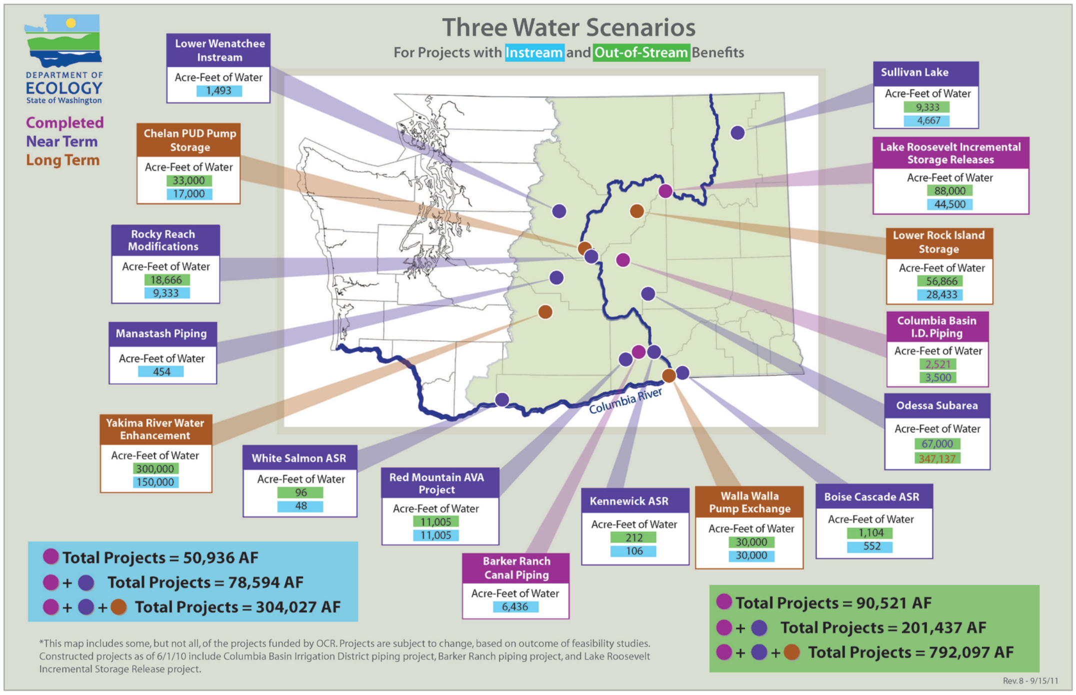

Figure 23. Map of OCR projects for Water Capacity Scenario.

Table 9. Water capacity projects and associated water quantities.

Water Capacity Scenario	Project	In stream (aft)	Out-of-stream (aft)	Counties
Low				
	Barker	6,436	0	N/A
	Columbia Basin ID Pumping	0	2,521	Grant
	Lake Roosevelt Incremental Storage Releases		15,000	ADAMS
			11,341	BENTON
			21,975	CHELAN
			3,579	DOUGLAS
			3	FERRY
			4,387	FRANKLIN
			8,687	GRANT
			765	KITTITAS
			6,323	KLICKITAT
			4,818	LINCOLN
			3,345	OKANOGAN
			2,075	SKAMANIA
			337	STEVENS
			5,364	WALLA WALLA
Medium				
	Lower Wenatchee	1,493	0	
	Rocky Reach	9,333	18,666	
	Manastash	454	0	
	White Salmon	48	96	
	Red Mountain	11,005	11,005	
	Kennewick ASR	106	212	
	Boise	552	1,104	
	Columbia Basin I.D. Pumping	0	3,500	
	Sullivan	4,667	9,333	
	Odessa	0	176,343	
High				
	Chelan PUD	17,000	33,000	
	Yakima River Water Enhancement	117,000	234,000	
	Walla Walla Pump Exchange			
	Lower Rock Island Storage			
	Odessa		115,000	ADAMS
			34,500	FRANKLIN
			69,000	GRANT
			11,500	LINCOLN

3.2.4.3 Water Pricing for Cost Recovery

The Office of the Columbia River is considering charging for water made available through new projects to recover direct costs of project development. This pertains primarily to issuing new rights that would result in newly irrigated land. Some of the additional water made available is to be used to address interruptible rights holders in drought years mainly along the Columbia mainstem and in the Benton County area.

Cost recovery would be achieved through a per unit fee charged to users. It is important to be clear about terms such as cost, fee, price, and value since these are often used interchangeably but have different, albeit related meanings. Water prices are determined differently than most other goods because there is typically not a well functioning market for water that determines prices. In this case, prices are set by the agency that manages and regulates water use. How then should prices be determined? Rogers, Bhatia, and Huber (1998) differentiate between two different types of full-cost pricing; full supply costs and full economic cost.

Full supply costs: includes capital charges and operation and management (O&M). Capital charges typically include depreciation charges, interest, treatment plants, and conveyance and distribution systems. Price equal to supply costs reflect long-run marginal costs.

Full economic costs: in addition to full supply costs, full economic costs include opportunity costs of water and externalities. Opportunity costs are the value of water when put to the highest valued alternative use. Externalities are costs imposed on others that are not internalized into the price. The full economic cost approach would improve the efficiency of water use by internalizing these costs. Negative externalities could include both economic costs to other users of water, and environmental externalities. Externalities can be positive such as the case where surface water diversions recharging groundwater aquifers.

Quantifying all of these costs on a project specific basis is beyond the scope of this research project. OCR's stated objective in considering cost recovery by charging for water is to recover some or all of the supply costs for given projects. A large number of projects are being considered and many are at a very early stage of consideration. If detailed capital costs and O&M costs were available then we could derive long-run marginal costs. Since it is not, we ask the opposite question. What costs could be recovered if a certain price were charged?

The prices considered are $25, $100, and $200 per acre foot. Other projects in the region have charged around $35 per acre foot. $100 would represent the high end of what has been observed in actual market transactions for agriculture in the region. The highest price of $200 is meant to represent a potential high price in the future under conditions where water resources are scarcer than they are now. In certain situations these costs may be enough to reflect capital charges, O&M, opportunity costs, and externalities, or they may not even cover capital charges. This is not a determination that we attempt to make. The cost recovery estimates from this study provide estimates that will provide OCR with a general idea of what costs could be recovered at given prices.

We use the standard net present value approach to convert the stream of payments received for charging for water over some number of years into the future into a single present value. The assumption that has the largest impact on results is the discount rate. The discount rate captures the fact that a dollar received a year from now is worth less than a dollar received now. This is because the dollar received now can be put towards another use that generates a return. At the very least it would generate interest. The approach developed under the Water Resources Development Act of 1974 is to base the discount rate on the average yield of long term government securities. A historical plot of this series is shown in Figure 24. This approach is not without controversy as it has been argued that the return on capital in private markets should be used, which would likely be higher (Powers, 2003). However, private markets typically entail more risk which in part determines the higher rate. Discount rates are historically low as of 2011 due in part to the sluggish economy which reduces the demand for borrowing. In this environment the opportunity cost of capital is lower than if the economy were growing at a faster rate. Taking all these factors into consideration three values of discount rates were used: 2%, 4%, and 6%.

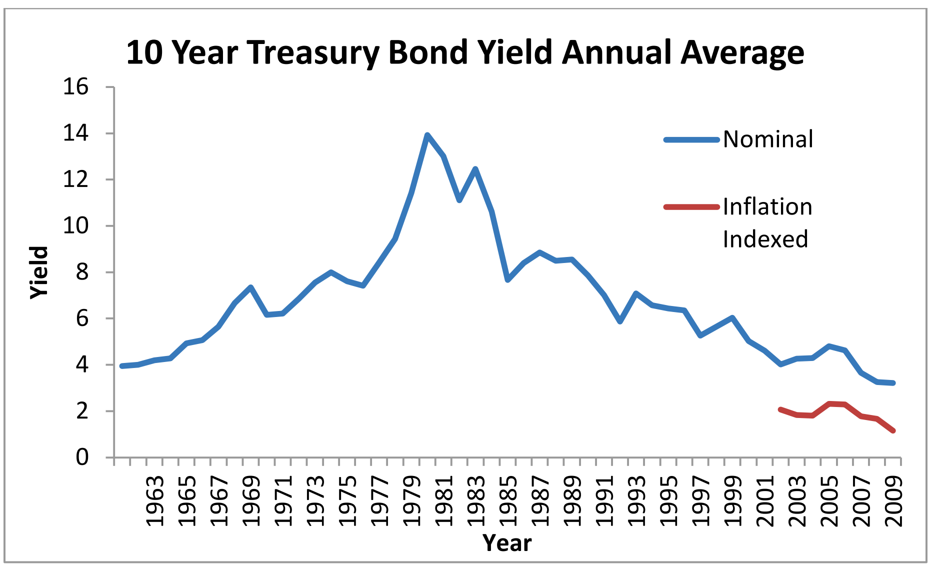

Figure 24. Average yield of long term government securities.

The cost recovery results are considered within the context of the water capacity scenarios. Once the discount rate is determined and the water quantity is known, the analysis is straight forward. We simply calculate the present value of the water charges over some number of years in the future. If the charges are made in perpetuity then the present value (PV) from a stream of payments an infinite number of years into the future is given by

$$PV = \frac{\text{Price} \times \text{Quantity}}{i}$$

If charges are made over a finite number of years then the present value would be

$$PV = (\text{Price} \times \text{Quantity}) \times \frac{1-(1+i)^{-t}}{i}$$

The only additional element that needs to be considered is the relationship between quantity of water demanded and price. In a meta-analysis of studies estimating irrigation demand elasticities, Scheierling et al. (2005) show that estimates can vary widely from almost perfectly inelastic to highly elastic depending only on the type of study (mathematical programming, econometric, etc.). Because there are only a small number of cases of water markets in Washington it is not possible to have empirically estimated irrigation demand elasticities at any sort of significant range of water prices. Therefore, we rely on previous studies to provide estimates of elasticities specific to crops and water prices. Producer response is more elastic as water price increases.

3.3 Overview of the University of Washington Water Supply Forecast, and Relationship to WSU Efforts

For this water supply and demand Forecast, we leverage the modeling tools and datasets developed by the University of Washington Climate Impacts Group (UW CIG) as part of the Washington Climate Change Impacts Assessment (WACCIA) which was funded by the Washington State Legislature through House Bill 2860. WACCIA involved the development of historical and future climate datasets and assessment of impacts of projected climate change on agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. For assessing impacts on hydrology and water resources, Elsner et al. (2010) implemented, calibrated, and evaluated the VIC model over the PNW region at a spatial resolution of 1/16th degree. We directly apply the Elsner et al. (2010) calibrated hydrology model (VIC) implementation for the water supply forecast portion of this study (http://www.hydro.washington.edu/2860/). We also directly apply the UW CIG historical and future downscaled gridded climate data, the reservoir model (ColSim), and the simulated streamflow bias correction data and processing programs developed by UW CIG, all of which are described in further detail below.

We have expanded on the UW CIG efforts by incorporating the water demand forecast and the coupled dynamics between supply and demand. The primary unique additions to the modeling framework include the following: 1) full integration of the VIC land surface hydrology model to a cropping system model (CropSyst), 2) simulation of water curtailment and prorationing using instream flow rules, and 3) integration with economic modeling of both short- and long-run agricultural producer response. Details for each of the unique components are provided below.

3.4 Integrated Modeling Framework

3.4.3 Overall Modeling Framework

An overview of the entire modeling framework is given in Figure 25 below. The framework includes a biophysical modeling component and an economics modeling component. The biophysical modeling framework includes a hydrology model (VIC), a crop growth model (CropSyst), a physical system of reservoirs and dams (ColSim), and rule-based curtailment and prorationing modeling; all of which interact with each other as described in the following sections. The biophysical models also interact with the economic models for short- and long-run producer response.

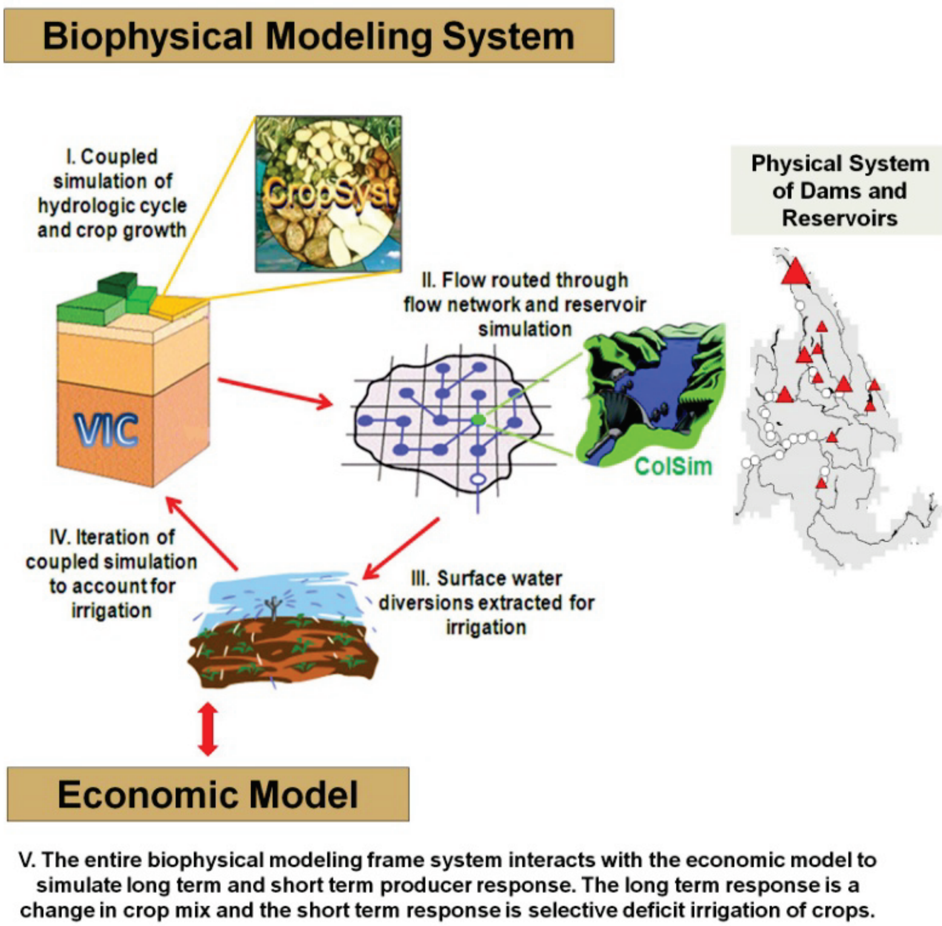

Figure 25. Overview of the entire modeling framework.

3.4.4 Descriptions of Biophysical Modeling Components

3.4.4.1 Hydrologic Model, VIC

The Variable Infiltration Capacity (VIC) (Liang et al., 1994, 1996; Gao et al. 2010) model is used to simulate land surface hydrology in the biophysical framework. It uses physically based mathematical formulations to solve energy and water balance equations at every time step (24 hr for this study) and for every grid cell ($1/16^{th}$ degree for this study). A schematic of the model is shown in Figure 26 below. The VIC model uses meteorological forcing data (daily minimum and maximum temperature, precipitation and wind speed), soil, terrain and land cover inputs to compute energy (e.g., latent and sensible heat) and water balance (e.g., surface runoff, infiltration and baseflow) components. The VIC model is run at a grid cell scale and uses the time-before–space conceptualization; i.e., the entire period of simulation is executed for a grid cell before moving to the neighboring grid cell. The VIC model saves the time series of runoff and baseflow generated at each grid cell. A separate routing model (Lohmann et al., 1998) then performs the streamflow routing as an off-line process after all of the grid cells in the basin are executed by VIC.

The VIC model has been widely used for basins across North America (Christensen et al., 2004; Vanrheenen et al., 2004; Hayhoe et al., 2007; Maurer, 2007). More specifically VIC has been implemented to assess the climate change impacts over the Columbia River basin (Hamlet and Lettenmaier, 1999; Payne et al., 2004; Elsner et al., 2010) for different Intergovernmental Panel on Climate Change (IPCC) future scenarios (1995, 2001 and 2007).

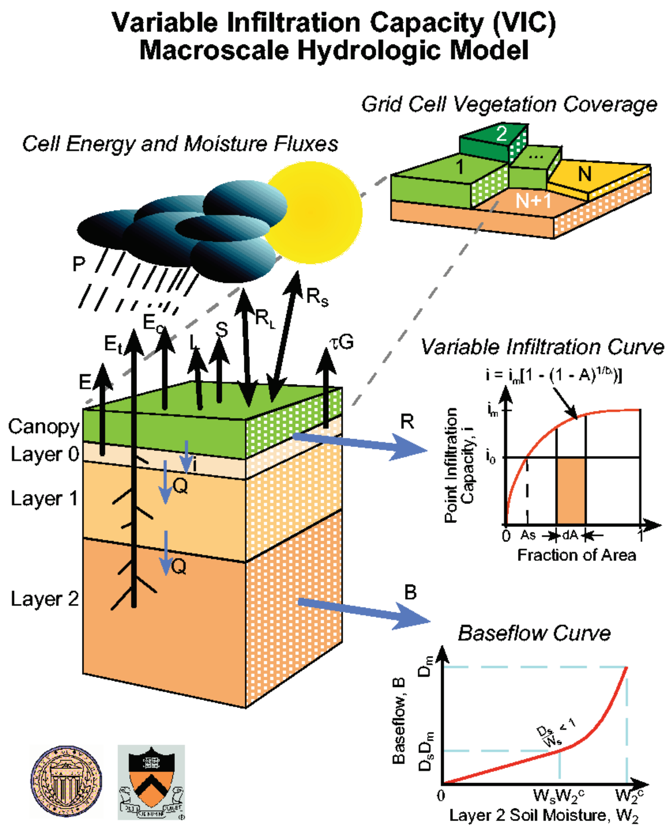

Figure 26. Schematic of the VIC Model

3.4.4.2 Cropping Systems Model, CropSyst

To provide crop simulation capabilities, the CropSyst model (Stöckle et al. 1994; Stöckle et al. 2003) is used. CropSyst is a cropping systems model based on mechanistic principles, allowing for applications to a large number of crops in any location word wide. CropSyst is a multi-year, multi-crop model developed to serve as an analytical tool to study the effects of climate, soils, and management on cropping systems productivity, nutrient cycling and fate, and the environment. Management options include crop rotation, cultivar selection, irrigation, nitrogen fertilization, tillage operations, and residue management. Depending on the process, CropSyst calculations are made at hourly or daily time steps. For this project, a simplified version of CropSyst that focus on water use and productivity was extracted for coupling with the VIC model. We ran the model at a daily time-step.

CropSyst has been evaluated and used in the PNW (e.g., Pannkuk et al. 1998; Peralta and Stöckle 2002; Stöckle and Jara 1998; Kemanian 2003; Kemanian et al., 2007) and in many other locations worldwide (e.g., Stöckle et al. 2003; Sadras 2004; Benli et al. 2007; Todorovic et al., 2009). In addition to capabilities to evaluate cropping systems, carbon sequestration dynamics and greenhouse gas (GHG) emissions (e.g., Badini et al. 2007; Stockle et al. 2010a; Kemanian and Stöckle 2010), CropSyst was recently enhanced to assess the effect of climate change on agricultural systems, particularly regarding plant responses to increasing warming and atmospheric carbon dioxide. These capabilities were utilized to assess the impact of climate change on agriculture in eastern Washington (Stöckle et al., 2010b), and to assess the potential for carbon sequestration and carbon credits in the same region (Stöckle et al. 2010a; Zaher et al. 2010).

3.4.4.3 Reservoir Model, ColSim

We use the Columbia Simulation Reservoir Model (ColSim) (Hamlet et al. 1999) to model the reservoir operations on the Columbia and Snake Rivers. ColSim is a system dynamics model that represents the key physical characteristics of the Columbia River water resources system and models the main storage reservoirs and run-of-the-river reservoirs on the Columbia mainstem. It also includes the Snake, Kootenai, Clark Fork and Pend Oreille tributaries (Figure 27). Other smaller tributaries such as Yakima are ignored (although we incorporate important smaller reservoirs in a separate reservoir framework, as will be described below). The model runs at a monthly time step and uses routed VIC-simulated streamflow as its input (which have been aggregated from a daily to monthly time-step). These streamflow inputs have been bias-corrected against naturalized streamflow data products prior to reservoir simulation. ColSim requires a January to September forecast of simulated streamflow; hence it assumes a "perfect forecast". The operation rules of the water resources system for hydropower production, flood evacuation and major flow targets that existed in 1999 were originally used in Hamlet et al. (1999) and have been minimally modified since then to capture important changes to the operating rules (personal communication Alan Hamlet).

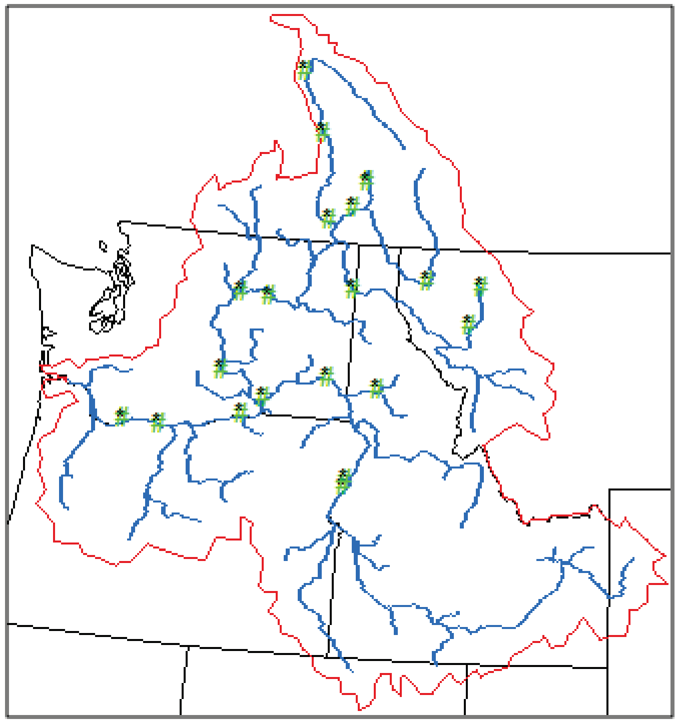

Figure 27. Schematic of the locations of reservoirs modeled in ColSim (Hamlet et al. 1999).

In addition, using tools provided by Alan Hamlet at UW CIG, we developed a system dynamics model for the Yakima system. Multiple reservoirs in the Yakima complex are operated together as one system and we model the combined storage of these reservoirs based on a simplified set of operating rules as described in USBR (2002). The controlling point for the Yakima reservoirs is the streamflow gage located at Parker. Monthly inflows are used from VIC-CropSyst and the system is modeled to reach reservoir refill in June and simultaneously ensure that there is free reservoir space available to capture any flood events. Withdrawals are made based on irrigation demands calculated by VIC-CropSyst. Curtailment decisions in the Yakima are made by comparing demand against "Total Water Supply Availability" (runoff estimate + usable return flow + reservoir storage). If the available water is not expected to meet all entitlements, the proratable water rights are prorated (i.e., they receive only a percentage of allocated water) to make up the deficit. A schematic of the model is shown in Figure 28.

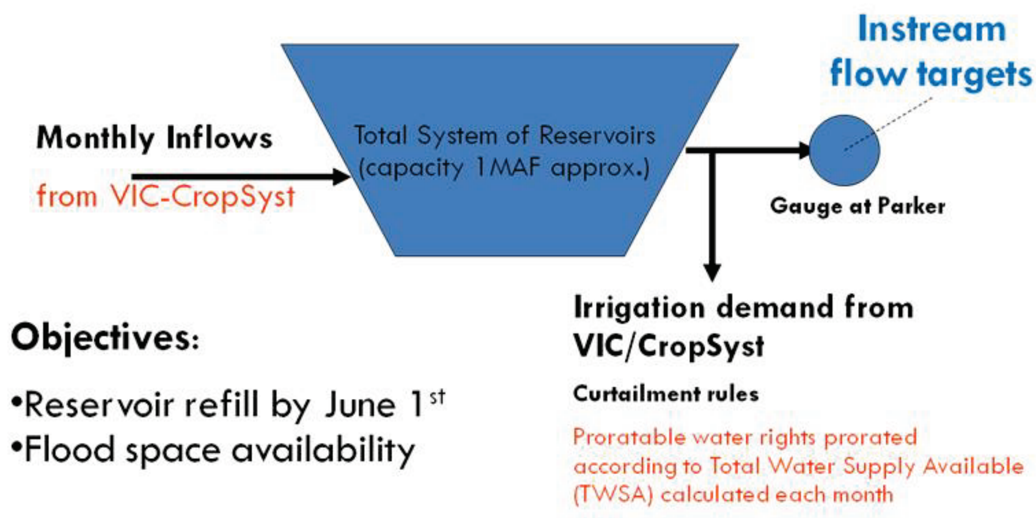

Figure 28. Schematic of the simplified Yakima Reservoir model.

3.4.5 VIC-CropSyst Integration

The two physically based models VIC and CropSyst were integrated so as to enable seamless running of the coupled VIC-CropSyst model for all of the selected crops across the Columbia River basin. The land cover distribution within a grid cell controls when the crop model is invoked within the VIC model. Figure 29 shows an example of the land cover distribution in a grid cell. Note that VIC does not recognize the geographical location of a land cover type within a grid cell. It only knows the list of land cover types and their proportion within the grid cell. For this example, the original VIC implementation would be run once for the non-crop type land-cover and CropSysyt will be invoked twice for simulating the crop growth for two different crops. The fluxes generated from the three sub-grid runs would be aggregated based on their land-cover proportions in the grid cell.

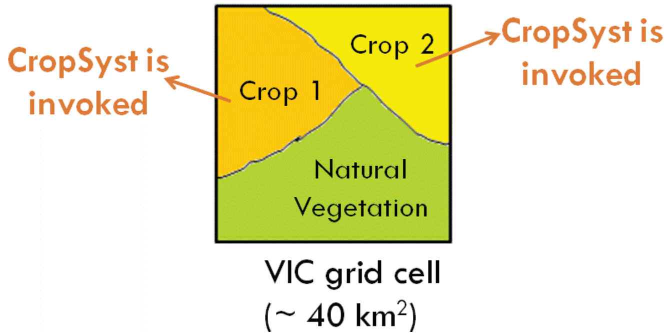

Figure 29. An illustration of land-cover distribution in a VIC grid cell.

Figure 30 shows the group of variables that are communicated between VIC and CropSyst when CropSyst is invoked for each crop land-cover type. Figure 31 illustrates the overall interaction between the two models. The VIC model initiates a call to the CropSyst model when it encounters a crop class within a grid cell. On the first day of the simulation, VIC passes to the crop model a) soil information such as soil layer thickness and soil water content, and b) the crop type to be simulated. The weather data such as daily minimum and maximum temperature, wind speed, solar radiation and relative humidity, and the amount of infiltrated water are communicated to CropSyst at every time step.

In turn, the CropSyst model starts looking for an appropriate sowing date (in case of an annual crop) or active growth start day (for perennial crops) based on simulated crop characteristics and weather conditions. This day can differ from crop to crop, based on the optimum accumulated number of degree days required by the crop. When an appropriate sowing day or active growth stage day is found, the CropSyst model indicates to the VIC model that crop growth has begun.

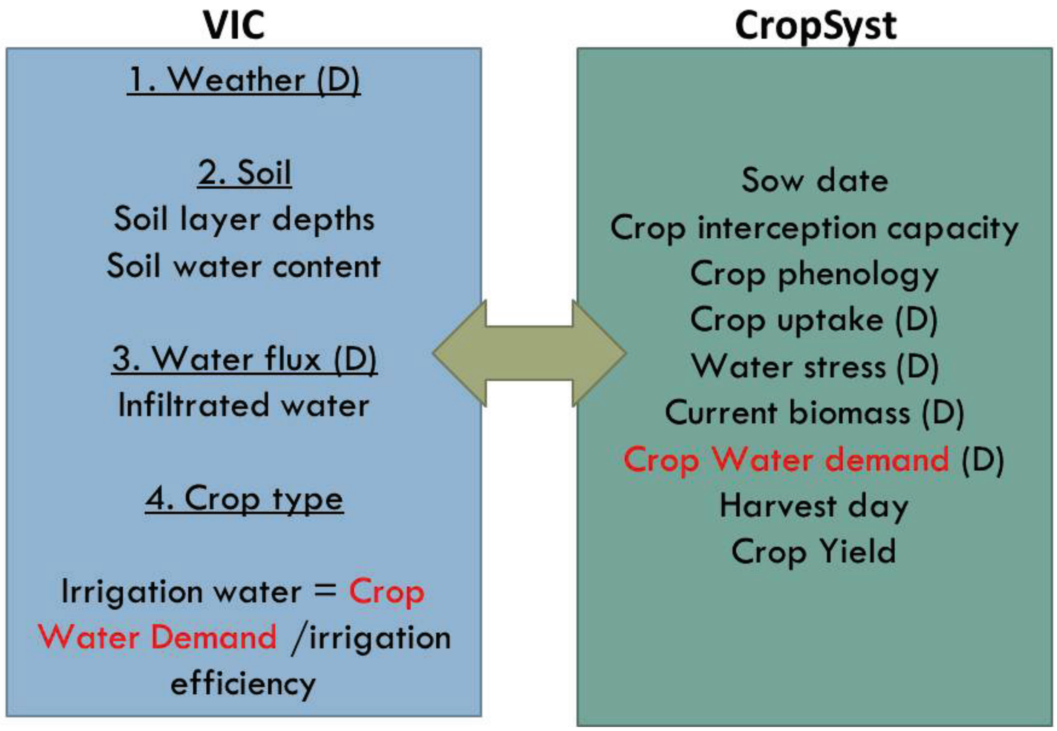

Figure 30. Data exchanges between VIC and CropSyst.

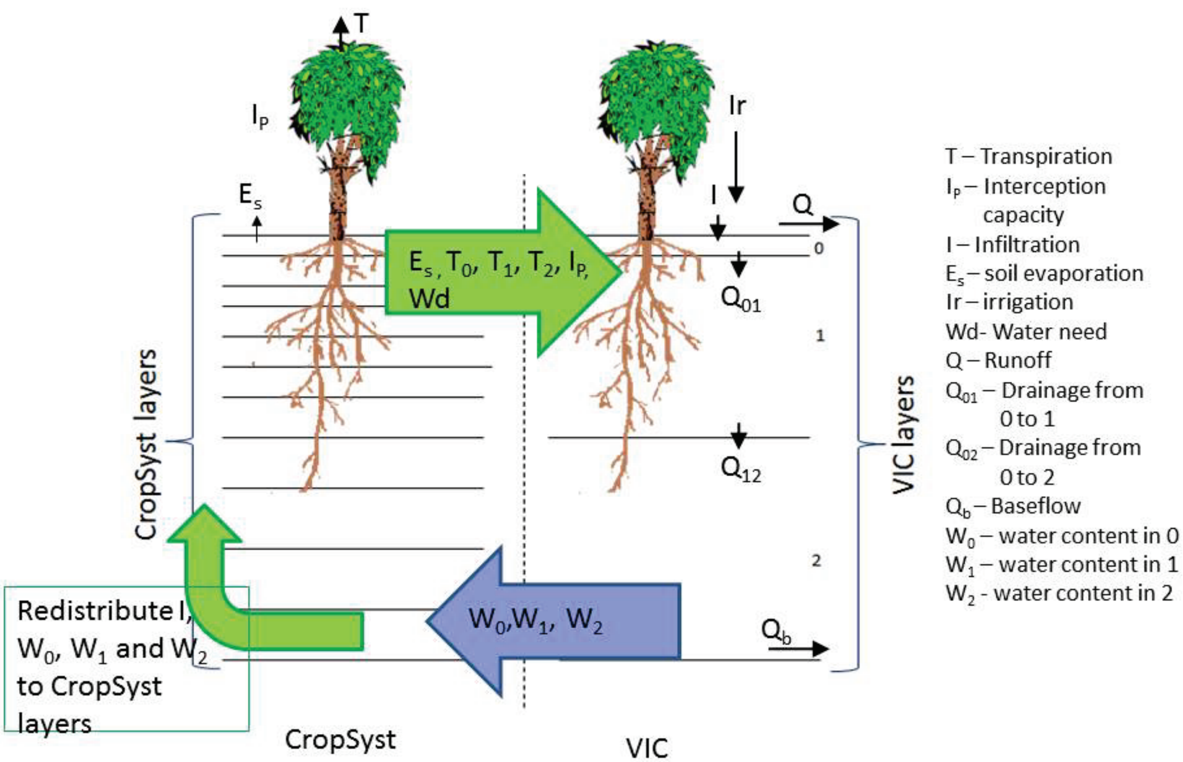

Figure 31. Structure difference and physical interactions between VIC and CropSyst.

One of the main differences between VIC and CropSyst hydrology is in the way they characterize their subsurface profile. VIC is usually run with three soil layers while CropSyst has many more depending on the depth of the soil (Figure 31). For the rest of the growing season, each model does its own subsurface drainage and CropSyst estimates transpiration from its soil layers as a function of crop phenology, growth stage, and the available water. CropSyst then aggregates transpiration from its soil layers to the corresponding VIC soil layers. CropSyst also passes back to VIC soil evaporation, growth stage of the crop, crop interception capacity, current crop biomass, and crop water need.

The transpiration and the soil evaporation amounts are used by the VIC to update its soil water contents thereby closing the water balance loop. This also influences the drainage pattern in VIC and hence the baseflow generation (which always occurs from the bottom soil moisture layer). The growth stage of the crop is used to ascertain when the crop is harvested. The interception potential provided by CropSyst is used by VIC to estimate the interception water amount during a precipitation event. The water infiltrating into the soil layer is based on the variable infiltration framework of VIC and passed on to CropSyst. This amount is used by the CropSyst model to update its corresponding soil water contents.

At each time step, CropSyst determines the water stress and the need for irrigation. The CropSyst-simulated crop water need is used to irrigate the crop only when it is known to be irrigated. For an irrigated crop, when the water need crosses a certain threshold I_x, this threshold amount of water is added to the top of the soil layer. The assumption behind this condition is that crops are not generally irrigated when there is only small water deficit and the maximum amount of irrigation water that can be applied is a function of the irrigation method. Currently I_x is set to be 20 mm and is held constant in time and space. The total irrigation water demand is then estimated as I_x/ε, where ε is the efficiency of the irrigation method.

When the crop reaches maturity, CropSyst harvests the crop and communicates the crop yield back to VIC. CropSyst also sends back variables such as current growth stage and biomass of the crop. Comparison of harvest day and day of emergence determines the length of the growing season for each crop.

3.4.6 Integration with Water Management

3.4.6.1 Bias Correction

We applied the bias correction methodology explained in Wood (2002) and Hamlet et al. (2003) to VIC-CropSyst routed flows to address the systematic biases in the model results before they are used as input to the reservoir models. The methodology is a percentile-based bias correction technique which uses simulated historical flows and naturalized observed historic data (see Section 3.1.5.2) to create statistics which help translate any simulated data point to its corresponding observed data point. This is accomplished by using the percentile of the simulated data in the simulated sample space and finding the point which falls on the same percentile in the observed sample space. An example from the technical document by Hamlet et al. (2003) is shown in Figure 19. A fuller description of this methodology is provided by Hamlet et al. (2003).

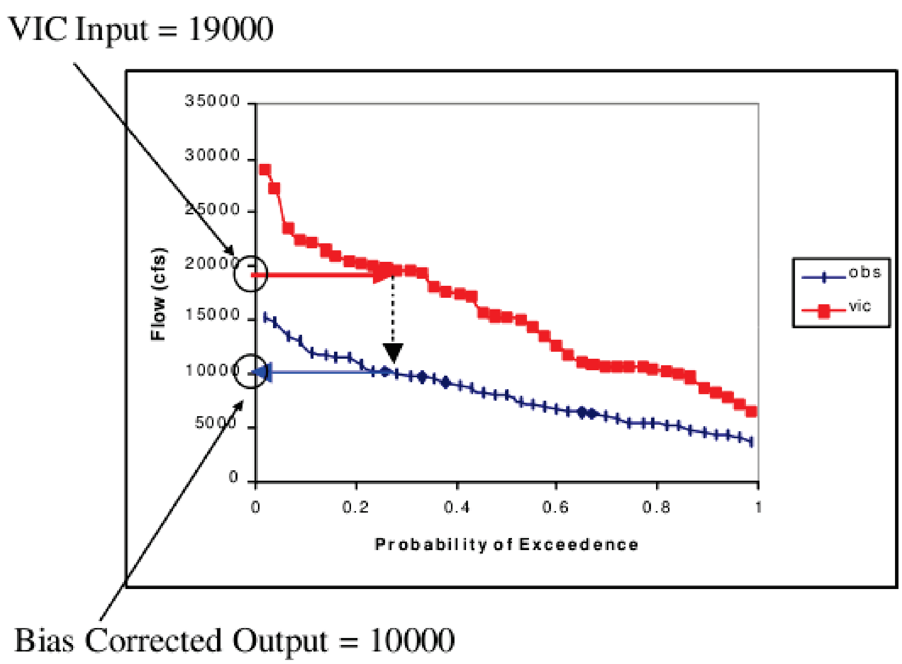

Figure 32. Bias correction example from Hamlet et al. (2003).

3.4.6.2 Reservoirs

For all locations modeled in the reservoir models, the VIC-CropSyst streamflows to those locations (after bias correction) and the full crop irrigation demands upstream of the location (until the location just upstream of it) are given as inputs to the reservoir model (in addition to other inputs) at a monthly time step. The reservoir model will deduct the demands and give estimates of resulting stream flows at the location so that it can be compared to target instream flow requirements in the location.

3.4.6.3 Curtailment

For the locations in Washington state at which instream flow targets exist, if the routed VIC-CropSyst streamflow from which surface water irrigation demand (including conveyance loss estimates) has been removed, is less than the target instream flow in any month, the demand from interruptible grid cells associated with that location are curtailed for that month as described in Section 3.4.7.2.

3.4.6.4 Separating irrigation demand into surface water withdrawal sources and groundwater withdrawal sources

Irrigation demand estimates generated by VIC-CropSyst are total "top of crop" irrigation demand, and there is no distinction between demand met by groundwater sources and surface water sources. For considering irrigation demands in surface water management tools like reservoir models, we need to separate out the irrigation demand met by surface water sources. Due to a lack of spatially disaggregated information to make this split, we assume a 20%-80% split between groundwater and surface water sources for all areas other than Yakima and the Odessa area, based on the USGS estimates of water use in Washington in 2005 that suggest that approximately 17% of irrigation usage in eastern Washington is from groundwater (Lane 2009). We assume a 10%-90% split in Yakima based on information related to groundwater pumpage for irrigation as per Vaccaro et al. (2006) and total adjudicated irrigation water demand in Yakima as per USBR (2002). In Odessa, we used a GIS map provided by the US Bureau of Reclamation to identify grid cells catered to by groundwater and surface water sources. We allocate 100% of the irrigation demand generated in the groundwater sourced grid cells and surface water sourced grid cells to groundwater sources and surface water sources respectively. For the future 2030s scenarios, we assume that groundwater sources will be unavailable in the Odessa area and the demands in all the grid cells in the Odessa area will need to be met with surface water sources.

3.4.7 Integration of Biophysical and Economic Modeling

This integration is currently done for the Washington state part of the Columbia River basin only. The biophysical modeling is integrated with the economic modeling, to account for long term as well as short term producer response. At this point in model development, this integration is only sequential in that results from one component are taken and used in the other component. This is in contrast to a directly coupled modeling framework where some aspect of economic decision making is embedded within the biophysical modeling, for example. This type of integration was not possible in this iteration of the study but is planned for future forecasts.

3.4.7.1 Long-Run Producer Response to domestic economic growth and international trade

In economics, the difference between the short run and the long run is where fixed inputs can be adjusted. In the short run a producer can only change variable inputs like irrigation quantity or fertilizer but cannot buy new land, plant new orchards, or buy new machinery. In the long run all inputs into production can be adjusted. Long run responses in this analysis are limited to changes in crop mix in the economic growth and international trade scenarios. Producers decide to change their rotation of annual crops or switch into or out of perennial crops because they think there are long run changes in the profitability of a particular enterprise relative to what they were previously doing. Crop mix is only one type of long run response. Other large scale investments like those previously mentioned can also impact the profitability of farm operations. A more complete set of long-term responses is planned for future studies.

The long-run producer response to domestic economic growth and international trade is a change in the crop mix for the future scenarios. Crop yields under an altered future climate and historical crop mix is used along with economic trends to determine the new crop mix for the future scenario runs. In changing the crop mix we make sure that the total irrigated extent in the area is kept constant (i.e., we do not add additional irrigated acreage, but just redistribute the acreage).

3.4.7.2 Short-Run Producer Response (Selective Deficit Irrigation)

Short-run producer responses are the decisions that can be made in the time frame of a growing season or a year. These tend to focus on inputs to production like labor, fertilizer and water availability. In-stream flow requirements often lead to curtailments in permissible water diversions for producers with interruptible water rights. This has a negative impact on production as producers must reduce the amount of water that they apply to their fields. In the short term, producers can take two general approaches when this happens. Less water can be applied to certain fields while total irrigated acreage is maintained, or the total amount of irrigated acres can be reduced in order to achieve full irrigation on specific fields. The prior is referred to as deficit irrigation. In economics a general term used to describe deficit irrigation is change at the intensive margin while reduced total irrigated acreage is a response at the extensive margin. Determining whether it is optimal for a producer to respond to being curtailed at the intensive or extensive margin is a complicated problem that requires detailed information on a number of relationships. Also, the optimal response is likely to differ for different crop mixes. Considering all these factors was beyond the scope of this study, so it was necessary to take a more simplified approach that still captured some degree of farm level management.

The objective was to estimate the economic value of production lost as a result of curtailing interruptible rights holders. The assumption made in terms of farm level response was that producers will respond to curtailment by deficit irrigating crops according to their economic value. The short-run producer response to curtailment is modeled as the lower value crops in a grid cell being selectively deficit irrigated while giving the higher value crops the maximum amount of water possible. We divide all our crops into three categories (Low value, Medium value and High value) and calculate the demand for each of these crop groups in the interruptible grid cells. The amount of water to be curtailed is applied to Low value crops first. If more curtailment is needed, it is applied to Medium value crops next and finally curtailment is applied to High value crops only if the other two crop groups are unable to absorb all the curtailment requirements. The assumption here is that there is perfect transfer of water within a grid cell.

The coupled VIC/CropSyst model determines how much less water is available for irrigation and the reduction in production following the on-farm response just described. The production units in CropSyst cannot be directly translated into production quantities that are sold in markets. Therefore, reduction in production quantity was translated into an acre basis by multiplying quantity by the inverse of yield (acres/weight) as they are measured in CropSyst to get an acre equivalent. This was then multiplied by value of production on a per acre basis for each crop to arrive at the lost production in terms of economic value. It is important to note that this analysis only captures the impact to producers with interruptible rights.

3.4.8 Calibration and Evaluation

3.4.8.1 Hydrology

We retain the Elsner et al. (2010) calibrated parameters for the original VIC implementation. The routed flows to select locations were calibrated against observed naturalized stream flows for specific time frames. Soil-related parameters (such as the middle and bottom soil moisture layer depths, the infiltration curve shape parameter, and the baseflow shape parameters) were calibrated by Elsner et al. (2010).

3.4.8.2 Calibration of Yield Using NASS Statistics

Farmers may employ a variety of management practices (i.e., irrigation and fertilization rates, soil conservation best management practices, etc…); furthermore, crops can be affected by stressors such as pests, diseases, weeds, poor initial stand, lack of uniformity in management, soil conditions, and topography. These factors, which may affect crop yield production, are typically not accounted for by CropSyst (it only accounts for water stress), and at the scale of the entire Columbia River basin, it is infeasible to simulate all of these variables because such detailed information is not available; hence simulation results would not consistently match recorded local historical records.

To account for the site-specific and local variation in biomass production, an adjustment factor for canopy growth (ultimately affecting biomass production) was prepared for each crop occurring in each of the Washington, Idaho and Oregon counties. The adjustment factor was applied to the expected maximum canopy cover and green and total canopy cover at maturity. CropSyst-simulated yields for each crop were aggregated to the county level and compared with historical county records as described in Section 3.1.2.3 to derive the adjustment factor. The simulation was then run again applying the adjustment factor for the respective crop in the cells falling in the respective counties, to get the final results used for the economic analysis.

3.4.8.3 Phenology Adjustments Due to Temperature Issues

From initial simulations, we discovered that simulated thermal time accumulation was resulting in growing season durations inconsistent with historical records (Usual Planting and Harvesting Dates for U.S. Field crops USDA NASS Agricultural Handbook Number 620; (http://usda.mannlib.cornell.edu/usda/nass/planting/uph97.pdf)

In some regions specific crops did not reach maturity before winter. We determined that grid cell average daily air temperature in the Elsner et al. (2010) meteorological data were discrepant from point-scale temperature observations by as much as ±5°C for some locations and times of the year. Discrepancies could be due either to point- versus grid-scale mismatches, or due to the temperature adjustments made by Elsner et al. (2010) for orographic effects (using the Parameter-elevation Regression on Independent Slopes Model, PRISM) or for long-term spurious trends (see Elsner et al. 2010 and Hamlet and Lettenmaier 2005 for details on these adjustments). For certain situations, this caused a significant error in thermal time accumulation upon which the CropSyst phenology model depends. Season durations either exceeded historic harvest dates, or maturity occurred so quickly that biomass accumulation was too low for expected yields. Therefore, it was necessary to adjust the CropSyst crop phenology parameters to accommodate for these temperature discrepancies.

An adjustment of the thermal time required to reach crop growth stages was determined for each crop and for each grid cell. The phenology adjustment is a multiplier factor with the value of 1 being no adjustment. Values less than 1 foreshortened the accumulated thermal time required to achieve phenologic growth stages, and values greater than 1 prolonged the season. The calibrated adjustment factor was applied to the crop phenologic growth stage thermal time parameter (accumulated thermal time in °C-days) values at run time. Grid cells at lower elevations (such as in the river valleys of the Colombia basin) had gridded temperature data that were generally cooler than historical measurements, thus requiring recalibration adjustment factors less than 1. Grid cells at higher elevations were generally warmer than historical data, thus requiring recalibration adjustments greater than 1.

The adjustment factor is calculated using the following steps:

1. Determine the sowing date as the first day of the year where the last day of a 7-day window, with average daily air temperature greater than the base temperature crop parameter, occurs after the earliest historical sowing (or fruit tree restart date).
2. Accumulate thermal time for the historical number of days to maturity and tally the accumulated thermal time to maturity.
3. Take the mean of the accumulated thermal time (degree days) to maturity.

The phenology adjustment is mean degree days divided by the typical (historical) maturity degree days for the crop.

3.4.8.4 Conveyance Losses

VIC-CropSyst estimated irrigation demands are “top of crop” demands and do not include conveyance loss estimates which need to be associated with surface water irrigation demands. VIC-CropSyst surface water irrigation water demands estimates were compared to actual diversion data at Bank's Lake (catering to the Columbia Basin Project irrigated area in central Washington). Based on 2008, 2009 and 2010 data, actual irrigation diversions from Bank's lake are in the range of 2.5 to 2.7 million ac-ft per year. VIC-CropSyst "top of the crop" simulated demands for the period 1977 to 2006 are on average approximately 2.2. million ac-ft for the same area. Because this "top of the crop" demand does not include conveyance losses, the difference of 15-20% between the simulation results and actual diversions could be attributed to losses and is within a reasonable range of expected losses.

These results were discussed with the Washington Department of Ecology, and as per communications with Dan Haller, we decide to assume a conveyance loss of 15% for irrigation demands originating from the Columbia Basin Project region. As per communications with Dan Haller we also assumed a lower conveyance loss of 10% for irrigation demands originating within a one mile corridor or the Columbia River mainstem (this is assuming that the place of use of withdrawn water is closer to the point of withdrawal and there is less scope of losses associated with travel through a canal system). As per communications with Christopher Lynch of the United States Bureau of Reclamation, Yakima office, we assumed a conveyance loss of 25% for irrigation demand in the Yakima region. We assumed the same 25% loss for all other watersheds in Washington with a canal system, with the exception of Methow where we assume a loss of 40% as per Methow's watershed plan. For watersheds without a canal system we assumed a loss of 10%. We came up with one loss percentage for each watershed as a weighted average of the proportion of demands originating from the Columbia River one mile corridor, Columbia Basin Project area and the remaining area in the watershed. The average conveyance loss percentage calculated for eastern Washington was around 20% and we assumed this loss percentage for demands originating outside of the state of Washington.

Lack of good metered data at the watershed scale hindered our efforts to perform similar comparisons at the watershed scale. There are some crop acreage and irrigation demand estimates indicated in the watershed plans of individual WRIAs, but these numbers are associated with large uncertainties and are not appropriate for model evaluation purposes. It is important to perform evaluations at this scale. This is a data gap that will need to be addressed in the future.

3.5 Modeling Application

The modeling framework described above is run for a 30-year time frame corresponding to historical climate and a 30-year time frame corresponding to future climate in the 2030s centered around 2035. It is run under different simulation scenarios as described in Figure 33 below.

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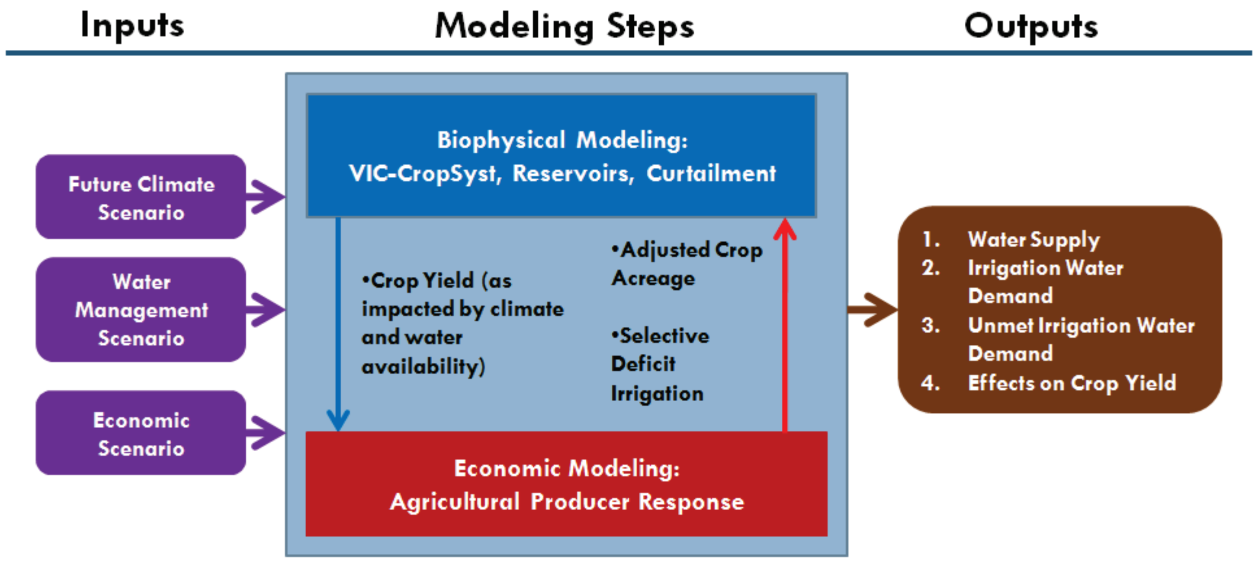


Figure 33. Framework of model runs.

3.5.1 Water Supply Forecast

Water supply is reported as the routed, bias-corrected streamflow before demands are accounted for; therefore supply is generated from the original VIC implementation of Elsner et al. 2010. We report supply at each of the spatial scales of interest: Tier I for the Columbia River basin outlet, Tier II for outlets from the watersheds, and Tier III for locations of interest along the Columbia mainstem. In cases of watersheds for which data for bias correction were not available, supply is defined as the sum of runoff and baseflow generated within the watershed. Methow, Okanogan, Chelan, Colville, Little Spokane, Hangman, Palouse, Walla Walla, Wenatchee and the three Yakima watersheds have bias correction information for the tributary outlets. All other watersheds in Washington, east of the Cascade Mountains have supply defined as the sum of the runoff and baseflow in all the grid cells within the watershed. Recall that, at the watershed scale, supply does not include access to supply from the Columbia mainstem and demands can therefore appear to be unrealistically high as compared to supply available within the basin. Also, for watershed boundaries that cross the Washington state boundary, only supply generated within the Washington side is considered.

3.5.2 Water Demand Forecast

Water demand is also reported at different scales, but the definition is the same for all scales. It is the sum of the crop irrigation demand output by VIC-CropSyst in all of the grid cells within the area of interest. VIC-CropSyst outputs "top of crop" demand which includes actual crop irrigation requirement as well losses related to on-field irrigation efficiencies. Conveyance losses are added to the VIC-CropSyst output to obtain estimates of total irrigation demand.

3.5.3 Simulation Scenarios

3.5.3.1 Climate

We ran five simulations of climate scenarios to capture a range of future climate possibilities. Climate scenarios are run while keeping the economic response constant at medium levels of domestic economic growth and international trade.

3.5.3.2 Economics

To capture a spread of the long term economic response, we ran sets of runs corresponding to low, medium, and high levels of domestic economic growth and international trade. These runs are done for the middle climate scenario only.

3.5.3.3 Water Management (water capacity and water pricing)

The water capacity scenarios involved creating capacity for new additional irrigation acreage as detailed in Section 3.2.4.2. In order to estimate irrigation demands from this additional acreage, we did not perform a separate run, and instead assumed that the new acreage would have a crop mix similar to the existing crop mix, and scaled up the demand results from the run with the existing crop mix.

3.5.4 Wet/Dry/Average Quantification

The wet/dry average year quantifications are based on the percentiles of water supply. 20th percentile is considered a dry year, 50th percentile an average year and 80th percentile a dry year.

3.6 Survey of Regional Water Supply Changes

In developing any long-term water supply and demand forecast for the Columbia River basin it is important to recognize that waters are shared by seven US states and British Columbia. This fact significantly complicates efforts to forecast Washington water supplies as changes in tributary inflows to the state could be adversely impacted by upstream diversions. In order to help conduct Washington's current planning efforts, key federal, state, and tribal organizations within the other entities sharing Columbia River basin water were contacted to determine if there were future projects that might impact water availability in Washington and, if so, to investigate possible partnership opportunities related to planned storage projects. The intention was to summarize planning efforts of other states and provinces, and provide a coarse screen for water supply inputs to Washington for modeling purposes. Specific objectives were to identify potential future out-of-state water projects or changes in policy and management that could affect water supplies in Washington.

To accomplish this task, Ecology and WSU generated a list of water management contacts. The questions in the 2010 Survey of Water Managers, written by Washington State Department of

Ecology staff in collaboration with WSU researchers, consisted of 29 open-ended questions covering: a) water demand, b) water projects (focusing on information about potential or upcoming water diversions or storage facilities that might impact Columbia River flows), and c) general plans for managing jurisdictional water supplies. A copy of this survey is provided in Appendix C. Contact lists were provided by the Washington State Department of Ecology and covered geographic regions that were entirely or partially in the drainage of the Columbia River basin.

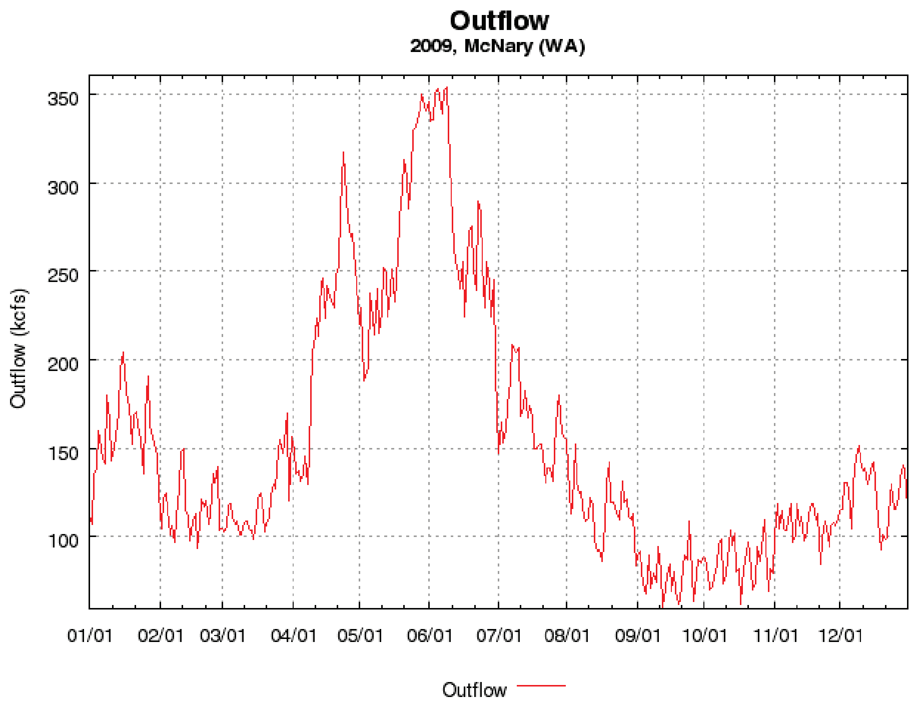
The survey was conducted by mailing copies to prospective participants; however a low response rate (only 14%) prompted a protocol change to telephone interviews. Phone interviews were conducted between August 12, 2010 and October 8, 2010. Twenty nine water managers were contacted and telephone interview responses were recorded digitally (with permission) for later analysis. Note that targeted high level contacts rarely participated in the phone interviews. Often the contact referred to a subordinate within their organization that had working knowledge at the watershed scale. In order to assess potential changes for the watershed as a result of any renegotiated treaty, WSU also attempted to contact those responsible for conducting the Columbia River Compact between US and Canada. To the extent possible, the results (presented in Chapter 5) summarize the responses of the survey in raw form without interpretation, while maintaining the confidentiality of respondents.

3.7 Hydropower Demand Assessment

Climate variability has a tremendous impact on hydropower production in the Columbia River basin. For example, as of February 2010, the National Weather Service's Northwest River Forecast Center predicted 79.2 million acre-feet of runoff from January through July measured at The Dalles, Oregon. This quantity represented 74 percent of the 30-year average of 107.3 MAF and would have been the lowest runoff since 2001. As a result of this Forecast, the Bonneville Power Administration (BPA) reduced its expectations for hydroelectric power revenue by more than $200 million. Based on the forecasts, BPA then estimated it would finish the fiscal year with a loss of $6 million in modified net revenues instead of the $231.9 million in positive revenues projected in the previous October. Cumulative runoff at The Dalles for January through July of 2010 was approximately 79.8 MAF.

Using a combination of seven different global climate change model outputs and six climate change scenarios, Markoff and Cullen (2008) created 24 projections of 2080 stream flows and changes in hydroelectricity production in the Columbia River basin, with 19 of 24 projections showing decreases in production. These results are consistent with those reported by Hamlet et al. (2009) who projected that hydropower production would increase by 7-10% during the winter and decrease by 18-21% during the summer by 2080, with overall annual reductions of 3.0-3.5%. Impacts slowly become evident over time with their 2025 forecast showing hydropower production increasing by 0.5-4% during the winter and decreasing by 9-11% during the summer. Total annual reductions were 1-4%.

Another significant issue is flow through the turbines versus excess discharge via a dam's spillway. Modification of hydrograph peaks due to climate change will likely result in more flow passing through the spillway and less through the turbines. Most dams were sized to optimize the trade-offs between powerhouse construction costs versus electricity generation. However, these tradeoffs were calculated using historical information rather than projected climate change effects. If we examine the flow at McNary Dam on the Columbia River system just downstream of the Snake and Columbia River confluence we can begin to understand the dilemma. Figures 35a and Figure 35b show discharge and spill data at the facility for 2009, a year in which water amounts were roughly average. Figures 36a and Figure 36b illustrate the low flow year of 2001 for comparison and Figure 37a and Figure 37b use the flow from the flood year of 1996 to demonstrate percent of flows not used to generate power.



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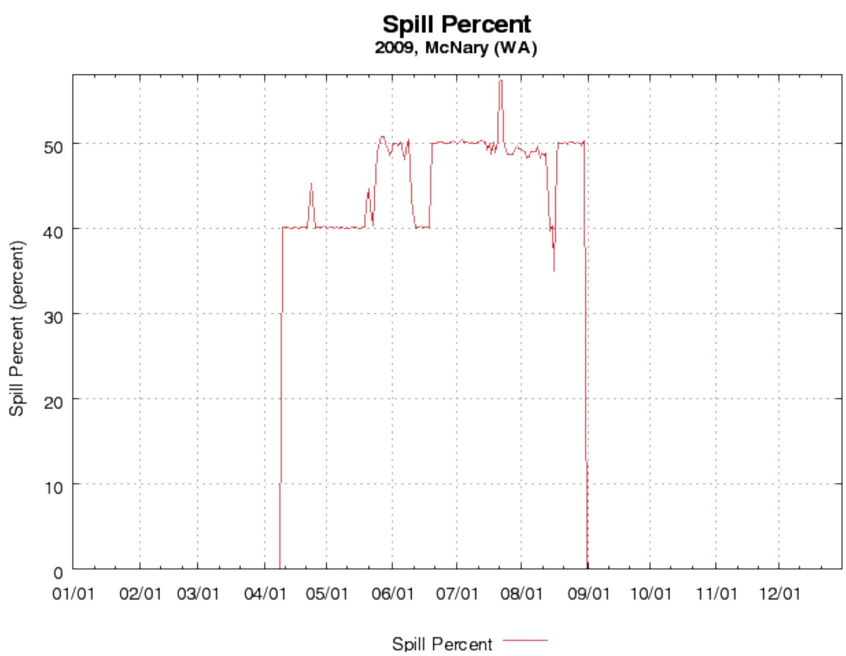
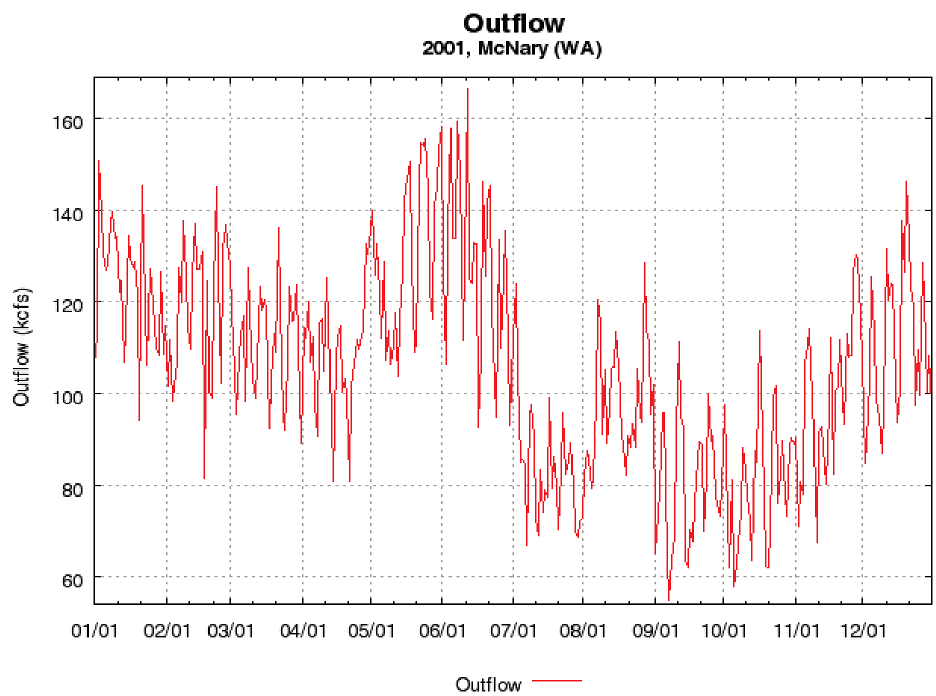


Figure 34. a) McNary 2009 outflow and b) McNary 2009 spill percent during an average flow year (Columbia River DART 2007).

a)



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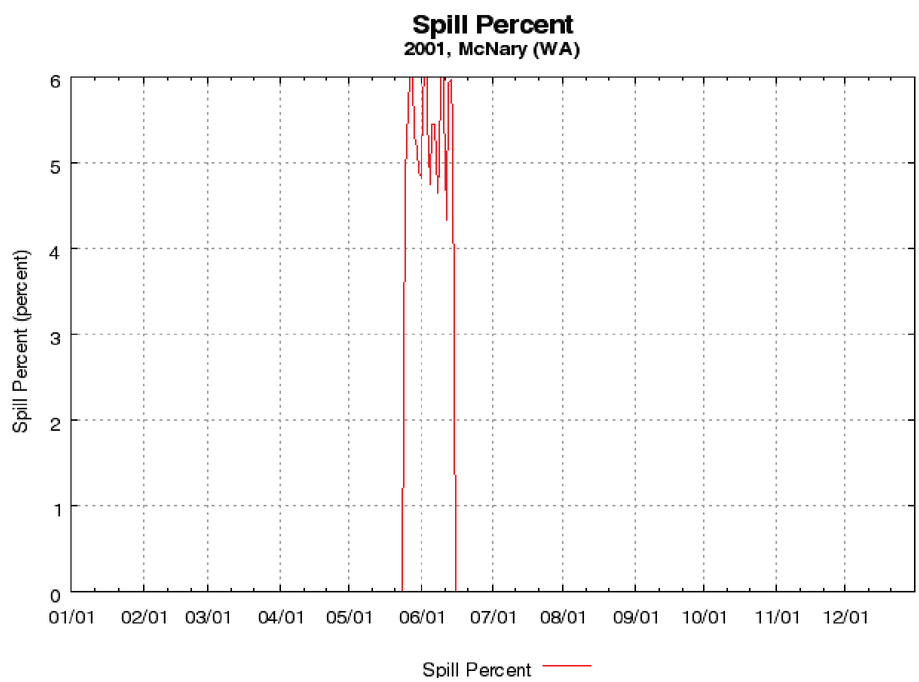
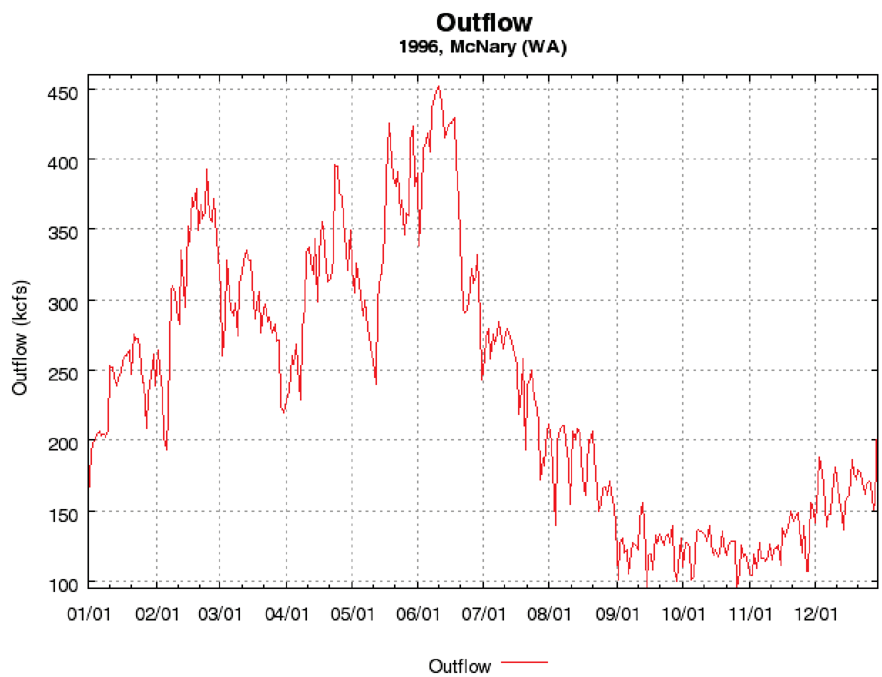


Figure 35. a) McNary 2001 outflow and b) McNary 2001 spill percent during a low flow year (Columbia River DART 2007).

a)



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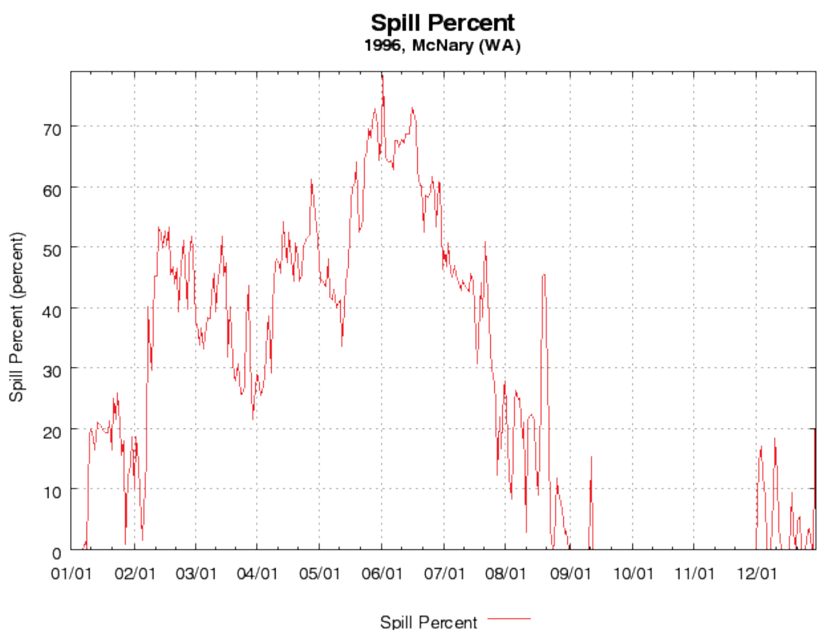

Figure 36. a) McNary 1996 outflow and b) McNary 1996 spill percent during a high flow year (Columbia River DART 2007).

If spills only occurred when flows exceeded capacity then it would be relatively straight forward to forecast the amount of future spill. For instance, the hydraulic capacity of McNary is 232,000 ft^3/s so whenever predicted flows exceed this amount, spills must occur. There are times, however, when spills occur even though streamflows do not exceed the capacity to generate electricity. Spring and summer spills at dams benefit juvenile salmonid out-migrations in the river for those fish that are not collected for transportation (particularly for Snake River fall Chinook salmon) (NOAA 2008). The guidelines for these spills are still under development as part of the adaptive management implementation plan (Salmon Recovery 2009).

In order to improve fish survival and meet the 2008 Biological Opinion (BiOp) performance standards and metrics (e.g. 96% dam survival for spring migrants), the Reasonable and Prudent Alternative (RPA) spill, bypass, and transport operations at mainstem Snake and Columbia River projects will be adaptively managed annually based on results of biological studies. So, even when finalized, the rules will not be prescriptive in that considerable weight will be given to project salmon survival. Thus, there will not be a single set of flow/spill rules that dictates a constant spill each year.

3.7.1 Review of Power Planning Strategies

Power entities in the northwest regularly carry out extensive forecasting of electricity demand and power-generating capacity. For this Forecast, Washington State University was asked to carry out a qualitative review of these existing projections with two specific objectives in mind:

- To find out whether regional and state level power entities felt that they would be able to meet anticipated growth in demand over the next 20 years.
- To determine whether or not there was a likelihood of any additional hydroelectric storage capacity being built within Washington over the next 20 years.

Available reports that were reviewed included those carried out by the Bonneville Power Administration (BPA), Northwest Power and Conservation Council (NWPCC), Avista, Idaho Power, Portland General Electric (PGE), and Grant County PUD (Canadian and U.S. Entities 2010, NWPCC 2010, Idaho Power 2011, Avista 2009, PGE 2009; Grant County PUC 2009).

3.7.2 Review of FERC Licenses

In addition to reviewing forecasts by existing power entities, we independently reviewed FERC licenses to determine whether any new hydroelectric projects were likely to be built in Washington state over the next 20 years. Any new hydroelectric project must be licensed with the Federal Energy Regulatory Commission (FERC). Three licensing processes exist for new hydroelectric projects: the Integrated, Traditional, and Alternative (ILP, TLP, and ALP, respectively). Effective July 23, 2005, the default process for licensing a new project is the Integrated Licensing Process (ILP), as outlined in Figure 38. Approval of the Commission is needed to use either the Traditional or the Alternative Licensing Process. Under all three processes, licensing generally begins many years prior to project construction. Some projects under 5 megawatts (MW) that propose to increase capacity of an existing dam may be exempt from licensing.

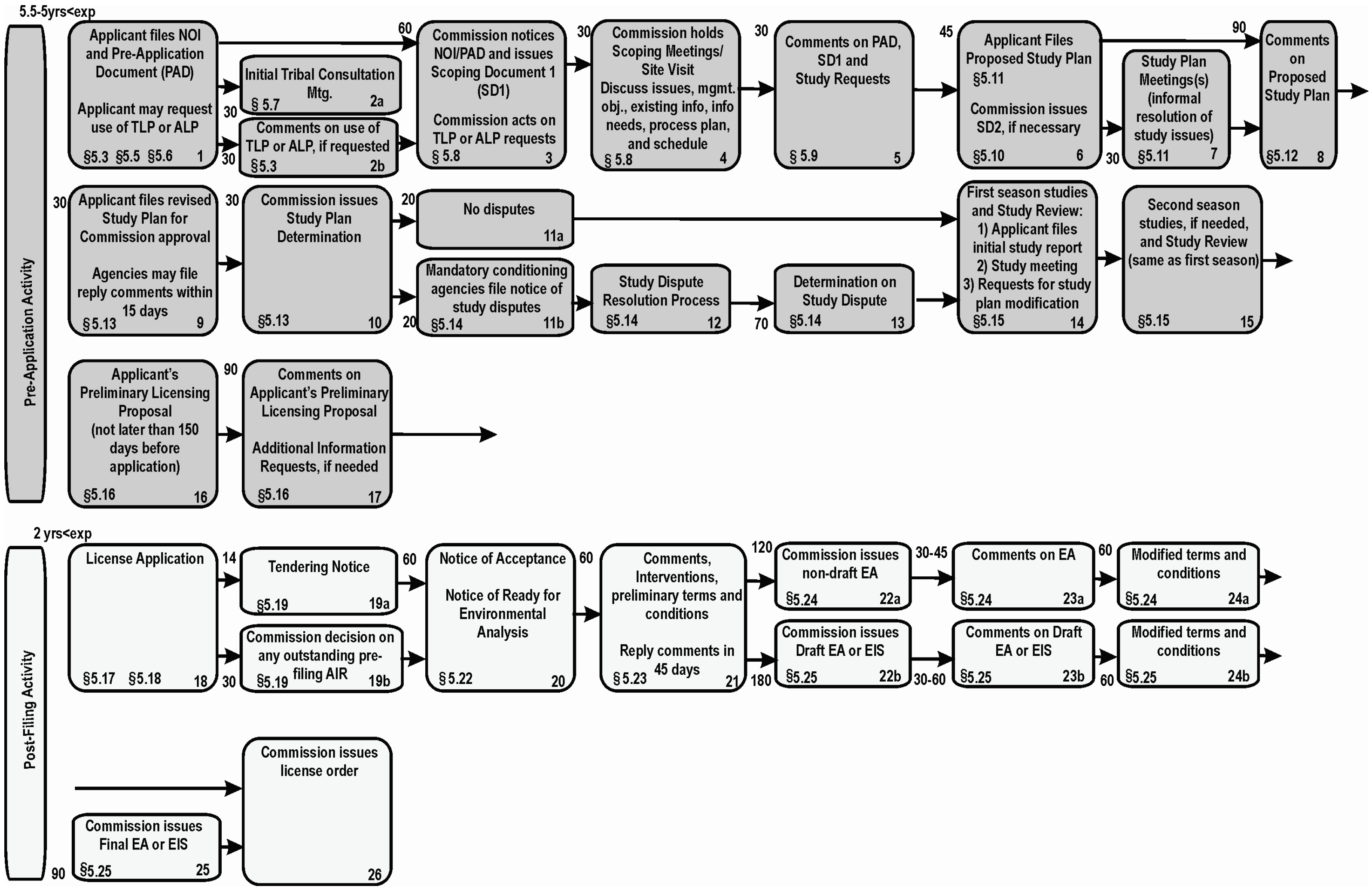

Figure 37. Integrated licensing process (ILP) (FERC 2004)..

3.8 Instream Demand Assessment

For the Columbia River basin, WSU was asked to complete an analysis of instream flow requirements across the basin, with a focus on how these could impact water entering the state of Washington. Within Washington, OCR compared the period of record historic flow data for dry, average and wet years to regulatory instream flow requirements for the Columbia River's mainstem and its major tributaries. The methodologies and the results of these two analyses are presented in this technical report.

Supplementing the work done by OCR, WDFW's "Columbia River Instream Atlas" assessed eight fish and low flow critical watersheds: Walla Walla, Middle Snake, Lower Yakima, Naches, Upper Yakima, Wenatchee, Methow, and Okanogan. One hundred eighty-nine stream reaches were evaluated for their potential to improve natural fish production through stream flow enhancement. Stream reaches were scored on three critical components: fish stock status and habitat utilization, fish habitat condition, and stream flow. The methodologies and results of this analysis are presented in the "Columbia River Instream Atlas," Department of Ecology Publication No 11-12-015 (Washington Department of Fish and Wildlife 2011).

3.8.1 Instream Flows Across the Columbia River Basin

With over 65% of Washington's area being within the Columbia River basin, the state has great interest in determining incoming flows (supply), with as much certainty as possible. Programmatic releases from dams and impoundments (minimum – maximum) during normal operating conditions and instream flow requirements legislated through water rights agreements, Endangered Species Act (ESA) requirements, adjudicated settlements, or other agreements entered into on a state to state or international (Canada, United States) basis impact these waters and thus were analyzed as part of the instream demand assessment.

With respect to each region's total individual land area, the Columbia River basin catchment area drains 95% of Idaho, 69% of Washington, 57% of Oregon, 17% of Montana, and 9% of British Columbia (BC) as well as relatively small percentages of Wyoming, Nevada, and Utah (Muckleston, 2003). Minimum instream flows from these upstream source areas have the potential to impact available water supplies in Washington by affecting inflows into the state and by setting limits on withdrawals and reservoir operations within the state.

There are currently two important unresolved concerns surrounding the legislated/mandated minimum instream flows on streams entering Washington and the available supply of water within the state. The first involves the overall state of water rights in the PNW and their ongoing adjudication (including Tribal claims). The second involves past and ongoing biological opinions (BiOp) relating to the ESA and their interpretation with respect to reservoir releases and hydropower operations. These two topics may impact the results of this study in the future. For the present, however, the current conditions were assumed to apply in the future. Furthermore, it is important to point out that most instream flows are junior to existing water rights so to the extent that these water rights are not currently taking their full allotments, the instream flow requirements do not guarantee that streamflows won't fall below that target.

The analysis of water entering Washington examined major tributaries ultimately entering the state from the states of Idaho, Oregon, Montana, and the province of British Columbia, Canada. Small headwater tributaries within the states of Nevada, Utah and Wyoming were assumed to be negligible in terms of their ability to affect the magnitudes of incoming flows at the Washington state boundary. An internet search was conducted of Idaho's, Oregon's, Montana's, and British Columbia's water/environmental web-sites for information relating to legislated/mandated instream flows. Specific information regarding the quantity, timing, and priority dates of existing statutory flow requirements was gathered. An internet search was also conducted of facilities operated by the U.S. Army Corps of Engineers (Army Corps), Bonneville Power Administration (BPA), Avista Utilities, and British Columbia Hydro (BC Hydro) for operational water releases from dams and impoundments that would affect the flows coming into the state of Washington.

In addition, phone contacts were made with representatives of BC Hydro, the Army Corps, Avista Utilities, Idaho Department of Water Resources, Montana Department of Water Resources, Montana Department of Fish and Wildlife, Oregon Department of Water Rights and Services, British Columbia Ministry of the Environment, US Fish and Wildlife Service (USFWS) in Portland, and the Confederated Tribes of the Umatilla. Phone conversations were necessitated for several reasons including ensuring that the proper location of an agency/company web-site was being accessed, direction to other publications and personnel, and in some cases verification of when the data was obtained.

3.8.2 Instream Flows in Washington State

The full protocol followed by OCR for this analysis is covered in Appendix D, Historic Streamflow Data by WRIA. The goal of this analysis was compare historic low, average, and high flow water years to state and federal minimum instream flow targets. This work was intended to improve understanding of:

- How reliably minimum flow targets in fish critical basins are currently being met.
- How often water users subject to minimum flow targets are curtailed.
- Whether trends exist in the historic data relative to water availability, the shape of the hydrograph, or drought severity.
- Where opportunities exist to improve stream conditions by re-timing or re-locating water.

3.9 Water Allocation Assessment

Water rights information was collected from WaDOE's digital water-rights database, the Water Rights Tracking System (WRTS). Within the database, water allocation documents are tracked according to the following information: identification/control number, priority date, one or more purposes of use, the total annual amount of appropriated water, the total instantaneous amount of water use allowed, one or more points of withdrawal /diversion (POD), and a place of use (POU).

However, much of the data in WRTS is incomplete, often due to underlying uncertainty in the water rights records. This is particularly true for claims, which represent individuals' claims that they have rights to water use that began prior to the establishment of written water law in the state of Washington (prior to 1917 for surface water rights or 1945 for groundwater rights). For most claims, there has been no agency or court review of whether the claim is valid. For each WRIA within the Forecast study area, our analysis determined the amount of water that was allocated annually **for water documents that had this information** in WRTS, plus the proportion of documents which lacked total annual amounts (as an indication of the amount of uncertainty associated with the total). Annual totals were presented separately for claim documents and for permits/certificates.

WRTS had 260,478 water right documents in total. Our analysis screened out water right documents that were inactive (31,714 documents) that were outside of the study area (in WRIAs 1-28), or that represented temporary uses or changes for which there was likely to be a parent record (Change Applications, Change/ROE, New Application, Temporary Use, Short Term, and Drought). The final document types considered were Claims, Claim Short Forms, Claim Long Forms, Certificates, Adjudicated Certificates, Permits, Quincy Basin Permits, Superseding Certificates and Superseding Permits. For Yakima, due to the surface water right adjudication that is nearing completion, 854 older surface water WRTS data records were replaced with 2060 data records from the conditional final order (CFO), obtained from Ecology in April 2011.

Remaining records were divided into either certificates/permits, or claims for analytical purpose, using the following groups:

- Permits, certificates, adjudicated certificates, Quincy Basin Permits, superseding certificates, and superseding permits, and
- Claim, claim long form, and claim short form.

After initial screening of the records, there were 26,348 permit/certificate documents for further analysis including the Yakima surface right records, and 71,682 claim documents.

We then screened documents to try to eliminate non-consumptive uses of water, which were not the focus of the allocation analysis. This process was complicated by the fact that water allocation documents often have more than one purpose, and may in some cases have one purpose that is consumptive (e.g. irrigation) and another that is non-consumptive (e.g. power). Water allocation documents with the purpose codes for fish propagation, wildlife propagation, recreation, environmental, groundwater preservation only or a combination of two or more of these purposes were removed. Water rights with a purpose of power only were also removed, as were water rights with a purpose of instream flow or storage only. Water allocation documents that had mixed consumptive and non-consumptive purposes of use, with power as one of the uses, were checked to see if they contained a number of irrigated acres. Records with no irrigated acres were removed.

Within each WRIA, records were divided into three categories: groundwater, surface water and reservoir rights, based on their unique control numbers. Reservoir rights create a potential issue, in that in some cases, water rights are issued supplemental to the reservoir rights, such that the documents in effect "double count" the water use. Thus, for the top 20 reservoir rights (in terms of total annual water use), we manually went back to the associated water rights documents to figure out whether or not there were also water rights issued separately for use. In cases where there were, the reservoir rights were eliminated.

In total, for permit and certificate documents, 436 records were removed because they were identified as non-consumptive uses. This included 100 reservoir rights that were eliminated as non-consumptive rights. This left 25,912 documents. For claim documents, 101 documents were removed as non-consumptive rights, leaving 71,581 documents.

Within each document group type, our analysis then determined the amount of water that was allocated annually for each WRIA (for documents that included this information), plus the proportion of documents which lacked total annual amounts (as an indication of the amount of uncertainty associated with the total).

3.10 Outreach

The objective of the outreach strategy for the 2011 Forecast was to gather input to improve the development of the Forecast, focusing on assessment of projected medium-term (2030) changes in supply and demand that require adaptation by policy-makers, resource managers and water users. Outreach efforts targeted four different groups, each with a different area of expertise:

1. National review panel (individuals with academic expertise in the methodologies used in the WSU portion of the Forecast)
2. Regional review panel (individuals with academic expertise in agriculture and water issues in eastern WA)
3. Policy Advisory Group (stakeholders in this region with expertise and interest in water issues, environment, tribal issues, power generation, municipal water, agriculture, etc.)
4. Interested members of the public (participation primarily by individuals involved in water issues at local or regional levels)

Stakeholder input was used to facilitate model development, and to build stakeholder trust in results and the policy that may be implemented as a result of lessons learned through the Forecast. Each of these goals has been shown to be relevant in other public stakeholder processes (Borsuk et al. 2001; Hale 1993). Research also indicates that stakeholders value "two-way communication", when stakeholders know that their input is actually used (Borsuk et al. 2001; Stave 2002). The process for gathering feedback was thus structured to not only to increase public awareness of the Forecast, but also to allow the public an opportunity to assist in the development of the Forecast. Public feedback was gathered prior to finalizing results of the Forecast, with significant changes made to portions of the modeling effort, to the presentation of results, and to the descriptions of results, to respond to the comments received.

3.10.1 National Review Panel

The national review panel comprised four external experts in economics, modeling, and water issues:

- Ari Michelson, PhD, Department of Agricultural Economics, Texas AgriLife Research Center, Texas A&M University, El Paso, TX (economics of water resources related to agriculture and climate change, state water assessments for Texas)
- Jeff Peterson, PhD, Department of Agricultural Economics, Kansas State University, Manhattan, KS (regional and rural economic development relating to water)
- Robert Mahler, PhD, Plant Soils, and Entomological Sciences Department, University of Idaho, Moscow, ID (coordinates the water quality program for the College of Agriculture, regional water issues, extension/outreach)
- Alan Hamlet, PhD, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA (VIC modeling, regional downscaling of climate projections).

The review panel convened for two day-long reviews, once near the beginning of the project, as work was getting underway (May 2010) and once near the end of the project, after initial results had been generated and as final methodological issues were being addressed (May 2011). During these meetings, members of the review panel commented on the work, and gave suggestions for improvements relating to their areas of expertise.

3.10.2 Regional Review Panel

To complement the review provided by the national review panel, and to provide a regional check on results, an early draft report (August 2011) with preliminary WSU modeling results was reviewed by three individuals with broad knowledge of agricultural and water issues in the Pacific Northwest:

- Hal Collins, PhD, USDA-ARS

- Sandy Halstead, US Environmental Protection Agency
- David Granatstein, Center for Sustaining Agriculture and Natural Resources, Washington State University

3.10.3 Office of Columbia River Policy Advisory Group

Interactions with the Department of Ecology's Office of Columbia River Policy Advisory Group (PAG) were designed particularly to guide early development of the Forecasting effort, and gather early feedback on methods from local stakeholders with an interest in the use of the Forecast results. Based on the sophistication of the modeling methods used, it was helpful to receive feedback from a group with representative stakeholder interests, who could attend multiple in-depth presentations of methods on various aspects of the Forecast (e.g. biophysical modeling, economics, Columbia River Instream Atlas, etc.) during the early stages of project development and provide ongoing feedback. Feedback was used to refine methodology and to identify and prioritize issues most critical to stakeholders.

Members of the Policy Advisory Group included:

- Dale Bambrick, NOAA Fisheries-US Department of Commerce
- Brenda Bateman, Oregon Water Resources Department
- Gary Chandler, Association of WA Business
- Kathleen Collins, Water Policy Alliance
- Jon Culp, WA State Conservation Commission
- Jim Fredericks, U.S. Army Corps of Engineers
- Michael Garrity, American Rivers
- Tony Grover, NW Power and Conservation Council
- Mike Leita, Yakima County Commissioner
- Joe Lukas, Grand County PUD
- Mo McBroom, WA Environmental Council
- Darryll Olsen, Columbia-Snake Rivers Irrigation Association
- Gary Passmore, The Confederated Tribes of the Colville Reservation
- Rudy Peone, Spokane Tribe
- Rudy Plager, Adams County Commissioner

- Phil Rigdon, Yakama Nation
- Dave Sauter, Klickitat County Commissioner
- Mike Schwisow, Columbia Basin Development League
- Teresa Scott, WA State Dept. of Fish and Wildlife
- Craig Simpson, East Columbia Basin Irrigation District
- Rich Stevens, Grant County Commissioner
- Leo Stewart, The Confederated Tribes of the Umatilla Indian Reservation
- John Stuhlmiller, WA State Farm Bureau
- Rob Swedo, Bonneville Power Administration
- Matt Watkins, City of Pasco
- Bill Gray, Bureau of Reclamation
- Lisa Pelly, Washington Rivers Conservancy

3.10.4 Public Stakeholder Workshops and Public Comment

Preliminary results of the Forecast were presented at three public stakeholder events in Wenatchee, Spokane and the Tri-Cities in early September 2011 (Figure 39, Figure 40, and Figure 41). A draft report was released at the end of September and public comment was accepted for 30 days after this release.

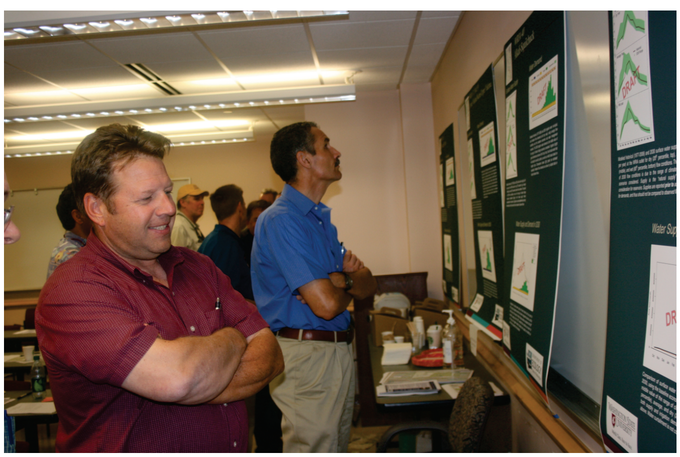

Figure 38. Participants review draft Forecast results in Richland, WA (Photo: Tim Hill, Ecology).

Figure 39. Workshop participants review draft Forecast results in Wenatchee, WA (Photo: Tim Hill, Ecology).

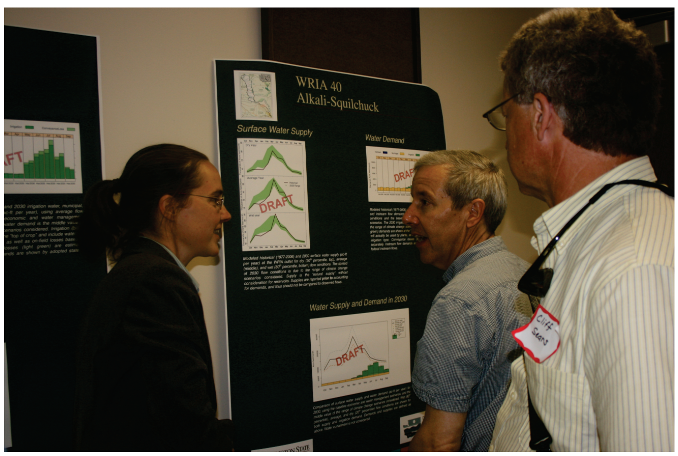

Figure 40. Workshop participants (right) discuss draft Forecast results with Dr. Jennifer Adam, Department of Civil and Environmental Engineering, Washington State University, in Spokane, WA (Photo: Tim Hill, Ecology).

The computer modeling that was central to the 2011 Forecast was assumed to be challenging material for a public outreach process. Research suggests that public knowledge about the nature and purpose of scientific models is generally low (Schwarz and White 2005). Based on this, stakeholder workshops provided a non-technical overview of the methodologies used, followed by guided discussion to elicit participant questions and guide discussion of issues important to stakeholders.

The workshops and comment period collected both quantitative and qualitative feedback, through a survey and open-ended questions, respectively. This feedback, gathered via workshops, on-line forums, and the draft comment process, was used to fine-tune economic and biophysical modeling assumptions and to finalize results. Feedback from the stakeholder process, and the actions taken by OCR in response, are described in the Summary of Responses to the Draft 2011 Legislative Report for the Columbia River Basin Long-Term Water Supply and Demand Forecast (Ecology Publication 12-12-04).

4.0 Summary of Significant Findings

Significant findings summarized in this chapter are detailed in Chapters 5, 6, and 7 of this technical report, as well as in the Columbia River Instream Atlas (Ecology Publication 11-12-015), and (where identified) from other outside sources.

4.1 Surface Water Supply in the Columbia River Basin

Modeling forecast results for 2030 suggest that compared to historical (1977-2006) supplies:

- A small increase of around 3.0 (±1.2)% in average annual supplies will occur.[1]
- Timing changes will shift water away from the times when demands are highest. Unregulated surface water supply at Bonneville will decrease an average of 14.3 (±1.2)% between June and October by 2030, and increase an average of 17.5 (±1.9)% between November and May.
- Annual water supplies entering Washington are forecasted to increase for most rivers entering the eastern portion of the basin, and the direction of change is unclear for most rivers entering the northern portion of the basin.
    - Annual water supplies entering Washington will increase by approximately 3.7 (±1.3)% on average for the Columbia, Pend Oreille, Spokane, Clearwater, Snake, and John Day Rivers by 2030.
    - The direction of change for annual water supplies entering Washington is unclear for the Similkameen and Kettle Rivers, +1.4 (±1.9)% on average by 2030.

The regional survey of water managers throughout the Columbia River basin was used to complement modeling results. Given that modeling assumed similar management in 2030, and did not anticipate large new water supply projects outside of Washington, in upstream portions of the Columbia River basin, the survey was a useful tool. The survey revealed that efforts to improve flow or aquatic habitat conditions in portions of the Columbia River basin outside of Washington State typically involve relatively minor changes to management of winter or peak flows at existing projects. Little definitive action is currently being taken to build large water infrastructure projects due to a lack of funding and willingness to pay for water. Overall, the results of the survey confirmed that the current upstream management scheme could be used for modeling.

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[1] When discussing modeled supply and irrigation demand results, "average flow conditions" refers to the 50th percentile (middle) value under the middle climate scenario. "Average" by itself refers to the average value over all climate scenarios and flow conditions, and a 90% confidence interval around that average.

The survey also indicated that a lack of regional and cross-jurisdictional communication hampers planning efforts. Improving communication may be a first step to creating more purposeful opportunities for partnership.

Annual surface water supplies within the Washington portion of the Columbia River basin are expected to increase for most tributaries of Washington:

- Walla Walla (7.2 ±1.9%)
- Palouse (5.9 ±3.6%)
- Colville (9.5 ±2.8%)
- Yakima (4.4 ±2.3%)
- Wenatchee (5.9 ±1.8%)
- Chelan (5.8 ±1.5%)
- Methow (7.7 ±2.3%)
- Okanogan (4.3 ±2.4%)
- Spokane (6.6 ±2.2%)

Within the Washington portion of the Columbia River basin, the Forecast shows a fairly consistent pattern in changes of surface water supply timing, with higher flows in late fall, winter and spring by 2030, and lower flows in the summer and early fall. Exact timing varies by watershed.

4.2 Cumulative Water Demands in the Washington State Portion of the Columbia River Basin

This section presents cumulative forecasted demands for the Washington state portion of the Columbia River basin. These results should be understood within a likely context of increasing demands across the entire Columbia River basin, particularly during summer low flow conditions.

Historical (1977-2006) out-of-stream diversion demands within the Washington State portion of the Columbia River basin for municipal and agricultural irrigation water (excluding irrigation conveyance losses) were estimated to be in the range of 6.3 (±0.1) million ac-ft. Forecasted increases in water demands in eastern Washington for 2010 to 2030 are summarized in Table 10. The Forecast anticipates

- 170,000 (±18,000) ac-ft per year of additional *total* (ground and surface) water agricultural irrigation demand. This number assumes no change in irrigated acreage, and no additional water supply development. This number represents demands for surface and groundwater as applied to crops, plus the additional water needed to account for irrigation application inefficiencies.

- 430,000 (±14,000) ac-ft per year of additional *surface* water agricultural demand. This number includes new demands that will be met only by surface waters, and assumes that historical groundwater irrigation demands in the Odessa area will be new surface water demands in the future.
- 117,500 ac-ft per year in additional total diversion demands for municipal and domestic water.
- 500,000 ac-ft per year of unmet tributary instream flows, and 13.4 million ac-ft per year of unmet Columbia River mainstem instream flows, based on observed deficits during the 2001 drought year.
- No demand for new water storage for hydropower generation purposes.

Table 10. Forecast increases in demands by sector from 2010 to 2030 in eastern Washington.

Demand Type	**Estimated Volume (acre feet)**	**Source**
2030 New Irrigation Demand[a]	170,000	WSU Integrated Model
2030 New Municipal and Domestic Demand (including municipally-supplied commercial)	117,500	WSU Integrated Model
Unmet Columbia River Instream Flows[b]	13,400,000	Ecology data, McNary Dam, 2001 drought year
Unmet Tributary Instream Flows[c]	500,000	Ecology data, tributaries with adopted instream flows, 2001 drought year
2030 New Hydropower Demand	0	WSU Surveys and Planning Forecast Review
Alternate Supply for Odessa	164,000	Odessa Draft Environmental Impact Statement (October 2010)
Yakima Basin Water Supply (pro-ratables, municipal/domestic and fish)	450,000	Yakima Integrated Water Resource Management Plan (April 2011)
Unmet Columbia River Interruptibles	40,000 to 310,000	Ecology Water Right Database (depending on drought year conditions)

[a] Additional irrigation demands were modeled assuming an equivalent land base for irrigated agriculture, under a scenario of medium growth in the domestic economy, and medium growth in international trade. Acreage currently irrigated by groundwater in the Odessa was assumed to be new surface water demand in 2030, and thus is not reflected in changes in total demand, which includes both surface and groundwater. Increases in total demand are thus due to the combined impacts of climate change, and changes in crop mix driven by growth in the domestic economy and international trade.

[b] Unmet Columbia River instream flows are the calculated deficit between instream flows specified in Washington Administrative Code (WAC) and 2001 (drought condition) actual flows at McNary Dam.

[c] Unmet tributary instream flows are the combined deficits between current instream flows specified in WAC and 2001 actual flows at Walla Walla River near Touchet, Wenatchee River at Monitor, Entiat River near Entiat, Methow River near Pateros, Okanogan River at Malott, Little Spokane River near Dartford, and Colville River at Kettle Falls.

New irrigation and municipal demands do not include improvements in conservation, which could decrease the new demands that need to be met, but might also have complex impacts on return flows. For example, if all municipal and domestic users were able to conserve 10% of their water supplies by 2030, then new municipal demand might drop from 117,500 acre-feet to about 105,000 acre-feet. However, many municipal conservation techniques are non-consumptive in nature. For example, fixing leaky pipes and installing low flow showers and toilets reduce diversions, but with a corresponding reduction in water returned (via wastewater treatment plants or underground). Alternatively, some conservation measures, such as reducing lawn size, do reduce consumptive use. In addition, conservation is often less expensive than new water supply development.

In addition to these new demands by sector, other studies suggest several areas of unmet demand, some of which are not reflected in these totals. These other studies used different methods of calculating demand, and thus, should not be directly compared to the totals above.

- The draft Environmental Impact Statement for Odessa suggests a preferred alternative of supplying 164,000 ac-ft per year of surface water to current groundwater users in this area. This amount is not included in the total irrigation demands above, which shows changes in total (combined groundwater and surface water) demand between the historical period (which includes Odessa) and 2030.
- The Yakima Integrated Water Resource Management Plan suggests that 450,000 ac-ft per year will be needed for pro-ratable, municipal-domestic and fish needs. These demands overlap partially with the demands shown above.
- The Ecology Water Right Database indicates that in years in which the mainstem Drought Program is run, there are 40,000 to 310,000 ac-ft per year of unmet needs by interruptible water users, depending on the drought year conditions. These amounts are currently unmet, so are not reflected in the numbers above.

Together, these current and new demands are likely to exacerbate water supply issues in some locations, particularly during the summer.

4.3 Water Demands in the Columbia River Basin by Sector

4.3.1 Agricultural Water Demands

The agricultural portion of the Forecast focused on irrigation water demands. The 2030 forecast of demand for irrigation water across the entire Columbia River basin (seven U.S. States and British Columbia) was 13.6 million ac-ft under average flow conditions, assuming an equivalent land base for irrigated agriculture in the future (Table 11). The range of estimates was from 13.1–14.1 million ac-ft during wet and dry years, respectively (20th and 80th percentile).[2] This

[2] On average, one in five years will be wetter than the 80th percentile, or dryer than the 20th percentile.

irrigation demand was roughly 2.5% above modeled historic levels under average flow conditions. Conveyance losses, that occur as water is transported through irrigation ditches and canals, were estimated separately.

Table 11. Top of crop agricultural demands under the baseline economic scenario (medium domestic economic growth and medium growth in international trade), excluding conveyance losses, in the Columbia River basin in the historical and 2030 forecast period. Estimates are presented for average years, with range in parentheses representing wet (80th percentile) and dry (20th percentile) years.

	Historical (1977-2006) million ac-ft per year	**2030 Forecast** million ac-ft per year	**% Change**
Entire Columbia River Basin	13.3 (12.6-13.9)	13.6 (13.1-14.1)	2%
Washington Portion of the Columbia River Basin	6.3 (6.0-6.5)	6.5 (6.2-6.6)	2%

Seasonal timing of forecasted water supply and irrigation water demand is shown in Figure 42, with irrigation demands taking a larger proportion of water supplies in summer months by 2030. Instream, hydropower and municipal water demands will also need to be met from these water supplies.

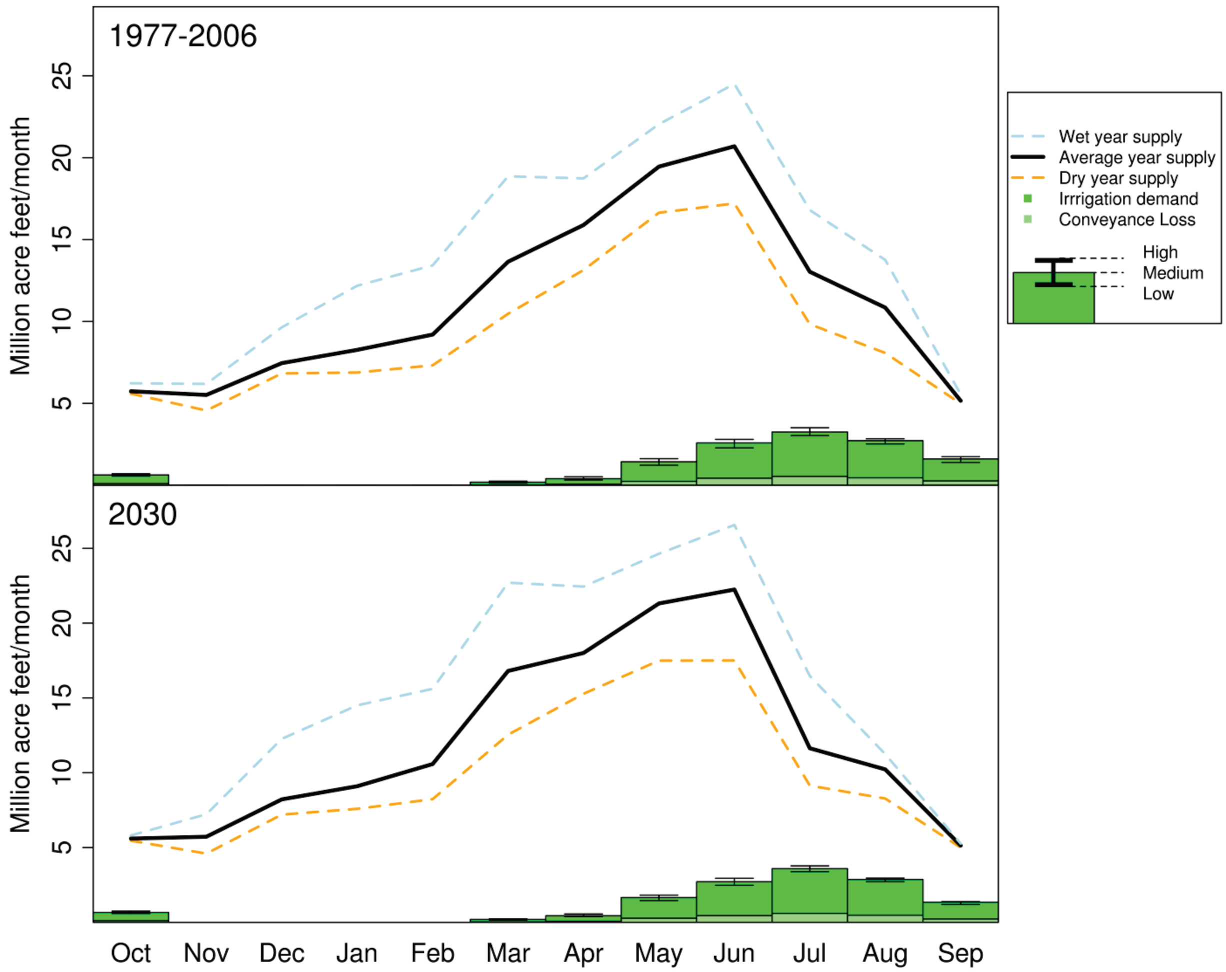


Figure 42. Comparison of regulated surface water supply and surface water irrigation demands for the historical (top) and 2030 forecast (bottom) periods under the medium-growth, medium-trade economic scenario across the entire Columbia River basin, including portions of the basin outside of Washington State. Wet (80th percentile), dry (20th percentile), and average (50th percentile) flow conditions are shown for both supply and demand.

Within the Washington State portion of the Columbia River basin, results were similar (Figure 42):

- Forecast increases in irrigation water demand were an average of 170,000 (±18,000) ac-ft per year, roughly 1.9% above historical conditions, assuming an equivalent land base for irrigated agriculture, and a crop mix influenced by medium growth in the domestic economy and international trade.
- Considering only the climate impacts of temperature and precipitation variations on the irrigation demand, there would be a 3.7% increase in demand. When economic

impacts resulting in a new crop mix are considered in addition to the climate impacts the increase in demand reduces to 1.9%.

Modeling under alternate economic scenarios was used to give information about the potential range of future water demands from irrigated agriculture, if growth in the domestic economy and international trade were higher or lower than anticipated.[3] Higher income growth leads to an expansion of high value crops like fruits and vegetables at the expense of low value crops. Similarly, stronger growth in exports has a disproportionate impact on higher value crops, although wheat and alfalfa are also sensitive to fluctuations in trade. Production patterns were generally more sensitive to assumptions about trade than to assumptions about economic growth. One exception was wine grapes where most of the growth in demand is expected to come from domestic consumers rather than international exports.

- The low, medium and high economic scenarios forecast increases of 200,000 (±17,000) ac-ft, 170,000 (±18,000) ac-ft and 140,000 (±18,000) ac-ft over historical demands under average flow conditions within the Washington portion of the Columbia River basin.
- These estimates assumed no change in the land base for irrigated agriculture, thus differences in the agricultural water demand between different scenarios were due to changes in crop mix and crop water demands under future climate conditions.

Additional scenarios considered the potential impacts of additional water capacity in specific locations corresponding to projects proposed by OCR. Under some scenarios, new water was provided at no cost to users, while in other scenarios, users were charged per unit fees to recover some development costs.

- The development of roughly 200,000 ac-ft of annual water capacity (the medium scenario considered) caused demand for irrigation water to increase by 46,400 (±640) ac-ft per year over baseline 2030 demands (under the medium economic scenario) in the Washington portion of the basin.

4.3.2 Municipal Water Demands

Municipal demands, including domestic and municipally-supplied industrial, are likely to increase throughout the entire Columbia River basin over the next 20 years. By 2030, U.S. Census estimates show population growth in Idaho (25.6%), Oregon (26.2%), and Montana (5.6%). Although some new municipal demands will likely be met by deep groundwater supplies, others will likely come from shallow groundwater or surface water. These additional

[3] Domestic economic growth was 1.3-1.8% under low and high scenarios, while international trade included scenarios of low and high growth in trade for specific crop groups (e.g. vegetables, wheat, etc.).

demands will likely reduce inflows into some parts of Washington. For example, an Idaho study of the Spokane River basin projected an additional demand on the river of 31 cfs by 2060.[4]

Within eastern Washington, the Forecast found that:

- Domestic and industrial diversion demands in rural and urban areas (excluding self-supplied industries) were forecasted to be 569,000 ac-ft per year in 2030, an estimated 26% increase over 2010. Consumptive demands are approximately 51% of this amount.
- Per capita water demands varied considerably throughout eastern Washington, with an average total demand (including system losses) of approximately 277 gallons per capita per day (gpcd).[5]

4.3.3 Instream Water Demands

Across the Columbia River basin, the Forecast found that:

- Decreases in surface water supplies in summer and early fall may increase the challenge of meeting water needs for fish across the Columbia River basin by 2030.
- Re-negotiation of the international Columbia River Treaty could change the amounts and timing of water available to meet instream needs in the Columbia River mainstem.
- Quantification of tribal water rights, while outside the scope of this Forecast, could also change surface water supplies for meeting instream demands in unpredictable ways.

Within eastern Washington, the forecast of demand for water to support instream flows found the following:

- In many rivers in eastern Washington, stream flows are below state or federal instream flow targets on a regular basis, particularly in late summer. Surplus water exists in many of these same rivers at other times of year.
- Decreases in surface water supplies in tributaries in summer and early fall may lead to more weeks when instream flows are not met by 2030. This may result in a higher frequency of curtailment of interruptible water right holders in basins with adopted instream flow rules.

[4] 31 cfs = 22,443 ac-ft/year

[5] 277 gallons per day = 0.429 cfs = 311 ac-ft/year

- An evaluation of fish, flows, and habitat in eight fish critical basins, available in the Columbia River Instream Atlas (Ecology Publication 11-12-015), will help target investments to maximize the positive impact on fish populations.

4.3.4 Hydropower Demands

Across the Columbia River basin, the forecast of hydropower demands found the following:

- Demand for water storage to supply hydropower facilities is anticipated to remain unchanged in 2030. Utilities expect to be able to meet projected steady growth in peak winter and summer energy demands through conservation and integration of other energy sources, including those required under Washington's passage of Initiative 937.
- Several power entities are concerned that climate change and the possible renegotiation of the international Columbia River Treaty will affect hydropower generation capacity.

4.4 Water Demands in Washington State Watersheds

Surface water supplies and water demands were forecasted for each WRIA in eastern Washington. Major results for each WRIA are presented in Chapter 6, Tier II Results. Cumulatively, the following results were found:

- The greatest concentration of current and future agricultural irrigation and municipal water demands are in the southern and central Columbia basin, including Lower Yakima (37), Lower Crab (41), and Esquatzel Coulee (36), as well as Rock-Glade (WRIA 31), Walla Walla (32), Lower Snake (33), Naches (38), Upper Yakima (39), and Okanogan (49). Irrigation dominates the demand for water in these WRIAs.
- Unmet demand due to curtailment of interruptible and pro-ratable water rights or insufficient water at the watershed scale was forecasted for Walla Walla (WRIA 32), Yakima (37, 38, & 39), Wenatchee (45), Methow (48), Okanogan (49), Little Spokane (55), and Colville (59).
- Unmet demand for surface water was forecasted for the Odessa due to existing groundwater declines in Palouse (WRIA 34), Esquatzel Coulee (36), Lower Crab (41), Grand Coulee (42), and Upper Crab (43).

4.5 Surface Water Supply and Demand on Washington's Columbia River Mainstem

Modeled historical and 2030 forecast surface water supplies were compared to state-level instream flow targets and the Federal Columbia River Power System Biological Opinion (FCRPS BiOp).

- Under normal flow conditions, modeled regulated surface water supplies *prior to* meeting cumulative demands were close to Washington State instream flow regulations in fall/early winter at Priest Rapids Dam (both historical and 2030 forecast), and in July and August at Priest Rapids Dam and McNary Dam (for the 2030 forecast).
- Under normal flow conditions, modeled regulated surface water supplies *prior to* meeting cumulative demands were not sufficient to meet target flows under the FCRPS BiOp in April, July, and August at McNary Dam, and from November – January at Bonneville Dam. Imbalances were smaller in the 2030 forecast than the historical case for the late winter/spring months, and larger for the late summer.
- Along the mainstem, there are 379 interruptible water rights, the majority of which are agricultural surface water rights. These water users are particularly vulnerable to the potential impacts of water shortages.

4.6 Conclusion

Collectively, these results suggest that meeting water demands will be more challenging by 2030 as increased demands are placed on limited supplies. Solutions will require combinations of conservation, water banking/marketing, and new supplies based on groundwater and/or storage of water in peak runoff seasons.

For solutions requiring additional investment in water supply infrastructure, the Forecast's results suggest that at prices in the range of those currently being charged by the Office of Columbia River for new water it may be feasible to recover some or all water supply costs from new users without significantly decreasing the quantity of water demanded by users.

Projects associated with the medium water capacity scenario of an additional 200,000 ac-ft per year for out-of-stream uses were estimated to lead to total employment impacts (including indirect and induced effects) of 6,600 jobs. State and local tax impacts were estimated at about $37 million. These estimates do not subtract the jobs and taxes associated with production if land associated with the new capacity was previously under dryland cultivation. These estimates include economic activity generated from downstream processing of agricultural products that occurs within Washington. While not quantified, it is recognized that maintenance of and improvement to instream flows would also have positive economic impacts on tourism and recreation, generating additional jobs and tax revenues.

This Forecast improves our understanding of future surface water supplies and instream and out-of-stream demands, and will serve as a capital investment planning tool to maintain and enhance the region's economic, environmental, and cultural prosperity. Future forecasts will build upon and expand this knowledge to include assessments of groundwater supplies, the Columbia River Treaty and other pertinent issues.

5.0 Tier I Results - Columbia River Basin

Tier I, the Columbia River basin, focused on a broad assessment of the basin as a whole, with in-depth analysis of the Washington portion of the basin. To accurately forecast Washington's water supply and demand, it is necessary to understand water supply and demand throughout the entire Columbia River basin. The major water contributors are British Columbia, Washington, Idaho, Montana and Oregon, while Wyoming, Utah and Nevada are minor contributors by area (Figure 43). The amount and timing of water entering Washington State within the Columbia River basin is highly impacted by existing infrastructure and management in British Columbia, Idaho, Montana, and Oregon.

Figure 43. Columbia River Basin.

Throughout this report, WSU modeling results are presented using specific definitions of supply and demand, described in Section 1.3 of this report.

5.1 Water Supplies Entering Washington

5.1.1 Modeled Surface Water Supplies Entering Washington

Modeling results indicated a number of important changes in surface water supply entering Washington between the historical period (1977-2006) and 2030. These changes reflect the impacts of climate change (Figure 44, Figure 45):

- Annual water supplies for most of the eastern incoming rivers, including the Columbia, Pend Oreille, Spokane, Clearwater, Snake, and John Day will increase by 2030, an average of 3.7 (±1.3)%.[1]
- The direction of change for annual water supplies entering Washington is unclear, 1.4 (±1.9)% on average, for the Similkameen and Kettle Rivers.
- Within a season, surface water supplies entering Washington will generally increase by 2030 in late fall, winter and spring, and decrease in the summer and early fall. This pattern applies to both eastern and western portions of the basin, and is evident at most points where significant amounts of water enter Washington, including the Columbia River and the Snake River. The exact timing may vary somewhat by river.

[1] When discussing modeled supply and irrigation demand results, "average flow conditions" refers to the 50th percentile (middle) value under the middle climate scenario. "Average" by itself refers to the average value over all climate scenarios and flow conditions, and a 90% confidence interval around that average.

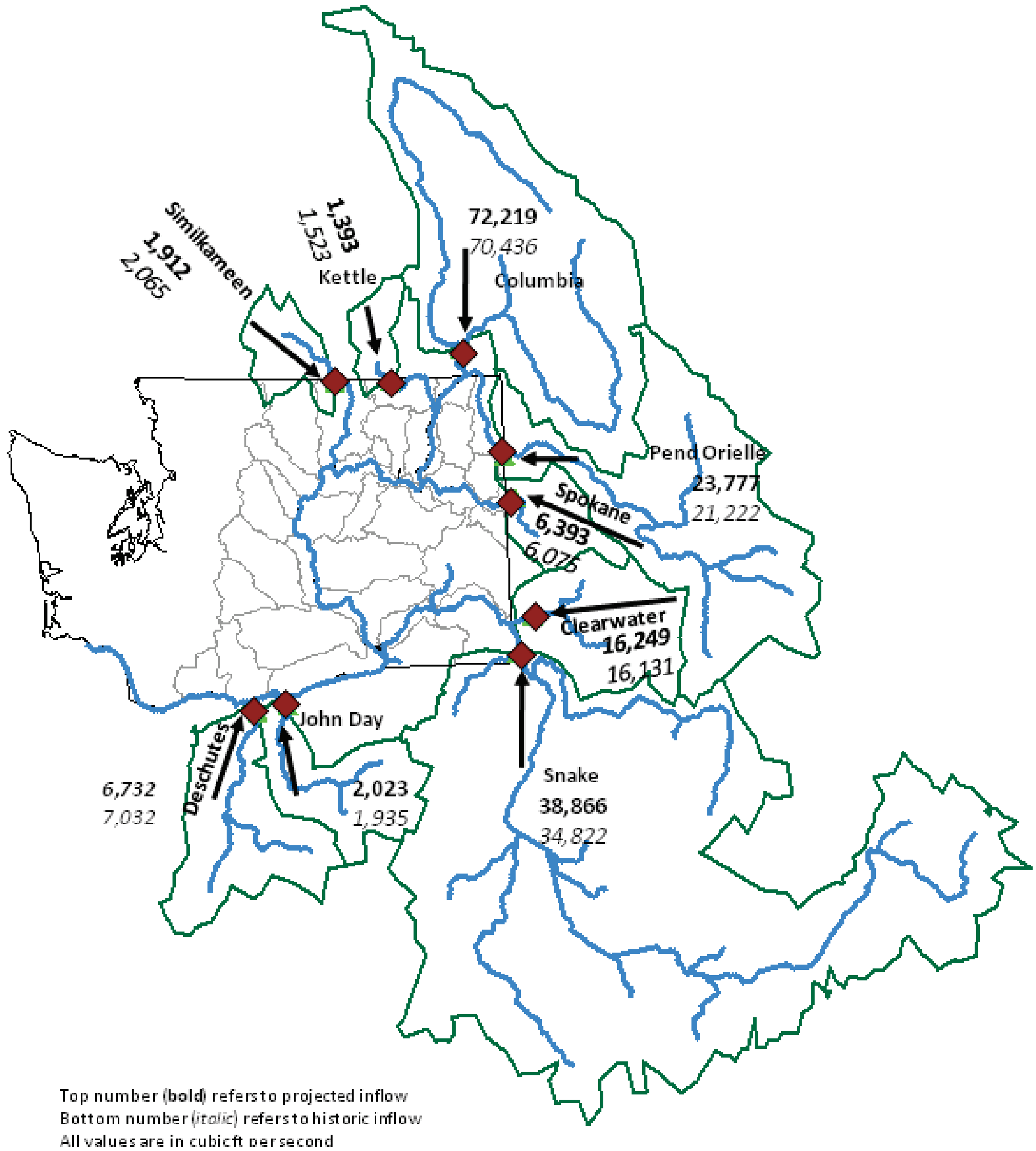


Figure 44. Surface water flows for major tributaries upstream of the point where the rivers enter Washington State. Top number (bold) refers to 2030 forecast water supplies for average (50th percentile) flow conditions and the middle climate change scenario, while the bottom number (italic) refers to historical (1977-2006) water supplies. All values are in cubic feet per second.

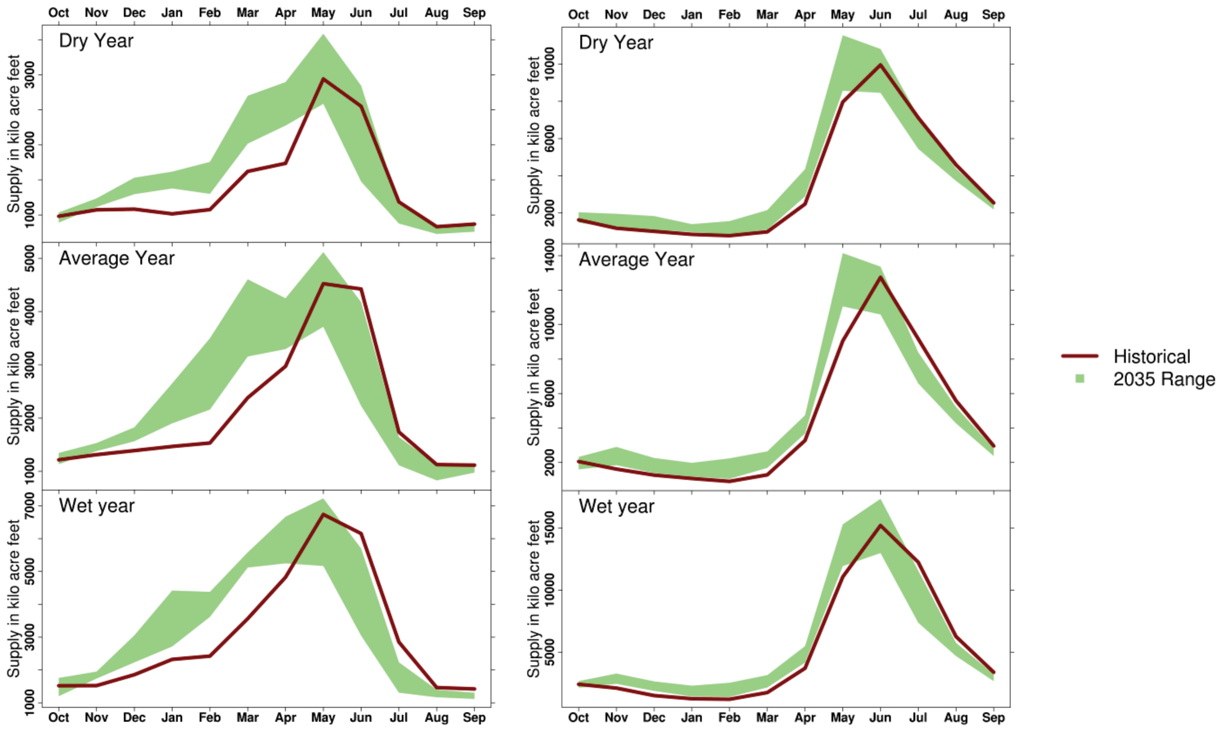


Figure 45. Historical (1977-2006) and 2030 forecast regulated surface water supplies on the Snake and Columbia Rivers upstream of the point where they enter Washington State for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions. The spread of 2030 flow conditions is due to the range of climate change scenarios considered.

5.1.2 Columbia River Basin Surface Water Supply and Seasonal Availability

The forecast of surface water supply and timing in 2030 for all areas of the Columbia River basin upstream of the Bonneville Dam noted the following changes compared to the historical flows (1977-2006) (Figure 46):

- A small increase of around 3.0 (+/-1.2)% in annual supplies.
- Timing changes will shift water away from the times when demands are highest. Unregulated surface water supply at Bonneville will decrease an average of 14.3 (±1.2)% between June and October, and increase an average of (17.5 (±1.9)% between November and May.

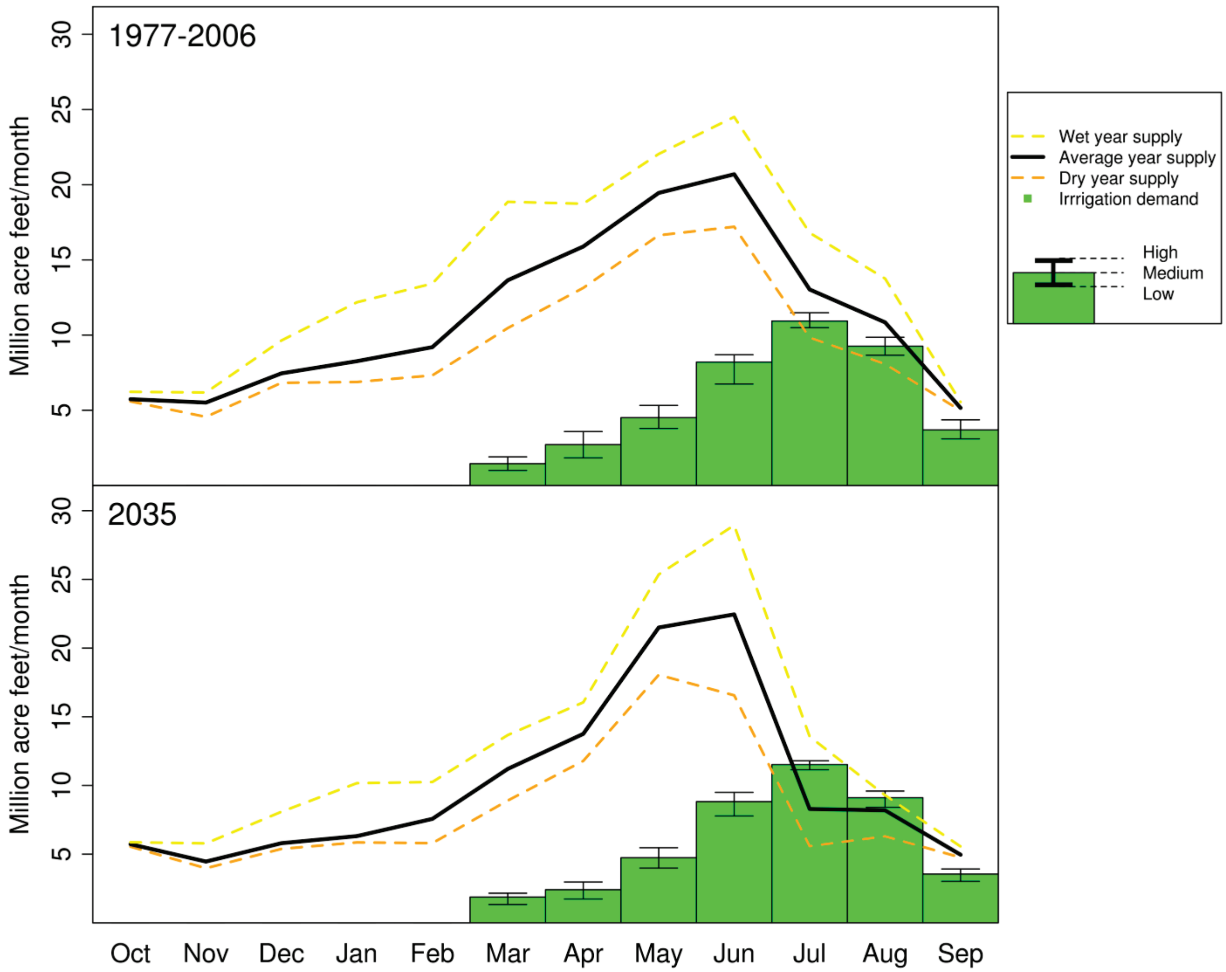


Figure 46. Comparison of regulated surface water supply and irrigation water demands for the historical (top) and 2030 forecast (bottom) periods under the medium-growth, medium-trade economic scenario across the entire Columbia River basin, including portions of the basin outside of Washington State. Wet, dry, and average flow conditions are shown for both supply (dotted lines) and demand (error bars).

5.1.3 Regional Survey Results

The 2010 regional survey to assess potential changes in Columbia River and tributary inflows into the State of Washington consisted of 29 questions covering water demand, water projects, and general plans for managing jurisdictional water supplies. The questions included in the survey are available in Appendix C.

5.1.3.1 Survey Results Regarding Water Supply and Demand

As discussed in the detailed methodology provided in Section 3.6, the survey questions on water supply and demand resulted in a wide range of answers reflecting the diversity of agencies and large geographical regions contacted. Nevertheless, several interesting themes surfaced.

- Only 52% felt that they currently had enough water supply to meet existing demands. (In some cases respondents knew only about out-of-stream demands; in other cases respondents included both out-of-stream and instream demands.) This was qualified by several respondents who pointed out that water supplies varied throughout the state with some areas having shortages and other areas having sufficient water. Some also stated that low-flow years posed problems for meeting the instream demands of fish.

- 40% reported that they already face water shortages in at least parts of their states.

- Nearly 88% expected that water demands for their states would increase in the future for a wide variety of reasons. Although population increase was most often cited (44 %), additional needs for environmental protection, agricultural expansion, high tech and industrial uses, micro hydro, and recreation demands were also mentioned.

When asked specifically about the implications of climate change, responses again varied widely. Overall, many agencies and groups were incorporating factors related to climate change into their forecasting efforts. Respondents whose agencies were incorporating climate change reported that their climate change forecasting efforts generally looked at time horizons of 20 to 50 years and nearly all acknowledged that assumptions had to be made in the process. Utah's political objections to climate change affects incorporation of climate change impact into their planning efforts.

5.1.3.2 Survey Results: Water Development Projects

Nearly half of those interviewed knew of future projects planned within their jurisdictions. Except for two aquifer storage and recovery projects, all of the other projects were either relatively small projects or projects primarily in the early planning stages. One project (USBR Hungry Horse) s looked at either the implications of operational changes, while several other projects proposed conservation efforts.

Because of the preliminary nature of the projects, it was too soon to tell if projects were feasible. However, most of the projects (including the aquifer storage and recovery projects) took water during high flow periods when it would be unlikely to impact water flows into Washington negatively, though it is worth monitoring future progress of these projects.

Although managers knew about planning efforts, often their responses indicated general awareness, without detailed knowledge of capacity and/or exact location. In part, this appears to be due to the conceptual and preliminary nature of new projects as well as diffuse nature of water management at the watershed scale.

5.1.3.3 Survey Results: Managing Jurisdictional Water Supplies

Changes in the management of existing water supplies were primarily focused on incremental evolution to improve efficiencies. A notable exception is the Okanagan Nation's legal actions to settle the dispute regarding their water right claim, which has the potential to change management of existing water supplies much more significantly. Litigation might change reservoir operations and a few respondents mentioned that state legislative changes may mandate development of state water management plans.

About 25% felt that increased water storage capacity would be needed in their regions. Several possible future projects appeared to be based on satisfying municipal demands. It was not immediately clear if this was due to economics, growth, or a combination of these and other factors.

The survey may not have reached the right people with respect to the topic of "Do you currently have plans to expand agricultural acreage?" (Question #22), and subsequent follow-up questions. This is something to consider in follow-up activities or future surveys where perhaps more irrigation districts, commodity groups, hydropower operators, or large farm operators are targeted.

On a more general note, it seemed that the survey did not always reach respondents with comprehensive knowledge of the variety of issues covered by the survey. Generally, the survey strategy began by targeting leads of heads within organizations, though interviewers were often referred to others with more specific program knowledge. Our mixed success may result from a combination of targeting the wrong individuals initially, as well as the fact that it is difficult to find individuals within agencies who have knowledge covering the wide breadth of the survey questions, and yet also with knowledge of specific details that were of interest (e.g. the specific capacity of proposed projects). In addition, agencies may not be aware of projects planned by private entities are planning until they submit a formal application.

Despite these limitations, the broad objectives of the regional survey were met. In summary, there did not appear to be any projects that would lead to significant changes in flows in the Columbia River or its tributaries. At the scale of the current modeling effort, we therefore did not feel the need to alter inflows due to upstream changes in demands. However, the implications of the Columbia River Treaty between the U.S. and Canada are not well understood at this time, and could significantly impact the timing of flows entering the State of Washington. Complete analysis of this was beyond the scope of this Forecast.

5.2 Water Demand Forecast

5.2.1 Columbia River Basin Agricultural Water Demand

The 2030 forecast of demand for agricultural irrigation water across the entire Columbia River basin was 13.6 million ac-ft per year under average (50^{th} percentile) flow conditions, with the range of low and high estimates under different weather conditions from 13.1–14.1 million ac-ft per year (20^{th} and 80^{th} percentile) (Figure 46). When compared to average historical (1977-2006) conditions, this represented an increase of 0.33 million ac-ft, or approximately 2.5% above estimated demands for the historical period of 13.3 million ac-ft per year (Table 12).

Table 12. Top of crop agricultural demands under the baseline economic scenario (medium domestic economic growth and medium growth in international trade), excluding conveyance losses, in the Columbia River basin in the historical and 2030 forecast period. Estimates are presented for average years, with low and high quantities in parentheses representing wet (80th percentile) and dry (20th percentile) years.

	Historical (1977-2006) **million ac-ft per year**	**2030 Forecast** **million ac-ft per year**	**% Change**
Entire Columbia River Basin	13.3 (12.6–13.9)	13.6 (13.1–14.1)	2%
Washington Portion of the Columbia River Basin	6.3 (6.0–6.5)	6.5 (6.2–6.6)	2%

These demand results should be thought of as the upper bound of “top of crop” water demand under the medium growth, medium trade scenario, assuming no change in the land base for irrigated agriculture. This is because this value represents water demand after changes in crop mix have occurred in response to changes in the domestic economy and international trade flows. As described more fully in Chapter 3, Methodology, constraints on water availability (including physical availability or regulatory curtailments) are assumed to result in deficit irrigation of nearby less profitable crops; other producer responses that would minimize the production impacts of water shortages are outside the scope of this Forecast. This would include strategies such as changes in crop mix to favor less water intensive crops, or investments to increase the efficiency of irrigation.

Results for the Washington State portion of the Columbia River basin are similar, suggesting that 2030 irrigation demands will be roughly 1.9% above historical. This change is due to a combination of two factors: climate change and changes in crop mix driven by the economic scenario considered. Considering the climate impacts of temperature and precipitation variations alone on the irrigation demand, there is a 3.7% increase in demand. When economic impacts resulting in a new crop mix are considered in addition to the climate effects, the increase in demand reduces to 1.9%.

These changes in total irrigation demand do not include additional surface water demands that may result from the need to supply water to agricultural producers in the Odessa area who currently receive groundwater. These demands were treated as groundwater demand in the historical case, and surface water demands in 2030. In the 2030 forecast, this area represented 240,000 ac-ft per year of surface water irrigation demand.

5.2.1.1 Impact of Variation in Assumptions about Economic Growth and Trade on Water Demand in Washington

The irrigation demands presented above were run under a medium growth, medium trade scenario, reflecting 'most likely' future conditions. Low and high alternate scenarios captured the range of possible future economic conditions within Washington, considering both growth of the domestic economy, and growth in international trade in agricultural goods. Overall, the low, and medium economic scenarios forecasted an estimated 6.5 million ac-ft of average irrigation demand and the high medium scenario forecasted an estimated 6.4 million ac-ft of average irrigation demand within the Washington portion of the Columbia River basin, assuming that the extent of irrigated acreage stayed constant (Table 13).

Table 13. Top of crop agricultural demands under the three economic scenarios (low, medium, and high), excluding conveyance losses, in the Columbia River basin for the 2030 forecast period. Estimates are presented for average years, with low and high quantities in parentheses representing wet (80th percentile) and dry (20th percentile) years.

	2030 Forecast Under Varied Economic Scenarios million ac-ft per year		
	Low	**Medium**	**High**
Washington Portion of the Columbia River Basin	6.5(6.2–6.6)	6.5(6.2–6.6)	6.4(6.2–6.6)

Over the range of scenarios considered, variation in assumptions about economic growth generally resulted in modest changes in production relative to the impact of international trade. Domestic income growth was projected to be 1.6% per year in real income per capita for the "medium" scenario, 1.3% under the low scenario, and 1.8% under the high scenario. Domestic income growth impacts water demand because consumers have more money to spend on food which places upward pressure on food prices which incentivizing producers to increase production. As a result of assumptions made in the economic model, population growth impacted all crops equally, while income growth had a larger impact on high value crops such as cherries and wine grapes. However, these changes still caused relatively small changes in total irrigation water demand. While many of the crops that are more sensitive to changes in income are irrigated, including apples, wine grapes, and cherries, they each occupy 200,000 acres or less in Washington. This is a relatively small area compared to wheat, cropland pasture, and forage crops, which together account for more than 80% of all cropland in the state. Among these latter crops, non-irrigated acreage will not significantly impact irrigation water demand, although it may influence water availability by influencing surface water flows.

Assumptions about international trade had a more significant influence on crop mix than assumptions about domestic income growth. The similarity in the income and trade scenarios is that higher rates of either resulted in increased substitution into high value crops. An exception to this was irrigated wheat production where there was little variation between the low and high scenarios, based on the expectation that export demand for wheat will remain fairly steady.[2] In contrast, fruit and vegetable production varied more between low and high scenarios because there has been robust growth in exports of these crops over the last decade.[3] In contrast to most fruit-based products, demand for Washington wine grapes and wine production is expected to be primarily dependent on growth in the domestic rather than foreign markets. For alfalfa, traditional exports to South Korea, Taiwan, and Japan are expected to stay at historic levels although new demand centers in other parts of Asia are likely to continue to grow exports.

The implication of assuming different rates of domestic economic growth and international trade is that it affects both the value of water associated with irrigated agriculture and the economic impact of irrigated agriculture. Basic economic theory says that the value of allocating additional water towards some productive use depends on the value of what is being produced. A change in crop mix towards crops like tree fruit and vineyards that are often processed off the farm affects economic impact estimates for water development. An important caveat is that the scope of the the economic analysis only considered the agricultural sector.

5.2.1.2 Impact of Additional Water Capacity Development and Cost Recovery for New Water Provision on Forecast 2030 Irrigation Water Demand in Washington

The baseline scenarios presented in this Forecast do not include any changes in water management. This was done to isolate the impact of changes due to larger market forces from those resulting from state level policy. It is also a prudent approach given the legal, political, and financial obstacles to changes in water management. As described more fully in Chapter 3, Methodology, in comparison with that baseline, OCR asked for analysis of a number of scenarios that included development of approximately 100,000, 200,000, and 500,000 ac-ft of additional

[2] Exports of Washington wheat have fluctuated around an average of $380 million for the last decade, and tend to spike when there are significant weather induced shocks to other major wheat growing regions. Climate change predictions suggest that weather-induced crop reductions could become more common in places like Russia and Australia, elevating the average level of Washington exports somewhat.

[3] Fruit and vegetable exports fruit and vegetable exports have grown at approximately 5% per year for fruit and 3% for vegetables over the last decade, with simultaneous growth in domestic markets.

water capacity at specific locations in the state, and potential recovery of development costs at a variety of prices, including zero. In interpreting the results of this analysis, it is important to recognize that this Forecast does not include benefit-cost studies for any particular water development projects.

Projects associated with the medium water capacity scenario of 200,000 ac-ft per year were estimated to lead to approximately 62,000 acres, including both newly irrigated lands, and replacement water for acreage in Odessa currently irrigated by groundwater. The economic impacts associated with production on this acreage would generate an estimated agricultural output of $169 million, or about $2,700 per acre. This estimate does not subtract the value of production if land were currently under dryland cultivation. Total economic impacts of the additional production were estimated with the Implan® economic input-output model to be an additional $120 million in indirect and induced effects.[4]

The economic impact of this increased production was estimated to be 6,600 jobs, which included employment related to crop production and food processing industries. State and local tax impacts were estimated at about $37 million, with most of this coming from indirect business taxes, including taxes incurred in the ordinary operation of business (such as sales taxes, excise taxes, and property taxes).[5] The values of output and other estimated economic outputs are reported in current terms, reflecting the fact that the input-output model shows the current economy in terms of wages, production technologies, and many other factors. To put this into perspective, there are approximately 62,000 jobs in Washington directly related to crop production and almost half are in fruit farming. There are an additional 31,000 jobs in agricultural support activities and 12,000 jobs in relevant food processing industries.

Information on the disposition of agricultural production to specific processing industries is not generally available so it was necessary to make a few general assumptions to include processing industry impacts. According to USDA statistics about 18% of apple and cherry production enters into processing. Thus, 18% of new fruit production was assumed to be processed within the state, in the canning industry. For vegetables, potatoes, sweet corn, and onions constitute more than 90% of Washington's vegetable acreage. About 75% of potato production is allocated to the frozen food industry. Nearly all sweet corn production is processed. Data is not available for onions, though it is likely that less are processed. Combining all this information, it was simplistically assumed that 75% of the additional vegetable production would be processed

[4] This estimate included additional economic activity generated through backward linked industries, such as machinery repair and fertilizer sales (indirect effects), and spending throughout the rest of the economy that are impacted by additional household income (induced effects).

[5] Total taxes also included employer contributions to social insurance, proprietor income, indirect business tax, taxes on household income, and taxes on corporate profits.

within the state and that all of it went towards frozen foods (though in reality there is some processing in other industries such as snack food manufacturing). Additional wine grapes were assumed to be processed in Washington by the wine industry.

While not quantified, it is recognized that maintenance of and improvement to instream flows would have positive economic impacts on tourism and recreation, generating additional jobs and tax revenues.

Cost recovery scenarios considered various possible scenarios of prices that could be charged for new water capacity for cost recovery purposes ($25, $100, and $200 per ac-ft per year). These prices correspond respectively to the range of prices being charged for projects in current development, a higher price that has been charged elsewhere for water projects, and a possible high price in the future. The total amount that could be generated for cost recovery purposes was determined by discounting the stream of payments received over time into a single present value. At low prices, agricultural producers are likely to use all water made available because their net revenue would still be greater by irrigating than under dryland production. At higher prices it is possible that not all of the water will be used.

As is typical for this type of analysis, results varied significantly depending on the assumption of the discount rate, which is usually based on either yields of long-term government bonds (low estimate) or on the rate of return on capital in private markets (high estimate). An assumption of a lower discount rate leads to a higher present value. Depending on whether the discount rate considered is 2%, 4%, or 6%, cost recovery from charging $25 per ac-ft for 200,000 ac-ft in perpetuity would be $250 million, $125 million or $83 million, respectively. The cost recovery estimates are shown in Table 14 and Table 15. Each table shows how results vary assuming the different discount rates for the low, medium, and high water capacity scenarios. The Office of Columbia River is considering charging until project construction costs are recovered. Because construction cost data was not available for this project, and it was impossible to determine when costs would be recovered, two different time frames were examined. Table 14 assumes that the unit price for new water continues to be charged in perpetuity. Table 15 assumes that new water users are charged for 20 years.

Table 14. Present value of cost recovery scenario from charging in perpetuity (units in millions of dollars).

	Discount Rate Low (2%)	Medium (4%)	High (6%)
100,000 ac-ft			
$25 ac-ft	$125,000,000	$62,500,000	$41,666,667
$100 ac-ft	$500,000,000	$250,000,000	$166,666,667
$200 ac-ft	$1,000,000,000	$500,000,000	$333,333,333
200,000 ac-ft			
$25 ac-ft	$250,000,000	$125,000,000	$83,333,333
$100 ac-ft	$1,000,000,000	$500,000,000	$333,333,333
$200 ac-ft	$2,000,000,000	$1,000,000,000	$666,666,667
500,000 ac-ft			
$25 ac-ft	$625,000,000	$312,500,000	$208,333,333
$100 ac-ft	$2,500,000,000	$1,250,000,000	$833,333,333
$200 ac-ft	$5,000,000,000	$2,500,000,000	$1,666,666,667

Table 15. Present value of cost recovery scenario from charging for 20 years (millions of dollars).

	Discount Rate Low (2%)	Medium (4%)	High (6%)
100,000 ac-ft			
$25 ac-ft	$40,878,583	$33,975,816	$28,674,803
$100 ac-ft	$163,514,333	$135,903,263	$114,699,212
$200 ac-ft	$327,028,667	$271,806,527	$229,398,424
$25 ac-ft	$81,757,167	$67,951,632	$57,349,606
$100 ac-ft	$327,028,667	$271,806,527	$229,398,424
$200 ac-ft	$654,057,334	$543,613,054	$458,796,849
500,000 ac-ft			
$25 ac-ft	$204,392,917	$169,879,079	$143,374,015
$100 ac-ft	$817,571,667	$679,516,317	$573,496,061
$200 ac-ft	$1,635,143,334	$1,359,032,634	$1,146,992,122

Table 14 and Table 15 show the net present value from charging $25, $100, and $200 per ac-ft for 100,000, 200,000, and 500,000 ac-ft. Each value is calculated for the low, medium, and high quantities of water and for a low, medium, and high discount rate.

5.2.2 Columbia River Basin Municipal Water Demand

The forecast of municipal demand in Washington should be understood within the context of likely increases in demand throughout the Columbia River basin. U.S. Census estimates show population growth over the next 20 years in Idaho (25.6%), Oregon (26.2%), and Montana (5.6%). Without concerted conservation efforts, population growth will certainly increase demands on water flowing into Washington State. Idaho has not released county-by-county growth projections, and it is difficult to predict which additional municipal demands will be met from deep groundwater supplies which would not impact surface water supplies. However, it is safe to assume that additional demands in Idaho will reduce inflows into some parts of Washington. A study of the Spokane River basin by the State of Idaho projected that they would place an additional demand of 31 cfs on the river by 2060.

WSU projected domestic and industrial diversion demands, excluding self-supplied industries, of 569,000 ac-ft per year in Washington in 2030, an estimated 26% increase over 2010 (Table 16). This increase of approximately 117,500 ac-ft per year compared to 2010 was driven by expected population growth. This expected population growth rate is similar to those estimated in the 2006 Forecast for 2005-2025.[6]

Per capita demands varied considerably throughout eastern Washington, with an average total demand (including system losses) of approximately 277 gpcd. These results are in line with a 2005 USGS study of domestic water use, which estimated 285 gpcd (Lane 2009), though higher than the estimates of 170 gpcd reported from the 2000 USGS study of domestic water use (Lane 2004).[7]

Table 16. Municipal diversion demands for the Washington portion of the Columbia River basin.

	2010 (ac-ft per year)	2030 Forecast (ac-ft per year)	% Change
Washington Portion of the Columbia River Basin	452,000	569,000	26%

Total consumptive demands for 2030 for eastern Washington were estimated to be 291,000 ac-ft per year in 2030, compared to 232,000 ac-ft per year in 2010. This represents approximately 51% of the total diversion quantity, which may be high compared to other investigations, but

[6] The forecast increase from 2006 through 2025 in the 2006 Forecast was 94,500 or 109,400 ac-ft per year, depending on the method used, as summarized in Section 2.3, Summary of 2006 Forecast, and described in detail in Golder and Anchor (2006).

[7] These estimates of 2000 water use carried out by the USGS were used in the 2006 Forecast.

nevertheless, represents an initial estimate. These amounts were distributed evenly throughout the year, with no attempt to account for seasonal variations in water use. Future analysis should examine monthly variations, and should also utilize the OFM's WRIA level population estimates to improve the assumed distribution of current and future populations by WRIA.

These estimates did not include the potential impacts of system repairs or conservation efforts on future demands. As an example of the impact this could have, eliminating system losses would result in a net savings of nearly 56,000 ac-ft per year currently and 70,000 ac-ft per year by 2030. Of equal importance is the potential impact of conservation practices. Reducing current demands by 10% would reduce current diversion requirements by 45,000 ac-ft per year and projected future diversion demand by 57,000 ac-ft per year and future consumptive use by approximately 29,000 ac-ft per year.

5.2.3 Columbia River Basin Instream Water Demand

Forecast changes in surface water supply timing are likely to increase the challenge of meeting instream demands throughout the Columbia basin river system. Increases in out-of-stream demands within and outside of Washington by 2030 are also likely to make it more difficult to meet instream demands by 2030. Lower flows, particularly in the summer and early fall, could negatively impact threatened and endangered fish in the Columbia River basin (Figure 10), as well as other fish important to the culture and economy of eastern Washington.

Several factors have the potential to impact future water supplies for meeting instream demands in ways that are difficult to predict, and thus were not feasible to capture in this analysis. The possibility for re-negotiation of the international Columbia River Treaty and unquantified tribal water rights, both discussed with water supply results in Section 5.1.2, could change the amounts and timing of water available to meet instream needs in the Columbia River mainstem.

5.2.3.1 Minimum Flows in the Columbia River Basin

The instream flow regulations and obligations of other states and BC were used to estimate the minimum quantities of water likely to enter Washington from upstream sources. For informational purposes, the legal process of adjudication is addressed in the section "Adjudicated Water Sources". The adjudication process is described as "a lawsuit to inventory the water rights of an entire stream system by deciding their nature, extent and priority" (SRBA Information). The Snake River is the only incoming source of water flow entering the State of Washington in the Columbia River basin that has been adjudicated. For comparison, to show the uncertainties of resolution (adjudication) of other water basins and water rights, a discussion of the current status of The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) water right claim is provided. All incoming flows into Washington in the Columbia River basin, adjudicated and non-adjudicated are addressed in the Sections "Minimum Instream Flows" and "Dams and Impoundments." In "Minimum Instream Flows," a categorical listing (state by state and one province) provides the sources of instream flows into the state of Washington. Minimum instream flow denotes the lowest legal flow, location, and time of year. In cases where the lowest flow is not legally binding (i.e., scenic waterway flows) it is noted. In "Dams and Impoundments," operational data which incorporates the Endangered Species Act (ESA), Biological Opinions (BiOps), and Federal Energy Regulatory Commission (FERC) requirements, were considered in a separate category due to federal mandates placed upon these facilities.

A summary of theoretical minimum flows set by statute or dam operating criteria is presented in Section 5.2.3.2**.**

Adjudicated Water Sources

Snake River Basin Adjudication

In addition to upholding the Swan Falls agreement, the Snake River Basin Adjudication (SRBA) framework addressed three separate components: (1) the Nez Perce Tribal component to resolve issues on and near lands ceded by the Tribe in the 1863 Treaty, (2) the Salmon/Clearwater component to protect flows and habitat within the Salmon and Clearwater River basins, and (3) the Snake River flow component to resolve issues involving the use of the Snake River above the Hells Canyon Complex.

Although, not directly related to the minimum flow entering the State of Washington, the Snake River segment of the SRBA anticipates 30-year Biological Opinions (BiOps) from the National Oceanic and Atmospheric Administration (NOAA) Fisheries and USFWS under the Endangered Species Act on continued operation of the Bureau of Reclamation's projects in the upper Snake River basin. These BiOps would address issues relating to flows from the Snake River above Brownlee Reservoir and the use of water for flow augmentation. The significant provisions of this component include the following:

- Minimum flows defined by the Swan Falls Agreement will be decreed by the SRBA Court to the Idaho Water Resources Board (Agreement Summary, May 2004).
- Instream flow cases related to the SRBA.

It was the determination of the Idaho State Court that the Idaho Department of Water Resources (IDWR) would aid (as technical experts) in the SRBA adjudication process and that individuals, companies, all levels of government, and tribes were compelled to participate. The IDWR represented permits, licenses, and beneficial use claims for the state, whereas the Attorney General represented federal interests (i.e., Tribal Rights, federal land holdings). For a complete list of SRBA minimum instream flows adjudicated for the State of Idaho their web site provides the pertinent information on a stream by stream basis at

http://www.idwr.idaho.gov/waterboard/WaterPlanning/nezperce/pdf_files/IWRB%2042-1507%20Recommendations.pdf (IDWR, 2005).

On the Federal side of the SRBA, the categories of reserved instream flow claims and reserved water right consumptive use claims were/are being adjudicated. As Table 17 indicates, all instream flow claims associated with this action have been settled (mostly dismissed) although in regard to consumptive use assertions, the National Park Service (Nez Perce National Monument), Nez Perce On-Reservation Claims (settlement signed, but pending), and the Army Corps at Dworshak Reservoir are still pending (Schaff, 2006).

Table 17. Summary of Federal Reserved Instream Flow Claims (Shaff 2006).

Agency	Allowed	Disallowed or Dismissed
Forest Service	7	3,762
Fish and Wildlife Service	0	4
Nez Perce/Bureau of Indian Affairs	0	1,133
Northwest Shoshoni	0	27
Shoshone Bannock Tribes	0	1,030
Shoshone-Paiute Tribes	0	7
TOTALS	7	5,963

The Confederated Tribes of the Umatilla Indian Reservation

When contacting other potential entities that may have minimum instream flow rights that could affect the volume of water entering the State of Washington in the Columbia River basin, we were directed to the Confederated Tribes of the Umatilla Indian Reservation (CTUIR). Their water status relating to minimum flows in Oregon and Washington was addressed in the following manner.

> "The CTUIR retains Treaty reserved instream flow water rights in the Walla Walla, Tucannon and mainstem Columbia Rivers to support the native fishery. In 2002, the CTUIR partnered with the [US Army] Corps of Engineers, States of Washington and Oregon, and basin stakeholders to restore flows in the Walla Walla basin and are currently preparing for a water rights settlement. The timeframe for settlement/adjudication completion is unknown at this time (Marks, 2011)."

At the present time, uncertainties in the quantities of water that will be allocated under this action make it impossible for us to accurately address this in the 2011 plan. This is, however, an issue that is potentially important for water managers to monitor for the future.

Minimum Instream Flows

Oregon

For the supply of water entering into Washington within the Columbia River basin from Oregon, the Deschutes, John Day, Umatilla, and Walla Walla Rivers were considered. The Grande Ronde is another major Oregon tributary to the Columbia River system, but since this flow is captured in the Snake River minimum flow requirement it was not examined separately. An individual at the department provided a map of Oregon instream water rights flowing into Washington (Figure 47), illustrating "minimum flow points" and "instream reaches," that enter Washington's Columbia River basin. Online searches at Oregon – Water Resource Department's "Water Rights Information Query" (http://apps.wrd.state.or.us/apps/wr/wrinfo/) verified the flow rates.

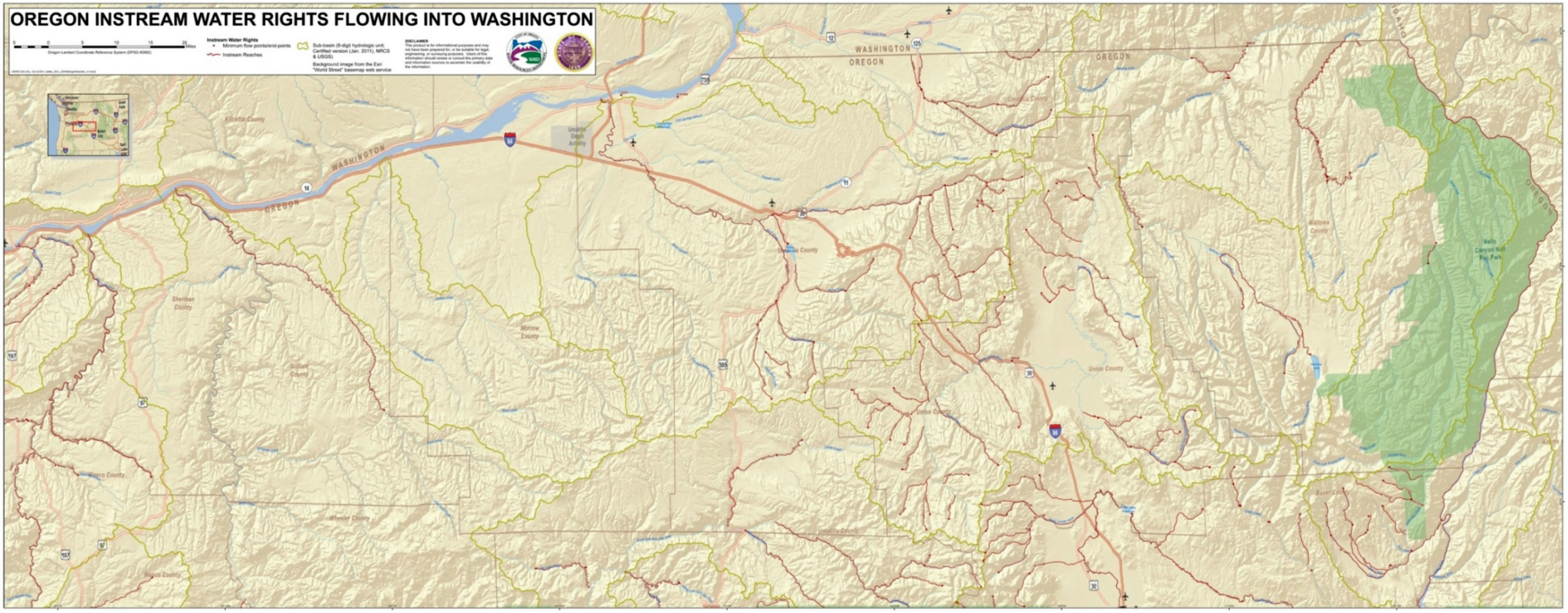


Figure 47. Oregon instream water rights flowing into Washington (from Harmon 2011 with permission).

Additional information was supplied on the mainstems of the Walla Walla, Umatilla, and Deschutes Rivers by Oregon Water Resource Department Field Offices and their associated personnel. The instream flow targets on the Walla Walla were considered insignificant in terms of flow into the Columbia River (e.g. < 1 cfs) and so are not presented in this document. Finally, instream flows for the John Day and Deschutes Rivers were supplied under the "Scenic Waterway Flows" category (Ladd, 2011). Information for the Deschutes and John Day Rivers were taken from their Certificate numbers because these represent guaranteed minimum flows whereas the "Scenic Waterway Flows" do not.

The results (flows and time periods) that were used for the final calculations are listed below in Table 18. The Oregon Water Resources Department (OWRD) uses the Willamette Meridian (WM) as their basis for location as indicated in Table 18. The values listed for the Deschutes represent the lesser of two certificates to insure the estimate was conservative. Other water sources that influence the amount of water entering the State of Washington but were not designated as "Scenic Waterway Flows" or are tributaries of the John Day and Deschutes Rivers can be found in Appendix E, Other Sources of Instream Flows.

Table 18. Minimum instream flows for the State of Oregon. (OWRD, 2011a).

River	Minimum Flow (cfs)	Location
Umatilla River > Columbia River		The Umatilla River from McKay Creek (SEC. 8, T 2N, R 32E, WM) to the mouth (SEC. 18, T 5N, R 28E, WM)
Certificate # 59837		
October 1 – November 15	300	
November 16 – November 30	250	
December 1 – June 30	250	
July 1 – July 31	120	
August 1 – September 15	85	
September 16 – September 30	250	
Walla Walla River		Flows in the Walla Walla River from the confluence of the North Fork and the South Fork (Section 22, T 5 N, R 36 E, WM) to the Little Walla Walla diversion (Section 12, T 5 N, R 35, E, WM)
Certificate # 59839		
October 1 – November 30	30	
December 1 – January 31	70	
February 1 - May 31	95	
June 1 – June 30	70	
July 1 – September 30	50	
John Day River		Scenic waterway flows at the mouth. Although not a guaranteed amount, "Scenic waterway flows are those flows necessary to maintain the free flowing characteristics of a scenic waterway." Also, Certificate # 66609 is for a withdrawal amount (located in Appendix E).
Application # SY90605A		
October 1 – January 31	500	
February 1 – February 28 (29)	1,000	
March 1 – June 30	2,000	
July 1 – September 30	500	
Deschutes River		Deschutes River at Pelton regulation dam at river mile 100.1 (SESW, Section 1, T105, R12E, WM) to the confluence with the Columbia River (SWSW, Section 24, T2N, R15E, WM)
Certificates #73188 and 73237		
October 1 – February 28 (29)	3,000	
March 1 – June 30	3,500	
July 1 – September 30	3,000	
** taking the lesser flow amount from the two certificates		

Idaho

In Idaho, the Clearwater, Priest, Snake, and Spokane Rivers were examined for existing minimum flows within the State of Idaho. Initial information regarding the closest geographical location to the State of Washington for each or these rivers and their minimum flow points was provided by the Idaho Department of Water Resources (IDWR). A breakdown of the seasonal restrictions on the minimum flow rate was determined by going to the "IDWR Water Right and Adjudication" web-site (http://www.idwr.idaho.gov/apps/ExtSearch/SearchWRAJ.asp) and entering the proper basin and sequence information. Additional information was supplied by Avista Utilities regarding flow rates of the Spokane River at Post Falls, Idaho.

On the Snake River, after Idaho's Fifth District Judge John Melanson's written decision not to revisit Idaho Power Company's water rights in the Swan Falls agreement, the average minimum daily flow at the Murphy gage (southern Idaho) was increased to 3,900 cfs during the irrigation season and 5,600 cfs during the non-irrigation season. The State mandated that it would manage the Snake River to meet or exceed the minimum average daily flow at Milner, Murphy, and Weiser. When the Hells Canyon National Recreation Act of 1975 precluded future hydropower development and designated the reach from Hells Canyon to Pittsburg Landing as "scenic and wild," it preserved the free-flowing characteristics and unique environment while providing for public use. The Act provided that no flow requirements of any kind may be imposed on the waters of the Snake River below Hells Canyon Dam (State Water Plan). In the future, hydropower water rights of the Hells Canyon Complex are subordinated to all future upstream consumptive uses. This requirement, along with minimum flow requirements for navigation, is designated by the Federal Power Commission as part of the FPC license (State Water Plan). For comparison purposes, minimum flows for Snake River reaches above the Murphy gage in southern Idaho (near Boise, ID) are listed in Appendix E.

For the Spokane, in addition to state adopted instream flow requirements, dam operators often negotiate minimum releases as part of their relicensing authorization process or, in some cases, to assist in helping solve local and regional water issues. As indicated in Table 19, the State of Idaho has set instream flow targets but natural flows may fall below these levels due to variations in hydrologic events and diversions by senior water rights. In this case, the absolute minimum instream flow is governed by releases from Lake Coeur D'Alene. Avista owns and operates the dam on the Spokane River at Post Falls, Idaho. Avista has agreed to maintain a minimum discharge of 600 cfs from the Project as measured at the USGS gage 12419000 (Spokane River at Post Falls) beginning on June 7 each year provided that inflows to Lake Coeur D'Alene are sufficient to maintain reasonable lake levels. If the elevation of Lake Coeur D'Alene falls below 2,127.75 feet during July, August, or September prior to the Tuesday following Labor Day ("low flow conditions"), Avista immediately reduces the discharge from the Project to 500 cfs and maintains that discharge until fall draw down (after the Tuesday following Labor Day) unless operating for purposes of the monitoring program described in Section B.2 of their FERC license (Federal Energy Regulatory Commission, 2009). This lake level agreement helps maintain the economic base of Lake Coeur D'Alene with respect to recreational activities tied to boating through the peak summer period. For the purpose of this study we assumed Idaho requirement as the minimum flow while acknowledging the Avista contribution as a backstop in very dry years.

Table 19. Minimum instream flows for the State of Idaho.

River	Minimum Flow (cfs)	Location
Snake River		
October 1 – June 30	13,000*	Lime Point
July 1 – September 30	5,000	Snake River recorded at Johnson's Bar
Clearwater River		Begins at the Potlatch River confluence in Lot 13, Section 7, T36N, R3W, B.M. and extends downstream approximately 13 miles to the beginning of backwater from the reservoir behind Lower Granite Dam in Lots 1 and 6, Section 32, T36N, R5W, B.M.
October 1 – October 31	4,498	
November 1 – July 31	5,910	
August 1 – September 30	4,498	
Spokane River		Commencing downstream from the Post Falls Dam at which the overflow channels converge with the main channel below the dam in S4, T50N, R5W and extending downstream to the Idaho-Washington state line in S12, T50N, R6W, Kootenai County
October 1 – October 31	951	
November 1 – June 30	2,495	
July 1 – September 30	951	
Priest River		Beginning at the confluence with the East River in Lot 5, Section 28, T58N, R04W, B.M. and extending downstream approximately 21.4 miles to the mouth of the Priest River at the confluence with the Pend Oreille River in Lot 6, Section 30, T56N, R04W, B.M.
October 1 – October 31	300	
November 1 – March 31	700	
April 1 – June 30	1,500	
July 1 – July 31	700	
August 1 – September 30	300	

*"*The project shall be operated in the interest of navigation to maintain 13,000 cfs flow in the Snake River at Lime Point (river mile 172) a minimum of 95 percent of the time, when determined by the Chief of Engineers to be necessary for navigation. Regulated flows of less than 13,000 cfs will be limited to the months of July, August, and September, during which time operation of the project would be in the best interest of power and navigation mutually agreed to by the Licensee and the Corps of Engineers. The minimum flow during periods of low flow or normal minimum plant operations will be 5,000 cfs at Johnson's Bar…*" (IDWR, 2012, State Water Plan – Snake River Policy).

<u>British Columbia</u>

Four rivers were considered for minimum flows entering the State of Washington. The Columbia, Kootenai, Okanogan, and Similkameen Rivers currently have no minimum flow regulations within Canada (Boyer 2011 and Symonds 2011; e-mail correspondence). Upstream reservoir operations on the Columbia (including the Kootenai contribution) control the flows entering Washington. These are reported separately from instream flow requirements in the discussion of dam and impoundments.

The Okanagan River flows through Osoyoos Lake which is a trans-boundary lake, with approximately 2/3 of the lake in Canada, and 1/3 in the United States. The level of Osoyoos Lake is managed within a relatively small operating range by Zosel Dam near Orville by the Washington State Department of Ecology. The Dam is operated in accordance with the orders of the International Joint Commission (IJC) which specify lake level targets. The IJC orders do not specify any minimum transboundary or Okanagan River flows (Symonds) although these orders are currently being re-examined for the next 25 year agreement.

There exists a nonbinding British Columbia – Washington State Cooperation Plan for Osoyoos Lake levels and trans-border flows (Jan 175 cfs, Feb 200 cfs, Mar 200 cfs, Apr 200 cfs, May 250 cfs, Jun 250 cfs, Jul 250 cfs, Aug 340 cfs, Sep 320 cfs, Oct 300 cfs, Nov 175 cfs, and Dec 175 cfs) (Symonds). These flows are controlled by reservoir operations upstream of Zosel Dam as Osoyoos Lake has a very limited amount of storage. The Similkameen is largely in a natural state with only limited opportunities for regulating flows.

<u>Montana</u>

Montana has two rivers that ultimately contribute to flow in Washington; the Clark Fork and the Kootenay Rivers. According to the Montana Department of Water Resources, there are currently no adopted minimum instream flow requirements on either of these two rivers (T. Bryggman, MDWR, personal communication, October 5, 2011). However, the Clark Fork watershed contains 21 reservoirs with storage volumes greater than 5,000 ac-ft (DNRC, 2004). Consequently, streamflow in these watersheds are significantly impacted by operational constraints placed on reservoirs. For example, on the lower Clark Fork, the FERC license for Cabinet Gorge establishes that the project maintain a total minimum total project discharge 5,000 cfs. Similarly, the instream flow below Thompson Falls Dam is the lesser amount of 6,000 cfs or the entire reservoir inflow. The potential impacts of dam releases are discussed in the next section.

There are other potential decisions that could impact instream flows in the long run. Specifically, in the Clark Fork, the off-reservation reserved and aboriginal water right claims by the Confederated Salish and Kootenai Tribes could result in more water in the stream or different operation of the reservoirs. For proposed actions in the Clark Fork basin, the reader is directed to the Clark Fork River Basin Management Plan (DNRC, 2004). Libby Dam, on the Kootenay system, could be operated differently depending on U.S.-Canada Treaty negations.

Dams and Impoundments

The operational minimum flows from five dams were considered since they would ultimately contribute to water entering the State of Washington's Columbia River basin. These requirements are often specified in FERC agreements or as agreed upon operational constraints in the case of U.S. government facilities.

<u>Albeni Falls Dam and Pend Oreille Lake</u>

Albeni Falls Dam is located on the Pend Oreille River at the downstream end of Lake Pend Oreille near the Idaho/Washington border. The dam was built at the site of a natural falls called Albeni Falls, named after an early settler, Albeni Poirier. Albeni Falls Dam was authorized for construction under the Flood Control Act of 1950 in response to a great flood that swept over the river valleys of the Columbia basin in 1948. The Army Corps dam was built from January 1951 to December of 1955 at a total cost of 34 million dollars. Today, it produces over 200 million kilowatt hours of electrical energy each year. The spillway can either store water for downstream power production and irrigation at other dams along the Pend Oreille and Columbia Rivers, or release water for upstream flood control.

Albeni Falls Dam was designed for water to flow under a series of 10 gates that can be lifted and lowered by the gantry crane on top of the spillway. The entire length of the spillway is 472 feet (144 meters). The lake has a maximum pool elevation of 2,075.9 feet and a minimum pool elevation of 2,049.7 feet. In times of high flood danger, all 10 gates are opened and the spillway is in the free-flow condition. In this configuration the spillway can release a maximum of 350,000 cfs of water. In summer, the spillway gates are closed to bring Lake Pend Oreille up to the normal summer range of 2,062.0 to 2,062.5 feet above sea level for recreational and ecological purposes. Usable storage within the preferred operating levels of 2,051 and 2062.5 feet are 1,155,200 ac-ft (Army Corps 2011c).

The minimum release from the dam is specified as 4,000 cfs. In 1992, the Idaho Department of Water Resources issued the Idaho Water Resources Board an instream flow right of 10,655 cfs immediately downstream of the dam. The water right (Permit No. 96-8730) established a constant year-round flow for the 2.4 mile river reach in Idaho to protect fish and wildlife habitat, aquatic life, and recreational values. However this right is junior to the dam so an instream flow of 4,000 cfs was adopted for this reach.

Hungry Horse Dam and Lake

Hungry Horse Dam is in the Flathead National Forest on the South Fork of the Flathead River, 15 miles south of the west entrance to Glacier National Park and 20 miles northeast of Kalispell, Montana. The construction contract for the dam and powerhouse was awarded in 1948 and the project was completed in 1953. The dam site is in a deep, narrow canyon which creates an active storage capacity of 2,982,026 ac-ft in the normal operating pool range from 3,336 feet to 3,560 feet. At the maximum regulated pool elevation (3,565 feet) there is 3,568,000 ac-ft of storage. The specified minimum discharge from the facility is 400 cfs (U.S. Department of the Interior, USBR).

Under the Endangered Species Act (ESA) Hungry Horse Dam is required to provide instream releases for local bull trout populations in the lower South Fork and Flathead rivers and releases in July and August for anadromous salmon species downstream of Grand Coulee Dam. Operations must maintain a 400-900 cfs minimum flow below Hungry Horse Dam and 3,500 cfs in the mainstem of the river. Pursuant to the voluntary agreement between the state of Montana and the USBR, during drought years the 3,500 cfs requirement on the mainstem can be reduced to 3,200 cfs. Since the 1995 ESA biological opinion for Columbia River salmon, the top 20-25 feet of reservoir storage has been available for salmon flows. All constraints are combined in integrated rule curves that are used to govern operation. Pursuant to the 2002 Biological Opinion issued by the National Marine Fisheries Service, USBR releases approximately 4,000 cfs from the dam in the months of July and August and has increased flows in June over prior operating rules (Clark Fork River Basin Management Plan, 2004). The flows used for this study are shown in Table 20. As indicated, the smaller value (3,500 versus 4,000 cfs) was used to estimate minimum transboundary flows to be conservative. This acknowledges the possibility that the BiOp flows may adapt in the future to changing conditions in the watershed related to ESA species.

Table 20. Reservoir operation releases from Hungry Horse Dam.

River	Minimum Flow (cfs)	Location
South Fork of Flathead		Minimum flow of 400 cfs immediately downstream of the dam in combination with a 3,500 cfs amount measured at Columbia Falls on the mainstem Flathead River. During downstream flooding events, dam discharges can be reduced to the physical minimum of 145 cfs.
October 1 – June 30	400	
July 1 – August 31	3,500	
September 1 – September 30	400	

Libby Dam and Lake Koocanusa

Libby Dam on the Kootenai River in Montana is one of 14 Federal Columbia River Power Systems (FCRPS) projects that have altered the natural river hydrology of the Columbia River and some of its major tributaries. The FCRPS storage projects: Libby, Hungry Horse, Dworshak, Albeni Falls, and Grand Coulee dams each store the spring snowmelt runoff to control floods and release water for multiple uses. Libby Dam was completed in 1973 with the first 4 units of the powerhouse completed in 1976 and unit 5 installed in 1984. Within the usable minimum and maximum pool elevations of 2,287 feet to 2,459 feet, respectively, Lake Koocanusa stores 4,979,500 acre-feet. As a result of the 172 foot operating range, irrigation supplies, hydropower generation, and populations of threatened and endangered fish in the Columbia River basin are affected by the altered hydrograph. Also, because of its capacity for flood control, reservoir operation could change dramatically in the future depending on the outcome of the Columbia River Treaty negotiations.

According to Army Corps Project Data, the minimum instantaneous discharge from the facility is 2,000 cfs and the minimum daily flow is 3,000 cfs. However, the 2010 Water Management Plan for Libby specifies 4,000 cfs as the minimum discharge. This value was used in the initial analysis recognizing that flows are likely to be considerably higher than this most of the time. In fact, in terms of potential flows entering Washington, this instream value is trumped by a larger downstream flow requirement at Corra Linn Dam.

Because the reservoir is used for flood storage, a big concern is actually accounting for maximum flow releases rather than minimum flow requirements. The reservoir is drawn down over winter following elevation targets based on runoff projections. In accordance with the Endangered Species Act (ESA), the Army Corps, the USBR, and the BPA engaged in formal consultation regarding the effects of FCRPS operations on anadromous and resident fish species listed as threatened or endangered. In the most recent Biological Opinion issued by the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) (2008 NMFS BiOp3), the effects of FCRPS operation on ESA species resulted in recommendations to implement VARQ (1) Flood Control and certain flow operations at Libby and Hungry Horse Dams to benefit listed fish species. Additionally, the Fish and Wildlife Program and the 2003 Mainstem Amendments issued by the Northwest Power and Conservation Council (NPCC) included a recommendation to adopt VARQ Flood Control Procedures with Q representing engineering shorthand for discharge. Releases from the reservoir can vary from the powerhouse capacity of 25,000 cfs up to 35,000 cfs (including 10,000 cfs spill) for white sturgeon flow augmentation depending on reservoir level which may vary from year to year. A more thorough discussion can be found at the USBR web site (USBR, 2008).

Although VARQ discharges at Libby Dam can be quite high, the reservoir is operated under seasonal ramp up/ramp down restrictions. Table 21 shows summer and winter ramp rates for Libby Dam used to protect resident fish and prey organisms in the Kootenay River. Notice the lower ramping down rates to avoid stranding of fish in floodplain pools.

Table 21. Ramp up/ramp down flow rates for Libby Dam.

Period	Downstream Discharge (cfs)	Maximum Hourly Change (cfs)
Summer (May 1 – September 30)		
Ramping Up	4,000 – 9,000	2,500
	9,000 – 16,000	5,000
Ramping Down	4,000 – 9,000	500
	9,000 – 16,000	1,000
Winter (October 1 – April 30)		
Ramping Up	4,000 – 9,000	2,000
	9,000 – 16,000	3,500
Ramping Down	4,000 – 9,000	500
	9,000 – 16,000	1,000

<u>Duncan Dam (six miles north of Kootenay Lake)</u>

Duncan Dam was the first of the three Columbia River Treaty dams to be built in the Canadian section of the Columbia River basin. Construction began on the dam in 1965 and was completed and operational in 1967, ahead of schedule. It is an earthfill dam with no power generation facilities. Its purpose is to control the flow of water from the Duncan River into Kootenay Lake in conjunction with the Libby Dam to assure operational water levels for the Kootenay Canal and the Corra Linn projects downstream. Duncan Lake was originally 25 km (15.5 mile) long, the reservoir is now 45 km (28 miles) in length. Water fluctuates up to 30 meters (98 feet) in elevation annually (Balance of Power).

Under terms of the Columbia River Treaty the minimum average monthly discharge from Duncan Dam is 106 cfs (3.0 m^3/s). In a slightly more restricted constraint, to maintain continuity of fish habitat along the river between the dam and the confluence with the Lardeau River, a minimum average daily release from Duncan Dam of 106 cfs (3.0 m^3/s) has also been adopted (BC Hydro). The flow rate used for calculations was 100 cfs as a weekly average (Kanbergs, Army Corps). Again, this value is superseded by the flow requirement at Corra Linn.

Corra Linn Dam – Kootenay River

Corra Linn Dam is located on the lower Kootenay River and was the first dam to create water storage on the Kootenay River system. The Kootenai River basin has a total drainage area of 16,180 square miles (41,910 km^2) and comprises parts of British Columbia, Montana, and Idaho (70%, 23% and 7% of basin area, respectively) (Burke et al., 2009). Constructed between 1930 and 1932, it was built with the goals of supplying Cominco with electricity for its fertilizer plant in Trail, BC and ensuring a constant water supply for the downstream West Kootenay Power dams that would occasionally go dry during the winter months. Kootenay Lake wanted to become a temporary reservoir to store the fall runoff behind Corra Linn. This task required the consent of the International Joint Commission (IJC), as water storage in Kootenay Lake would affect areas on both sides of the international border. The request for storage by Canada was continually denied and West Kootenay Power let the issue drop until the devastating floods in 1938. Permission was granted by the IJC in the fall of 1938 and Kootenay Lake became a reservoir (Balance of Power) and was allowed to raise the level of Kootenay Lake by 6.5 feet (2 meters). The dam, owned by FortisBC since 2003, can generate 49 MW of power.

Since Corra Linn is the lowest storage facility on the Kootenay River system, outflows dictate the flow contribution to Washington from this watershed. This means that releases from both Duncan and Libby are re-regulated through this facility to some extent. The minimum instream flow from Corra Linn is 10,000 cfs (McCroskey, Army Corps).

Hugh Keenleyside Dam (Arrow Lakes Reservoir 5 miles west of Castlegar)

Originally known as the High Arrow Dam and renamed in 1969 after the co-chairman of BC Hydro, Hugh Keenleyside Dam was completed in 1968. The second of the three Columbia River Treaty dams, it was built to control water levels downstream for power production at the Grand Coulee Dam in Washington State and for flood control in both Canada and the U.S. The dam contained no power generation facilities, though it did provide a lock to allow both industrial and recreational boat access through the dam. In 1999, the Columbia Power Corporation (a crown corporation owned and controlled by the Province of BC) with its partner the Columbia Basin Trust began to construct the Arrow Lakes Generating Station, a two-turbine powerhouse immediately downstream of Hugh Keenleyside Dam. Completed in 2002, the station produces up to 185 Megawatts, using the water previously allowed to spill over the dam during high-water levels (Balance of Power). It is located downstream of Mica and Revelstoke and therefore controls the flow on the mainstem Columbia River upstream of its confluence with the Kootenay River.

The reservoir pool levels typically range from 1,377.9 feet to 1,444 feet which provides approximately 7,000,000 acre-feet of storage. Including surcharge, the maximum pool elevation is 1,449 feet however the normal maximum operating pool is kept at 1,446 feet. The minimum average weekly outflow is 5,000 cfs although typical minimum flow range are from 5,000 cfs to 20,000 cfs (McCroskey, Army Corps). To be conservative, 5,000 cfs was used in this study.

Dworshak Dam (North Fork of Clearwater River)

Dworshak Dam and Reservoir is located in northern Idaho on the North Fork of the Clearwater River, near Orofino and about 35 miles east of Lewiston, ID. The project includes Dworshak Dam and Reservoir lands, a powerhouse, recreation facilities, wildlife mitigation, and Dworshak National Fish Hatchery. The dam is a straight concrete gravity dam with a structural height of 717 feet and a crest length of 3,287 feet at an elevation of 1,613 feet. Completed in 1973, the dam is located on the North Fork Clearwater River at River Mile 1.9. The dam is the highest straight-axis concrete dam in the Western Hemisphere and the 22nd highest dam in the world. Only two other dams in the United States exceed it in height.

The reservoir has a gross storage capacity of 3,453,000 acre-feet, of which 2,000,000 acre-feet is used for local and regional flood control; and for at-site and downstream power generation. At an elevation of 1,600 feet, the reservoir is 53 miles long, has a surface area of 19,824 acres, and extends into the Bitterroot Mountains. The reservoir provides substantial recreational and wildlife benefits, and transportation for timber (Army Corps, 2011b). The specified minimum reservoir release is 1,000 cfs. However, since this is upstream of the Clearwater instream flow requirement, the Dworshak discharge would only help support the overall requirement.

Because the reservoir is deep, water temperature in the impoundment is generally cold compared to other nearby water bodies. Consequently, reservoir operations are used to help ESA listed species downstream in the Lower Snake River. Specifically,

- The Project will release 4,000 to 6,000 cfs from Dworshak, if necessary, in order to move juvenile fish into the mainstem Clearwater River during the spring hatchery releases.
- Summer flow augmentation provided from Dworshak may be used to cool water temperatures in the lower Snake River (BPA).

The Agency's Action (Army Corps) plan to draft Dworshak to 1,535 ft. in August and draft approximately 1,520 ft. in September. The extension of the draft limit into September reflects assumed releases of 200,000 ac-ft consistent with the agreement with the Nez Perce Tribe and the Snake River Basin Adjudication process (2010 Water Management Plan).

5.2.3.2 Summary of Theoretical Minimum Flows Set by Statute or Dam Operating Criteria for the Columbia River and Major Tributaries Entering Washington.

The minimum flows that could theoretically be released by statue for waters entering the State of Washington's Columbia River basin from Oregon, Idaho, and dams in Montana, British Columbia appear below in Table 22 through Table 27**.** These values represent the least amounts of flow that would enter the State of Washington assuming that all upstream sources released only the minimum flows. Often this would not be physically possible for extended periods of time because high runoff events would cause dams to overtop. Thus, in almost all cases, flows are considerably higher than the minimums listed here. Conversely, during low flow periods, it is possible that streamflows could be less than adopted instream requirements because of senior water rights or physical limitations due to drought. Overall, the values should be seen more as targets rather than pre-scripted or fixed quantities of water.

Table 22. Minimum flows allowed by statute for waters entering Washington from Oregon.

	Tributaries				
Month	Umatilla (cfs)	Walla Walla (cfs)	John Day (cfs)	Deschutes (cfs)	Total (cfs)
January	250	70	500	3,000	3,820
February	250	95	1,000	3,000	4,345
March	250	95	2,000	3,500	5,845
April	250	95	2,000	3,500	5,845
May	250	95	2,000	3,500	5,845
June	250	70	2,000	3,500	5,820
July	120	50	500	3,000	3,670
August	85	50	500	3,000	3,635
September	167.5	50	500	3,000	3,718
October	300	30	500	3,000	3,830
November	275	30	500	3,000	3,805
December	250	70	500	3,000	3,820

Table 23 and Table 24 show minimum instream flows for water entering Washington from three Idaho tributaries (Snake, Clearwater, and Spokane) for high and low flow years as well as two important caveats (SpokaneAvista and Priest River). The SpokaneAvista column reflects additional protection on the Spokane against natural flows falling below the Idaho instream flow targets. Similarly, Priest River (which flows into Lake Pend Oreille near Albeni Falls Dam) provides assurances for the Albeni Falls reservoir releases shown in Table 25. The total instream flow column sums the values listed in the Snake, Clearwater, and Spokane River tributaries.

Table 23. Minimum flows allowed by statute for waters entering Washington from Idaho (in a high flow year).

	Tributaries					
Month	Snake (cfs)	Clearwater (cfs)	Spokane (cfs)	Spokane Avista (cfs)	Priest (cfs)	Total[1] (cfs)
January	13,000	5,910	2,495	600	700	21,405
February	13,000	5,910	2,495	600	700	21,405
March	13,000	5,910	2,495	600	700	21,405
April	13,000	5,910	2,495	600	1,500	21,405
May	13,000	5,910	2,495	600	1,500	21,405
June	13,000	5,910	2,495	600	1,500	21,405
July	5,000	5,910	951	600	700	11,861
August	5,000	4,498	951	600	300	10,449
September	5,000	4,498	951	600	300	10,449
October	13,000	4,498	951	600	300	18,449
November	13,000	5,910	2,495	600	700	21,405
December	13,000	5,910	2,495	600	700	21,405

[1] Snake + Clearwater + Spokane only.

Table 24. Minimum flows allowed by statute for waters entering Washington from Idaho (in a low flow year).

Month	Snake (cfs)	Clearwater (cfs)	Tributaries Spokane (cfs)	Spokane Avista (cfs)	Priest (cfs)	Total[1] (cfs)
January	5,600	5,910	2,495	600	700	14,005
February	5,600	5,910	2,495	600	700	14,005
March	5,600	5,910	2,495	600	700	14,005
April	5,600	5,910	2,495	600	1,500	14,005
May	5,600	5,910	2,495	600	1,500	14,005
June	5,600	5,910	2,495	600	1,500	14,005
July	3,900	5,910	951	600	700	10,761
August	3,900	4,498	951	600	300	9,349
September	3,900	4,498	951	600	300	9,349
October	5,600	4,498	951	600	300	9,349
November	5,600	5,910	2,495	600	700	14,005
December	5,600	5,910	2,495	600	700	14,005

[1] Snake + Clearwater + Spokane only.

Table 25. Minimum flows allowed by statute for waters entering Washington from dams in Montana and British Columbia.

Month	Albeni (cfs)	Hungry Horse (cfs)	Keenleyside (cfs)	Corra Linn (cfs)	Libby (cfs)	Duncan (cfs)	Total[1] (cfs)
January	4,000	400	5,000	10,000	4,000	100	19,000
February	4,000	400	5,000	10,000	4,000	100	19,000
March	4,000	400	5,000	10,000	4,000	100	19,000
April	4,000	400	5,000	10,000	4,000	100	19,000
May	4,000	400	5,000	10,000	4,000	100	19,000
June	4,000	400	5,000	10,000	4,000	100	19,000
July	4,000	3,500	5,000	10,000	4,000	100	19,000
August	4,000	3,500	5,000	10,000	4,000	100	19,000
September	4,000	400	5,000	10,000	4,000	100	19,000
October	4,000	400	5,000	10,000	4,000	100	19,000
November	4,000	400	5,000	10,000	4,000	100	19,000
December	4,000	400	5,000	10,000	4,000	100	19,000

Dams: Albeni, Hungry Horse, Keenleyside, Corra Linn, Libby, Duncan

[1] Albeni Falls + Corra Linn + Keenleyside

As previously mentioned, programmatic reservoir releases are often specified in operating rules governed by licenses, treaty, or other obligation. The mainstem Columbia, Kootenay, and Pend Oreille River systems are prime examples. Table 25 summarizes the minimum flows from the most downstream major storage projects on each system. It is important to recognize that flows often exceed these values. The table also illustrates the potential contributions from several upstream facilities. In particular, Libby is important because its operation could potentially change significantly if it takes on an even larger flood control role as a result of ongoing Columbia River Treaty discussions.

Table 26 and Table 27 present summaries of the minimum instream flow requirements and reservoir releases governing flows into the State of Washington. Table 26 shows values for high flow years and Table 27 shows values for low flow years.

Table 26. Total average monthly minimum flows allowed by statute for waters entering Washington in high flow years.

Month	Oregon (cfs)	Idaho (cfs)	Dams (cfs)	Total (cfs)
January	3,820	21,405	19,000	44,225
February	4,345	21,405	19,000	44,750
March	5,845	21,405	19,000	46,250
April	5,845	21,405	19,000	46,250
May	5,845	21,405	19,000	46,250
June	5,820	21,405	19,000	46,225
July	3,670	11,861	19,000	34,531
August	3,635	10,449	19,000	33,084
September	3,718	10,449	19,000	33,167
October	3,830	18,449	19,000	41,279
November	3,805	21,405	19,000	44,210
December	3,820	21,405	19,000	44,225

Table 27. Total average monthly minimum flows allowed by statute for waters entering Washington in low flow years.

Month	Oregon (cfs)	Idaho (cfs)	Dams (cfs)	Total (cfs)
January	3,820	14,005	19,000	36,825
February	4,345	14,005	19,000	37,350
March	5,845	14,005	19,000	38,850
April	5,845	14,005	19,000	38,850
May	5,845	14,005	19,000	38,850
June	5,820	14,005	19,000	38,825
July	3,670	10,761	19,000	33,431
August	3,635	9,349	19,000	31,984
September	3,718	9,349	19,000	32,067
October	3,830	9,349	19,000	32,179
November	3,805	14,005	19,000	36,810
December	3,820	14,005	19,000	36,825

5.2.3.3 Instream Flows in Washington State

Ecology's OCR completed an independent analysis of site specific flow levels, drought occurences, and how often instream flows have been met for tributaries to the Columbia River in Washington, using their database of historical flow information. Full results are provided in Appendix D, Historic Stream Flow Data by WRIA. As one example of the type of information that can be gained from these results, by graphing the 1963-2009 flows of the Wenatchee River at Monitor gauge (USGS # 1246200) (Figure 48) it is shown that

- Historic mean annual flows generally varied between 1.5 and 3 million ac-ft.
- Over the last 30 years, dry years (20th percentile or lower) occurred 6 times, with the worst stretch being 3 consecutive dry years in 1992-1994. During this same time period, the availability of water during dry years worsened (18% decrease).
- The instream flow rule is almost always met in average years except in late summer. In dry years, the instream flow is met in early summer and in the winter.
- The magnitude of unmet instream flows is small in this location. For example, in average years, the instream flow deficit for the entire year totals 2,000 ac-ft. The total annual deficit grows to 84,000 ac-ft in dry years.
- Water is available in-basin that could be used to address these instream shortages through OCR-funded projects (e.g. storage, conservation, or pump exchanges). At Wenatchee at Monitor, the annual amount of water surplus to instream flows during an average water year is 1.5 million ac-ft.

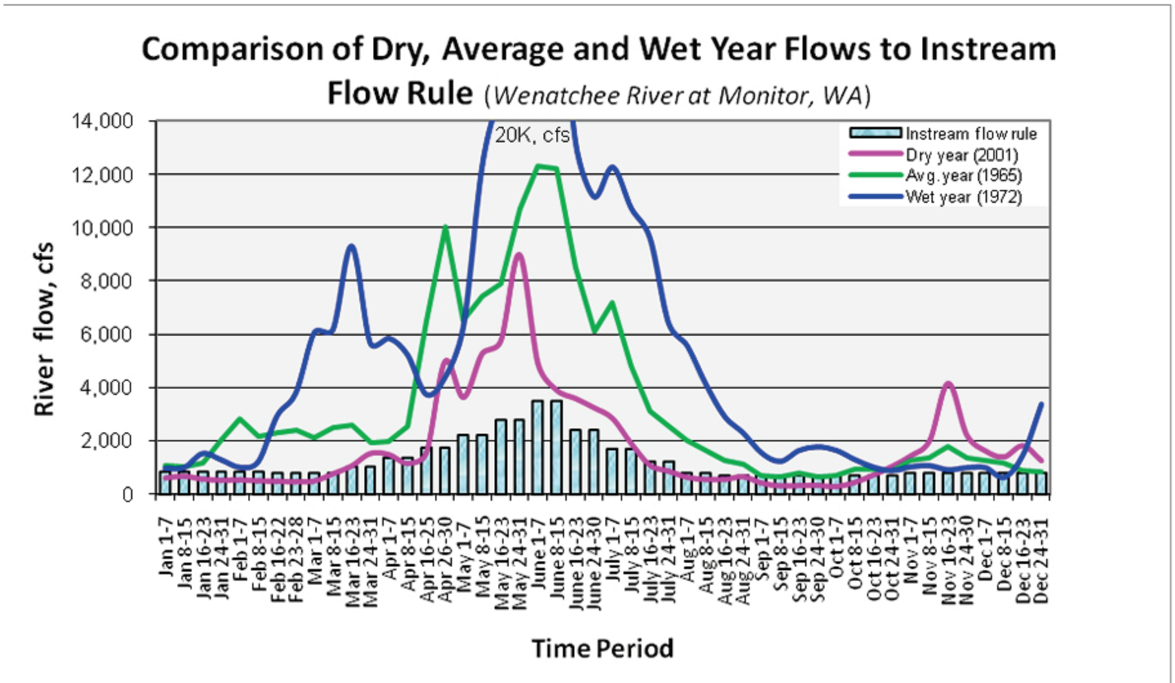


Figure 48. Comparison of actual (not modeled) historical flows (1963-2009) during dry (20th percentile), average (50th percentile), and wet (80th percentile) years to the instream flow rule for Wenatchee River at Monitor.

5.2.4 Columbia River Basin Hydropower Water Demand

Reports covering future hydropower demand for the Columbia River basin that were reviewed as part of the hydropower demand forecast are summarized below. This review included reports carried out in association with the Columbia River Treaty Review, by the Bonneville Power Administration (BPA), Northwest Power and Conservation Council (NWPCC), Avista, Idaho Power, Portland General Electric (PGE), British Columbia Hydro and Power Authority and public utility districts in Grant, Chelan, and Douglas counties in Washington State.

5.2.4.1 Columbia River Treaty Review, Phase 1 Report

In July of 2010, the United States and Canadian Entities of the Columbia River Treaty (Treaty)—Bonneville Power Administration and the Division Engineer of the Northwestern Division of the Army Corps for the U.S. and BC Hydro for Canada—released their Phase 1 Report for the 2014/2024 Columbia River Treaty Review. The Phase 1 Report only looked at future generation based on management of dams to meet power and flood control objectives, which were the two original purposes laid out in the Treaty (Canadian and United States Entities 2010). In September of 2010, the U.S. Entity independently released a Supplemental Report to the Phase 1 Report, which incorporates an additional management objective: the need to provide flows for fish as mandated under the Biological Opinion (BiOp) (NOAA 2008). Neither the Phase 1 Report nor the Supplemental Report incorporate effects of climate change or economic costs and benefits from hydropower, but the potential to include them in the future is there.

The Treaty's Flood Control Operating Plan (FCOP) specifies that flooding begins at approximately 450,000 ft^3/s as measured at The Dalles, Oregon and significant damages in the lower Columbia can occur at 600,000 ft^3/s. Management was assumed to keep flows below one or both of these two flood control thresholds under two alternate scenarios, one in which the Treaty was continued, and one in which the Treaty was terminated. Energy generation under continuation or termination of the Treaty, while keeping flows below the 600,000 ft^3/s flooding threshold is shown in Figure 49. Results which incorporated the 450,000 ft^3/s flood threshold level were generally the same as those that incorporated the 600,000 ft^3/s flood threshold.

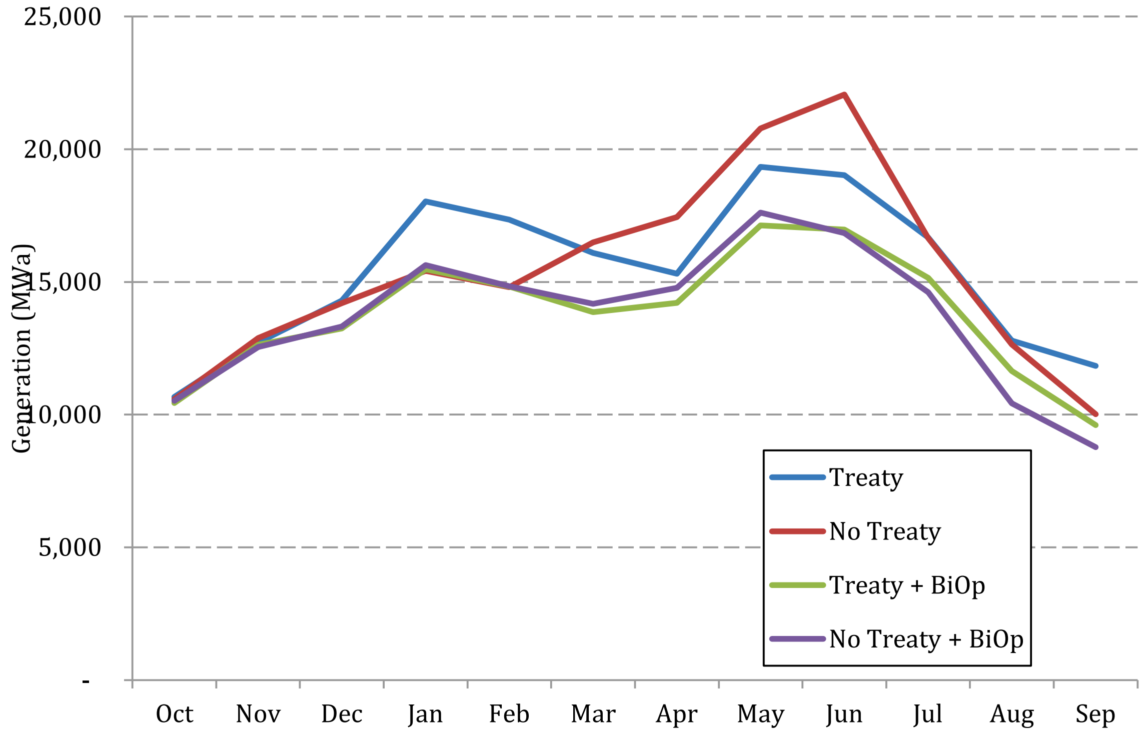


Figure 49. Seventy-year average U.S. system generation when managing dam operations to keep flows below a 600,000 ft^3/s flooding threshold at The Dalles, Oregon (Adapted from United States Entity 2010).

Under the scenarios analyzed, seventy year average U.S. system generation changed in the following ways compared to the baseline:

- Meeting the BiOp requirements and continuing the Treaty decreased U.S. generation potential by 85 to 2,500 aMW throughout the year with no seasonal increases.

- Meeting the BiOp requirements and terminating the Treaty decreased the U.S. generation potential
- In general, incorporating BiOp requirements decreased power generation potential in the U.S., whether or not the Treaty was terminated.

Assuming a goal of having a maximum 450k cfs at Bonneville then the difference between meeting the Biop requirements and not meeting the BiOp requirements is 1523 aMW (compared to 1572 aMW when the Bonneville flow target is 600k cfs) (United States Entity 2010).

Although climate change and economic cost/benefit analysis was not incorporated into the Phase 1 Report or Supplemental Report, the amount of hydropower generation projected by the U.S. Entity would likely be affected by this addition. For example, as temperatures increase, peak stream flows may occur earlier in the spring, and flows may be much lower in summer months. Because it is directly related to stream flows, hydropower production during summer could be further decreased.

5.2.4.2 Sixth Northwest Power Plan

Compounding the problem of decreased power generation is the projection of increased regional demands as discussed in the Northwest Power and Conservation Council's (NWPCC) Sixth Northwest Conservation and Electric Power Plan (2010). Their most recent 2020 and 2030 forecasts for average electricity demand in the region are shown in Table 28, reflecting increased demand due to economic and population growth. Their forecasts of peak power needs are higher than the average demand presented below; for example, winter-peak loads are projected to be approximately 43,000 MWa and summer-peak loads around 39,900 MWa under the medium growth scenario. The NWPCC reported that the current hydroelectric system has a 33,000 megawatt capacity, but it operates at about a 50 percent annual capacity factor because of limited water supply and storage. This may make it difficult for Pacific Northwest power providers to meet projected additional demand through hydropower alone.

Table 28. NWPCC 2010 average electricity demand forecast (MWa) (NWPCC 2010).

Economic Growth	**2007 Actual**	**2010 Projected**	**2020 Projected**	**2030 Projected**	**Growth Rate 2010-2020**	**Growth Rate 2020-2030**	**Growth Rate 2010-2030**
Low	19,140	18,860	20,463	22,010	0.8%	0.7%	0.8%
Medium	19,140	19,292	21,820	25,275	1.2%	1.5%	1.4%
High	19,140	19,591	22,651	27,761	1.5%	2.1%	1.8%

It may be possible to meet this additional demand through non-hydroelectric energy sources. However, other power sources have drawbacks, including a need for additional water for some sources. For instance, energy from biomass would require additional irrigation, while nuclear power would require water for cooling.

Another approach that could generate additional power to meet growing demand is pumped storage hydropower. Basically, these projects pump water during the winter-spring runoff season (when excess flows are spilled rather than used to generate power). Pumped water is then stored to generate electricity during times of the year when flows are lower. NWPCC reports that 13 pumped storage projects have been proposed in Idaho, Oregon, and Washington, suggesting no shortage of suitable sites. The projects range in size from 180 to 2,000 megawatts and total nearly 14,000 megawatts. Factors influencing the economic feasibility of the projects are site-specific and include the availability of water that can be used for one of the reservoirs (usually the lower), storage capacity, and transmission interconnection distance. Although $1,000 per kilowatt of installed capacity is often quoted as a representative cost of pumped storage hydroelectricity, NWPCC's review of available cost estimates suggests that $1,750 to $2,500 per kilowatt is more representative of current construction costs.

The primary constraints to pumped storage hydropower projects are the complexity and lead time of the development process, capital cost, operation and maintenance costs, and the recovery of revenues for the services provided. Use of renewable energy such as wind and solar to provide power for pumped storage has not been well studied at present but could be a means of lowering costs and providing integrated energy management.

5.2.4.3 Avista's Electric Integrated Resource Plan

In 2009, Avista released their Electric Integrated Resource Plan (IRP) outlining the economic growth forecasts for their service area (Avista Utilities 2009). Avista projects that due to the effects of climate change, summer demand for electricity in 20 years will be about 26 MWa higher than it has been over the last 30 years. Winter loads were forecasted to be approximately 40 MWa lower in 2029, resulting in a net decrease of 14 MWa due to the impacts of climate change alone. Nonetheless, Avista is expecting their annual electricity sales to rise by 1.7% over the next 20 years based on economic and population growth, with volumes increasing to an average value of 199 megawatts.

Avista maintains they will not need additional resources to meet new demands through 2017; however, they will need to change their energy mix in order to meet new regulatory requirements. Specifically, Initiative 937 (I-937), passed by Washington voters in 2006, requires power-generating entities to pursue Renewable Energy Certificates and other qualified renewable energy generation methods. Currently, existing or new hydropower is not considered renewable generation under I-937; however, efficiency improvements at existing facilities do qualify. To meet these requirements, Avista plans to add 150 MW of wind power by 2012 and an additional 200 MW over the resource plan timeframe of 20 years. Other proposed nonrenewable additions over this timeframe include the construction of 750 MW of clean-burning natural gas-fired plants and 5 MW of upgrades to the Little Falls and Upper Falls hydroelectric facilities on the Spokane River. Avista planned to examine larger hydropower upgrades in the 2011 IRP. Avista estimated that conservation could help reduce growth in power demands in their service area by up to 70-75 percent over the next twenty years. This aligns with the NWPCC's projection from its Sixth Power Plan that up to 85 percent of new demand over the next 20 years could be met by conservation.

5.2.4.4 Idaho Power's 2011 Integrated Resource Plan

In June of 2011, Idaho Power released its 2011 Integrated Resource Plan, which focuses on identifying the resources the investor-owned utility plans to utilize in serving their customers over a 20-year planning period. Idaho Power primarily serves Southwestern Idaho throughout the Snake River sub-basin. As outlined in their IRP, average monthly energy load is expected to increase from a median value of 1,819 MWa in 2011 to as much as 2,642 MWa by 2030, representing an average monthly increase of 1.0-1.8% annually from 2011 to 2030. Due to this increase in demand (driven by a projected rise in customers from 492,000 in 2010 to over 650,000 by 2030), Idaho Power believes it will require the addition of new resources to meet the increase in demand. Existing and new energy efficiency programs, which are expected to reduce average load by 233 MWa by 2030, will also be required.

For Idaho Power, development of new large hydroelectric projects is unlikely due to the low number of feasible sites and the environmental and permitting issues associated with the construction of new, large hydroelectric facilities. Small hydroelectric (small-hydro) facilities on the other hand have been widely developed in southern Idaho, namely on irrigation canals. Because small-hydro facilities generally use little to no impoundment of the waterbody (usually meaning a simpler permitting process than large hydroelectric), Idaho Power expressed an interest in evaluating it for its 2011 IRP. The Idaho Strategic Energy Alliance's Hydropower Task Force (2009) found that new small-hydro facilities could produce about 150 MW to 800 MW in Idaho. This was based on upgrading existing facilities, development of existing impoundments and water delivery systems (canals) without current generation, and in-stream flow opportunities.

5.2.4.5 Portland General Electric's Integrated Resource Plan

Portland General Electric's (PGE) 2009 Integrated Resource Plan outlines the investor-owned utility's power planning strategies for a 20-year timeframe. In regard to hydroelectric generation, PGE's two main plants, Pelton and Round Butte, are located on the Deschutes River near Madras, Oregon. PGE's share of output from these facilities is 73 MW and 225 MW, respectively. Pelton and Round Butte will account for about 15% of PGE's 2013 generation capacity, with another 25% coming from other PGE-owned hydroelectric generation and long-term contracts with Mid-Columbia entities. In exchange for paying a share of the plants' costs, PGE receives a proportional amount of output from Douglas County Public Utility District's Wells project and Grant County Public Utility District's Priest Rapids and Wanapum projects. The Wells contract, expiring in 2018, accounts for 147 MW of capacity and 85 MWa of energy under normal water conditions, while the contracts for output from Priest Rapids and Wanapum account for approximately 134 MW of capacity and 69 MWa of energy under normal water conditions (PGE 2009).

Although PGE anticipates needing more than 870 MWa of new resources by 2015 (2009), based on its 2009 IRP, it does not appear that PGE intends to expand its existing hydroelectric resources to achieve this goal.

5.2.4.6 British Columbia Hydro and Power Authority's Electric Load Forecast

Documentation available from BC Hydro is general in nature, but provides some information that helps shed light on future needs for hydroelectricity in Canada. BC Hydro expects that demands may grow as much as 40 percent across British Columbia over the next twenty years. Conservation and transmission improvements are described as playing an important role in meeting this anticipated new demand. Beyond that, Site C Clean Energy Project (outside the Columbia River basin, on the Peace River), if built, could provide up to 1,100 megawatts (MW) of capacity (450,000 homes). Additional capacity at Mica Dam on the Columbia River is anticipated to play a smaller role in meeting new demand; BC Hydro is currently working to add two new generation units (for a total of six). These additional units would not always operate, so although they will provide additional peak capacity of 1,000 megawatts, they are anticipated to serve only 80,000 homes.

5.2.4.7 Washington Public Utility Districts

To get a sense of whether small to medium-sized power providers were concerned about their ability to meet future power demands, we also examined the websites of Chelan, Douglas, and Grant County Public Utility Districts (PUDs) to see if they had any public information related to mitigating potential climate change impacts on hydrograph timing and power demands. Where necessary, this was supplemented with personal calls to selected individuals.

Chelan County Public Utility District

Chelan County Public Utility District (Chelan PUD) operates three hydropower projects: Rocky Reach and Rock Island on the Columbia River and Lake Chelan in WRIA 47. In 2006, a new 50-year license was issued to Chelan County PUD for the Lake Chelan Hydroelectric Project by the Federal Energy Regulatory Commission (FERC). A new 43-year FERC license to operate Rocky Reach Dam was granted in 2009. The license for the Rock Island Hydroelectric Project is valid through 2028. Through these facilities, conservation, and other ongoing activities, Chelan PUD currently feels it will be able to meet projected growth in local demand for electricity.

In 2009, Chelan PUD commissioners expressed interest in working with the Washington State Department of Ecology to identify water-storage sites in Chelan County that could also generate electricity, as part of an overall strategy to explore cost-effective solutions for future energy production.

Douglas County Public Utility District

Douglas County Public Utility District (Douglas PUD) owns and operates Wells Dam on the Columbia River. As anon-federal entity, Douglas PUD needs a license from FERC to operate the dam. As their current license expires on May 31, 2012, Douglas PUD is in the process of filing for a new 50 year FERC license for Wells Dam. Although Douglas PUD believes its resources are sufficient to meet projected future demands, they are considering alternative energy sources to supplement Wells Dam. Douglas PUD expects to receive 3 MWa annually from its shares in Energy Northwest's Nine Canyon Wind Project near Kennewick, Washington. It has also considered wind projects within Douglas County that could produce up to 80 MW at capacity if all sites are developed. While currently cost-prohibitive for Douglas PUD, fuel cell and solar generation are also being examined.

Grant County Public Utility District

Grant County Public Utility District (Grant PUD) operates two large run-of-the-river dams on the Columbia River mainstem, Priest Rapids and Wanapum. It also owns and operates two much smaller projects that are off the Columbia River mainstem, Potholes East Canal Headworks Project and the Quincy Chute Project. In 2008, Grant PUD received a new, 44-year license from FERC to continue operating both Columbia River dams. According to their integrated resource plan that was completed to meet the requirements of House Bill 1010 (HB 1010) concerning energy efficiency and renewable energy standards, peak power demand in Grant County can occur in summer or winter depending on annual temperatures (Figure 50).

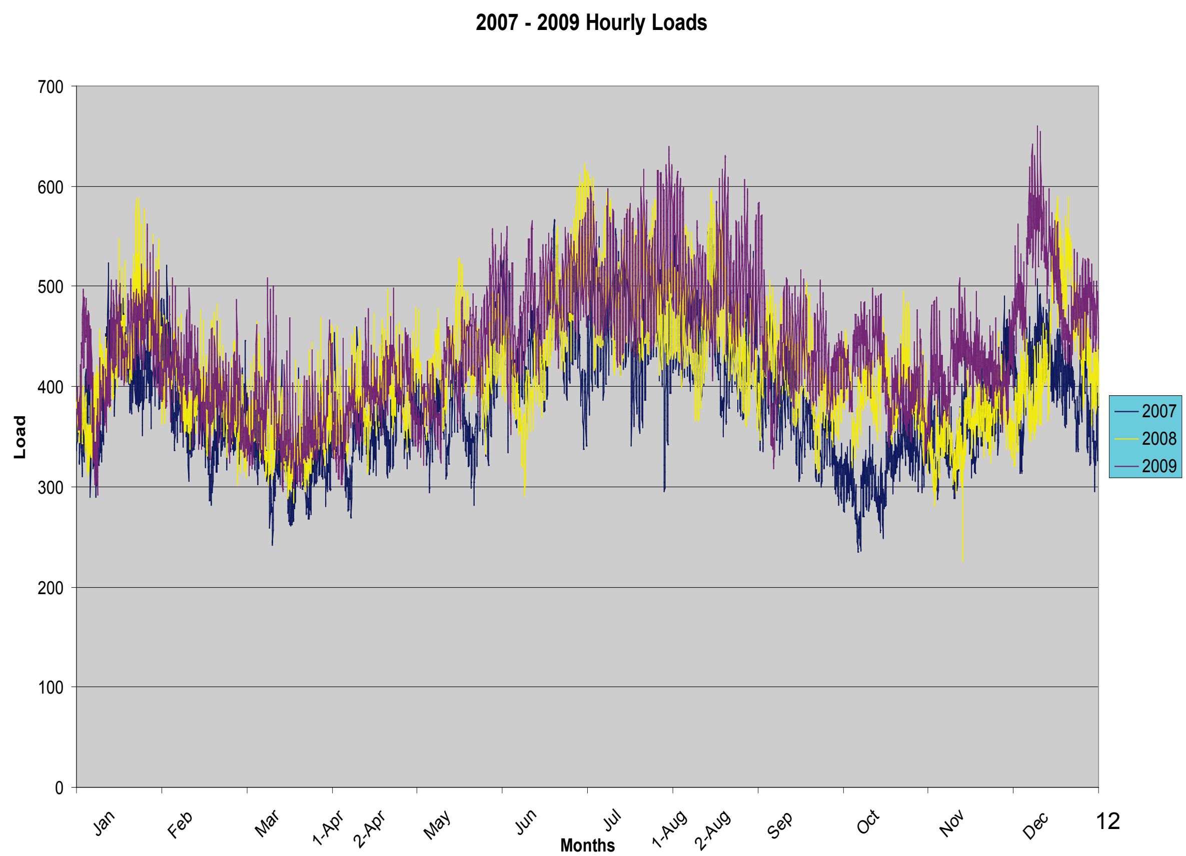


Figure 50. Variation in annual load shape for Grant PUD (from Grant PUD 2010 with permission).

With respect to I-937 and HB 1010, Grant PUD currently holds contracts for 12.54 percent of the power from the Nine Canyon Wind Project owned by Energy Northwest (Grant PUD 2010). This wind power, combined with conservation and improved efficiency efforts (incremental hydropower additions) will likely enable Grant PUD to meet its renewable energy obligations and its forecasted growth in power demands (Grant PUD, 2009). Other bioenergy, geothermal, natural gas, and solar options are constantly being evaluated.

The high capital costs associated with pumped storage hydro projects currently makes this option more expensive than natural gas options. As a result, Grant PUD is not focusing efforts on pumped storage projects at this time.

The PUD has expressed interest in interannual variability in amount and timing of runoff between years (whether or not they are tied to climate change), as this has the potential to impact their operation due to their limited storage potential. In average or above average water years, Grant PUD projects a surplus of energy through 2020. In critical water years, there is a slight deficit that it plans to make up from contract purchases and other options.

5.2.4.8 Review of FERC Licenses

The review of FERC licenses in Washington State found three large proposed projects as measured by proposed additional storage capacity, beyond what is currently in place (Table 29). All three of these projects have been issued a preliminary permit by FERC. Many other projects in the Pacific Northwest are listed on the FERC website. All proposed projects must ultimately obtain a license through FERC before construction. A preliminary permit, which is issued for up to three years, does not authorize construction; its purpose is to maintain priority of application for license while the prospective client studies the site and prepares their license application. It is not mandatory to obtain a preliminary permit in order to secure a license for the project, however, if another party does, they have first rights to the license and therefore the site. Thus, it is likely that projects that are being seriously considered and which are moving towards construction would be reflected in this list.

Table 29. Projects in Washington State issued preliminary permits by FERC (FERC 2011).

Project Name	Licensee	Waterway	Storage (AF)	MW	Iss. Date	Exp. Date
Shanker's Bend	PUD No. 1 of Okanogan County	Similkameen River	1,700,000	Varies	12/18/08	11/30/11
Banks Lake Pumped Storage	BPUS Generation Development	Banks Lake	700,000	1,040	03/06/09	02/28/12
JD Pool Pumped Storage	PUD No. 1 of Klickitat County	Closed System	22,025	1,129	05/05/09	04/30/12

FERC also lists many projects in the basin with pending preliminary permits. These represent preliminary permits which have yet to be approved by FERC. For Washington, the majority of projects at this stage are proposed for canals. The most notable proposed canal project is the Grand Coulee Irrigation District Kinetic Energy project from Pacific Rim Energy at a capacity of approximately 275 MW. Table 30 lists this project and the next five largest canal projects in terms of power generation in Washington. In addition to those listed, 11 other canal projects in Washington have pending preliminary permits, as well as 28 in Oregon and one in Idaho (a complete list can be found on the FERC website, www.ferc.gov). Because these projects are proposed for irrigation canals, they would only use slight changes in the elevation of the canals to produce power and do not intend to store water. In 2009, Grant PUD funded a study to look at the potential for additional hydrokinetic and conventional hydropower on Columbia Basin

Project canals and determined that expansion of the system beyond its current 145 MW could be viable (Knitter 2010).

Table 30. Canal projects in Washington State with pending preliminary permits (FERC 2011).

Project Name	Applicant	MW	Filing Date
Grand Coulee Irrigation District Kinetic Energy	Pacific Rim Energy	274.95	12/06/10
Sunnyside Valley Irrigation District KE	Pacific Rim Energy	27.60	12/06/10
Kittitas Reclamation District Kinetic Energy	Pacific Rim Energy	16.50	12/06/10
Roza Irrigation District Kinetic Energy	Pacific Rim Energy	11.10	12/06/10
Yakima-Tieton Irrigation District Kinetic Energy	Pacific Rim Energy	11.10	12/06/10
Ellensburg Water Company Kinetic Energy	Pacific Rim Energy	5.55	12/06/10

5.2.4.9 Conclusions of Hydropower Forecast

Based on the reviewed documents and FERC licenses, utilities throughout the U.S. portion of the Columbia River basin expect to be able to meet projected steady growth in peak winter and summer energy demands through conservation and integration of other energy sources. New non-hydroelectric projects will likely be needed to meet other requirements such as those in I-937.[8] In the Canadian portion of the Columbia River basin, BC Hydro expects that increases in demands will largely be met through conservation, transmission improvements, and potentially the Site C Clean Energy Project, if built (outside of the Columbia River basin). Two planned additional generation units at Mica Dam will also likely contribute.

Several power entities mentioned concerns about the potential for climate variability and possible renegotiation of the international Columbia River Treaty to disrupt or reduce

[8] I-937 requires that power-generating entities pursue Renewable Energy Certificates and other qualified renewable energy generation methods. Qualified methods do not include existing hydropower, except for new conservation and efficiency measures.

hydropower generation capacity. Potential impacts of the Columbia River Treaty are discussed in Section 5.1.2, covering water supply results.

Power entities in the Columbia River basin think it is unlikely that new storage reservoir projects will be needed solely to meet growing power demands within the next two decades, but they may be needed to help meet other future surface water supply demands. If additional storage projects are built for water supply purposes, pumping associated with the storage will likely create additional power demands, justifying the expansion or upgrading of hydroelectric facilities. It may also be feasible to generate power as an ancillary benefit at a new storage project, if one is built.

5.3 Impact of Deficit Irrigation on Crop Yield and Production Value

5.3.1 Impacts of Deficit Irrigation on Crop Yield

Figure 51 through Figure 53 below show the impact of curtailment on the yields of several representative crops (averaged over 30 years). Results for additional crops can be found in Appendix F. The figures represent impacts for the historical as well as the middle 2030s climate scenario and the values represent the fraction of full yields that are obtained under curtailment (on average over 30 years). For example, a value of 0.9 should be interpreted as 90% of the full yield being obtained under curtailment.

It must be noted that the future 2030s scenario for the Odessa area assumes that groundwater sources for irrigation are unavailable and hence does not fulfill any irrigation requirement of the crops. However, the model does not alter the 2030s crop mix to account for any conversion to dryland agriculture. In reality, if groundwater is not available for irrigation, the crop mix in those areas can be expected to change to some form of dryland agriculture (e.g. dryland wheat).

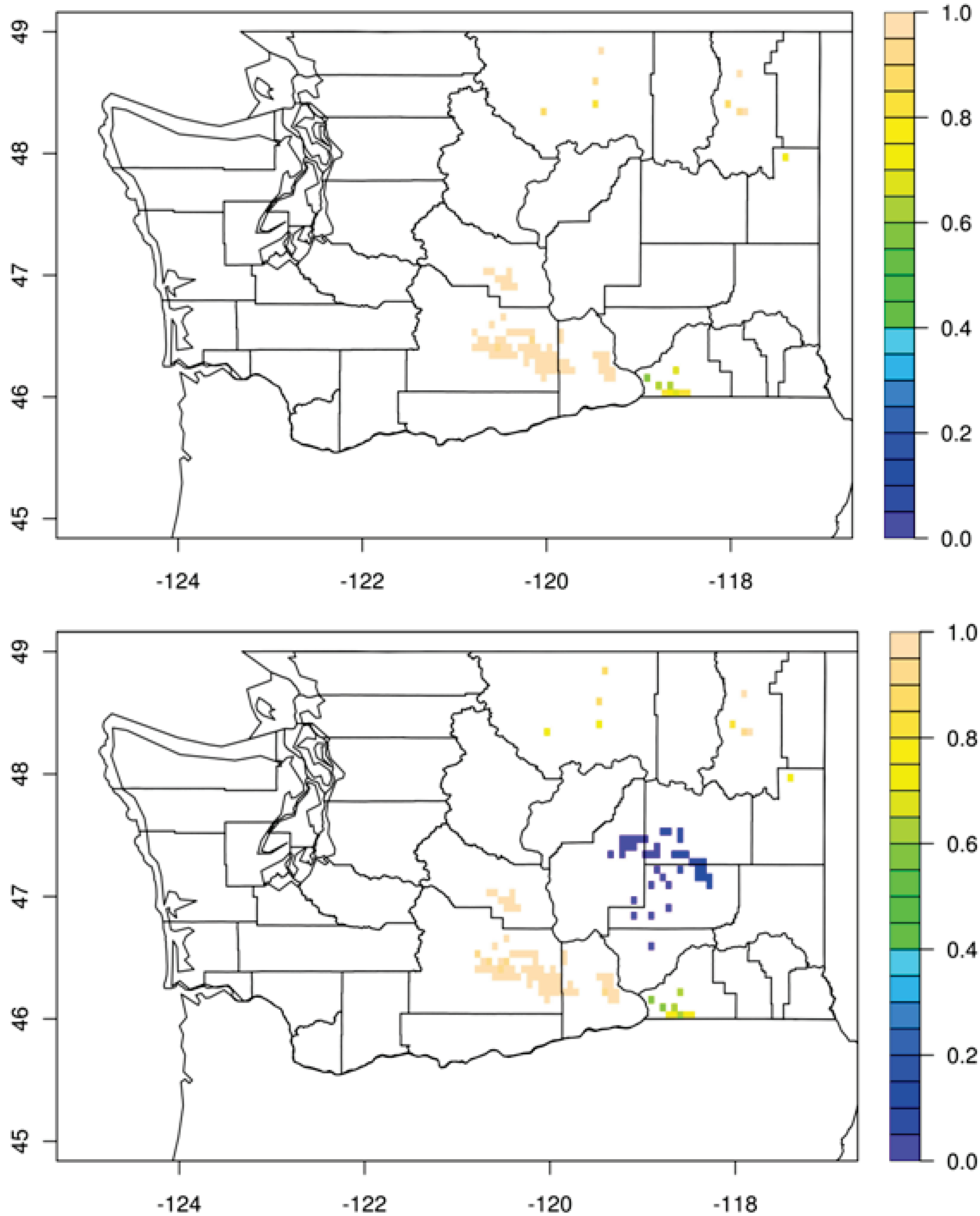


Figure 51. Impact of curtailment on alfalfa yields for the historical simulation (top) and future middle climate scenario (bottom).

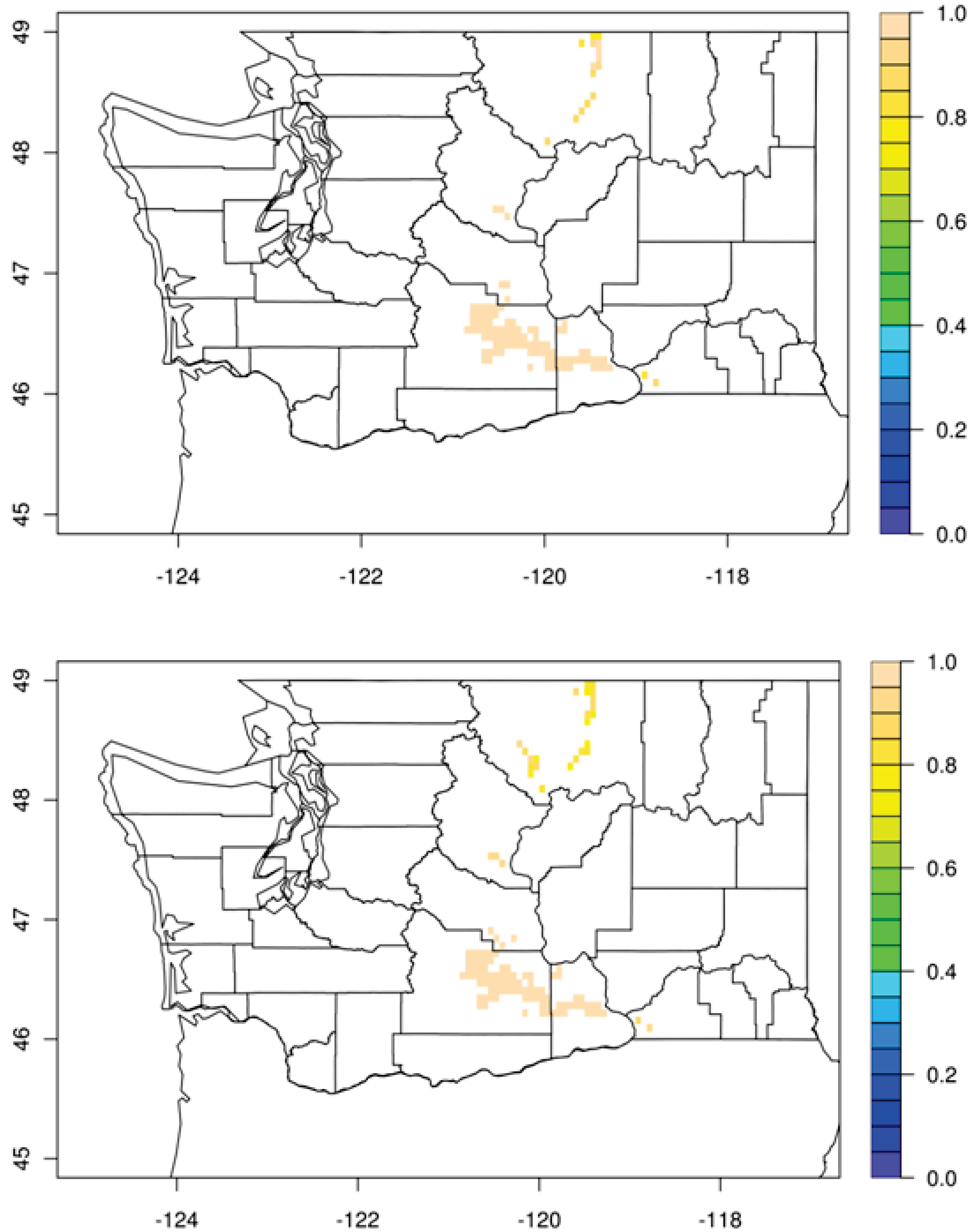


Figure 52. Impact of curtailment on apple yields for the historical simulation (top) and future middle climate scenario (bottom).

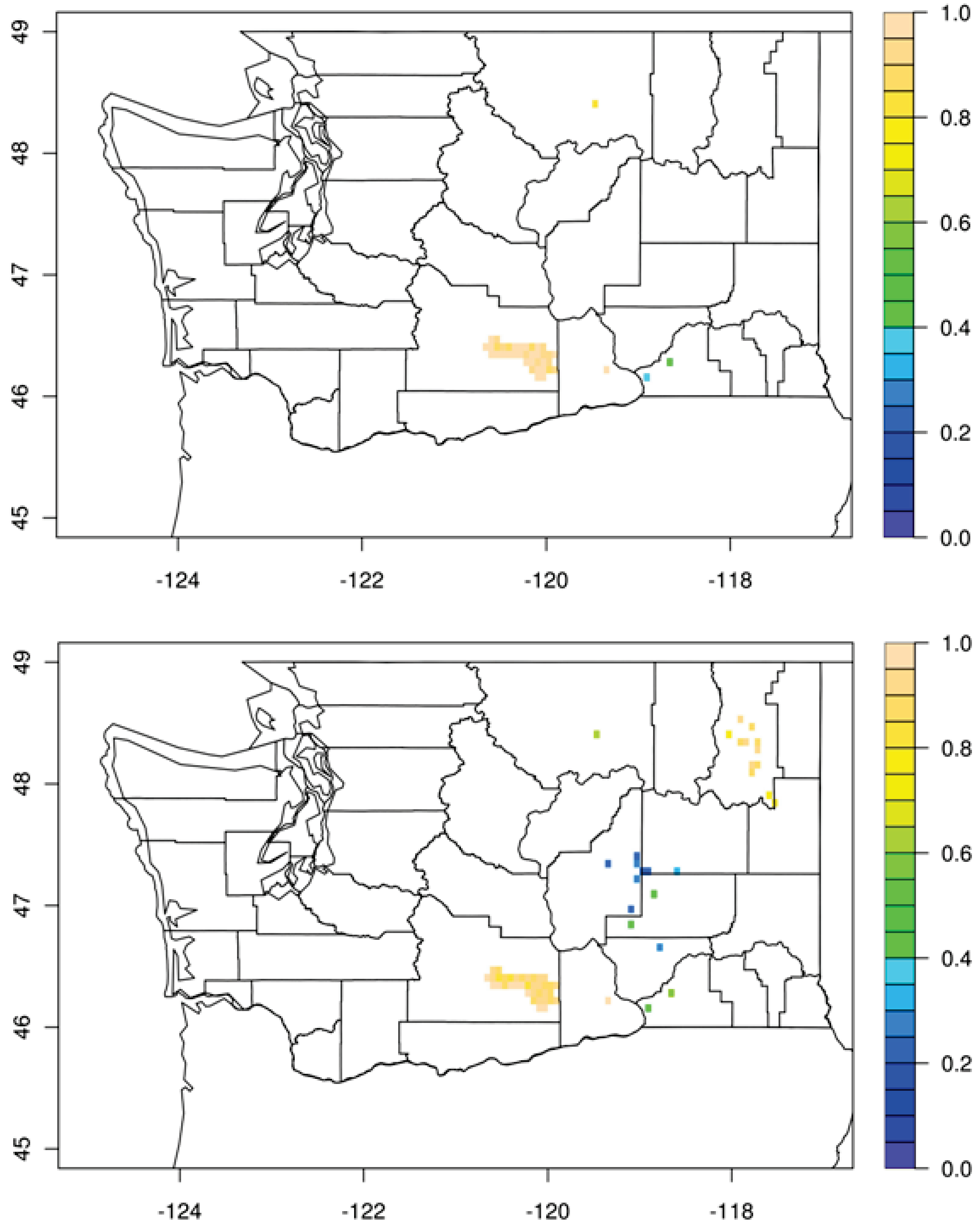


Figure 53. Impact of curtailment on corn yields for the historical simulation (top) and future middle climate scenario (bottom).

5.3.2 Impact of Deficit Irrigation on Production Value

Based on future yield and climate the value of lost production due to curtailment of interruptible rights holders was $80 million. These costs were concentrated in Walla Walla ($12 million), Yakima ($14 million), Grant ($12 million), and Lincoln ($30 million) Counties. Most of the lost revenue in Lincoln County was from winter wheat. Grant County primarily lost production of alfalfa. Lost production in Walla Walla and Yakima County was for forage crops.

There are contrasting reasons to suggest that these estimates could potentially be over or underestimated. They would be underestimated if there are a significant number of interruptible rights holders that only have land in high value crops and there is no potential for small scale water transfers. If they do not have low value crops to deficit irrigate and cannot obtain a one-time transfer of water from another rights holder then they would be forced to deficit irrigate a higher value crop. The rationale for these numbers being overestimated is that the potential for producers to increase the efficiency of their irrigation in the short was not considered. In some cases it is possible that production could be maintained with less water if a producer spent more time managing their irrigation schedule to improve efficiency. Of course, this additional time spent on managing irrigation scheduling would also represent a cost to the producer.

6.0 Tier II Results – Water Resource Inventory Area (WRIA) Level Results

WSU's modeling provided a spatial analysis that allowed for forecasting for eastern Washington's WRIAs (Figure 54). Results for individual WRIAs are presented in this chapter. Results for each WRIA comprise a summary of supply and demand results and information on the watershed's water management, and water allocation. Information on fish for fish-critical WRIAs can be found in the Columbia River Instream Atlas (Washington Department of Fish and Wildlife 2011). The scale of modeling did not allow for presentation of results at the sub-WRIA level.

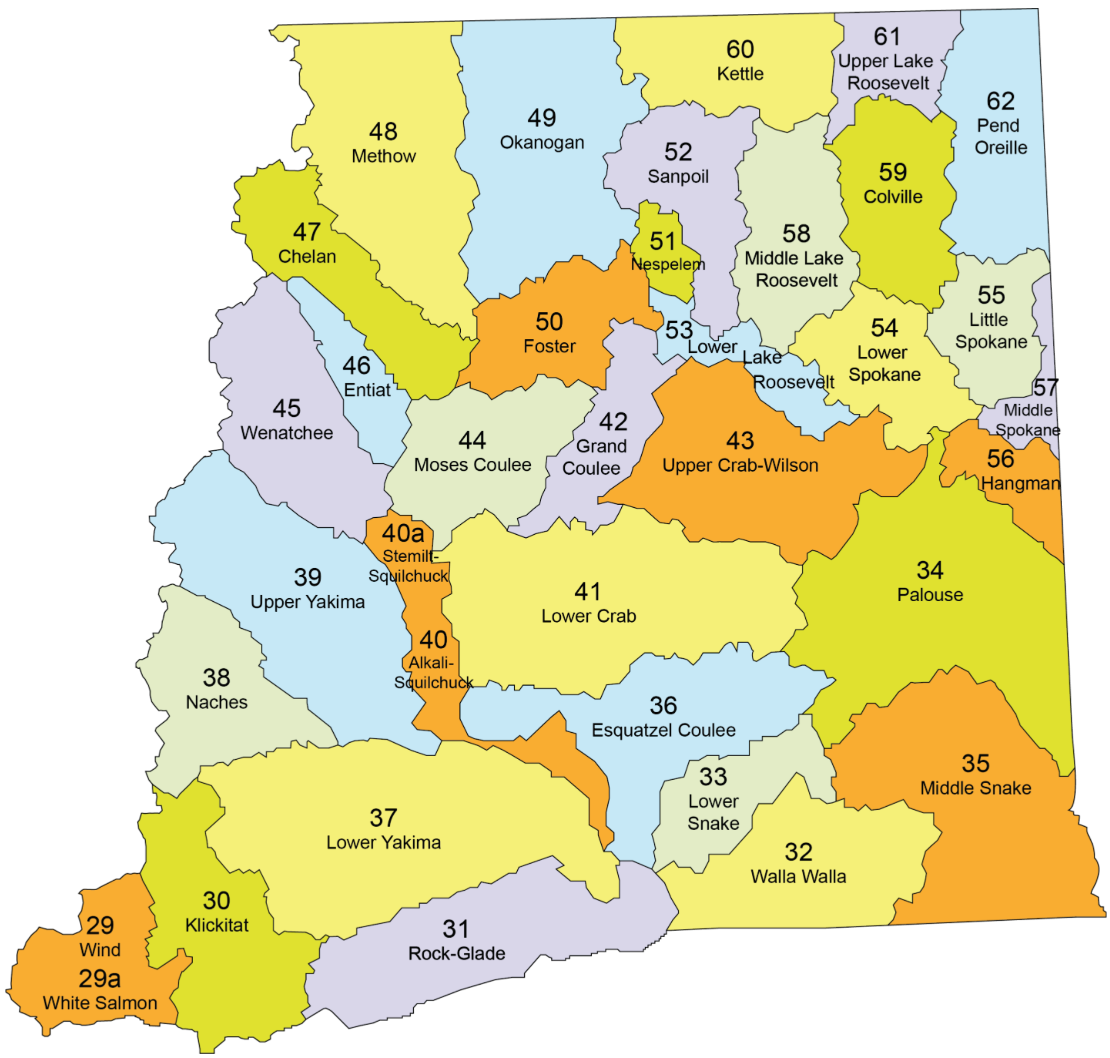


Figure 54. Water Resource Inventory Areas (WRIAs) in eastern Washington.

Definitions of water supply and demand are as described in Section 1.3, Definitions of Water Supply and Water Demand Used in the 2011 Forecast. It is also important when interpreting results to recognize that analysis of surface water supplies at the WRIA level focused on water supplies generated *within* the Washington WRIA. For this analysis, supplies exclude upstream areas that are outside Washington, as well as the mainstem Columbia and Snake Rivers. This was done because much of eastern Washington's water demands come from areas that cannot be hydrated by the Columbia River, but instead are supplied by the major tributaries.

In some watersheds that border the Columbia River, the mainstem supplies the majority of the water necessary to satisfy demands. In other watersheds, demands are met by supplies that come from upstream areas outside of Washington. Supplies on the mainstem are summarized in Chapter 7, Washington's Columbia River Mainstem: Tier III Results. Supplies in areas outside of Washington State are summarized in Chapter 5, Columbia River Basin: Tier I Results.

In addition to the results included in this section, a review of available information from Department of Ecology documents and from watershed planning documents was carried out, with summaries presented in Appendix G.

6.1 Surface Water Supplies in Washington Watersheds

Flows leaving major tributary areas make sizeable contributions to the Columbia as it makes its way from the Canadian border to Bonneville Dam. Figure 55 shows flows (prior to accounting for demands) from major tributary areas, including the portions of tributary areas that extend upstream outside of Washington State.

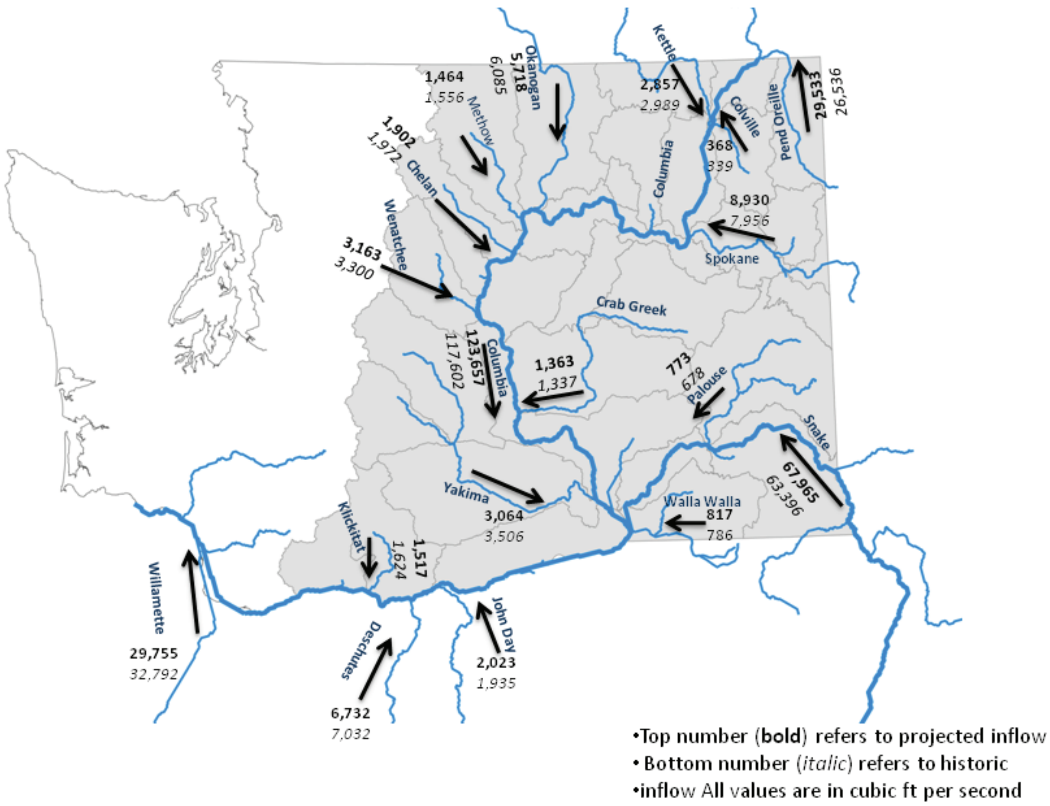


Figure 55. Contribution of flows (prior to accounting for demands) from tributaries to mainstem Columbia River, including all areas of tributary basins that extend outside of Washington State. Top number (**bold**) refers to 2030 forecast surface water supplies for average flow conditions. Bottom number (italic) refers to the historical (1977-2006) water supplies. All values are in cubic feet per second.

Annual surface water supply within the Washington portion of the Columbia River basin is expected to increase for most tributaries of Washington:

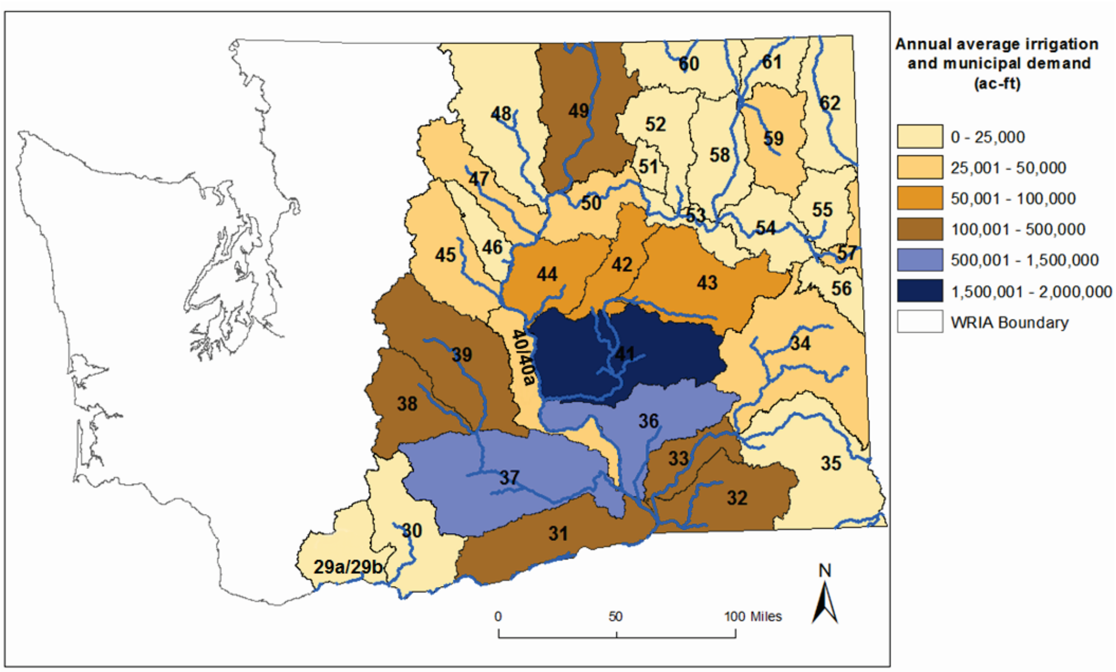
- Walla Walla (7.2 ±1.9%)
- Palouse (5.9 ±3.6%)
- Colville (9.5 ±2.8%)
- Yakima (4.4 ±2.3%)
- Wenatchee (5.9 ±1.8%)
- Chelan (5.8 ±1.5%)
- Methow (7.7 ±2.3%)
- Okanogan (4.3 ±2.4%)
- Spokane (6.6 ±2.2%)

6.2 Out-of-Stream Water Demands in Washington Watersheds

Historical and forecast water demands for combined agricultural irrigation and municipal uses, including both surface water and groundwater demands, is shown in Figure 56. Forecast water demand for combined agricultural irrigation and municipal uses in 2030 was concentrated within the southern and central Columbia basin, including Lower Yakima (37), Lower Crab (41), and Esquatzel Coulee (36), as well as Rock-Glade (WRIA 31), Walla Walla (32), Lower Snake (33), Naches (38), Upper Yakima (39), and Okanogan (49). These results are dominated by the impacts of irrigation water demand for most WRIAs. Figure 57 shows the difference in combined agricultural and municipal water demand between the historical and 2030 forecast, while Figure 58 indicates the percentage difference between the historical and 2030 forecast demand.

Changes in municipal demands are summarized in Table 31. In some cases, values in particular WRIAs may be impacted by forecast growth associated with nearby municipal areas, or the assignment of a municipal area to a particular WRIA.

Historical



2030 Forecast

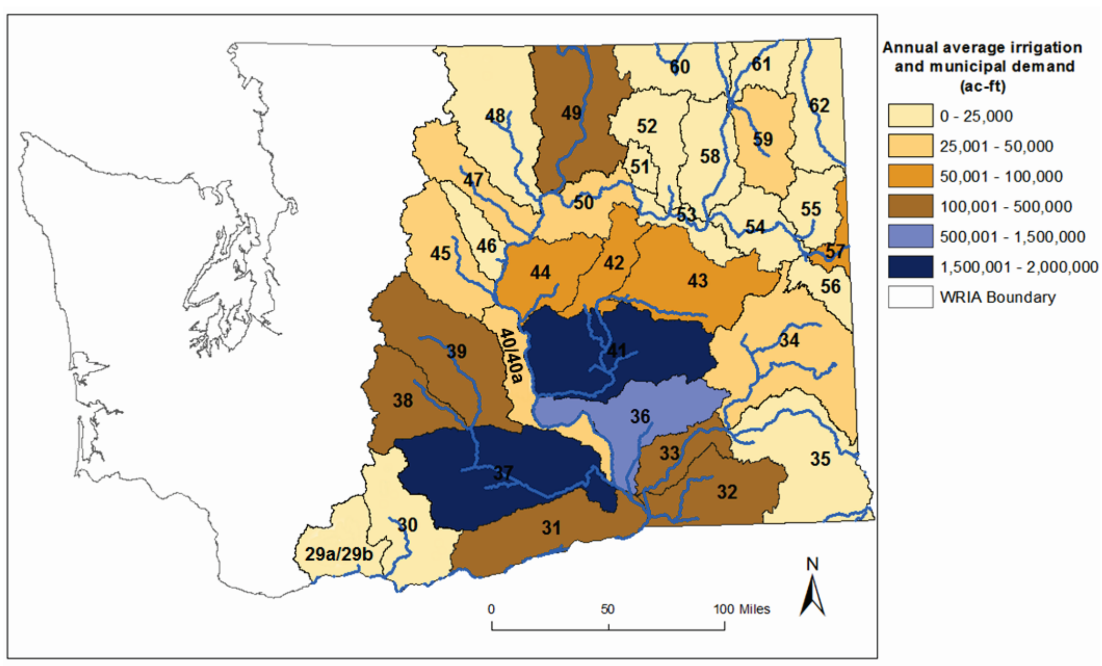


Figure 56. a) Historical and b) 2030 forecast total average annual water demands for combined irrigation and municipal uses (including self-supplied domestic) by WRIA. Demands include both surface and groundwater demands.

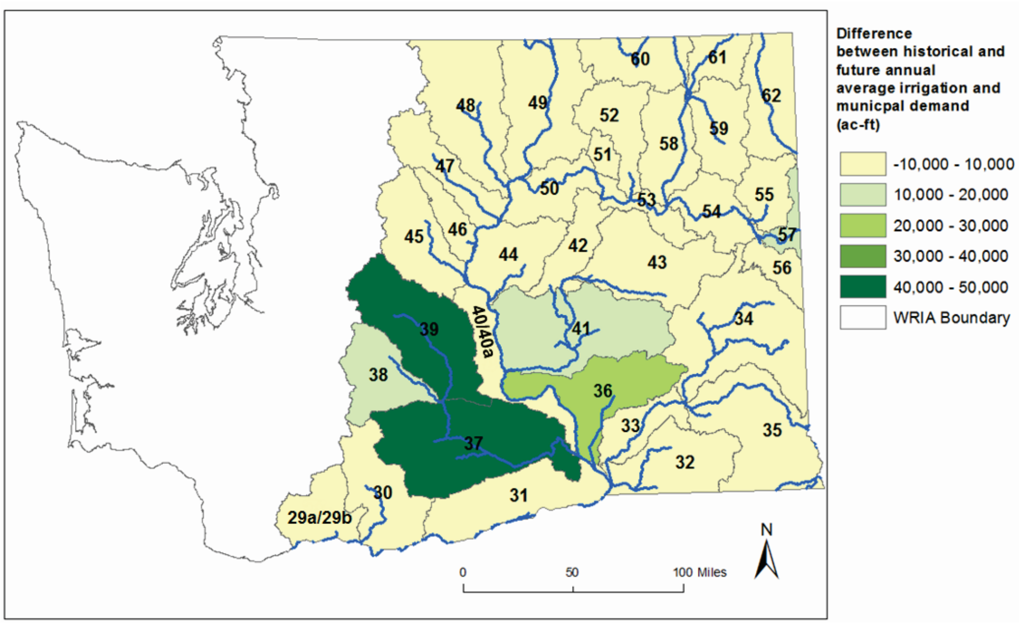


Figure 57. Absolute difference in total average annual water demands for combined irrigation and municipal uses (including self-supplied domestic) by WRIA. Demands include both surface and groundwater demands.

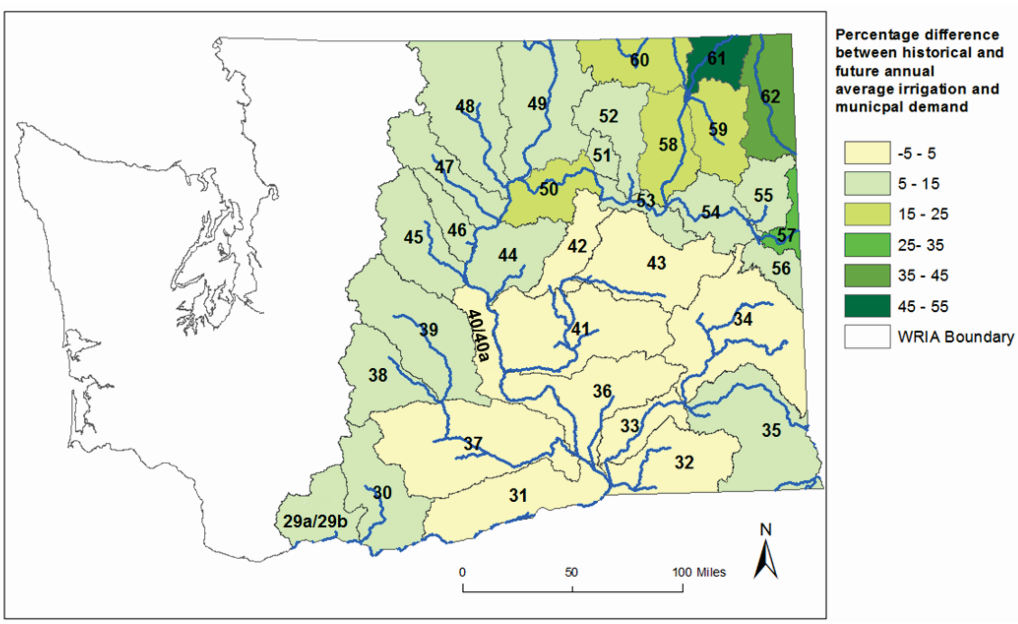


Figure 58. Percentage change in total average annual water demands for combined irrigation and municipal uses (including self-supplied domestic) by WRIA. Demands include both surface and groundwater demands.

Table 31. Changes in municipal demand for WRIAs in the Columbia River basin.

WRIA	WRIA Name	2010 Population Estimate	2030 Population Estimate	Population Increase 2010-2030 %	Change in Diversion 2010-2030 (ac-ft/year)	Change in Consumptive Use 2010-2030 (ac-ft/year)
29	Wind-White Salmon	10,710	23,564	120.0	1,961	351
30	Klickitat	23,275	28,003	20.3	2,383	791
31	Rock-Glade	93,685	104,313	11.3	1,836	615
32	Walla Walla	58,557	71,031	21.3	2,707	2,088
33	Lower Snake	65,377	76,115	16.4	2,755	291
34	Palouse	76,661	80,224	4.6	421	595
35	Middle Snake	26,344	29,699	12.7	1,630	1,215
36	Esquatzel Coulee	27,389	44,376	62.0	9,164	5,869
37	Lower Yakima	227,594	272,268	19.6	13,356	6,986
38	Naches	68,265	83,286	22.0	2,674	2,181
39	Upper Yakima	50,387	66,206	31.4	4,919	4,346
40	Alkali-Squilchuck	11,410	11,924	4.5	189	166
41	Lower Crab	74,527	95,981	28.8	12,377	6,286
42	Grand Coulee	16,214	15,389	-5.1	-223	-113
43	Upper Crab-Wilson	14,238	14,494	1.8	145	114
44	Moses Coulee	27,805	35,047	26.0	1,320	20
45	Wenatchee	50,530	65,673	30.0	5,284	2,137
46	Entiat	6,100	7,281	19.4	146	68
47	Chelan	14,701	19,419	32.1	1,164	478
48	Methow	11,975	14,362	19.9	835	264
49	Okanogan	22,583	27,544	22.0	1,767	635
50	Foster	11,453	14,121	23.3	851	490
51	Nespelem	1,198	1,358	13.4	45	3
52	Sanpoil	4,417	5,508	24.7	310	35
53	Lower Lake Roosevelt	4,367	5,435	24.5	421	238
54	Lower Spokane	76,440	101,152	32.3	6,329	1,467
55	Little Spokane	59,097	66,716	12.9	3,069	1,682
56	Hangman	56,051	61,374	9.5	701	316
57	Middle Spokane	254,751	342,462	34.4	29,201	12,779
58	Middle Lake Roosevelt	6,498	10,079	55.1	1,049	600
59	Colville	21,394	33,414	56.2	3,520	2,013
60	Kettle	4,518	6,286	39.1	518	296
61	Upper Lake Roosevelt	9,240	14,836	60.6	3,061	2,851
62	Pend Oreille	11,799	16,079	36.3	1,537	438
	TOTAL	**1,499,550**	**1,865,019**	**24.4%**	**117,422**	**58,591**

Table 32. Municipal and industrial consumptive use estimates for WRIAs in the Columbia River basin.

WRIA	WRIA Name	Consumptive Use 2010 (ac-ft/year)	Consumptive Use 2030 (ac-ft/year)
29	Wind-White Salmon	292	643
30	Klickitat	3,898	4690
31	Rock-Glade	5,425	6041
32	Walla Walla	9,808	11896
33	Lower Snake	1,775	2066
34	Palouse	12,840	13435
35	Middle Snake	9,544	10759
36	Esquatzel Coulee	9,462	15331
37	Lower Yakima	35,591	42577
38	Naches	9,910	12090
39	Upper Yakima	13,843	18190
40	Alkali-Squilchuck	3,676	3842
41	Lower Crab	21,837	28124
42	Grand Coulee	2,215	2102
43	Upper Crab-Wilson	6,339	6453
44	Moses Coulee	79	99
45	Wenatchee	7,130	9266
46	Entiat	353.5	422
47	Chelan	1,490	1968
48	Methow	1,322	1586
49	Okanogan	2,889	3524
50	Foster	2,104	2594
51	Nespelem	23.5	27
52	Sanpoil	140.8	176
53	Lower Lake Roosevelt	972.9	1211
54	Lower Spokane	4,538	6005
55	Little Spokane	13,049	14732
56	Hangman	3,325	3641
57	Middle Spokane	37,117	49896
58	Middle Lake Roosevelt	1,088	1688
59	Colville	3,583	5596
60	Kettle	757	1053
61	Upper Lake Roosevelt	4,708	7559
62	Pend Oreille	1,207	1645
	TOTAL	**232,331**	**290,922**

6.3 Instream Water Demands in Washington Watersheds

As described in the “Overview of the 2011 Forecast,” WDFW ranked fish stock status and habitat utilization, fish habitat utilization, and instream flows in 189 stream reaches in Walla Walla, Middle Snake, Lower Yakima, Naches, Upper Yakima, Wenatchee, Methow, and Okanogan WRIAs. While independent scores for each reach generated a range of results, it was determined that great opportunity to improve salmonid production exists by pursuing water acquisition in smaller, lower elevation streams with good to excellent habitat.

In addition, streams with good to excellent habitat in higher elevations or less populous areas are likely to benefit from flow augmentation, as are lower mainstems through which most stocks/species must migrate. Any flow augmentation could be helpful in salmonid restoration efforts, especially in smaller systems that have limited flow, in over-appropriated basins, or in combination with other recovery measures. Detailed results are available in the Columbia River Instream Atlas, Ecology Publication No 11-12-015.

6.4 Unmet Demand in Washington Watersheds

The Forecast calculated unmet demand due to curtailment of interruptible and pro-ratable water rights for each WRIA for the historical period (1977-2006) and for the 2030 forecast. Water curtailment included interruptions in water use when instream flows are not met, in accordance with the relevant portions of the Washington Administrative Code (or for Yakima, the federal flow targets and pro-rationing system). Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Unmet instream flow demands are discussed with the WRIA level results summaries for each WRIA that has instream flow rules specified in WAC.

Unmet demands due to curtailment of pro-ratable or interruptible rights, or to insufficient water to meet demands at the watershed scale were indicated for the historical period in the following WRIAs:

- Walla Walla (WRIA 32)
- Yakima (WRIAs 37, 38, & 39)
- Wenatchee (WRIA 45)
- Methow (WRIA 48)
- Okanogan (WRIA 49)
- Little Spokane (WRIA 55)
- Colville (WRIA 59)

Unmet demands were forecasted to impact additional WRIAs for the 2030 forecast. This group of WRIAs includes all watersheds that include land currently irrigated as part of the Odessa Sub-area. Within the Odessa, all lands that were irrigated by groundwater in the historical period (1977-2006) were assumed to have unmet surface water demands in the 2030 forecast, due to the existing groundwater declines. Unmet demands due to curtailment or unmet surface water demands in the Odessa were forecasted for the following watersheds:

- Walla Walla (WRIA 32)
- Palouse (WRIA 34)
- Esquatzel Coulee (WRIA 36)
- Yakima (WRIAs 37, 38, & 39)
- Lower Crab (WRIA 41)
- Grand Coulee (WRIA 42)
- Upper Crab (WRIA 43)
- Wenatchee (WRIA 45)
- Methow (WRIA 48)
- Okanogan (WRIA 49)
- Little Spokane (WRIA 55)
- Colville (WRIA 59)

Frequency and quantity of modeled unmet demands are described in more detail in the following sections covering individual WRIA results.

6.6 WRIAs 29a, Wind, and 29b, White Salmon

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." Results for WRIAs 29a and 29b are presented together due to limitations in the Department of Ecology GIS database. The tributary surface water supply forecast for Wind-White Salmon is characterized mostly by increases from late fall through mid-spring, with smaller decreases in the late spring and summer (Figure 59).

Irrigation is the dominant source of demand in WRIA 29, although it is smaller than irrigation demands in many other WRIAs of eastern Washington (Figure 60). Assuming no change in irrigated acreage, these demands are projected to increase in most spring and summer months (April through August), with little impact from the consideration of alternate future economic scenarios. Municipal demands are very small in comparison. They are projected to grow 120% by 2030, though the total municipal demand will still be quite small in comparison to other watersheds.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity) (Figure 61). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is forecasted to be sufficient to meet combined municipal and surface water irrigation demands on a watershed scale (Figure 62). Additional water supply is available in this watershed from the Columbia River, though separate analysis indicates that only about 5% of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Fish listed under the Endangered Species Act that spawn or rear in tributary waters of this watershed include Lower Columbia River Bull Trout, Lower Columbia River Chinook, Lower Columbia River Steelhead, Middle Columbia Steelhead, and Upper Columbia River Summer and Fall Run Chinook (Table 33).

6.6.1 WRIA 29 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 59 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include **only** supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

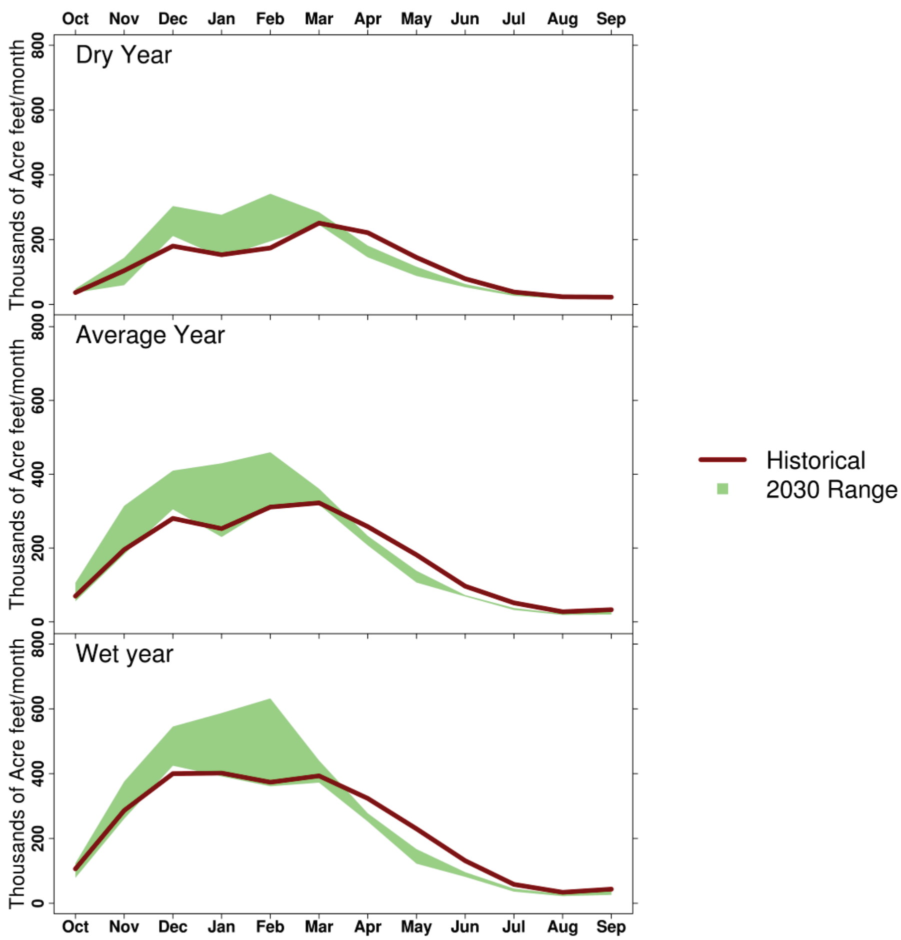


Figure 59. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.6.2 WRIA 29 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 60. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

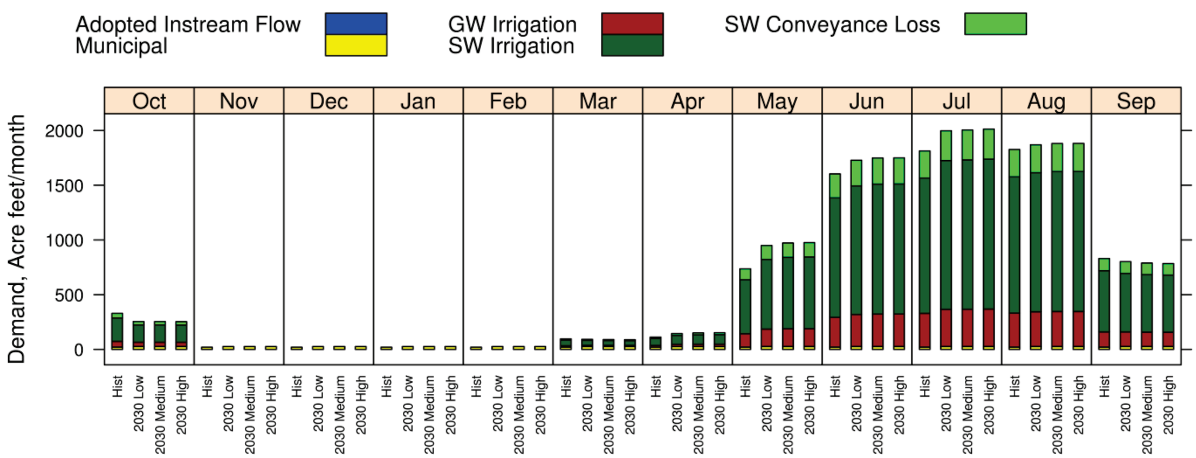


Figure 60. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.6.3 WRIA 29 Demand under Additional Water Capacity Scenarios

Figure 61 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

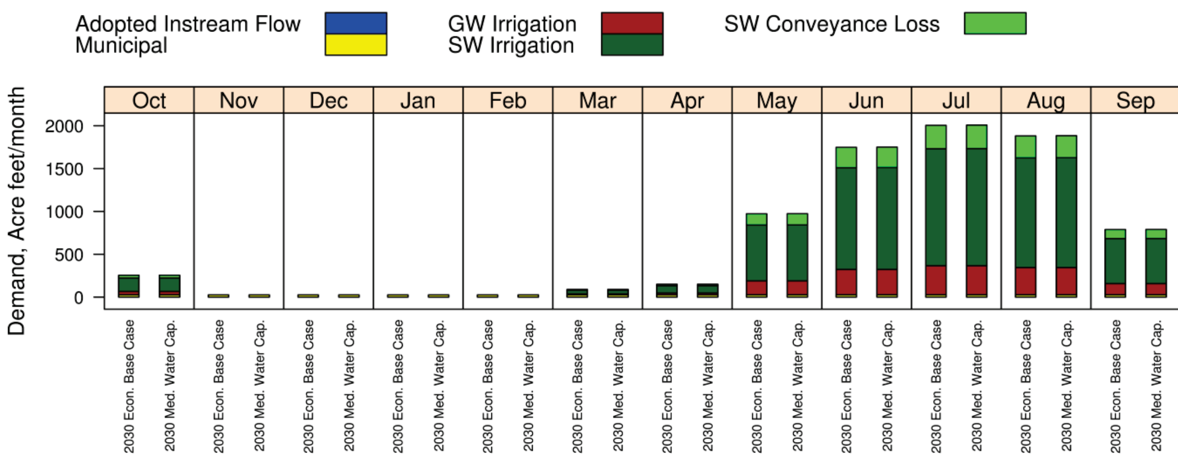


Figure 61. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.6.5 WRIA 29 Supply versus Demand Comparison

Figure 62 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

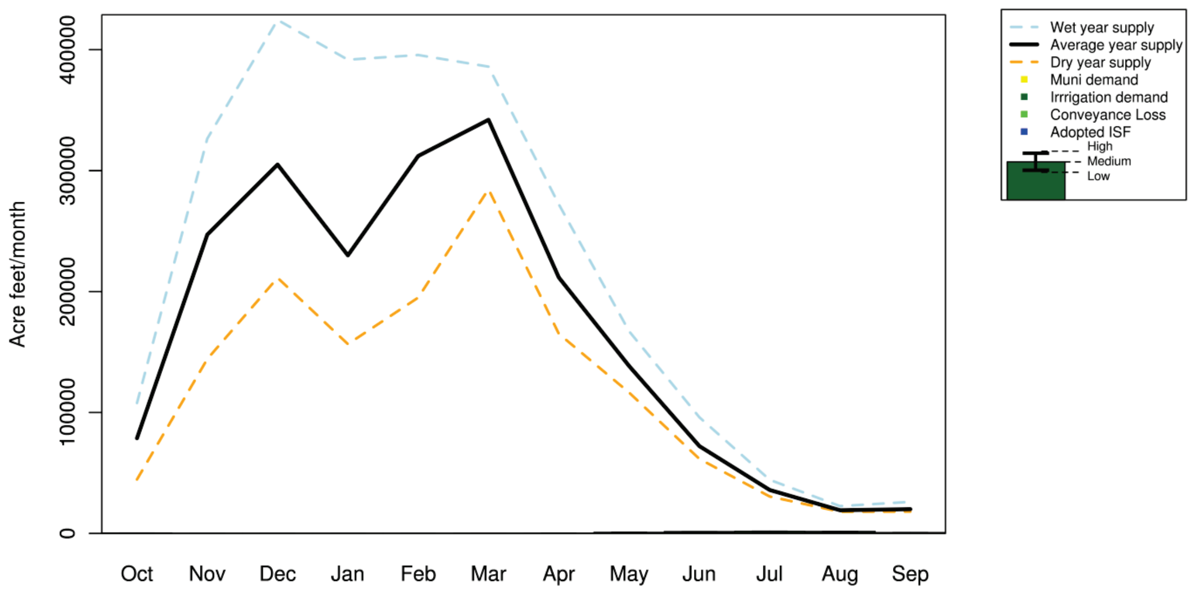


Figure 62. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.6.5.1 WRIA 29 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.6.6 WRIA 29 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 63). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

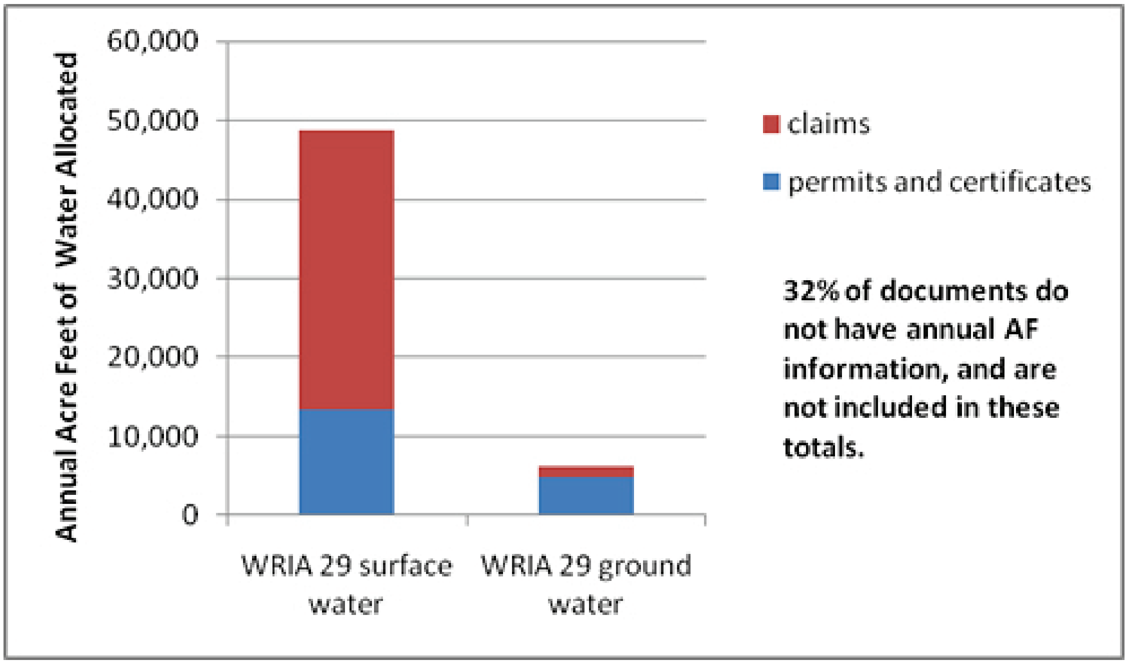


Figure 63. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.6.7 WRIA 29 Management Context

Some major management considerations for WRIA 29 are summarized in Table 33.

Table 33. Major management considerations in WRIA 29.

Management Context	
Adjudicated Areas	NO
Watershed Planning	WRIA 29a: Phase 4 (Implementation)
	WRIA 29b: NO (planning terminated)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Lower Columbia River Bull Trout
	Lower Columbia River Chinook
	Lower Columbia River Steelhead
	Middle Columbia Steelhead
	Upper Columbia River Summer and Fall Run Chinook
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.7 WRIA 30, Klickitat

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Klickitat is characterized mostly by substantial increases in the late fall, winter and early spring and decreases in late spring through early fall (Figure 64).

Irrigation is the dominant source of demand in WRIA 30, with municipal demands that are much smaller (Figure 65). Assuming no change in irrigated acreage, irrigation demand is forecasted to increase somewhat for most months of the irrigation season in the future, with small variations in impact when alternate future economic scenarios are considered. Municipal demands are expected to grow 20% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity) (Figure 66). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is projected to be sufficient to meet combined municipal and surface water irrigation demands on a watershed scale (Figure 67). Additional water supply is available in this watershed from the Columbia River, though separate analysis indicates that only about 5% of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Fish listed under the Endangered Species Act that spawn or rear in tributary waters of this watershed include Lower Columbia River Bull Trout and Middle Columbia Steelhead.

6.7.1 WRIA 30 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 64 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

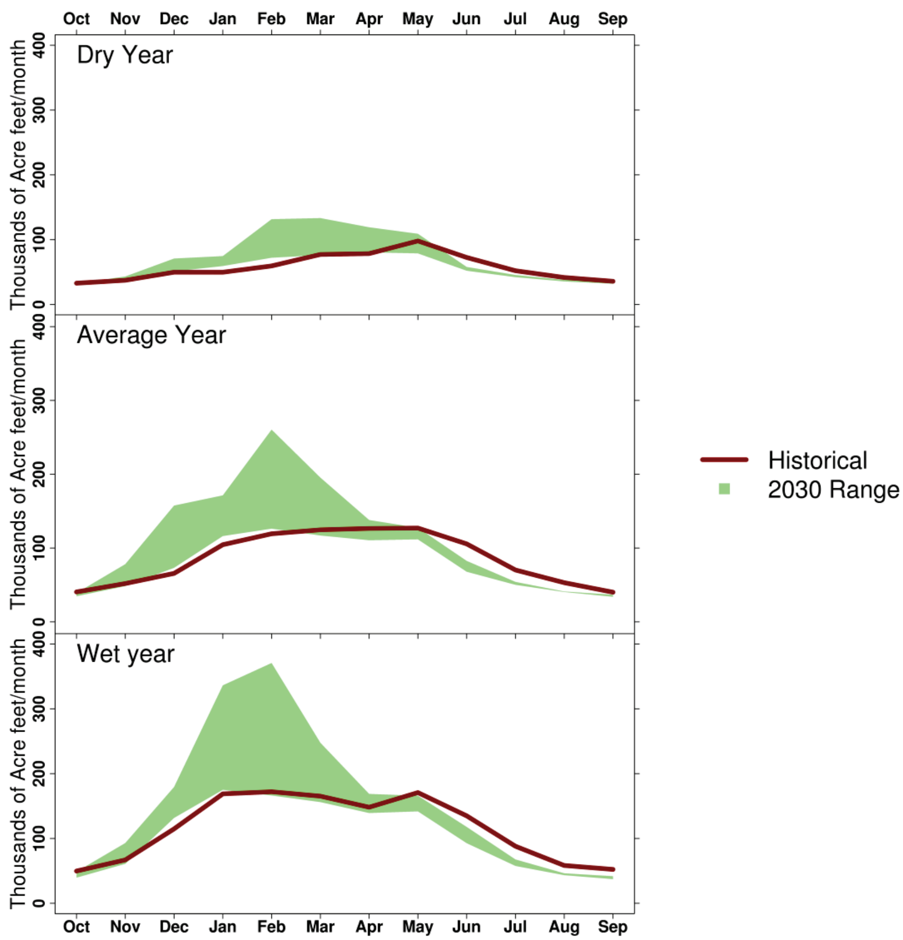


Figure 64. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.7.2 WRIA 30 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 65. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

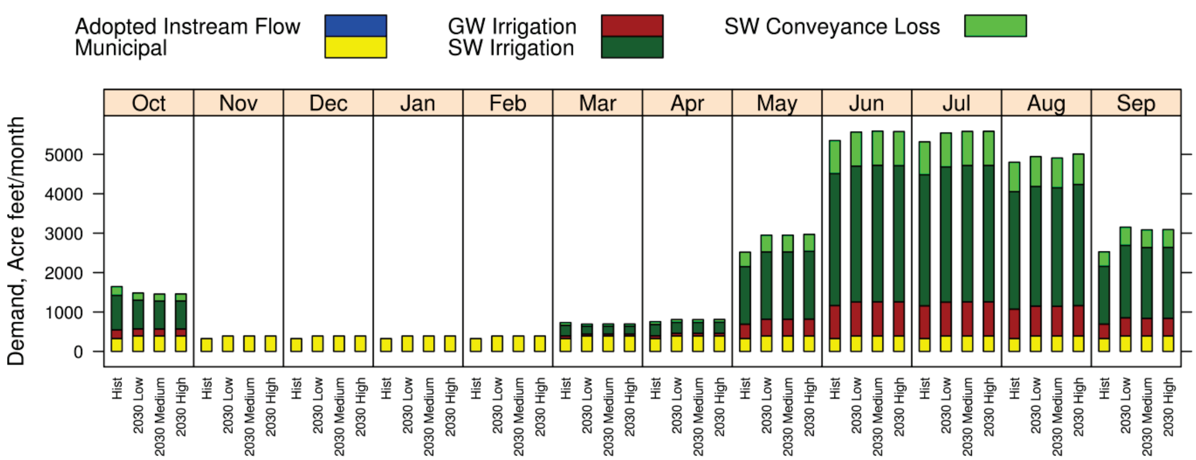


Figure 65. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.7.3 WRIA 30 Demand under Additional Water Capacity Scenarios

Figure 66 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

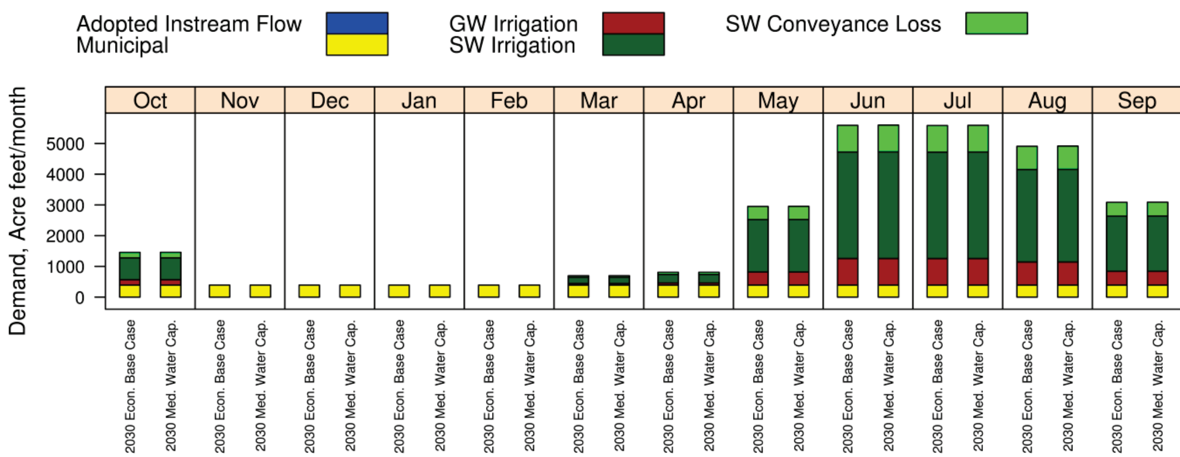


Figure 66. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.7.4 WRIA 30 Supply versus Demand Comparison

Figure 67 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

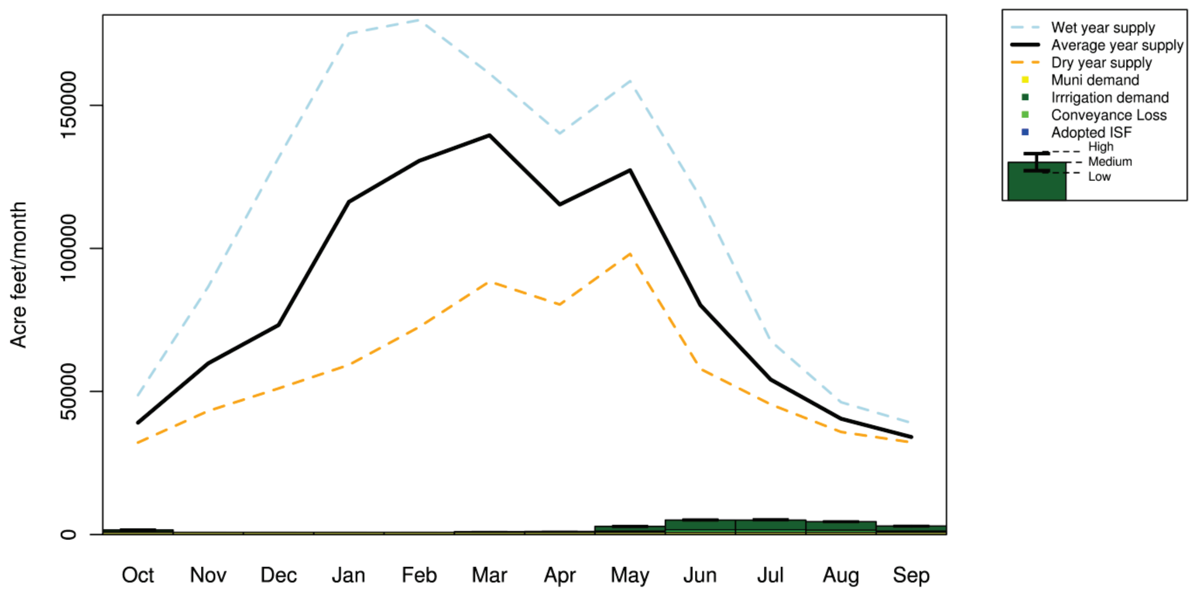


Figure 67. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.7.4.1 WRIA 30 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.7.5 WRIA 30 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 68). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

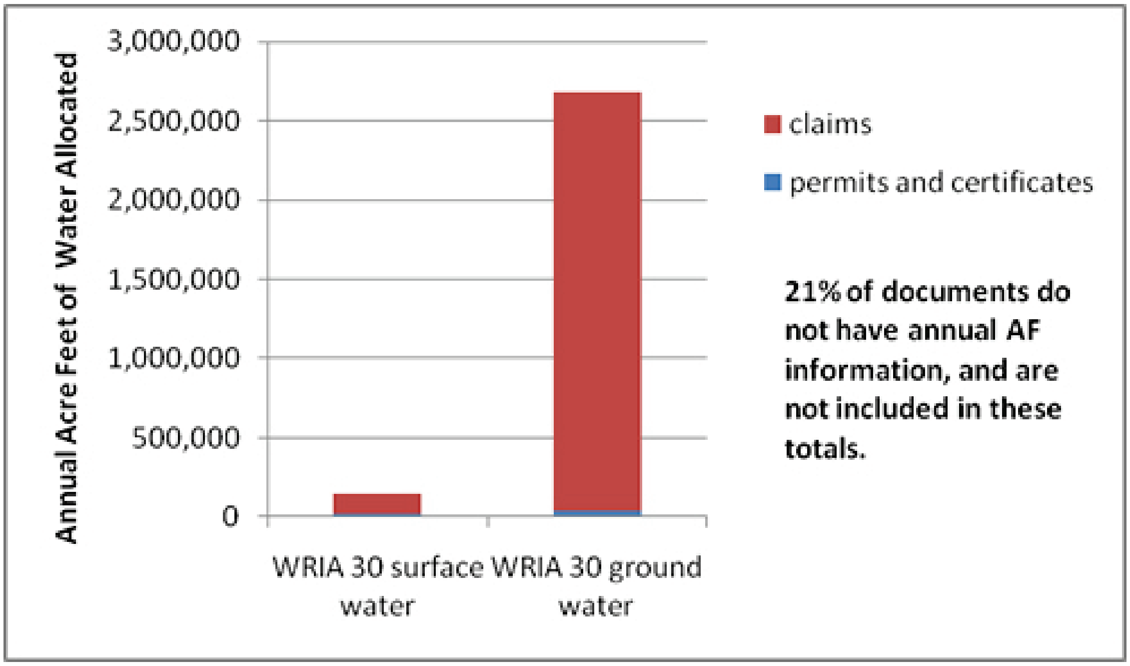


Figure 68. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.7.6 WRIA 30 Management Context

Some major management considerations for WRIA 30 are summarized in Table 34.

Table 34. Major management considerations in WRIA 30.

Management Context	
Adjudicated Areas	Bird-Frazier Creeks
	Bacon Creek
	Little Klickitat River
	Mill Creek
	Blockhouse Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Lower Columbia River Bull Trout
	Middle Columbia Steelhead
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.8 WRIA 31, Rock-Glade

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Rock-Glade is characterized mostly by slight increases during the winter.

Irrigation is the primary source of demand in WRIA 31, with much smaller municipal demands. Assuming no change in irrigated acreage, irrigation demand is projected to increase slightly during future summer months (June through August) but decrease in other months, with little impact on results from the consideration of alternate future economic scenarios. Municipal demands are expected to grow 11% by 2030, a smaller increase than in many other eastern Washington WRIAs.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, combined municipal and surface water irrigation demands are projected to outstrip unregulated tributary supply on a watershed scale during most years for May through September. Much of this demand is met from mainstem supplies, and separate analysis indicates that almost a quarter of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Fish listed under the Endangered Species Act that spawn or rear in tributary waters of this watershed include Middle Columbia Steelhead and Upper Columbia River Summer and Fall Run Chinook.

6.8.1 WRIA 31 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 69 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

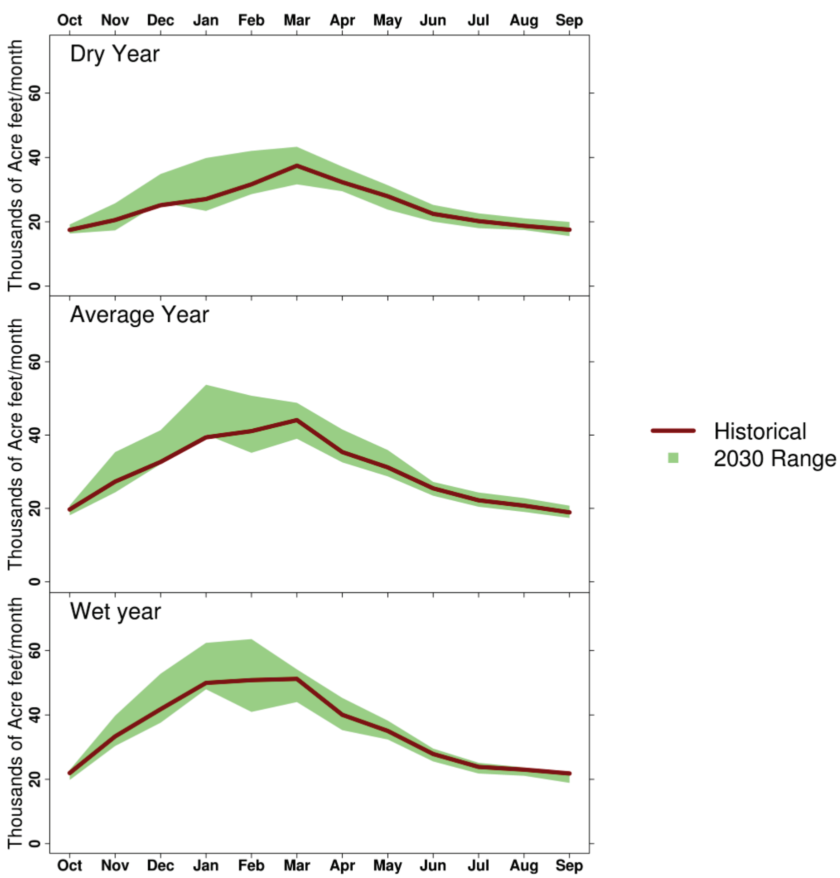


Figure 69. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.8.2 WRIA 31 Water Demand Forecast, Including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 70. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

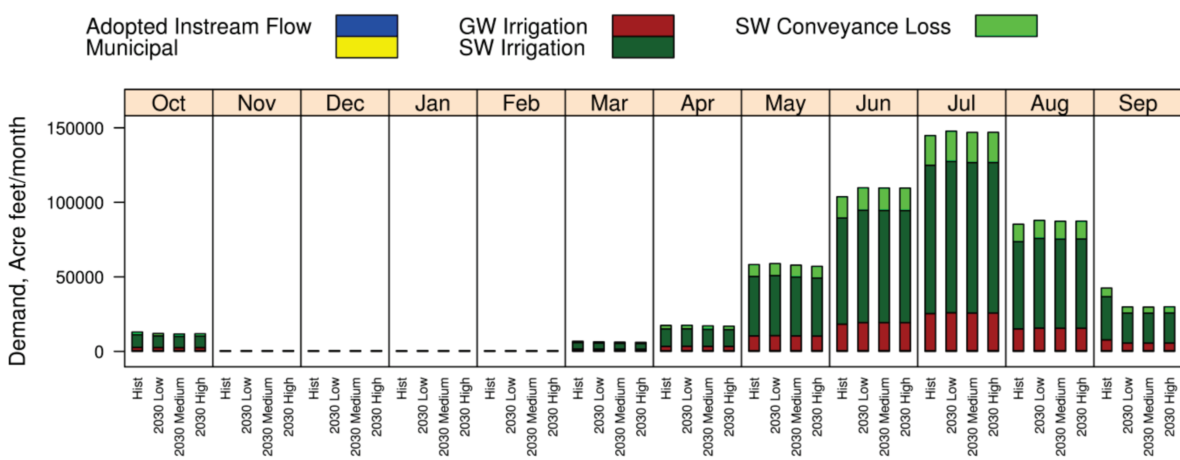


Figure 70. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.8.3 WRIA 31 Demand under Additional Water Capacity Scenarios

Figure 71 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

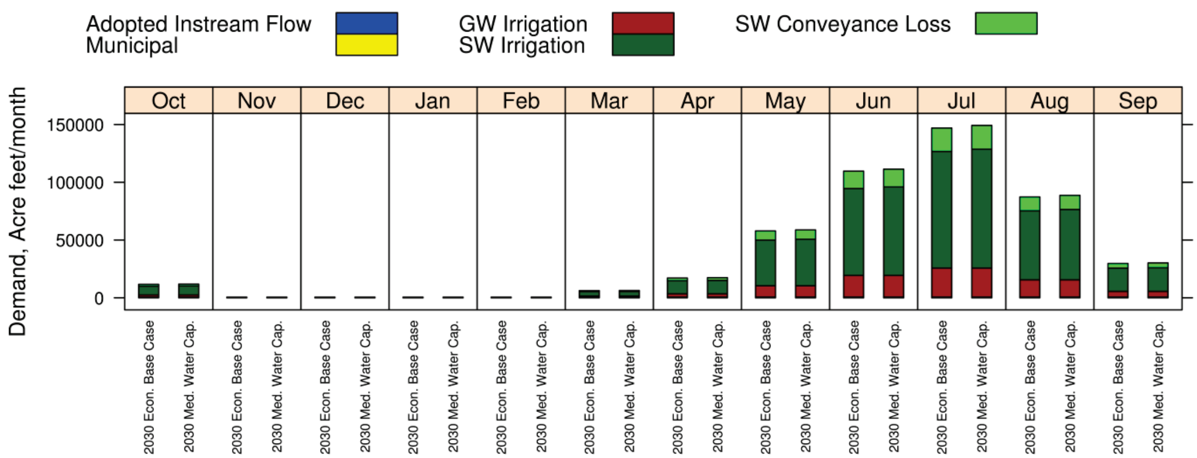


Figure 71. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.8.4 WRIA 31 Supply versus Demand Comparison

Figure 72 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

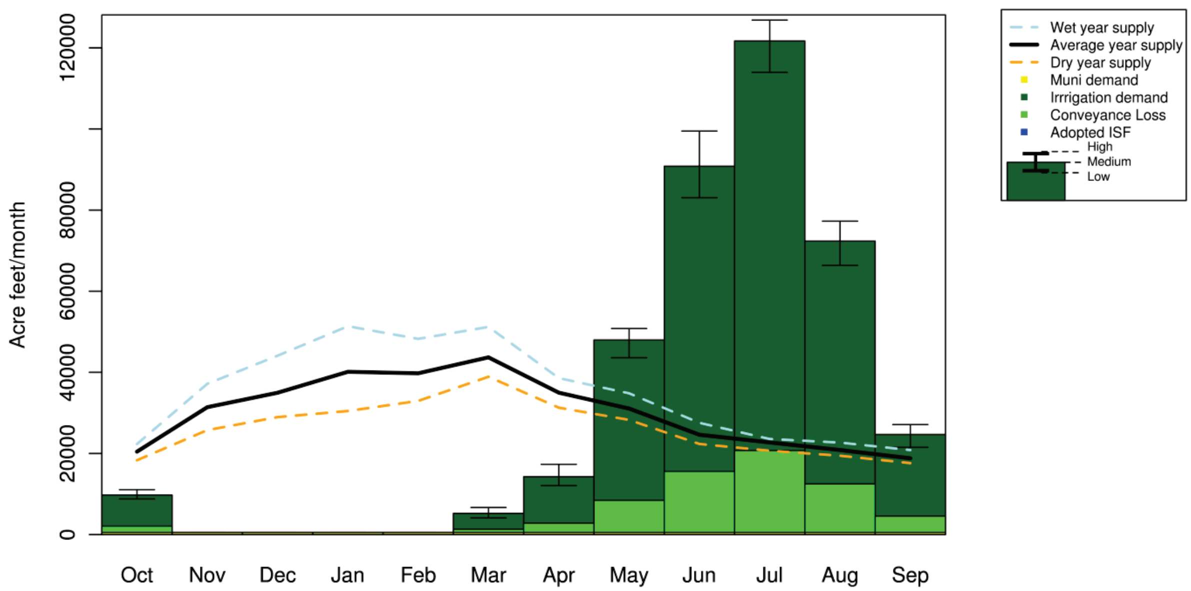


Figure 72. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.8.4.1 WRIA 31 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.8.5 WRIA 31 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 73). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

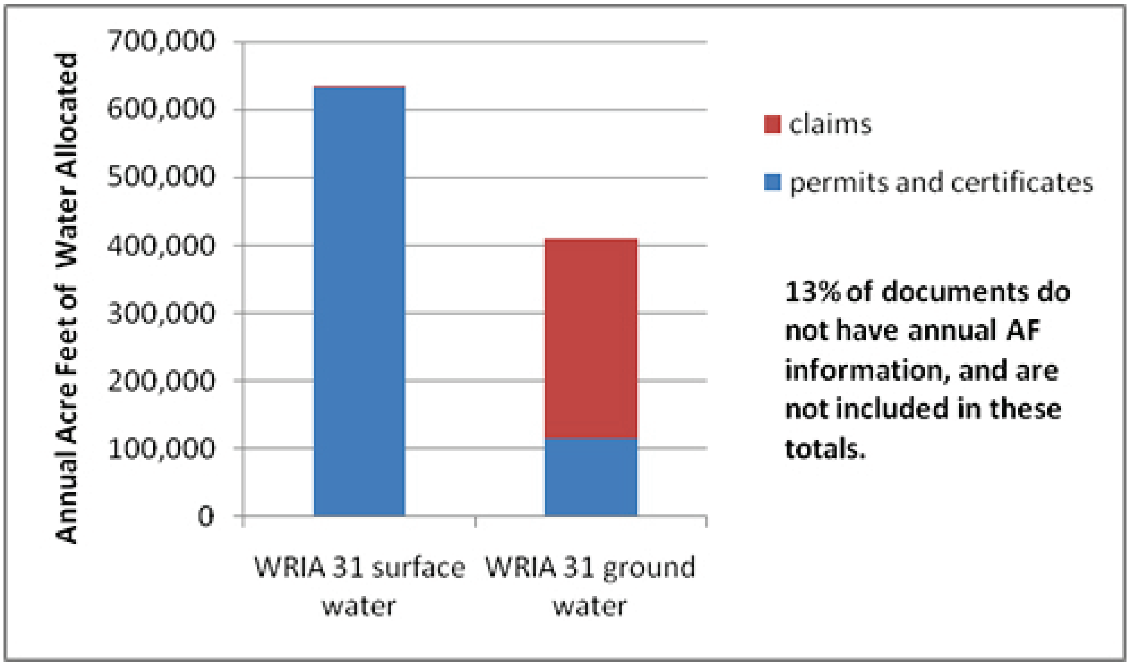


Figure 73. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.8.6 WRIA 31 Management Context

Some major management considerations for WRIA 31 are summarized in Table 35.

Table 35. Major management considerations in WRIA 31.

Management Context	
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Middle Columbia Steelhead
	Upper Columbia River Summer and Fall Run Chinook
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.9 WRIA 32, Walla Walla

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Walla Walla is characterized mostly by significant increases from late fall through early spring and slight decreases in late spring and early summer.

Primary demands are irrigation and instream flow requirements, with much smaller municipal demands. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in some months in the future (June, August, and October) and decrease slightly in other months, with small variations depending on the future economic scenarios considered. Municipal demands are projected to grow 21% by 2030. Because there are no adopted instream flows in Walla Walla at the mouth of the watershed, instream flows are shown as the highest quantified flow at any point for a given month, as specified in Chapter 173-532 WAC. For December through May, flows are shown at Walla Walla River at Detour road. For other months, when the Walla Walla River is closed to new uses, flows from other control points are shown.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is not anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, at the watershed scale, combined municipal and surface water irrigation demands and adopted instream flows are projected to outstrip unregulated tributary supply generated within the Washington portion of the watershed during average and dry years in June, and in most years for July through October. Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands.

Steelhead in the Walla Walla basin are part of the ESA-Threatened Middle Columbia steelhead population, while bull trout here are part of an ESA-Threatened Touchet/Walla Walla Oregon Recovery Unit. Summer Steelhead are primarily spawning in April-May, while spring Chinook spawn in the late summer and fall.

6.9.1 WRIA 32 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 74 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

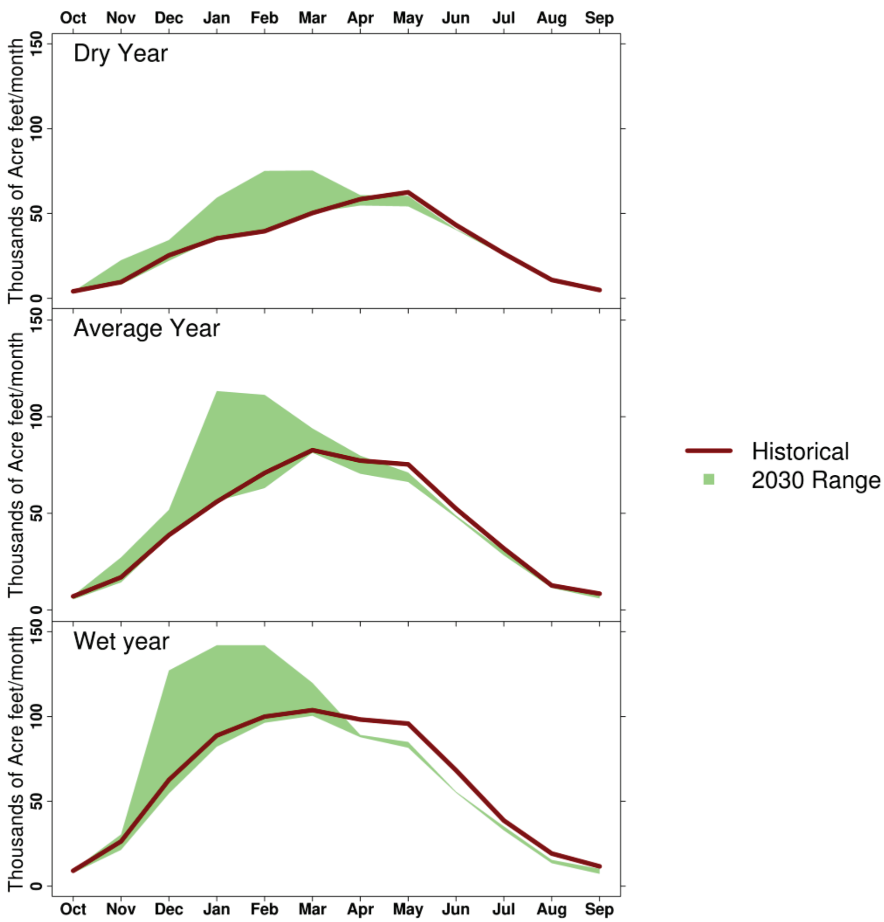


Figure 74. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.9.2 WRIA 32 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 75. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

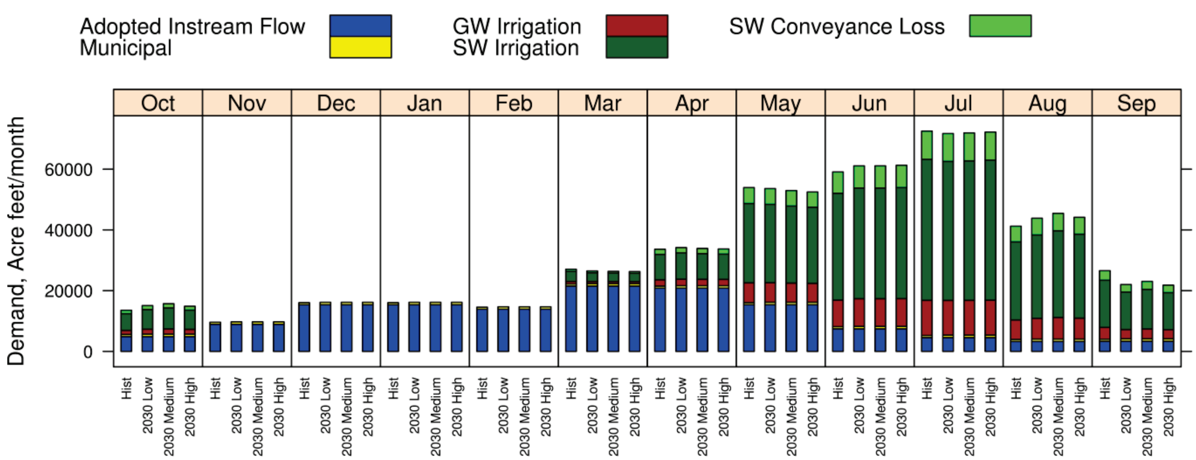


Figure 75. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.9.3 WRIA 32 Demand under Additional Water Capacity Scenarios

Figure 76 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

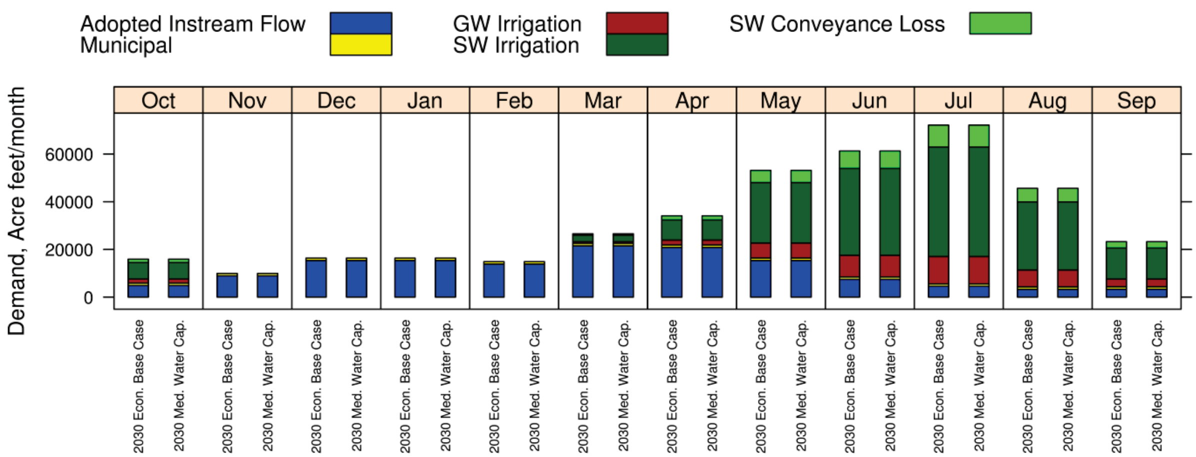


Figure 76. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.9.4 WRIA 32 Supply versus Demand Comparison

Figure 77 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

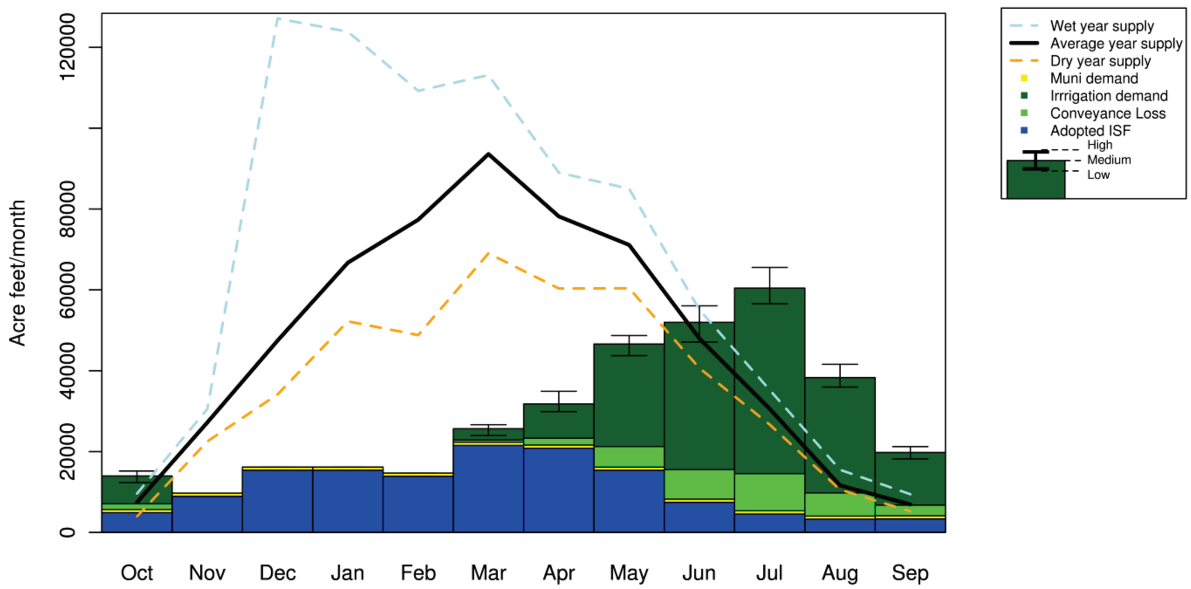


Figure 77. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.9.4.1 WRIA 32 Curtailment Analysis (for applicable WRIAs)

Modeling indicated that at the WRIA level there was insufficient water to serve all demands in every year between 1977 and 2006. The resulting unmet demand ranged from 19,589 to 64,692 ac-ft per year depending on yearly flow conditions, with an average of 44,257 ac-ft per year. Simulation of future insufficient water occurred in all the years for the middle climate scenario. The resulting unmet demand per year ranged from 19,679 to 69,149 with an average of 44,601 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

Modeling also indicated that at the WRIA level there was insufficient water to meet the instream flow targets in every year between 1977 and 2006. The resulting unmet instream flow ranged from 24,419 to 113,798 with an average of 49,563 ac-ft per year. Simulation of future insufficient water occurred in all the years for the middle climate scenario. The resulting unmet flow per year ranged from 21,325 to 74,915 with an average of 46,106 ac-ft per year.

6.9.5 WRIA 32 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water (Figure 78). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

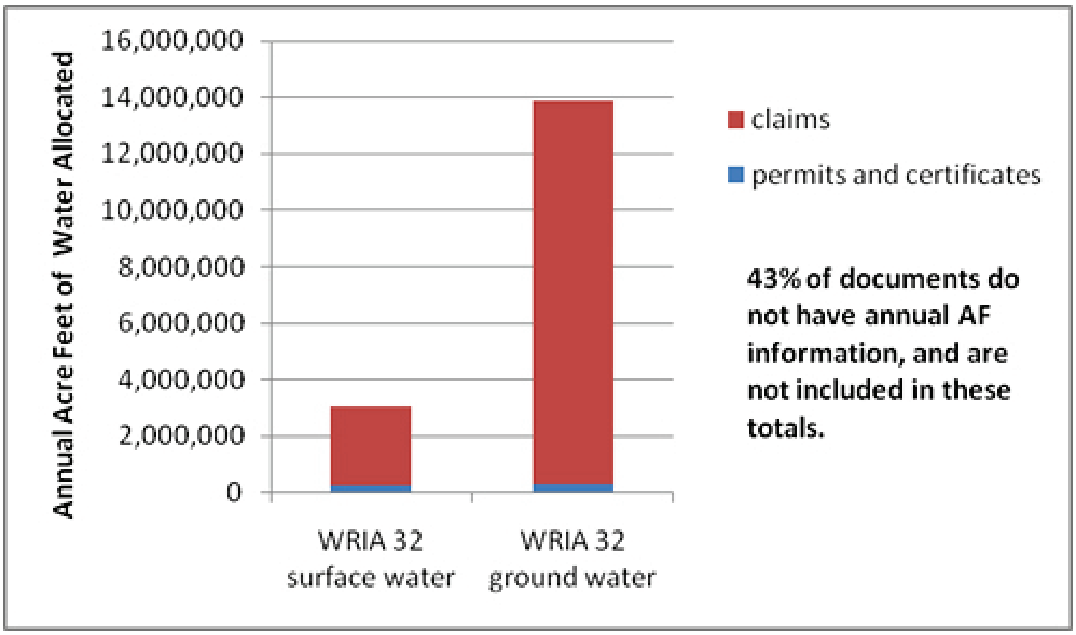


Figure 78. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.9.6 WRIA 32 Management Context

Some major management considerations for WRIA 32 are summarized in Table 36.

Table 36. Major management considerations for WRIA 32.

Management Context	
Adjudicated Areas	Touchet River
	Dry Creek
	Walla Walla River
	Stone Creek
	Doan Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-532 WAC)
Fish Listed Under the Endangered Species Act[1]	Middle Columbia Steelhead,
	Snake River Basin Steelhead,
	Touchet/Walla Walla (Oregon Recovery Unit) Bull Trout
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in WSU technical report)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.10 WRIA 33, Lower Snake

Supplies and demands are defined as described in Section 1.3 “Definitions of Water Supply and Water Demand Used in the 2011 Forecast.” The tributary surface water supply forecast for Lower Snake is characterized mostly by small increases in some years from late fall through mid-spring.

As in many other WRIAs in eastern Washington, irrigation demands dominate, and municipal demands are much smaller. Assuming no change in irrigated acreage, irrigation demands are projected to increase somewhat in most months of future irrigation seasons, with some variation in the magnitude of the increase depending on the economic scenario being considered. Municipal demands are expected to grow 16% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River “medium” scenario is not anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply would be insufficient to meet combined municipal and surface water irrigation demands at the watershed scale on its own during most years for May through October, and in some years in April. Additional water supply is available to some areas from the Columbia Basin Project. Other areas receive Snake River water supplies. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Fish listed under the Endangered Species Act that spawn or rear in tributary waters of this watershed include Snake River Basin Steelhead, Snake River Fall Run Chinook, and Snake River Spring and Summer Run Chinook.

6.10.1 WRIA 33 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 79 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

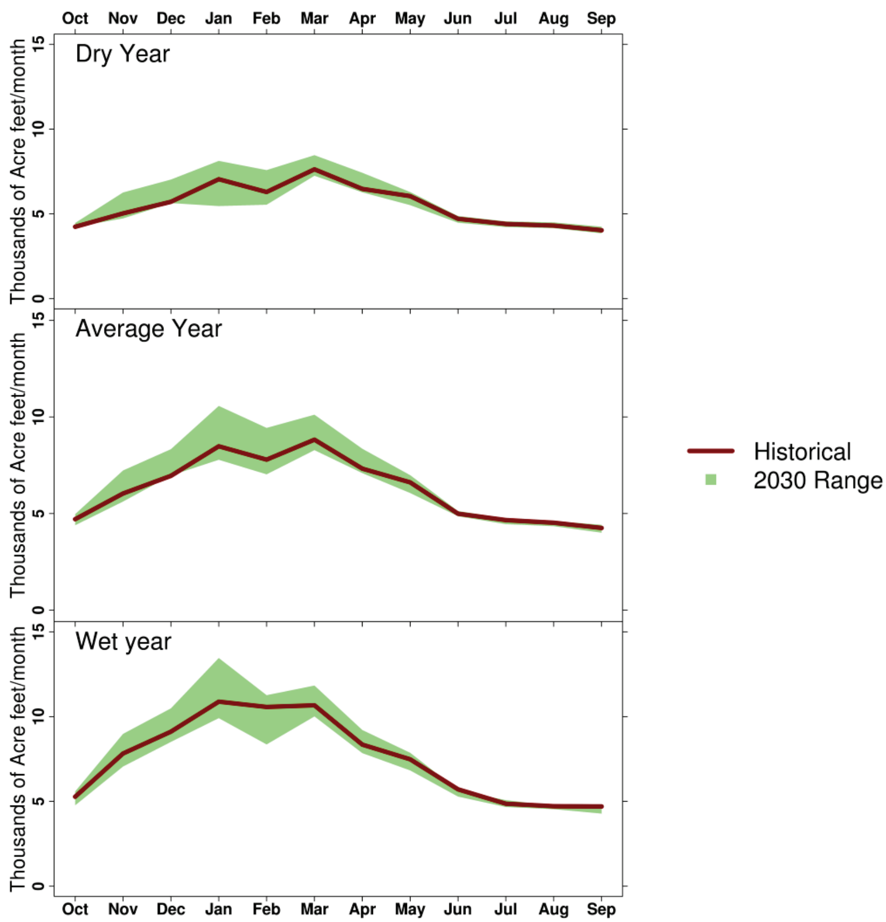


Figure 79. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.10.2 WRIA 33 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 80. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

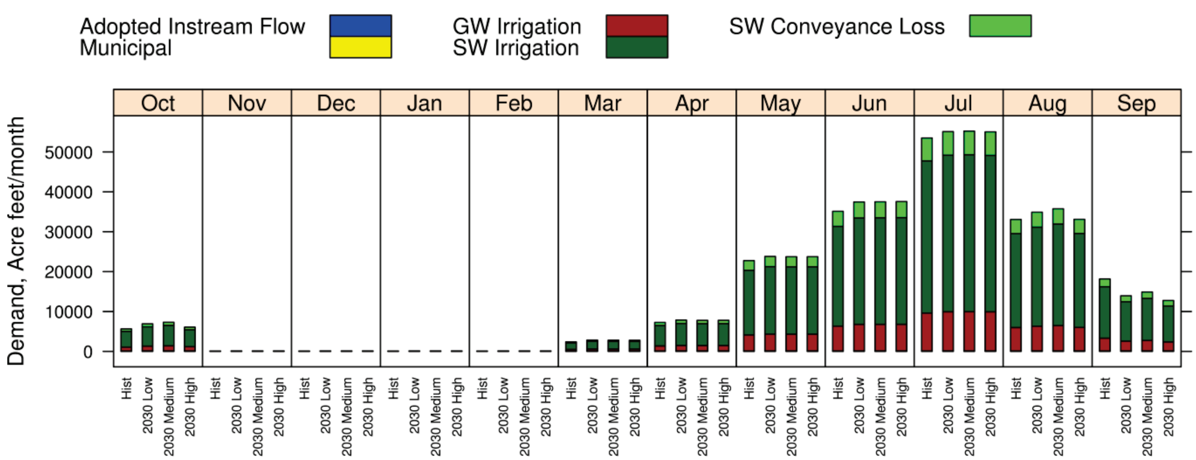


Figure 80. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.10.3 WRIA 33 Demand under Additional Water Capacity Scenarios

Figure 81 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

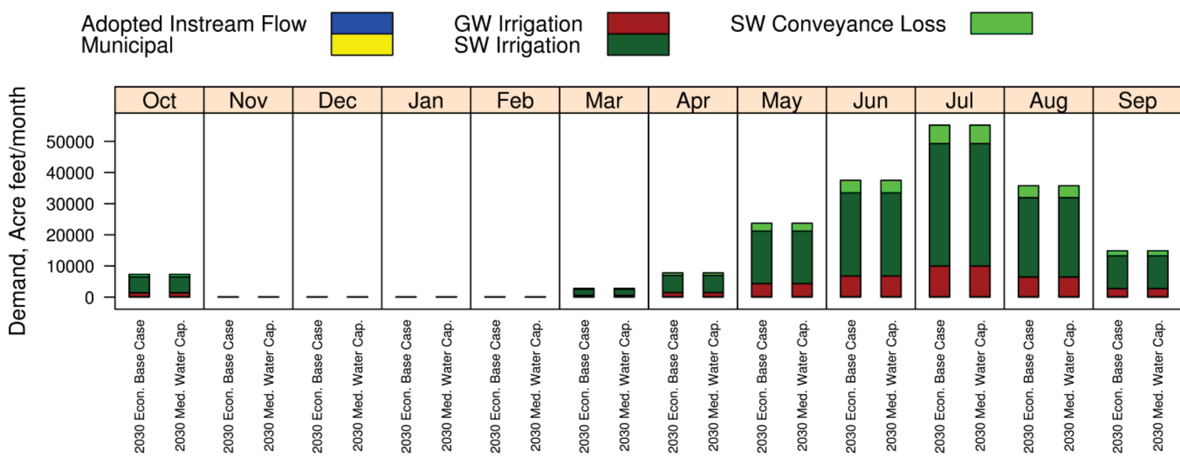


Figure 81. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.10.4 WRIA 33 Supply versus Demand Comparison

Figure 82 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

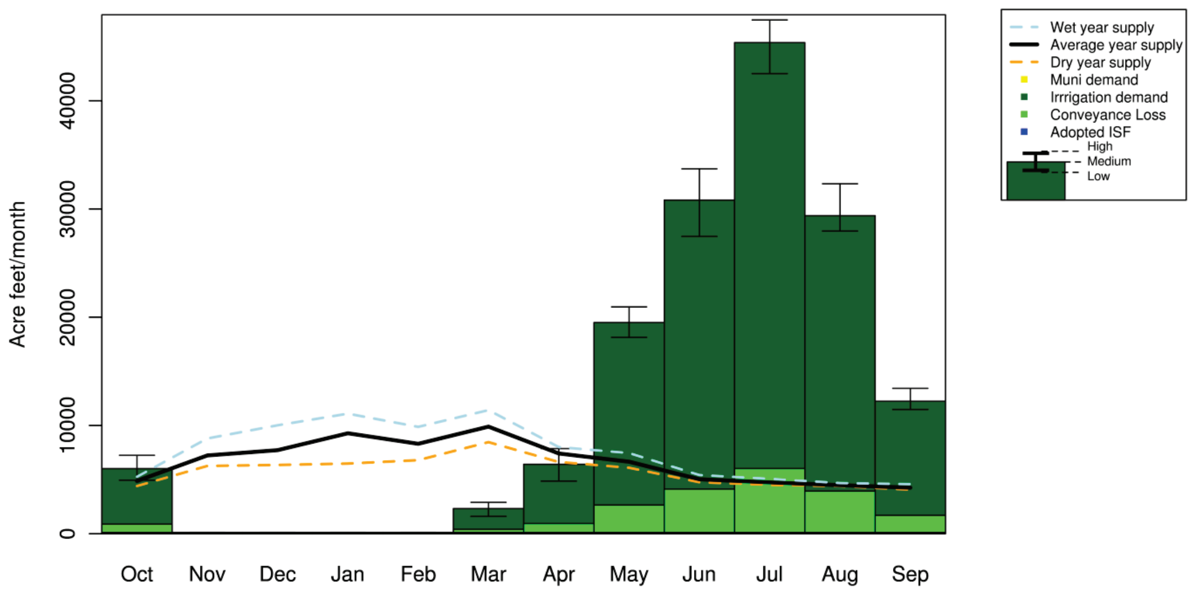


Figure 82. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.10.4.1 WRIA 33 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.10.5 WRIA 33 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 83). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

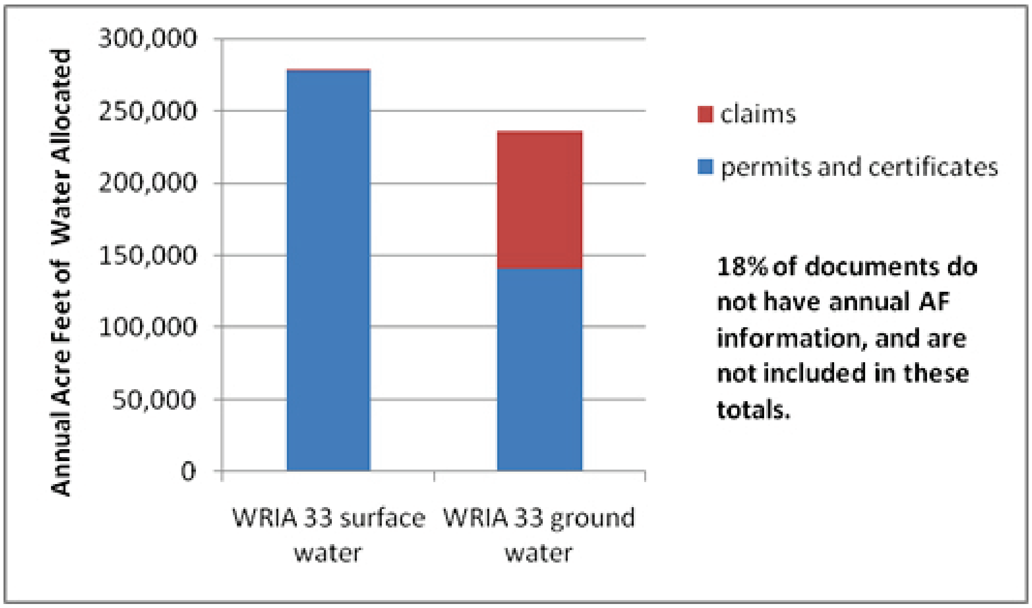


Figure 83. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.10.6 WRIA 33 Management Context

Some major management considerations for WRIA 33 are summarized in Table 37.

Table 37. Major management considerations for WRIA 33.

Management Context	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Snake River Basin Steelhead
	Snake River Fall Run Chinook
	Snake River Spring and Summer Run Chinook
	[Snake mainstem migratory corridor for Snake River sockeye]
Groundwater Management Area	YES (Franklin Co. portions are part of Columbia Basin GWMA)
Groundwater Studies	No WRIA level studies found (but see Appendix H for references on Columbia Basin Groundwater Management Area and Columbia Plateau Regional Aquifer System)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.11 WRIA 34, Palouse

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Palouse is characterized mostly by substantial increases in the winter.

Irrigation is the primary demand in WRIA 34, though municipal demands are also sizeable. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in most months of the irrigation season, with little impact on results from the consideration of alternate future economic scenarios. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2030 from groundwater to surface water. Municipal demands are projected to increase 5% by 2030, a smaller increase than in most other watersheds in eastern Washington.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, combined municipal and surface water irrigation demands at the watershed scale are projected to outstrip unregulated tributary supply generated within the Washington portion of the watershed during some years in July and October, and during most years for August and September. Upstream portions of the watershed outside of Washington provide some additional supplies, but may also have additional demands. Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand in 2030 under the baseline scenario, ranging from 5,503 to 6,675 with an average of 6,121 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of the Palouse watershed, but the Snake River in this area is the migratory corridor for a number of fish listed under the Endangered Species Act.

6.11.1 WRIA 34 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 84 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

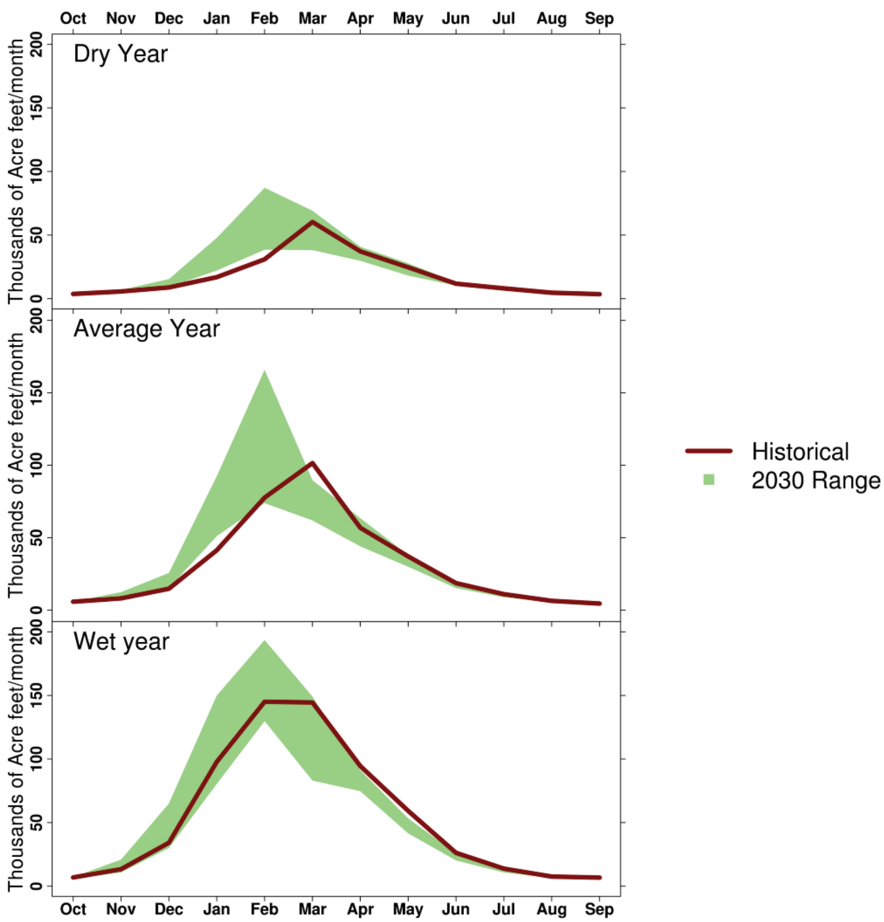


Figure 84. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.11.2 WRIA 34 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 85. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

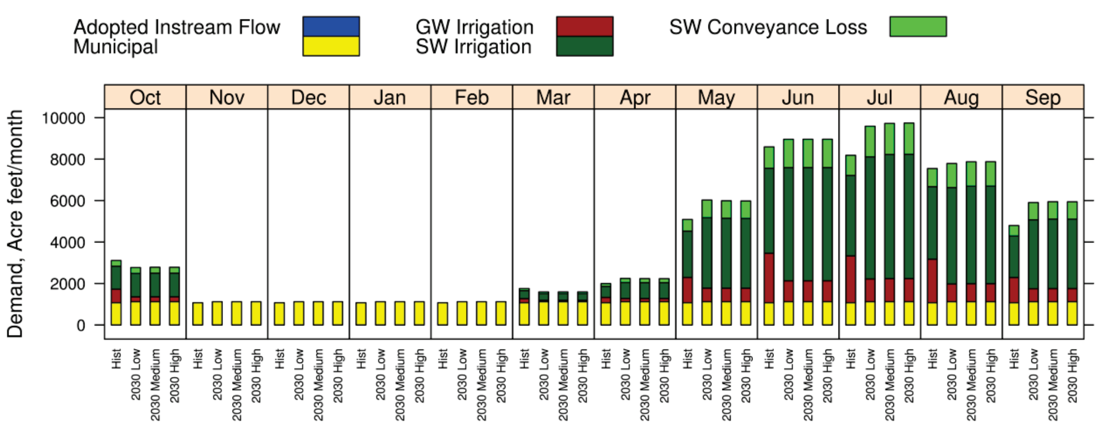


Figure 85. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.11.3 WRIA 34 Demand under Additional Water Capacity Scenarios

Figure 86 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

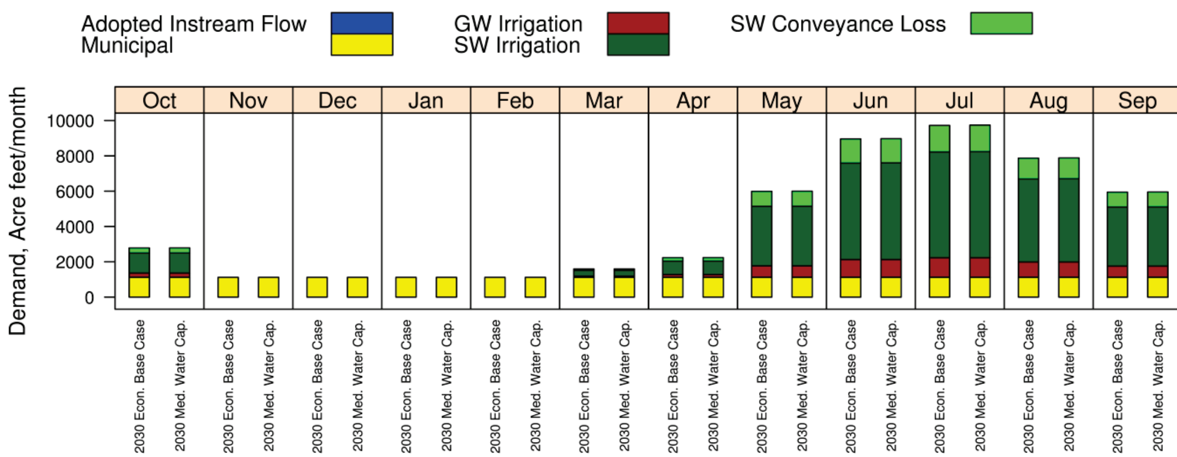


Figure 86. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.11.4 WRIA 34 Supply versus Demand Comparison

Figure 87 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

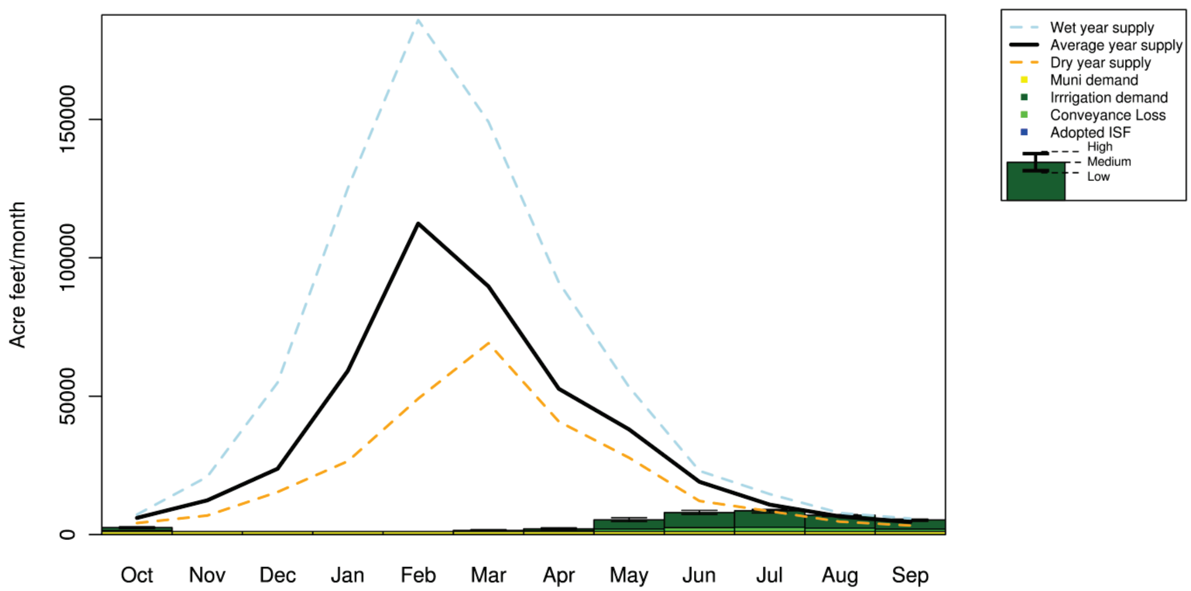


Figure 87. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.11.4.1 WRIA 34 Curtailment Analysis (for applicable WRIAs)

Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand in 2030 under the baseline scenario, ranging from 5,503 to 6,675 with an average of 6,121 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.11.5 WRIA 34 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 88). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

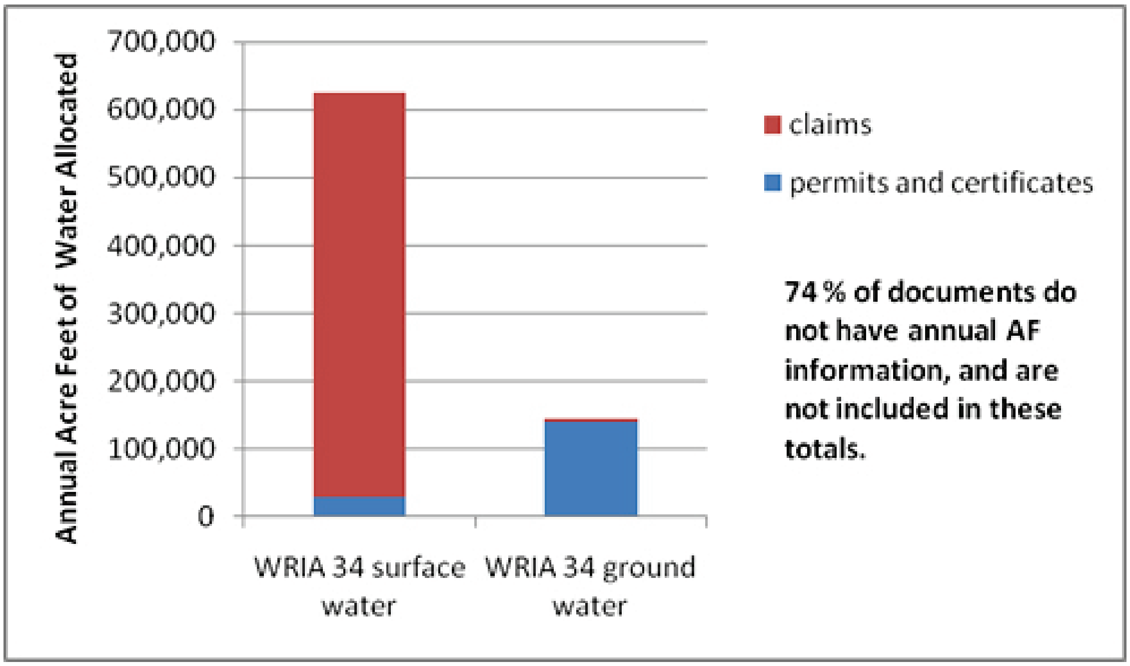


Figure 88. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.11.6 WRIA 34 Management Context

Some major management considerations for WRIA 34 are summarized in Table 38.

Table 38. Major management considerations for WRIA 34.

Management Context	
Adjudicated Areas	Cow Creek & Sprague Lake
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Snake mainstem migratory corridor for Snake River Basin Steelhead, Snake River Fall Run Chinook, Snake River Spring and Summer Run Chinook and Snake River sockeye]
Groundwater Management Area	YES (Lincoln and Adams Co. portions are part of Columbia Basin GWMA, and a portion of this is in Odessa Subarea)
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.12 WRIA 35, Middle Snake

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Middle Snake is characterized mostly by increases from late fall through early spring.

Overall demands are relatively modest compared to other watersheds in eastern Washington, with municipal demands that are generally larger than irrigation demands. Assuming no change in irrigated acreage, irrigation demand is expected to increase slightly in many months but decrease in others in the future, with little impact on results from the consideration of alternate future economic scenarios. Municipal demands are projected to increase 13% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is not anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply within the Washington portion of the watershed is forecasted to be sufficient to meet combined municipal and surface water irrigation demands and adopted instream flows at the watershed scale, and additional water supply is available in this watershed from the Snake River. Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

All wild salmon, steelhead, and bull trout stocks using the Middle Snake basin are listed as Threatened under the ESA, with the exception that sockeye are ESA-Endangered. Peak spawning of one species or another occurs from September through June. Anadromous juveniles are primarily out-migrating from March through June.

6.12.1 WRIA 35 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 89 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

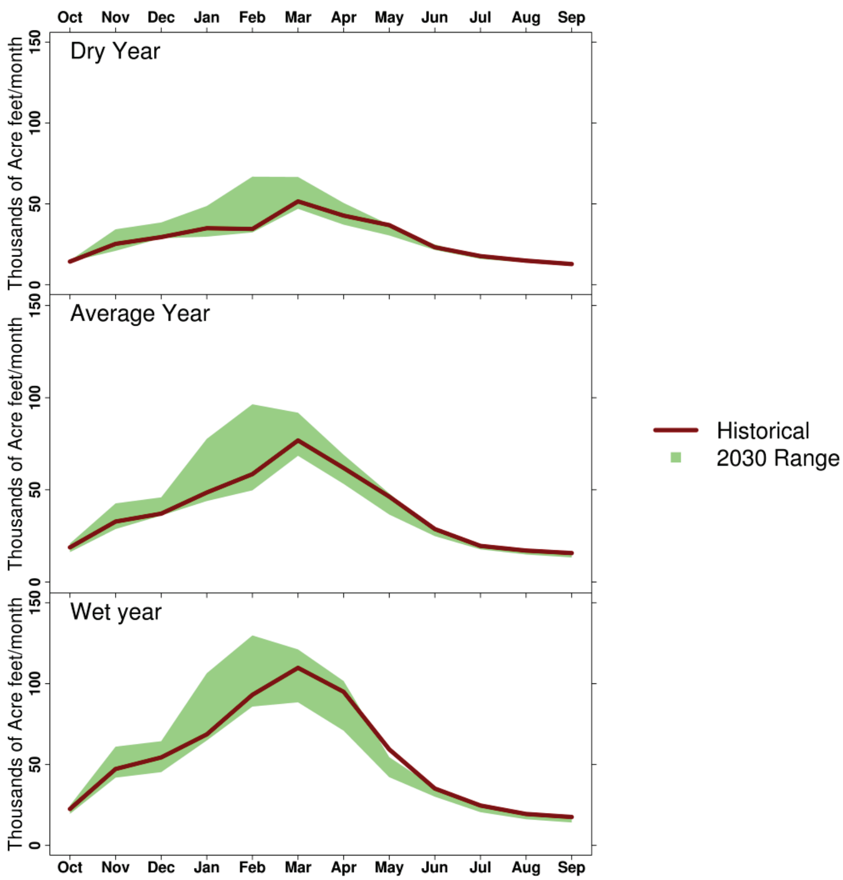


Figure 89. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.12.2 WRIA 35 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 90. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

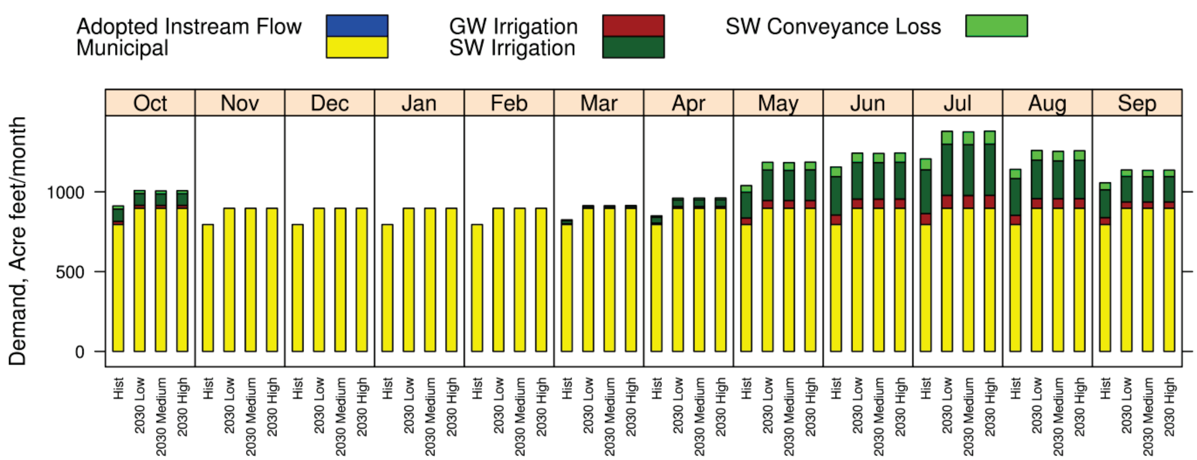


Figure 90. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.12.3 WRIA 35 Demand under Additional Water Capacity Scenarios

Figure 91 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as “2030 Medium” in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

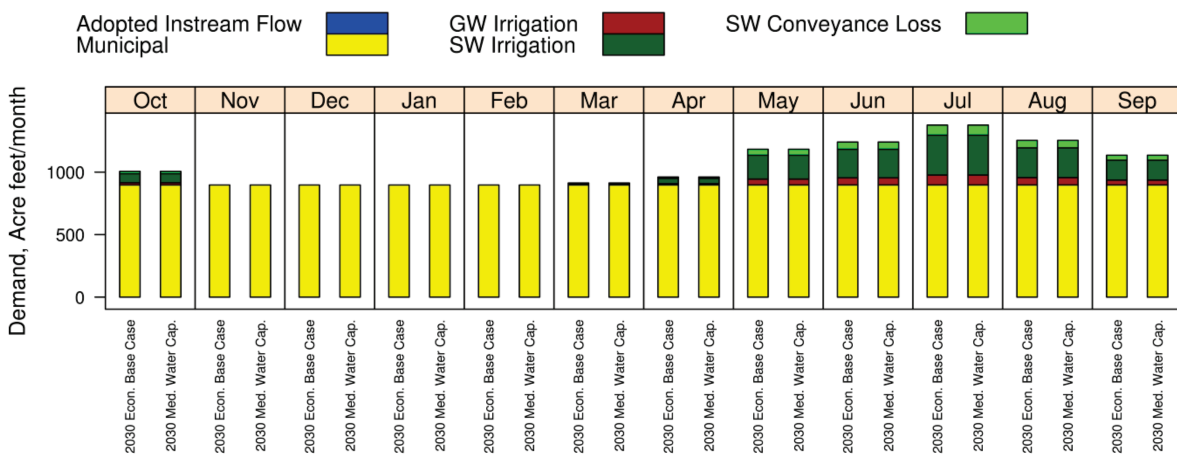


Figure 91. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.12.4 WRIA 35 Supply versus Demand Comparison

Figure 92 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

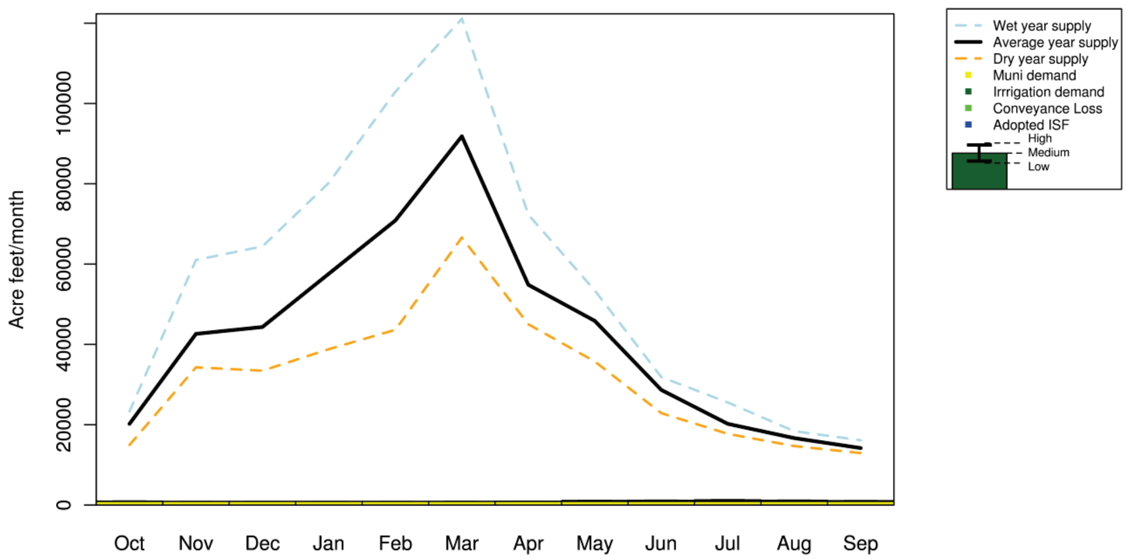


Figure 92. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.12.4.1 WRIA 35 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.12.5 WRIA 35 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 93). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

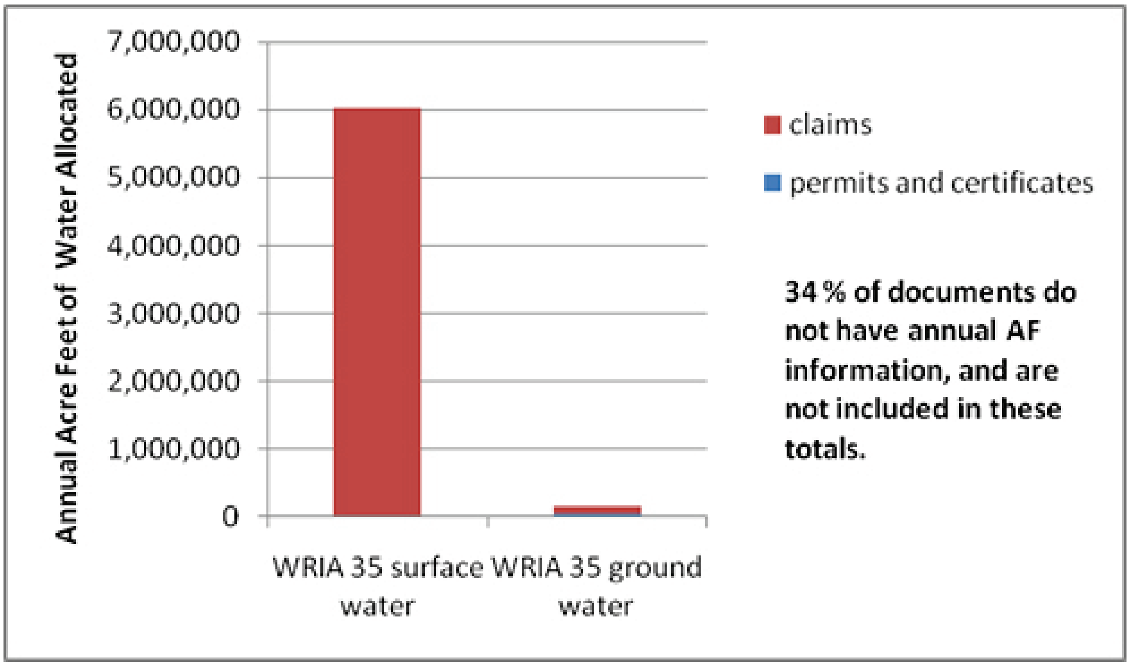


Figure 93. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.12.6 WRIA 35 Management Context

Some major management considerations for WRIA 35 are summarized in Table 39.

Table 39. Major management considerations for WRIA 35.

Management Context	
Adjudicated Areas	Deadman Creek
	Wawawai Creek
	Meadow Gulch Creek
	Alpowa Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Snake River Basin Steelhead
	Snake River Bull Trout
	Snake River Fall Run Chinook
	Snake River Spring and Summer Run Chinook
	[Snake mainstem migratory corridor for Snake River sockeye]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.13 WRIA 36, Esquatzel Coulee

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Esquatzel Coulee shows little change, with possible slight increases from mid-fall through mid-spring.

Irrigation is the most significant source of demand in WRIA 36. Municipal demands are quite small in comparison, though larger than those of many other eastern Washington WRIAs. Assuming no change in irrigated acreage, irrigation demand is expected to increase in many future months, but decrease in others. The magnitude of the increase in future demand varies by a small amount when alternate future economic scenarios are considered. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2030 from groundwater to surface water. Municipal demands are projected to grow 62% by 2030, though this may be impacted by forecast growth associated with the Quad Cities.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply would be insufficient on its own to meet combined municipal and surface water irrigation demands at the watershed scale during the irrigation season for most years, but a significant portion of demand in this WRIA is met by water supply from the Columbia River, including from the Columbia Basin Project. A separate analysis indicates that roughly one sixth of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand in 2030 under the baseline scenario, ranging from 60,581 to 70,687 with an average of 66,047 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed, but the Columbia River mainstem in this area is a migratory corridor for ESA-listed fish.

6.13.1 WRIA 36 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 94 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

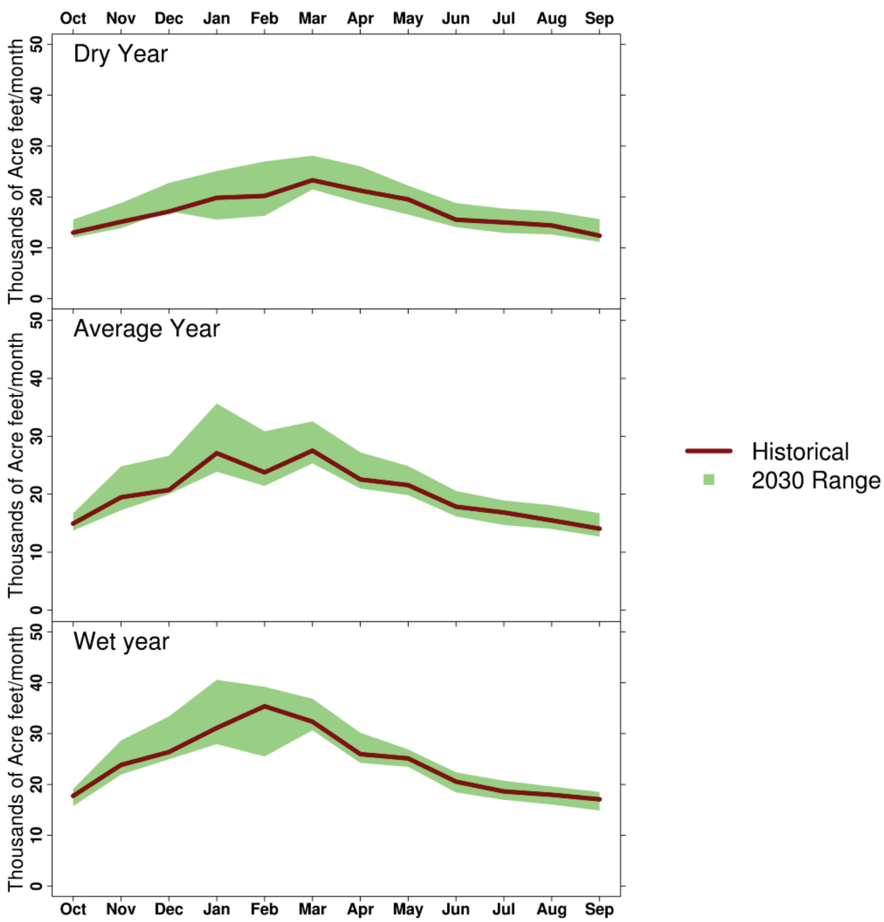


Figure 94. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.13.2 WRIA 36 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 95. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

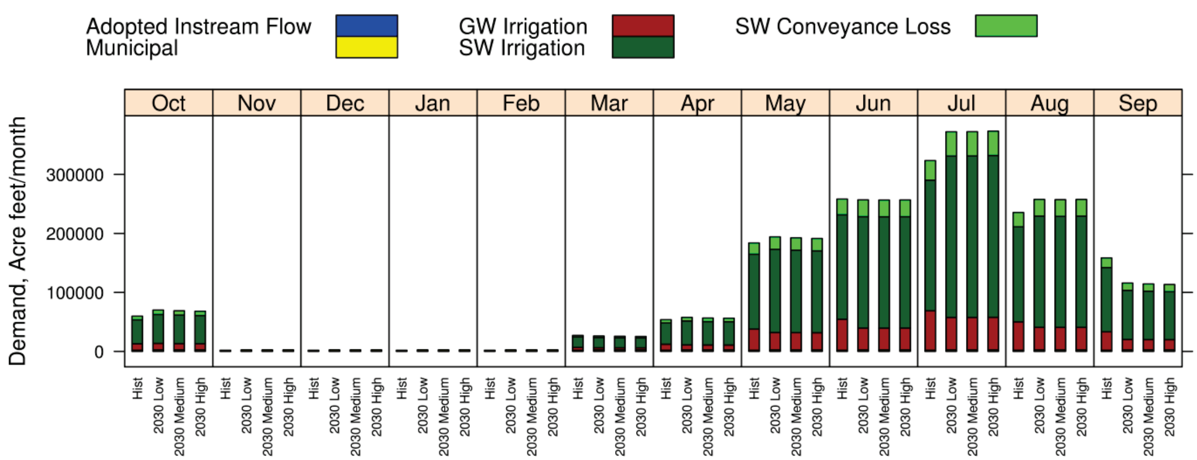


Figure 95. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.13.3 WRIA 36 Demand under Additional Water Capacity Scenarios

Figure 96 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

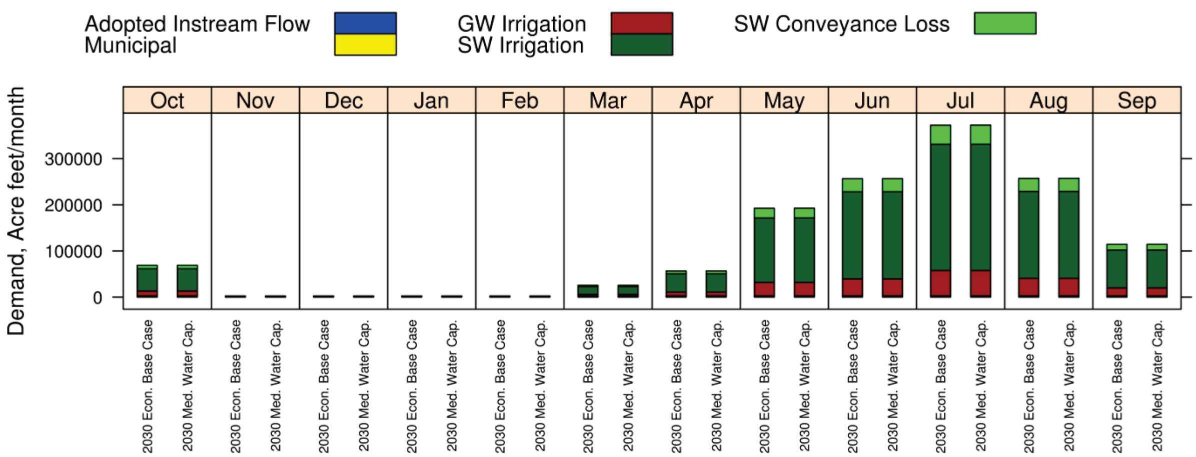


Figure 96. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.13.4 WRIA 36 Supply versus Demand Comparison

Figure 97 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

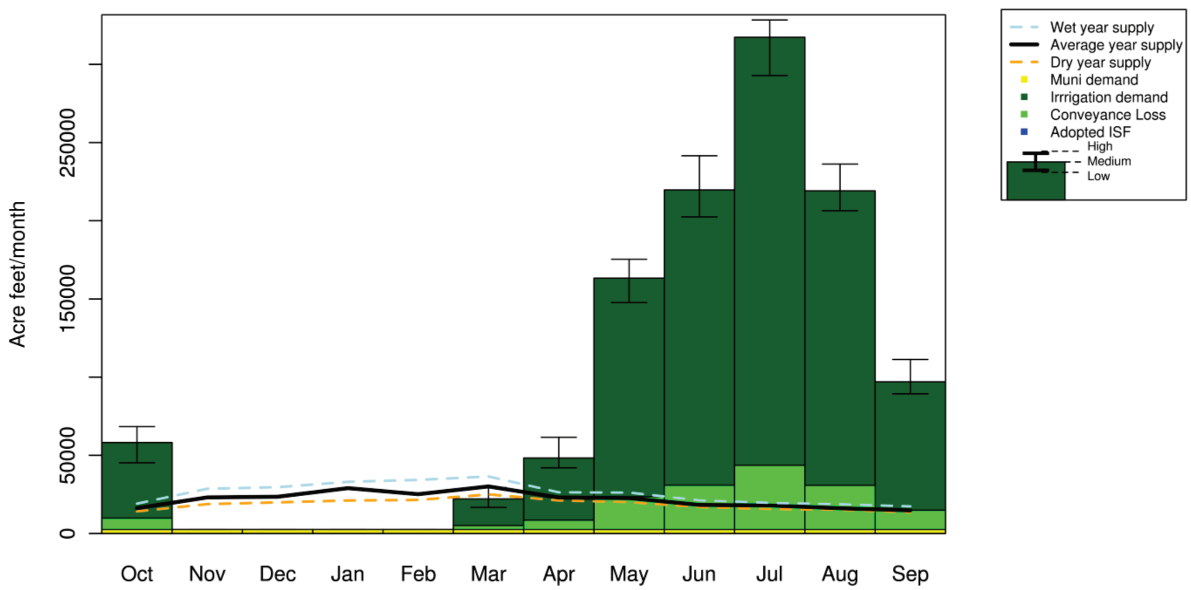


Figure 97. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.13.4.1 WRIA 36 Curtailment Analysis (for applicable WRIAs)

Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand in 2030 under the baseline scenario, ranging from 60,581 to 70,687 with an average of 66,047 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.13.5 WRIA 36 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 98). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

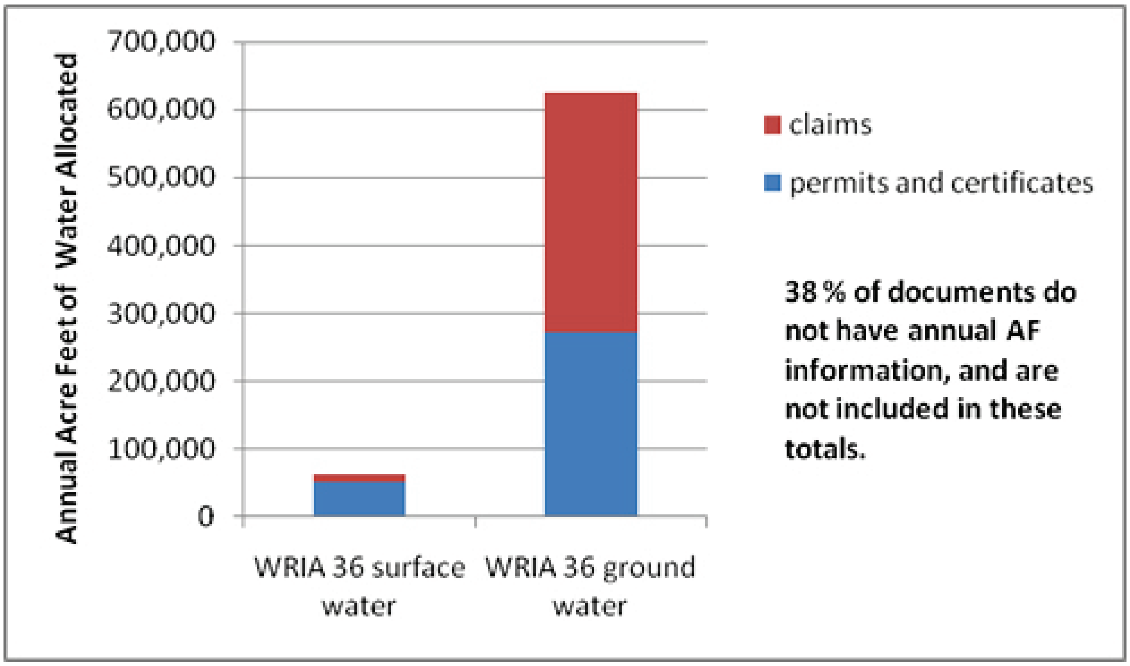


Figure 98. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.13.6 WRIA 36 Management Context

Some major management considerations for WRIA 36 are summarized in Table 40.

Table 40. Major management considerations for WRIA 36.

Management Context	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Columbia mainstem migratory corridor]
Groundwater Management Area	YES (Columbia Basin GWMA and Odessa Subarea)
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.14 WRIAs 37, 38, 39 Lower Yakima, Naches, Upper Yakima

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The regulated tributary surface water supply forecast for the Yakima is characterized by increases from late fall through early spring. Decreases are notable in the late spring and early summer under all flow conditions, continuing through the summer into mid-fall under average and wet flow conditions.

Irrigation is the primary source of demand in these WRIAs. Federal flow targets, shown for Yakima River at Parker for both the historical and the future case, are also important. While small in comparison with irrigation demands, municipal demands are significantly larger than most other WRIAs of eastern Washington. Assuming no change in irrigated acreage, irrigation demand is forecasted to increase in most months in the future, with small variations in the magnitude of this future increase when alternate future economic scenarios are considered. Municipal demand is projected to grow by 23% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, combined municipal and surface water irrigation demands and federal instream flow targets are projected to outstrip regulated tributary supply at the watershed scale during most years for June through October. Modeling of curtailment of pro-ratable irrigation water rights indicated that it occurred in 45% of years between 1977 and 2005. The resulting unmet demand ranged from 7200 to 278,600 ac-ft per year depending on yearly flow conditions, with an average of 108,000 ac-ft per year. Simulation of future curtailment suggested that it will occur in 90% of years for the middle climate scenario. The resulting unmet demand ranged from 14,300 to 434,000 with an average of 154,000 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet federal flow targets are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Yakima summer steelhead stocks are part of the ESA-Threatened Mid-Columbia steelhead listing unit. Juveniles are rearing year-round and outmigrating primarily in April and May. Coho and sockeye are being re-introduced to the Yakima system. Bull trout in the Yakima basin are part of the Middle Columbia bull trout listing unit.

6.14.1 WRIAs 37, 38, 39 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 99 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

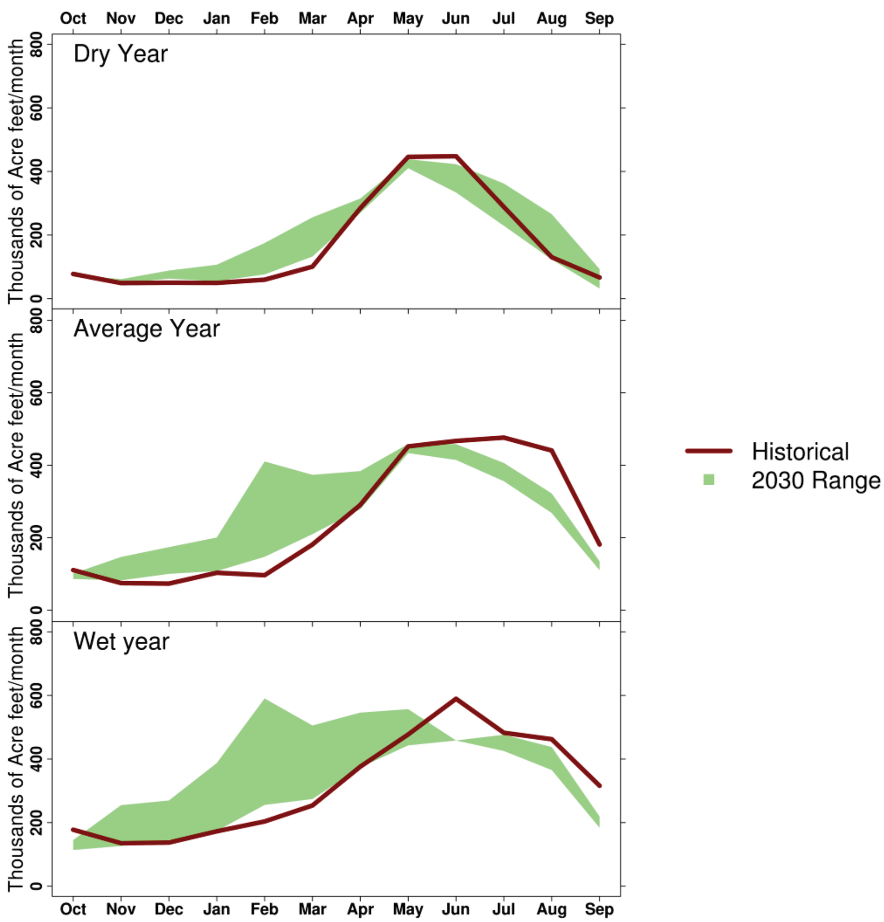


Figure 99. Modeled historical (1977-2006) and 2030 surface water supply generated within WRIAs 37, 38, and 39 (combinded) for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.14.2 WRIAs 37, 38, 39 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 65. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

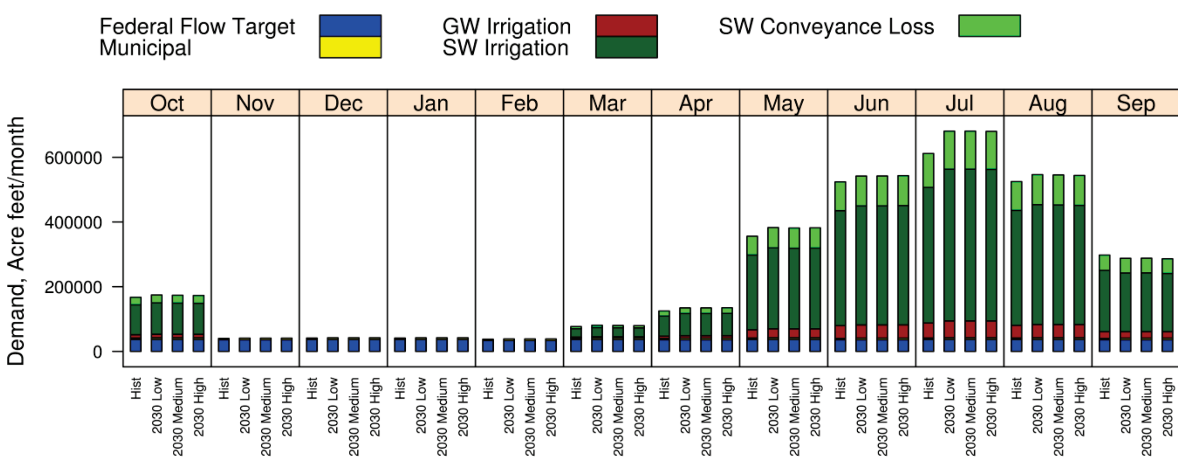


Figure 100. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.14.3 WRIAs 37, 38, 39 Demand under Additional Water Capacity Scenarios

Figure 101 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

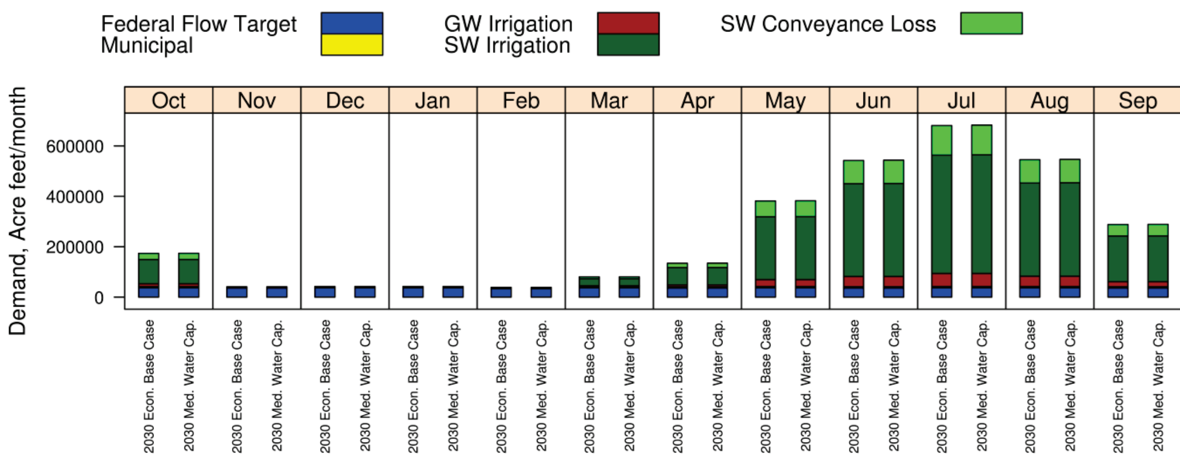


Figure 101. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.14.4 WRIAs 37, 38, 39 Supply versus Demand Comparison

Figure 102 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

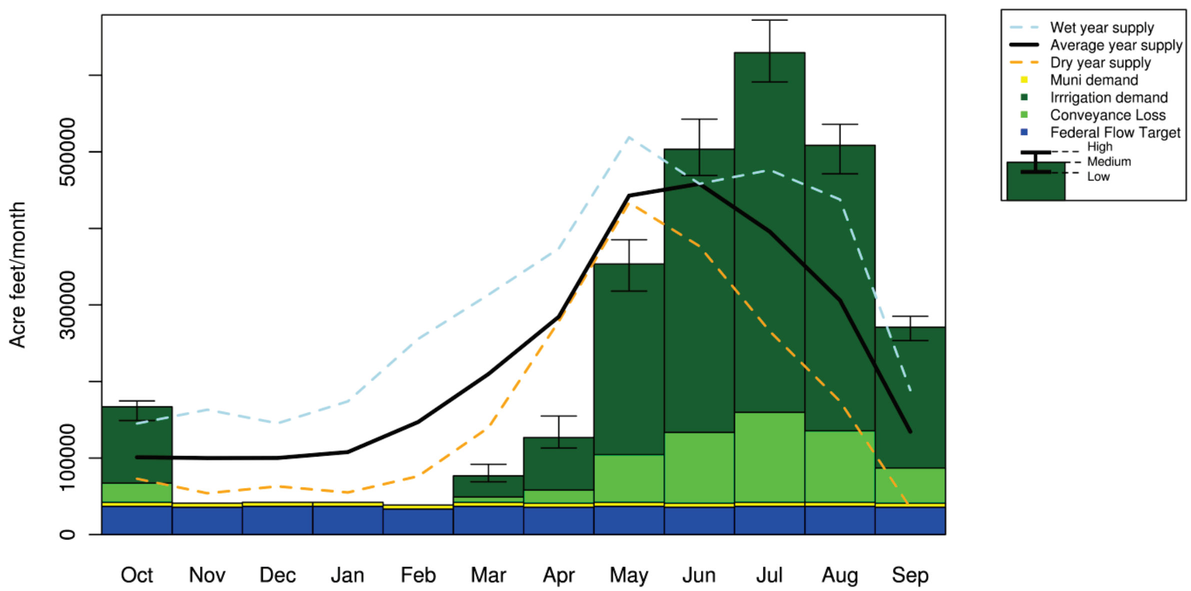


Figure 102. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.14.4.1 WRIAs 37, 38, 39 Curtailment Analysis (for applicable WRIAs)

Modeling of curtailment of pro-ratable irrigation water rights indicated that it occurred in 45% of years between 1977 and 2005. The resulting unmet demand ranged from 7200 to 278,600 ac-ft per year depending on yearly flow conditions, with an average of 108,000 ac-ft per year. Simulation of future curtailment suggested that it will occur in 90% of years for the middle climate scenario. The resulting unmet demand ranged from 14,300 to 434,000 with an average of 154,000 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet federal flow targets are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

6.14.5 WRIAs 37, 38, 39 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (

Figure 103). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

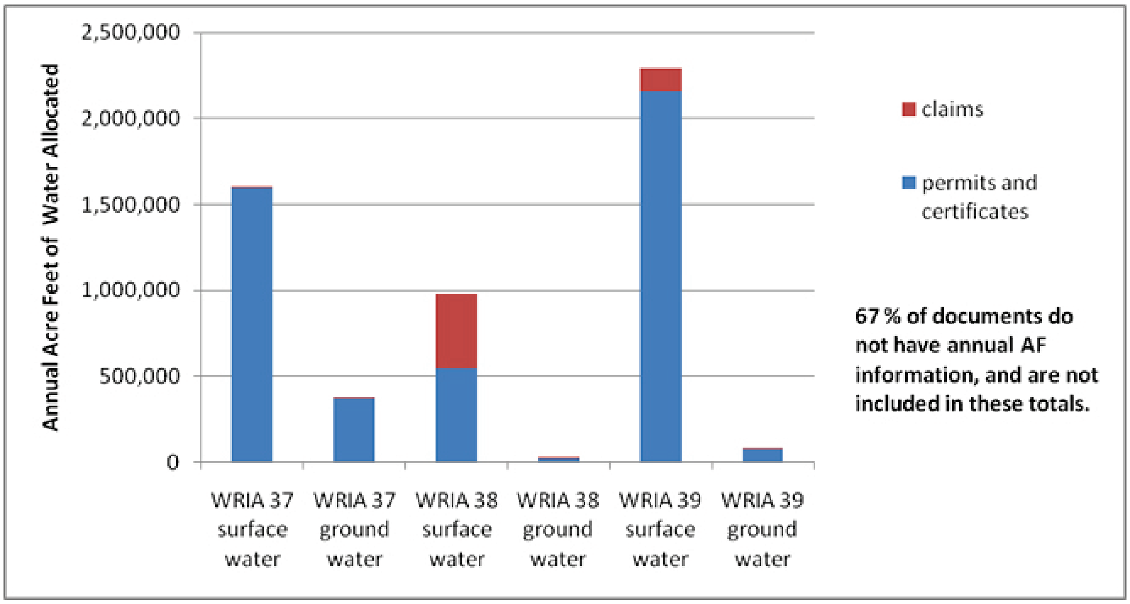


Figure 103. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.14.6 WRIAs 37, 38, 39 Management Context

Some major management considerations for WRIAs 37, 38, 39 are summarized in Table 41.

Table 41. Major management considerations for WRIAs 37, 38, and 39.

Management Context	
Adjudicated Areas	YES (basin-wide adjudication in process)
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Middle Columbia River Bull Trout
	Middle Columbia Steelhead
	[WRIA 37 is also Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.15 WRIA 40/40a, Alkali-Squilchuck and Stemilt Squilchuck

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Alkali-Squilchuck and Stemilt Squilchuck is characterized by small increases from late fall through winter.

Primary demands in WRIAs 40 and 40a are irrigation and municipal. Assuming no change in irrigated acreage, irrigation demand is forecasted to increase in some months and decrease in other months in the future, though the specific economic scenario being considered has more of an impact here than in other watersheds of eastern Washington. Municipal demands are expected to increase roughly 5%, a smaller increase than in many other WRIAs of eastern Washington. DOD lands contribute very little water demand or supply.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is projected to be sufficient to meet combined municipal and surface water irrigation demands at the watershed scale on its own in most months, except July under dry or average conditions. Additional water supply is available in some areas from the Columbia River, and a separate analysis indicates that most agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of WRIAs 40 and 40a, but the Columbia River mainstem in this area is a migratory corridor for ESA-listed fish.

6.15.1 WRIA 40/40a Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 104 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

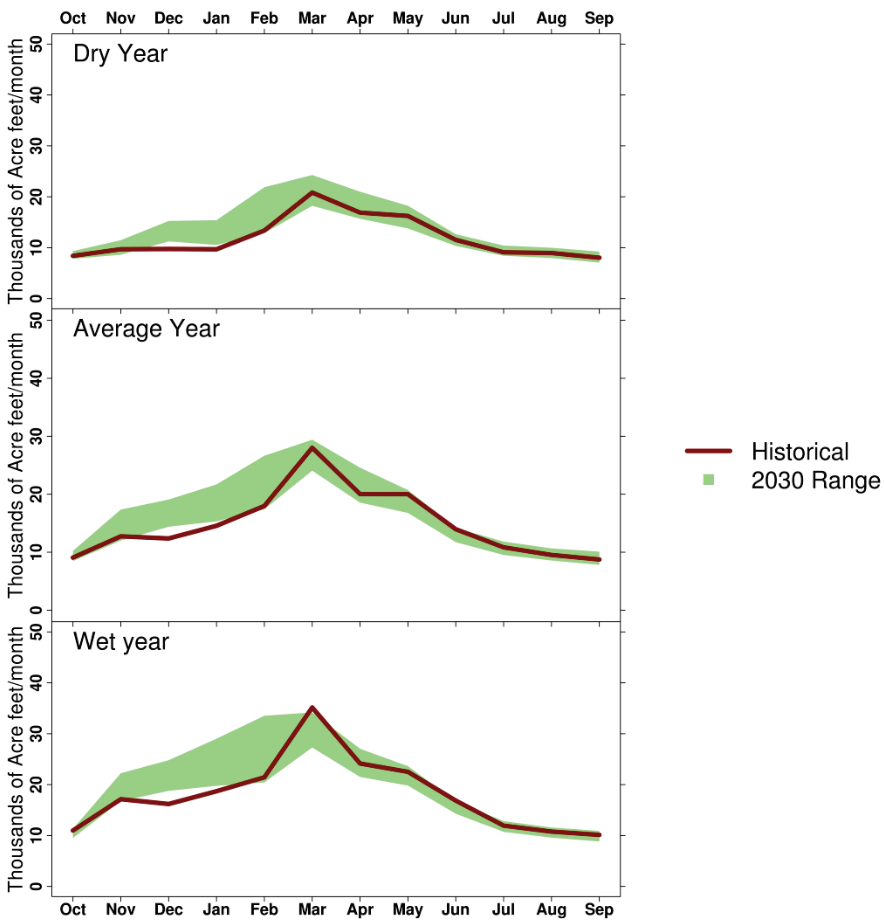


Figure 104. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.15.2 WRIA 40/40a Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 105. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

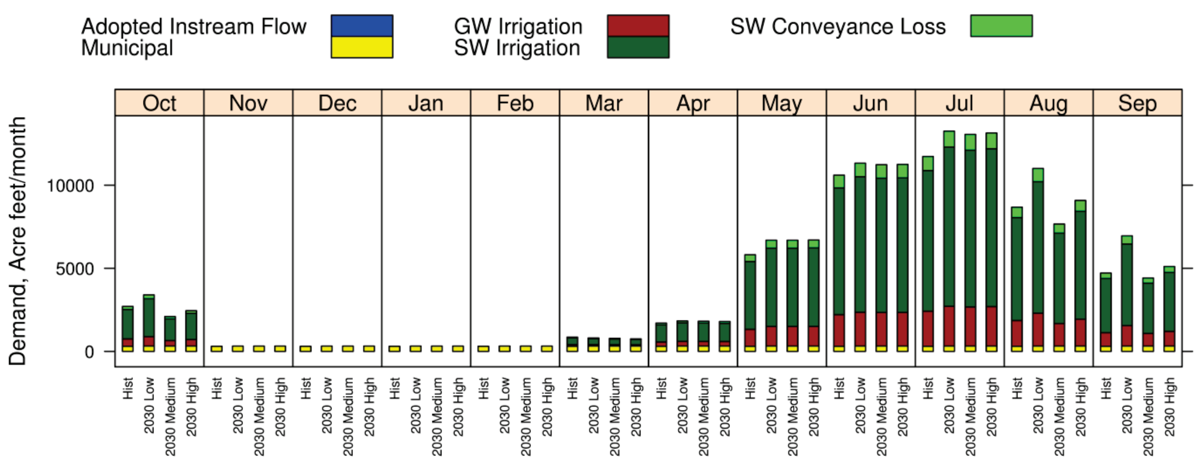


Figure 105. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.15.3 WRIA 40/40a Demand under Additional Water Capacity Scenarios

Figure 106 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

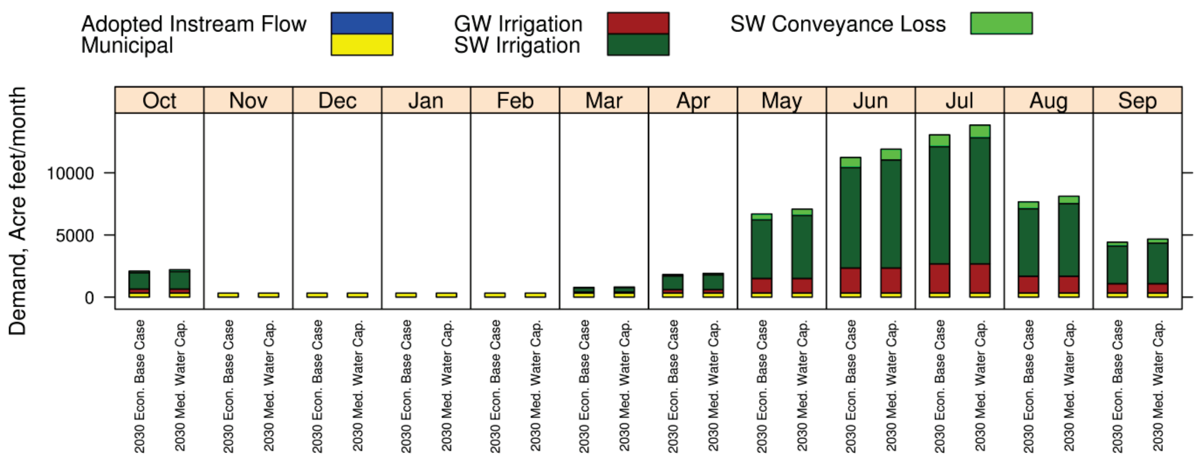


Figure 106. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.15.4 WRIA 40/40a Supply versus Demand Comparison

Figure 107 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

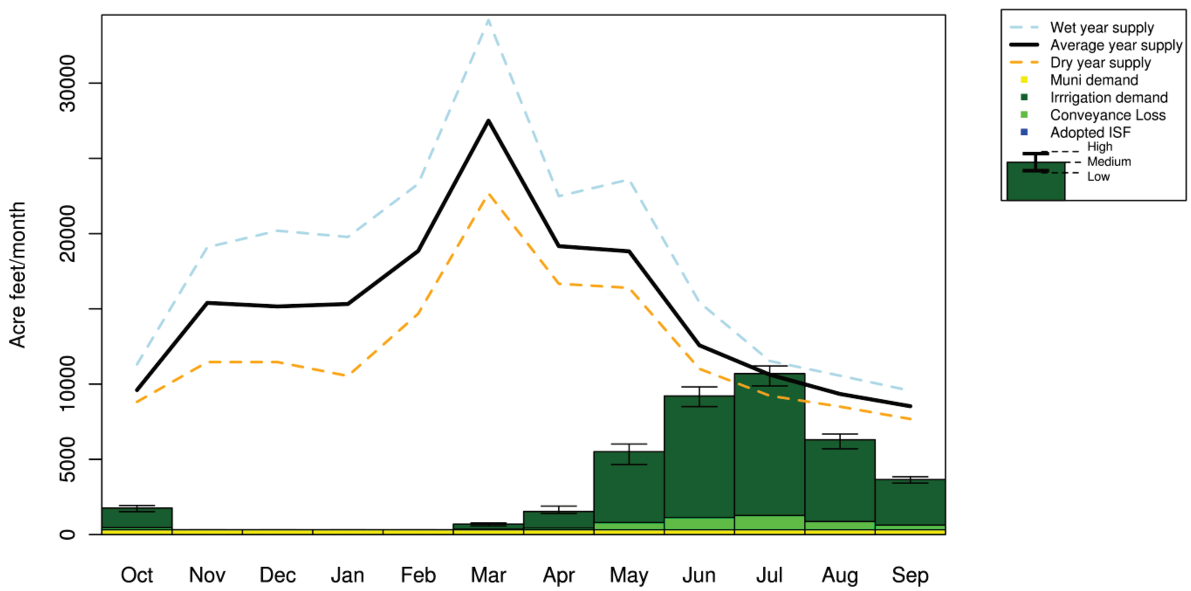


Figure 107. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.15.4.1 WRIA 40/40a Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.15.5 WRIA 40/40a Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (

Figure 108). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

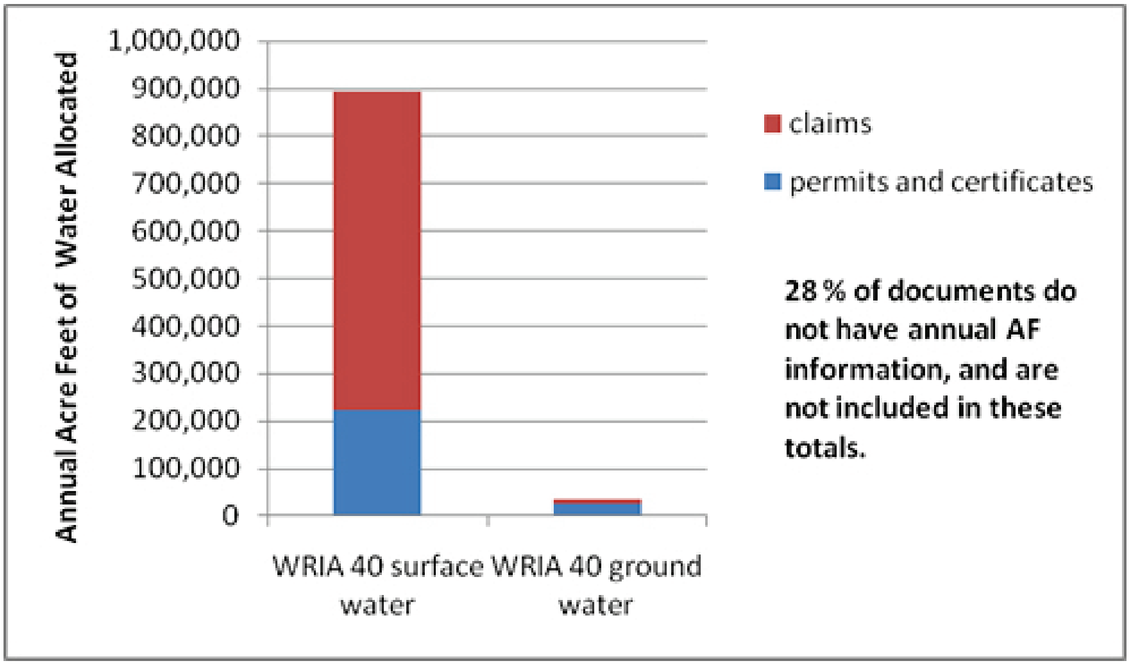


Figure 108. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.15.6 WRIA 40/40a Management Context

Some major management considerations for WRIA 40/40a are summarized in Table 42.

Table 42. Major management considerations for WRIA 40/40a

Management Context	
Adjudicated Areas	Stemilt Creek
	Squillchuck Creek
	Cummings Canyon Creek
Watershed Planning	WRIA 40a: Phase 4 (Implementation)
	WRIA 40: NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.16 WRIA 41, Lower Crab

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Lower Crab is characterized mostly by relatively little change in water supply, with a possible small increase in late fall and winter.

Irrigation is the primary source of demand in WRIA 41, with much smaller municipal demands. Assuming no change in irrigated acreage, irrigation demand is projected to increase in some months in the future, and decrease in others, with only slight variation when alternate future economic scenarios are considered. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2030 from groundwater to surface water. Municipal demands are projected to grow by 29% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supplies would be insufficient on their own to meet combined municipal and surface water irrigation demands at the watershed scale year-round for most years. However, additional water supply is available in many areas from the Columbia River, including from the Columbia Basin Project. A separate analysis indicates that about 5% of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand by 2030 under the baseline scenario. The resulting unmet demand per year ranged from 85,433 to 99,542 with an average of 92,038 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.16.1 WRIA 41 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 109 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

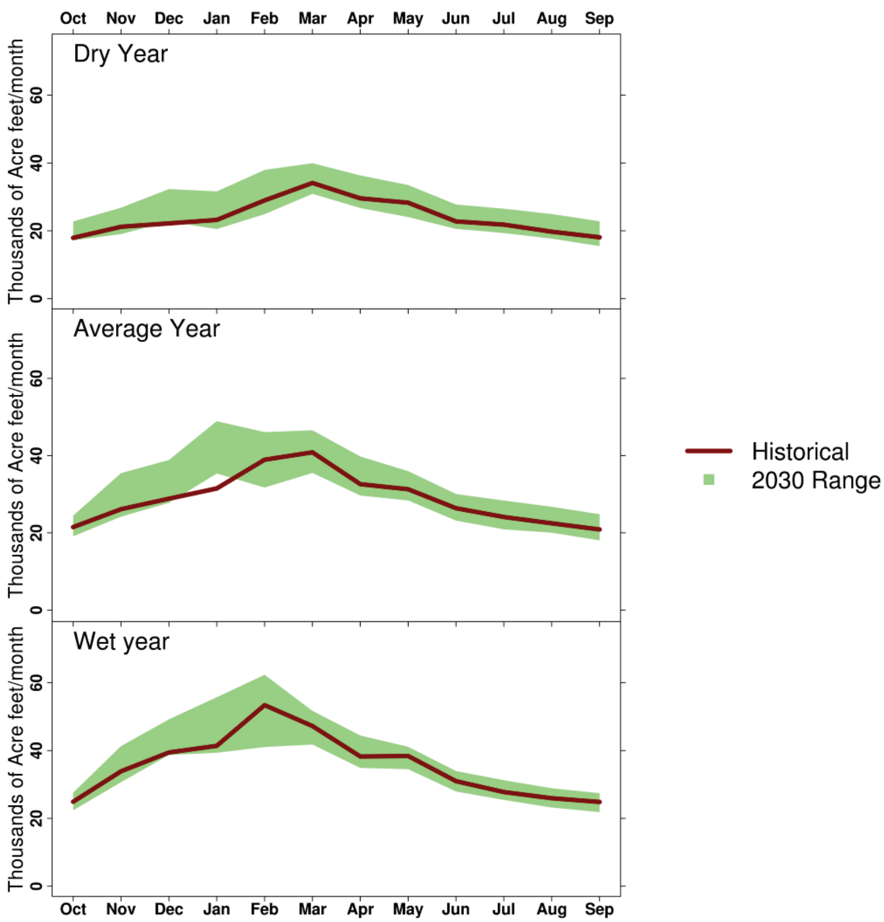


Figure 109. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.16.2 WRIA 41 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 110. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the “top of crop” and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

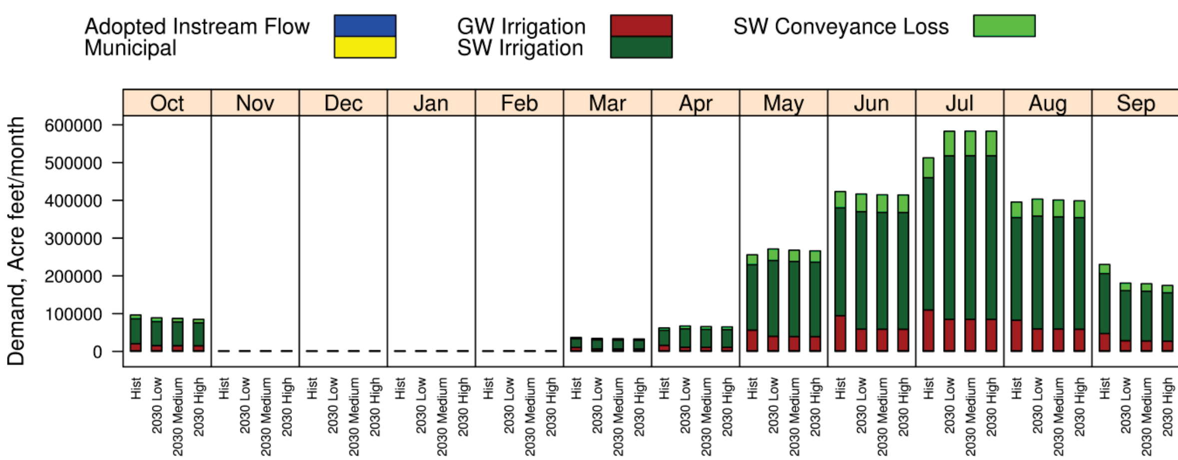


Figure 110. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.16.3 WRIA 41 Demand under Additional Water Capacity Scenarios

Figure 111 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as “2030 Medium” in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

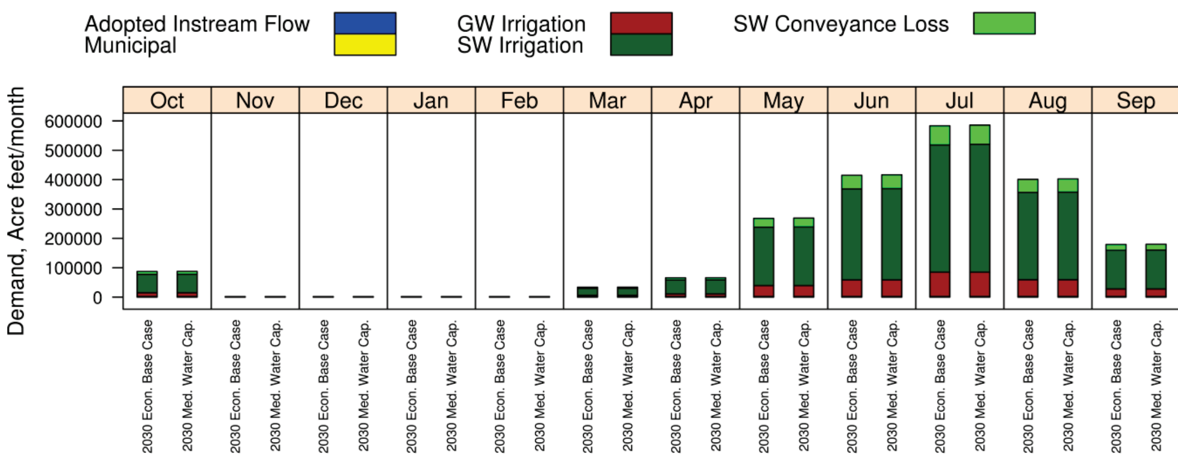


Figure 111. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.16.4 WRIA 41 Supply versus Demand Comparison

Figure 112 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

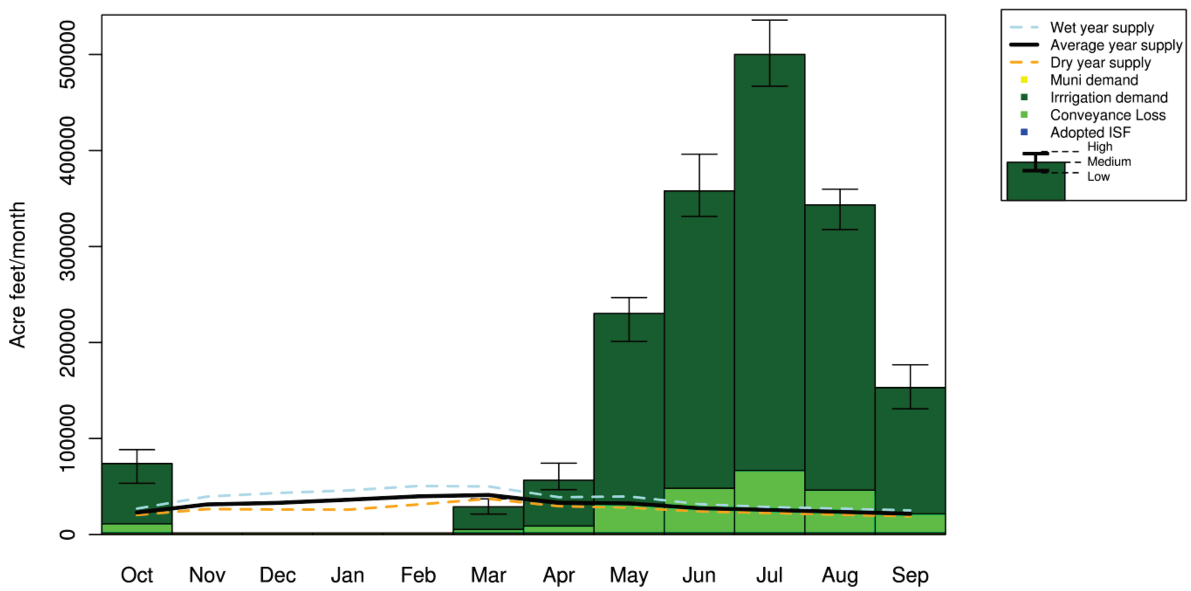


Figure 112. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.16.4.1 WRIA 41 Curtailment Analysis (for applicable WRIAs)

Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand by 2030 under the baseline scenario. The resulting unmet demand per year ranged from 85,433 to 99,542 with an average of 92,038 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.16.5 WRIA 41 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 113). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

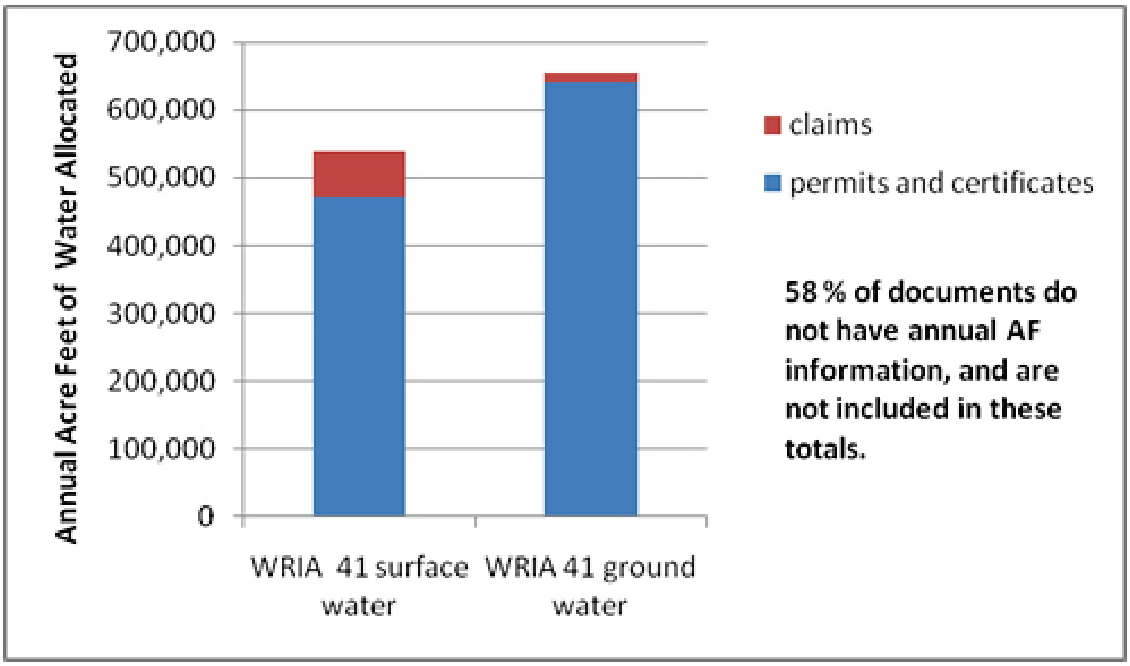


Figure 113. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.16.6 WRIA 41 Management Context

Some major management considerations for WRIA 31 are summarized in Table 43.

Table 43. Major management considerations for WRIA 41.

Management Context	
Adjudicated Areas	Crab Creek & Moses Lake
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	YES (Columbia Basin GWMA, Odessa Subarea, and Quincy Subarea)
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.17 WRIA 42, Grand Coulee

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Grand Coulee is characterized mostly by slight increases from late fall through early winter.

As in many other WRIAs of eastern Washington, municipal demands are much smaller than irrigation demands. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in some months in the future and decrease in others, with little variation in future demand when alternate future economic scenarios are considered. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2030 from groundwater to surface water. Municipal demand is projected to shrink by 5% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, combined municipal and surface water irrigation demands are forecasted to outstrip unregulated tributary supply at the watershed scale from May through September in almost all years. However, additional water supply is available to some areas from the Columbia Basin Project. Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand by 2030 under the baseline scenario. The resulting unmet demand per year ranged from 3,393 to 4,219 with an average of 3,896 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.17.1 WRIA 42 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 114 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

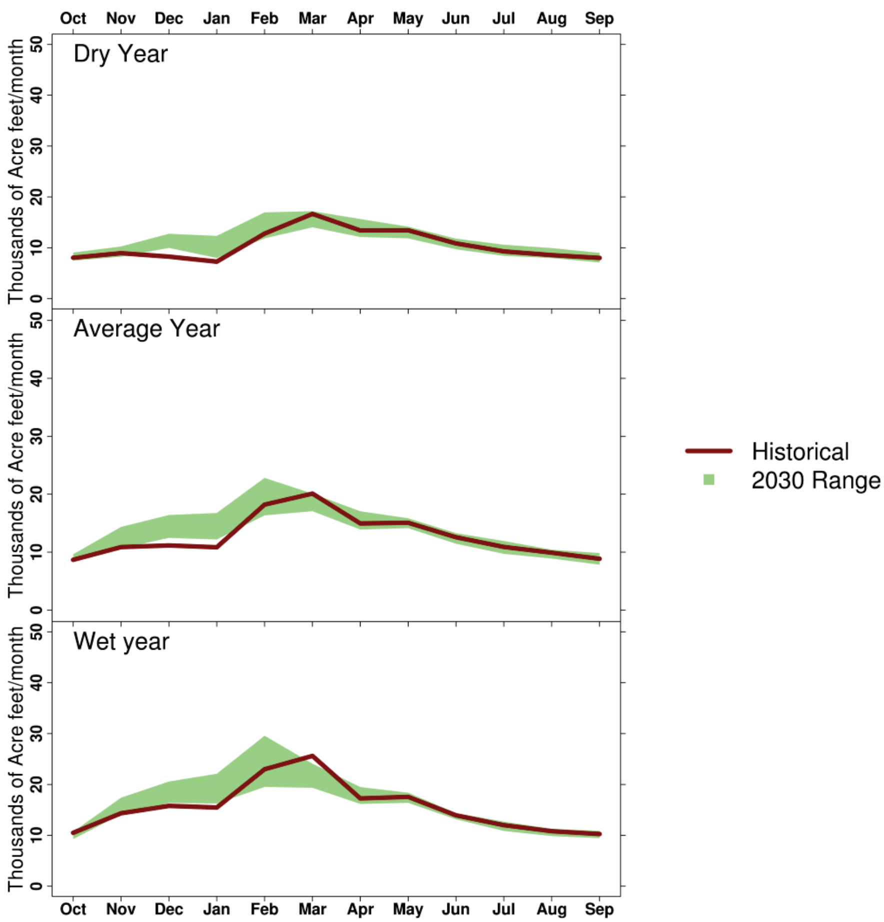


Figure 114. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.17.2 WRIA 42 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 115. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

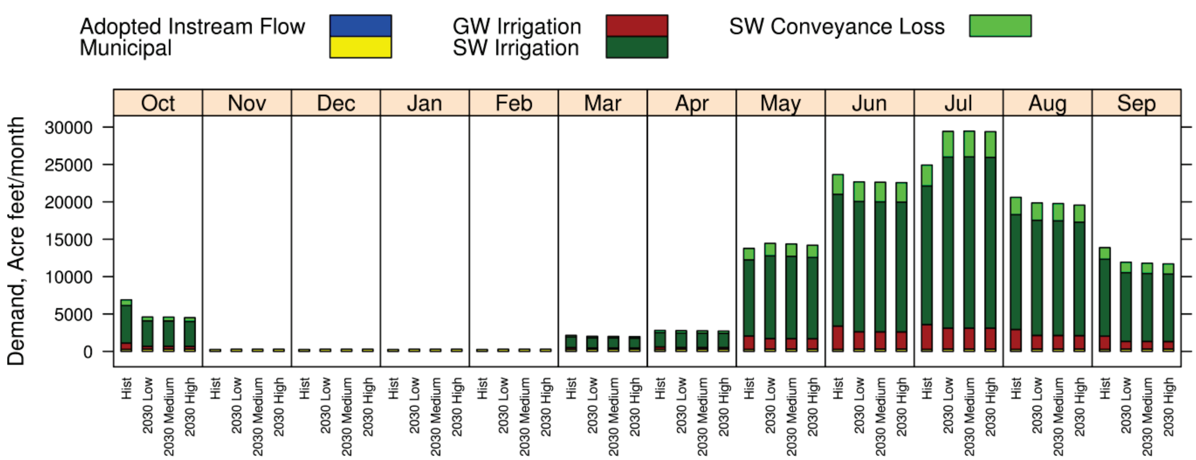


Figure 115. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.17.3 WRIA 42 Demand under Additional Water Capacity Scenarios

Figure 116 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as “2030 Medium” in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

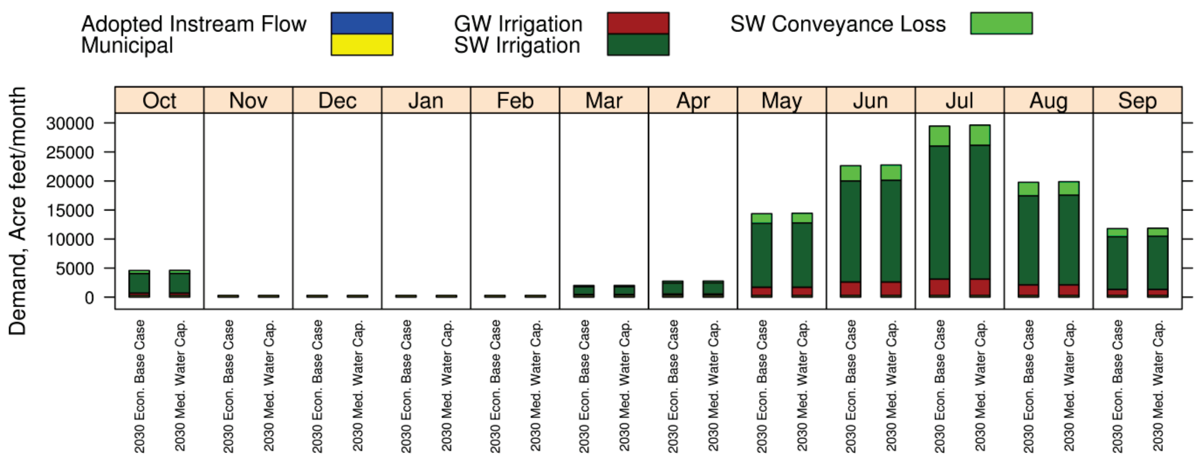


Figure 116. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.17.4 WRIA 42 Supply versus Demand Comparison

Figure 117 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

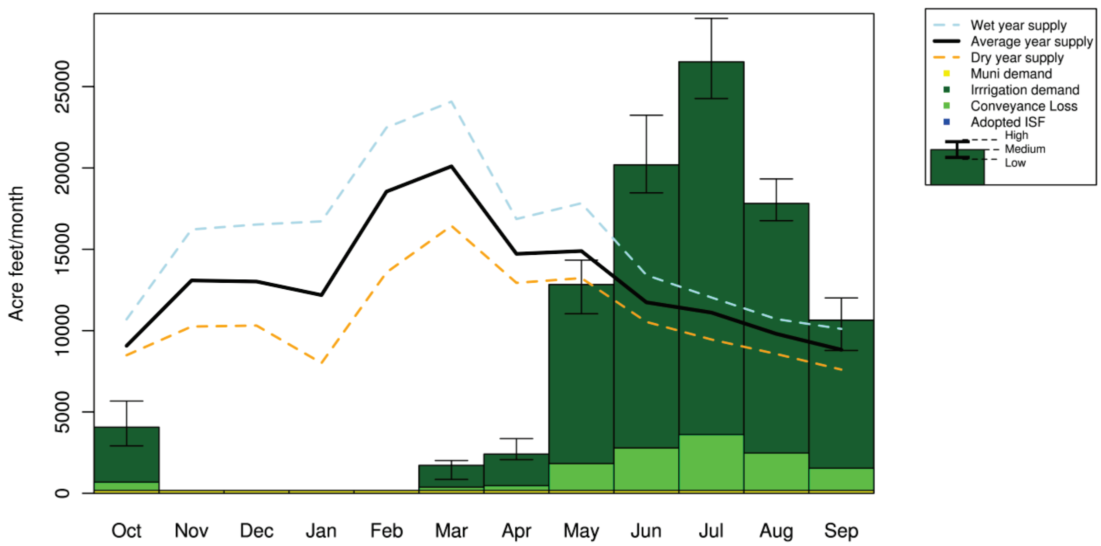


Figure 117. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.17.4.1 WRIA 42 Curtailment Analysis (for applicable WRIAs)

Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand by 2030 under the baseline scenario. The resulting unmet demand per year ranged from 3,393 to 4,219 with an average of 3,896 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.17.5 WRIA 42 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 118). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

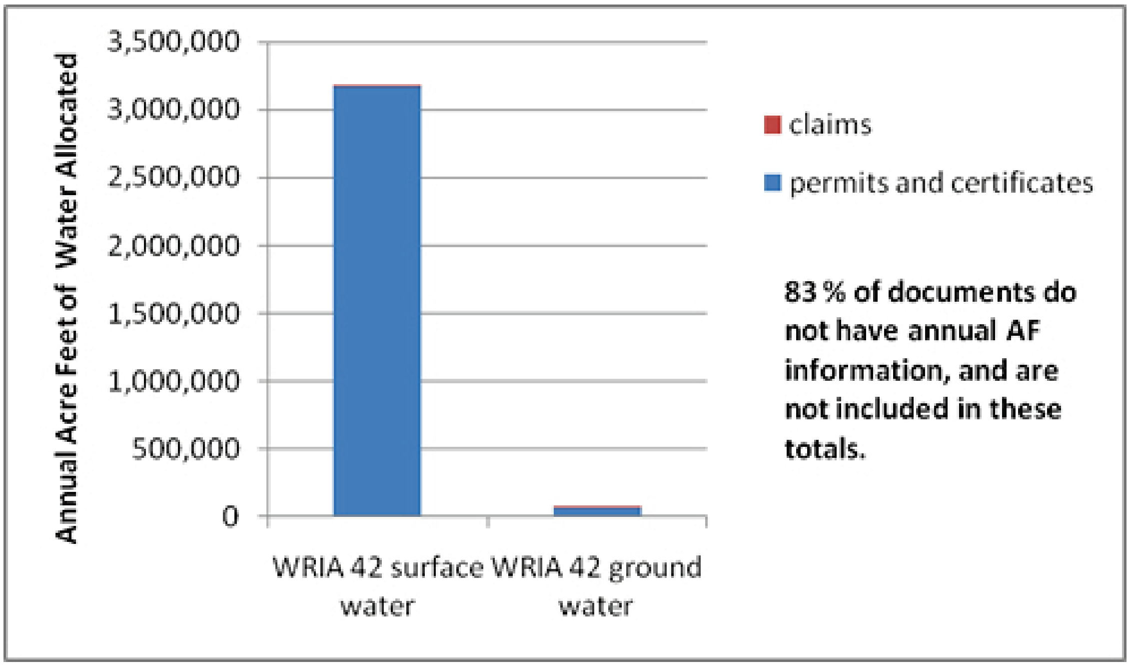


Figure 118. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.17.6 WRIA 42 Management Context

Some major management considerations for WRIA 42 are summarized in Table 44.

Table 44. Major management considerations in WRIA 42.

Management Context	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	YES (Columbia Basin GWMA, Quincy Subarea and small portion of Odessa Subarea)
Groundwater Studies	YES (references listed in WSU technical report)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.18 WRIA 43, Upper Crab-Wilson

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Upper Crab-Wilson is characterized mostly by a sharp increase in supply in the late winter.

As in many other WRIAs of eastern Washington, municipal demands are much smaller than irrigation demands. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase substantially in all months except October in the future, with slight variations in the magnitude of this increase depending on the alternate future economic scenario being considered. Because of declining groundwater in the Odessa area, irrigation demand is forecasted to shift by 2030 from predominantly groundwater to nearly all surface water. Municipal demands are projected to grow by 2%, a smaller increase than in many other watersheds of eastern Washington.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply will be insufficient on its own to meet combined municipal and surface water irrigation demands at the watershed scale across the irrigation season. Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand by 2030 under the baseline scenario. The resulting unmet demand per year ranged from 68,045 to 79,348 with an average of 73,405 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed. All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.18.1 WRIA 43 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 119 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

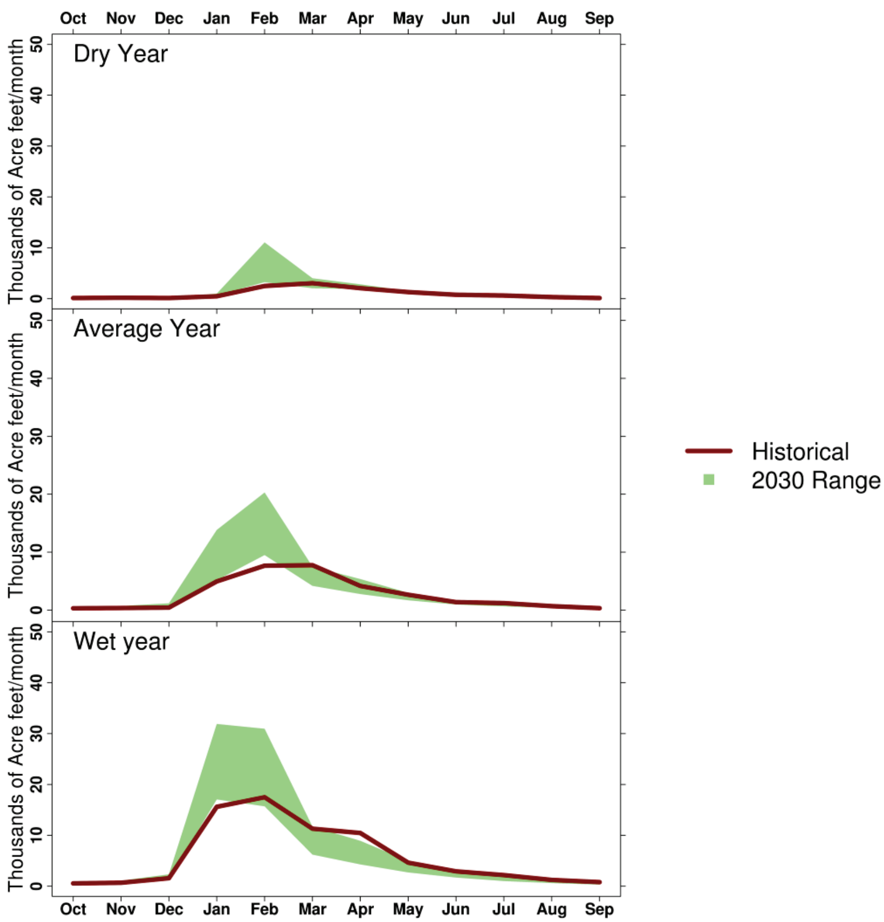


Figure 119. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.18.2 WRIA 43 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 120. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

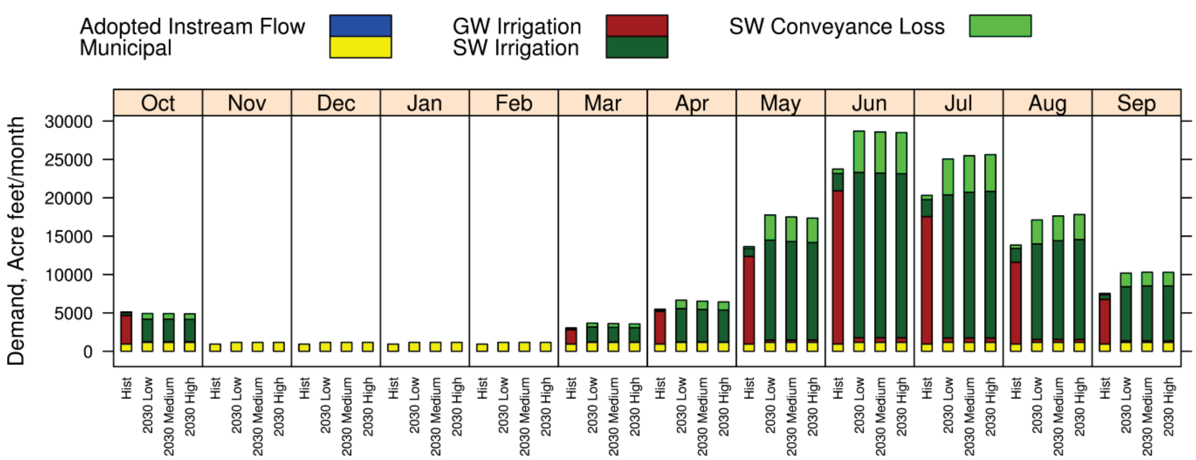


Figure 120. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.18.3 WRIA 43 Demand under Additional Water Capacity Scenarios

Figure 121 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

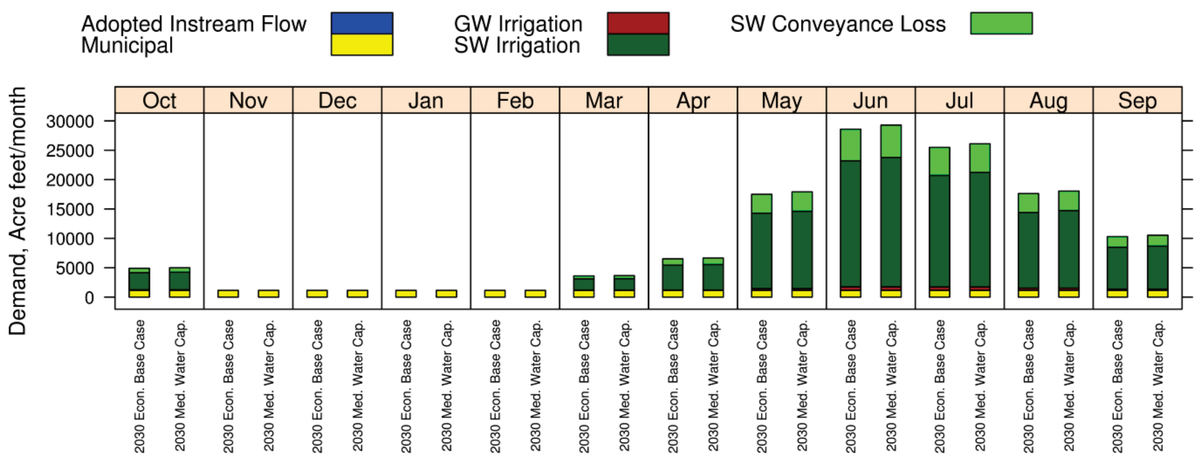


Figure 121. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.18.4 WRIA 43 Supply versus Demand Comparison

Figure 122 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

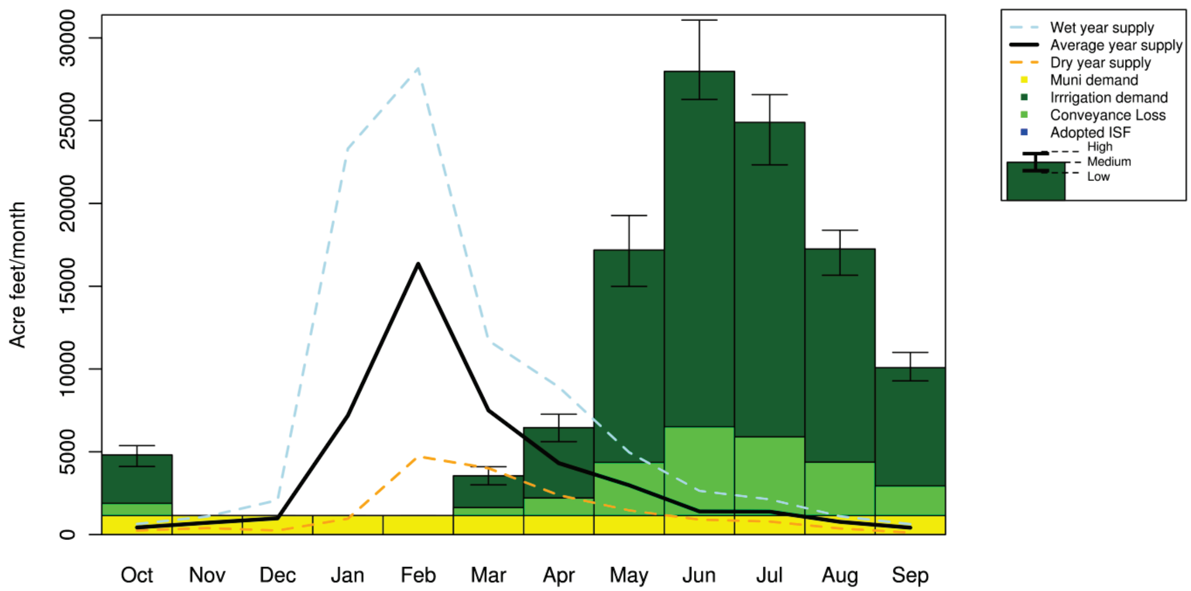


Figure 122. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.18.4.1 WRIA 43 Curtailment Analysis (for applicable WRIAs)

Modeling did not show curtailment of interruptible water rights holders between 1977 and 2005. Simulation of future curtailment occurred in 100% of years for the middle climate scenario, resulting from acreage currently receiving groundwater in the Odessa area. This area was assumed to have unmet surface water demand by 2030 under the baseline scenario. The resulting unmet demand per year ranged from 68,045 to 79,348 with an average of 73,405 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.18.5 WRIA 43 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 123). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

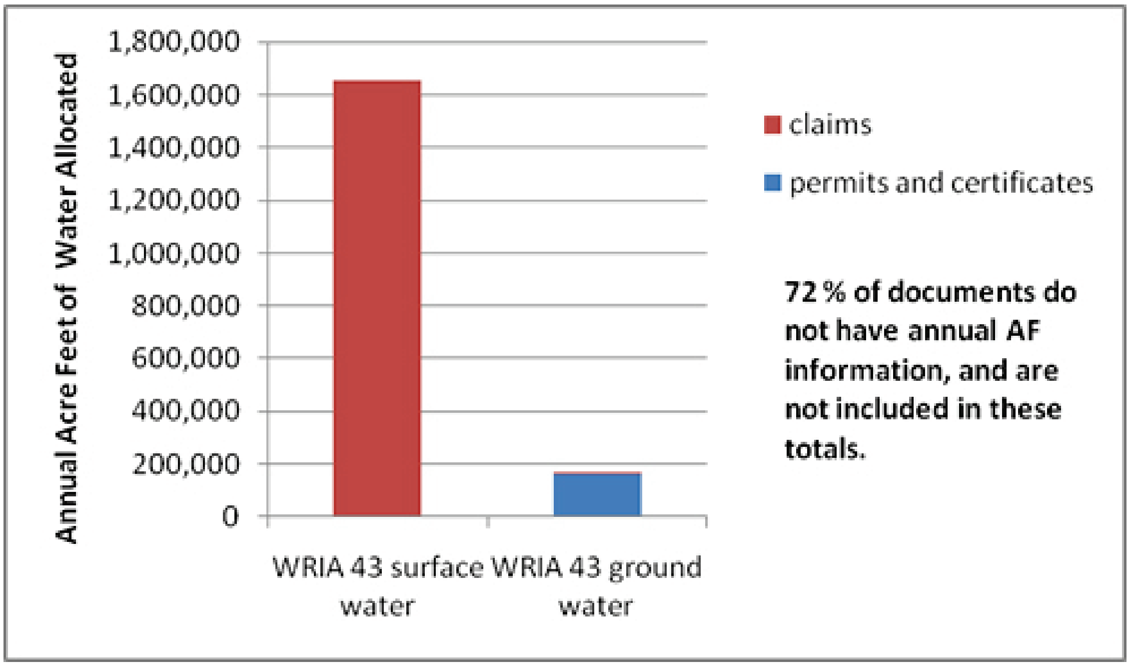


Figure 123. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.18.6 WRIA 43 Management Context

Some major management considerations for WRIA 43 are summarized in Table 45.

Table 45. Major management considerations in WRIA 43.

Management Context	
Adjudicated Areas	Crab Creek, Odessa
	Crab Creek, South Fork
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	YES (Grant and Lincoln County portions are part of Columbia Basin GWMA, and Odessa Subarea)
Groundwater Studies	YES (references listed in WSU technical report)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.19 WRIA 44 and 50, Moses Coulee, Foster

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Moses Coulee and Foster is characterized mostly by increases from late fall through winter and decreases in early spring.

As in many other watersheds of eastern Washington, municipal demands in these WRIAs are much smaller than irrigation demands. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase for future years from April through October, with small variations in the magnitude of change when alternate future economic scenarios are considered. Municipal demands are forecasted to grow by roughly 23% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply would be sufficient to meet combined municipal and surface water irrigation demands at the watershed scale on its own. Additional water supplies from the Columbia River are important to meeting demands in these WRIAs, and a separate analysis indicates that the majority of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Fish listed under the Endangered Species Act that spawn or rear in tributary waters of WRIA 50 include the Upper Columbia River Spring Run Chinook and the Upper Columbia Steelhead. No fish listed under the Endangered Species Act spawn or rear in tributary waters of WRIA 44, but the Columbia River mainstem in this area is a migratory corridor for ESA-listed fish.

All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.19.1 WRIAs 44 and 50 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 124 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

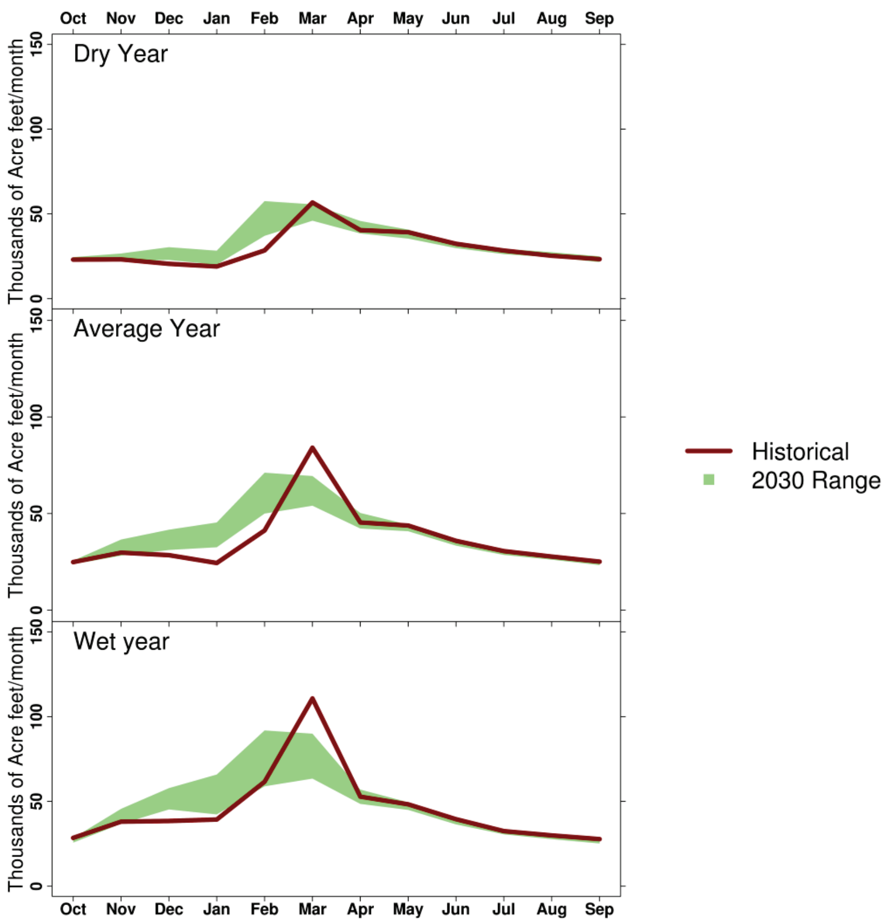


Figure 124. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIAs for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.19.2 WRIAs 44 and 50 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 125. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

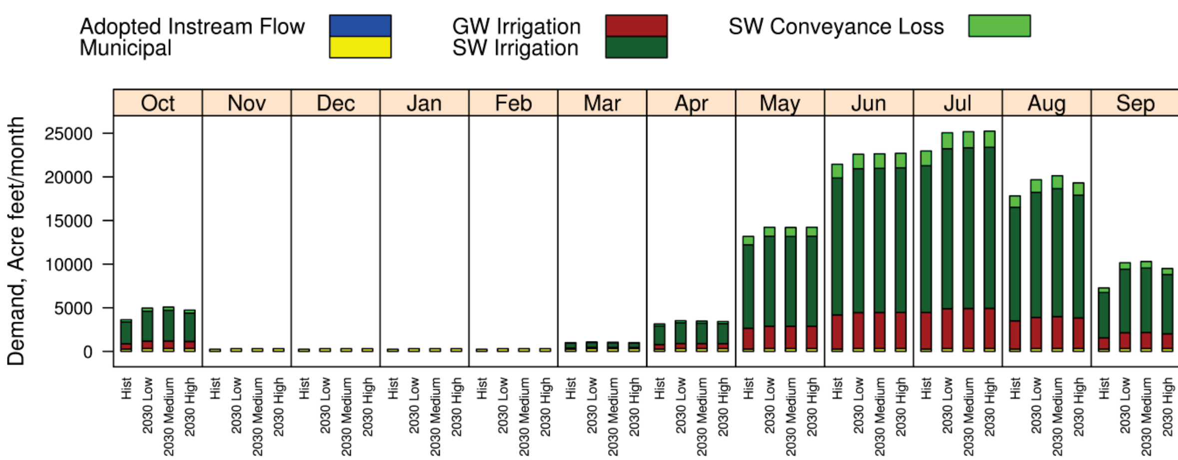


Figure 125. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.19.3 WRIAs 44 and 50 Demand under Additional Water Capacity Scenarios

Figure 126 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

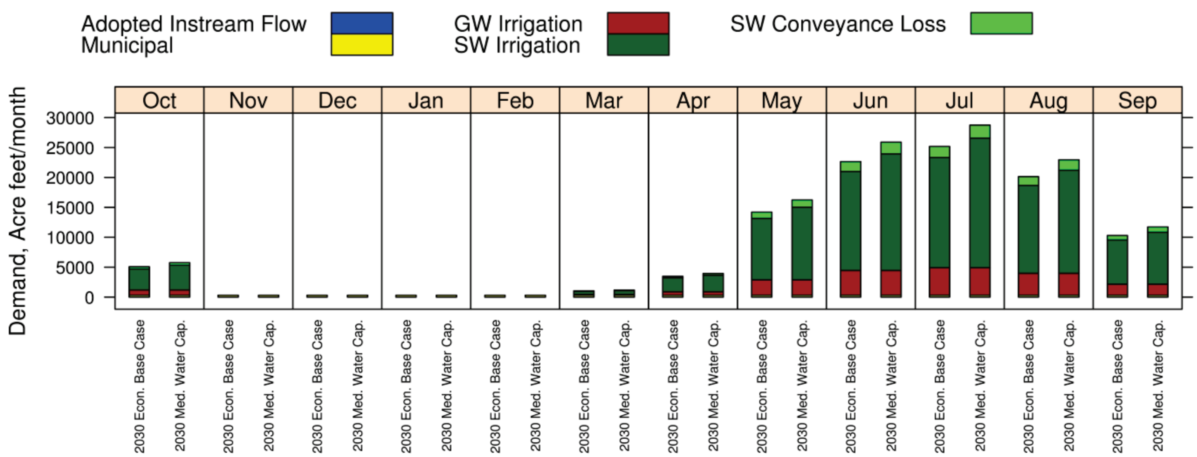


Figure 126. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.19.4 WRIAs 44 and 50 Supply versus Demand Comparison

Figure 127 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

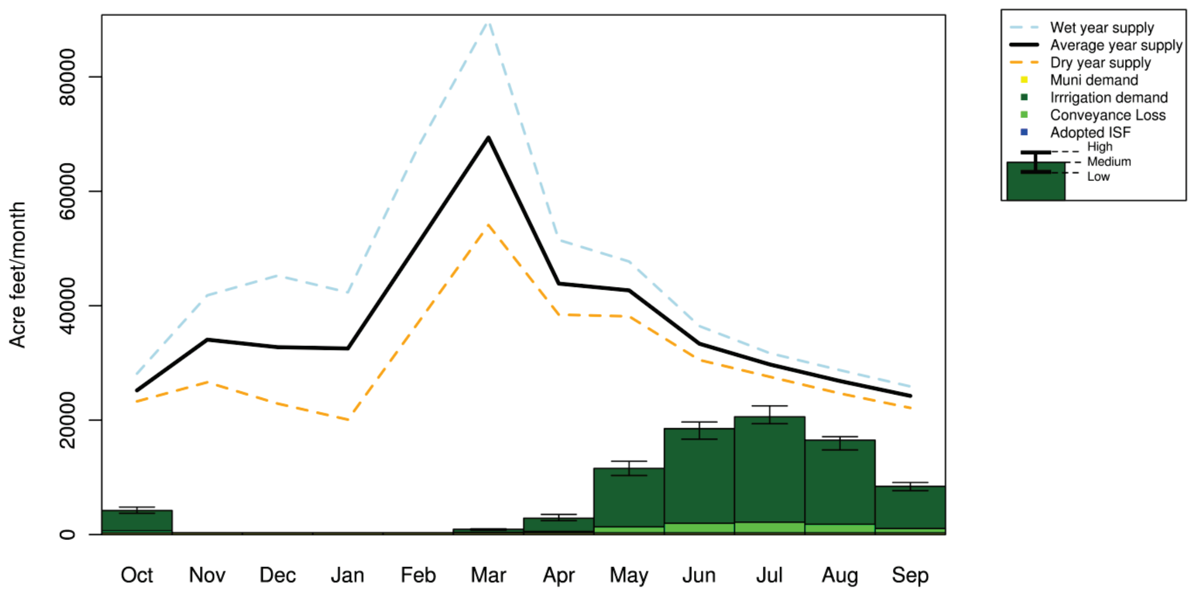


Figure 127. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.19.4.1 WRIAs 44 and 50 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.19.5 WRIAs 44 and 50 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 128). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

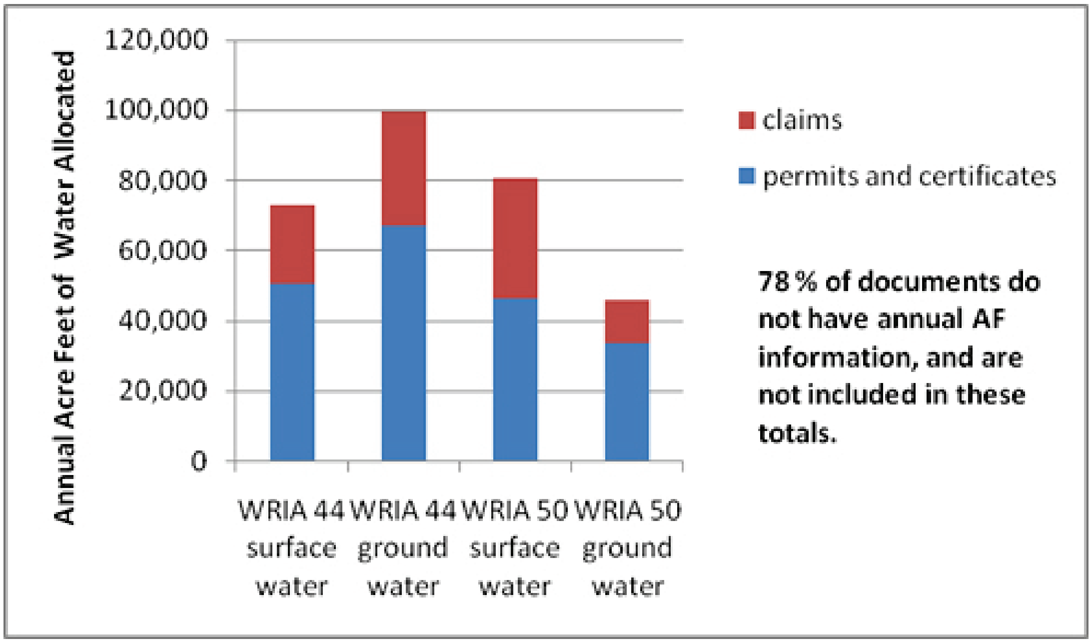


Figure 128. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.19.6 WRIAs 44 and 50 Management Context

Some major management considerations for WRIAs 44 and 50 are summarized in Table 46.

Table 46. Major management considerations in WRIAs 44 and 50.

Management Context	
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	WRIA 44: No ESA-listed fish spawn or rear in WRIA waters
	WRIA 50: Upper Columbia River Spring Run Chinook
	Upper Columbia Steelhead
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	No WRIA level studies found (but see WSU technical report for references on Columbia Plateau Regional Aquifer System)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.20 WRIA 45, Wenatchee

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Wenatchee is characterized mostly by substantial increases from fall through early spring and decreases in late spring through early fall.

Instream flow requirements are the largest water demand in WRIA 45, which has smaller irrigation demands and even smaller municipal demands in comparison. Instream flows based on watershed planning are shown for Wenatchee River at Peshastin, as specified in Chapter 173-545 WAC. Assuming no change in irrigated acreage, irrigation demand is projected to increase in many months in the future but decrease in others, with little difference when alternate future economic scenarios were considered. Municipal demands are forecasted to increase by 30% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, combined municipal and surface water irrigation demands and adopted instream flows are projected to outstrip unregulated tributary supply at the watershed scale in many years from July through March, and for almost all years from August through November. Additional water supplies from the Columbia River are available to meet demands in some areas of the WRIA, though a separate analysis indicates that less than 10% of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in 90% of years between 1977 and 2006. The resulting unmet demand ranged from 79 to 6,879 ac-ft per year depending on yearly flow conditions, with an average of 1,891 ac-ft per year. Simulation of future curtailment occurred in all the years for the middle climate scenario. The resulting unmet demand per year ranged from 97 to 8,908 with an average of 4,424 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet adopted instream flows are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

The Wenatchee River is home to bull trout, sockeye, Coho, steelhead, spring Chinook and summer Chinook. There are four distinct stocks of ESA-Endangered Upper Columbia spring Chinook in the Wenatchee. Spawning generally occurs in August and September, and most juveniles migrate out of the system the following April-May. Bull trout in the Wenatchee are part of the ESA-listed Upper Columbia Bull Trout population.

6.20.1 WRIA 45 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 129 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

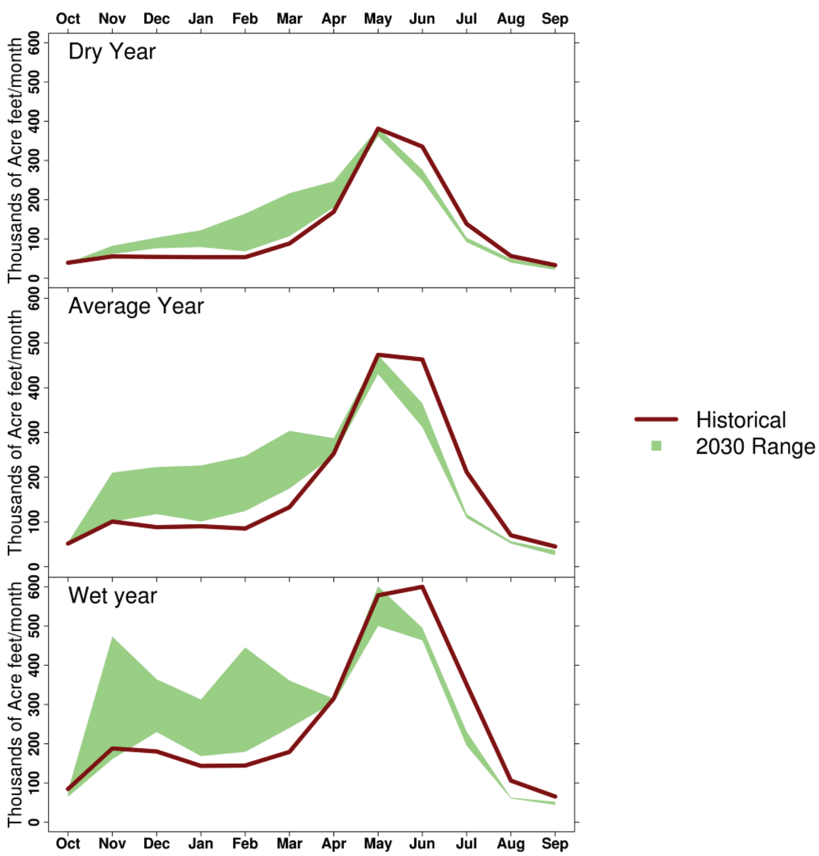


Figure 129. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.20.2 WRIA 45 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 130. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

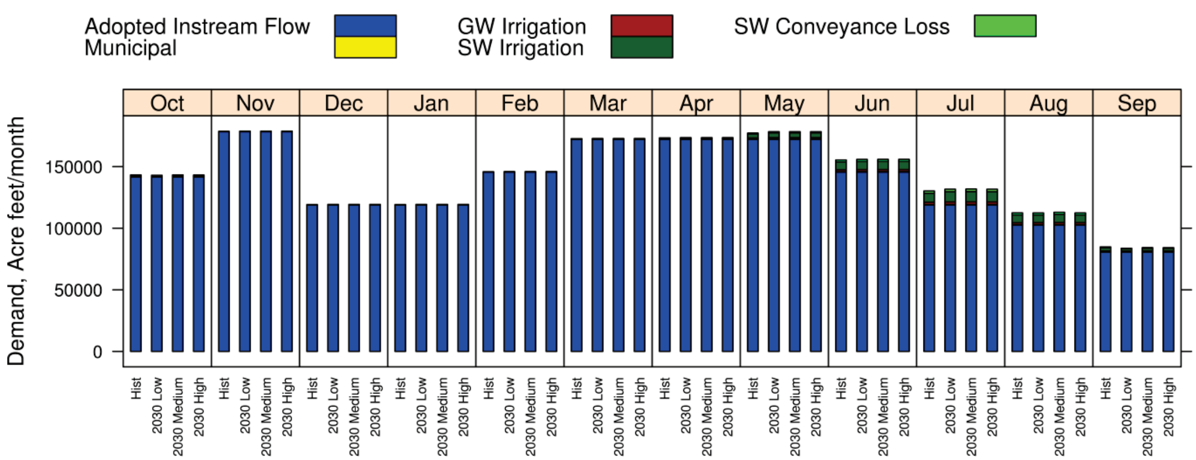


Figure 130. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.20.3 WRIA 45 Demand under Additional Water Capacity Scenarios

Figure 131 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

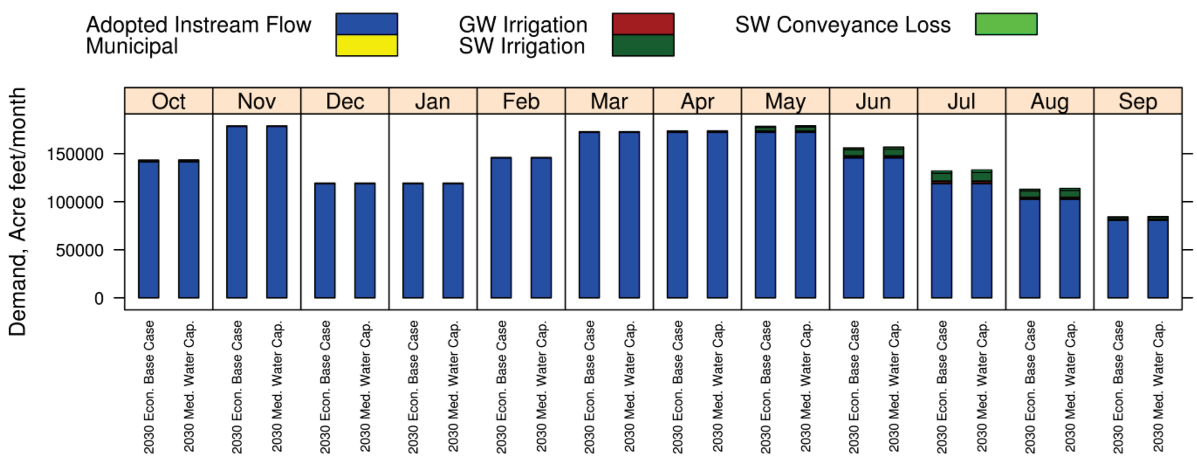


Figure 131. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.20.4 WRIA 45 Supply versus Demand Comparison

Figure 132 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

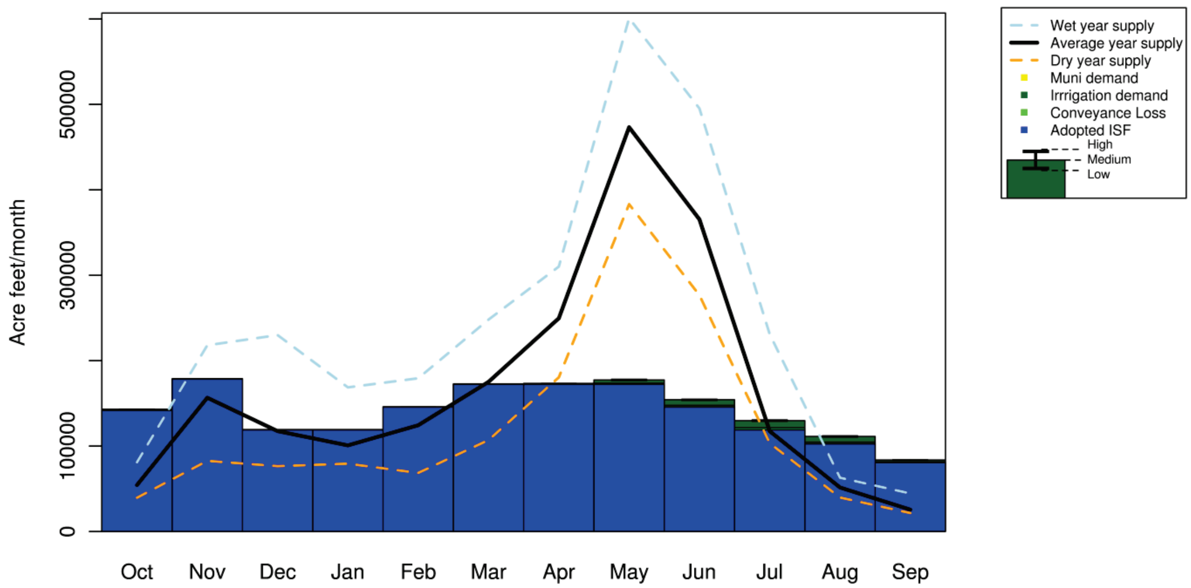


Figure 132. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.20.4.1 WRIA 45 Curtailment Analysis (for applicable WRIAs)

Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in 90% of years between 1977 and 2006. The resulting unmet demand ranged from 79 to 6,879 ac-ft per year depending on yearly flow conditions, with an average of 1,891 ac-ft per year. Simulation of future curtailment occurred in all the years for the middle climate scenario. The resulting unmet demand per year ranged from 97 to 8,908 with an average of 4,424 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

Modeling also indicated that at the WRIA level there was insufficient water to meet the instream flow targets in every year between 1977 and 2006. In order to calculate unmet instream flow, the most current flow targets from 2007 were used. Curtailment and associated unmet irrigation demands detailed in the paragraph above were based on of the older flow targets established in the year 1983, which the interruptible water rights are subject to. The resulting unmet instream flow ranged from 372,468 to 1,394,662 with an average of 830,206 ac-ft per year. Simulation of future insufficient water occurred in all the years for the middle climate scenario. The resulting unmet instream flow per year ranged from 6,799 to 650,469 with an average of 245,121 ac-ft per year.

6.20.5 WRIA 45 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 133). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

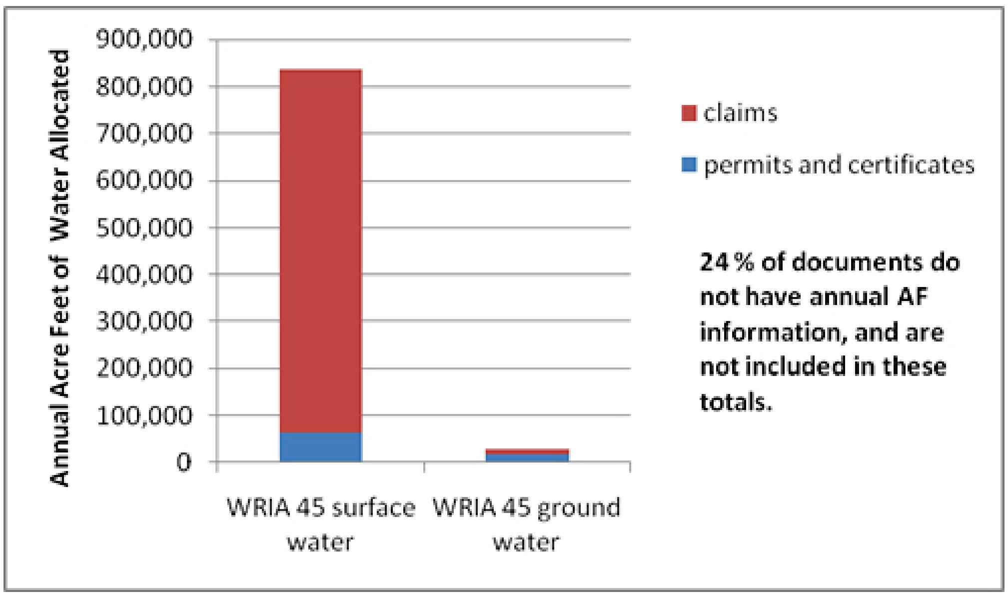


Figure 133. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.20.6 WRIA 45 Management Context

Some major management considerations for WRIA 45 are summarized in Table 47.

Table 47. Major management considerations in WRIA 45.

Management Context	
Adjudicated Areas	Chumstick Creek
	Icicle Creek
	Nahahum Canyon
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-545 WAC)
	(interruptible users curtailed annually)
Fish Listed Under the Endangered Species Act[1]	Lake Wenatchee Sockeye
	Upper Columbia River Bull Trout
	Upper Columbia River Spring Run Chinook
	Upper Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.21 WRIA 46, Entiat

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Entiat is characterized mostly by increases from late fall through spring and decreases during the late spring and summer.

Instream flow requirements are the largest demand in WRIA 46, with much smaller irrigation and municipal demands. Because the instream flows specified in Chapter 173-546 WAC are sometimes higher for the upper Entiat River near Ardenvior than for the lower Entiat near river mile 1.4, instream requirements are shown as the higher of these two instream flow requirements for each month, for both the historical and future period. Assuming no change in irrigated acreage, irrigation demand is projected to increase somewhat in future summers under all economic scenarios considered, and decrease for most future falls. Meanwhile, municipal demands are forecasted to increase by 19% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is forecasted to be insufficient to meet combined municipal and surface water irrigation demands and adopted instream flows at the watershed scale in most years from July through September. Additional water supplies from the Columbia River could meet demands in some localized areas of the WRIA, though a separate analysis indicates that very little agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet adopted instream flows are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Fish listed under the Endangered Species Act that spawn or rear in tributary waters of this watershed include the Upper Columbia River Bull Trout, the Upper Columbia River Spring Run Chinook, and the Upper Columbia Steelhead.

All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.21.1 WRIA 46 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 134 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

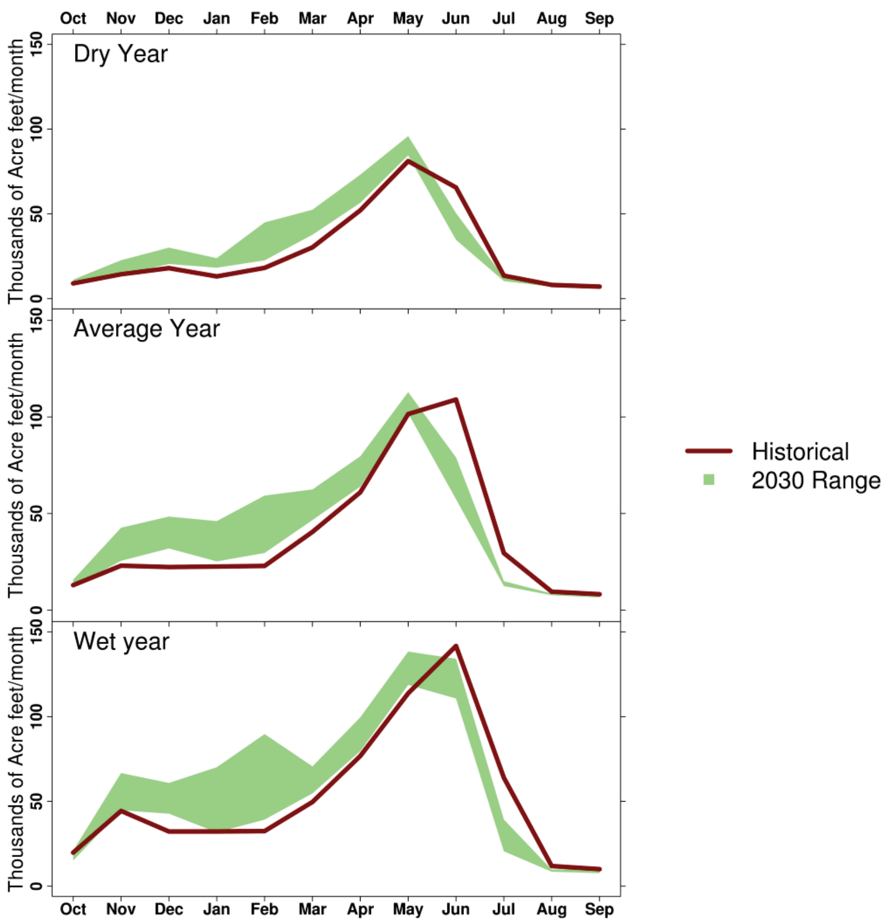


Figure 134. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.21.2 WRIA 46 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 135. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

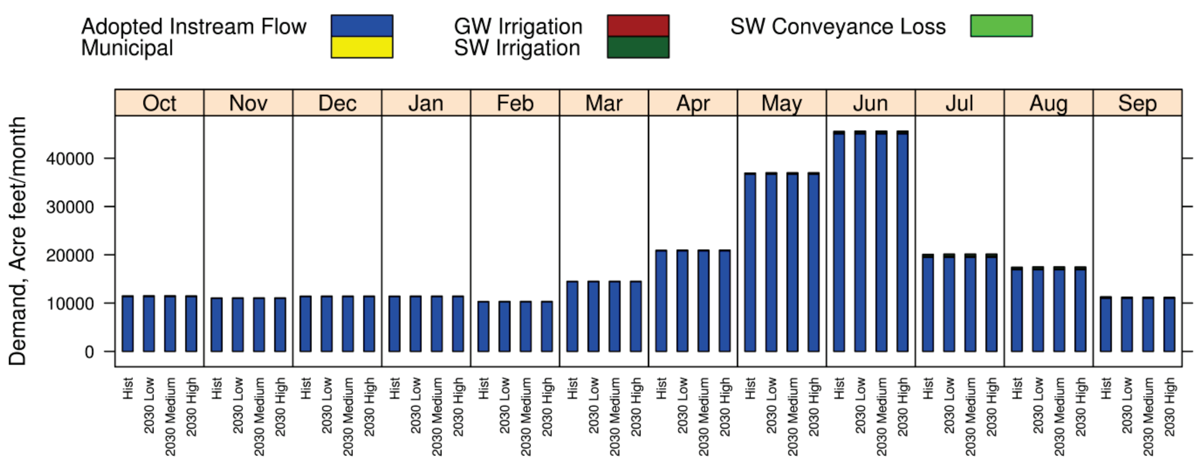


Figure 135. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.21.3 WRIA 46 Demand under Additional Water Capacity Scenarios

Figure 136 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

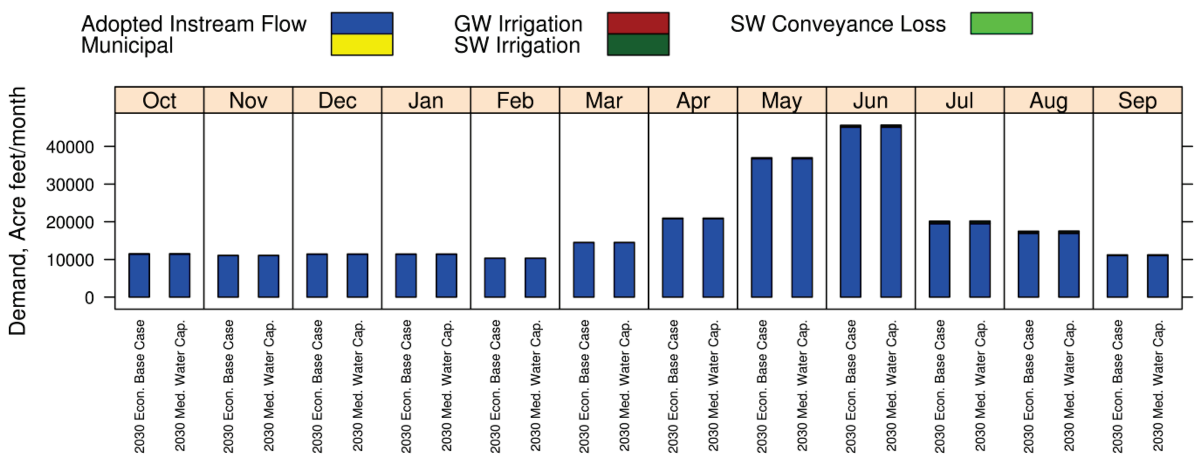


Figure 136. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.21.4 WRIA 46 Supply versus Demand Comparison

Figure 137 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

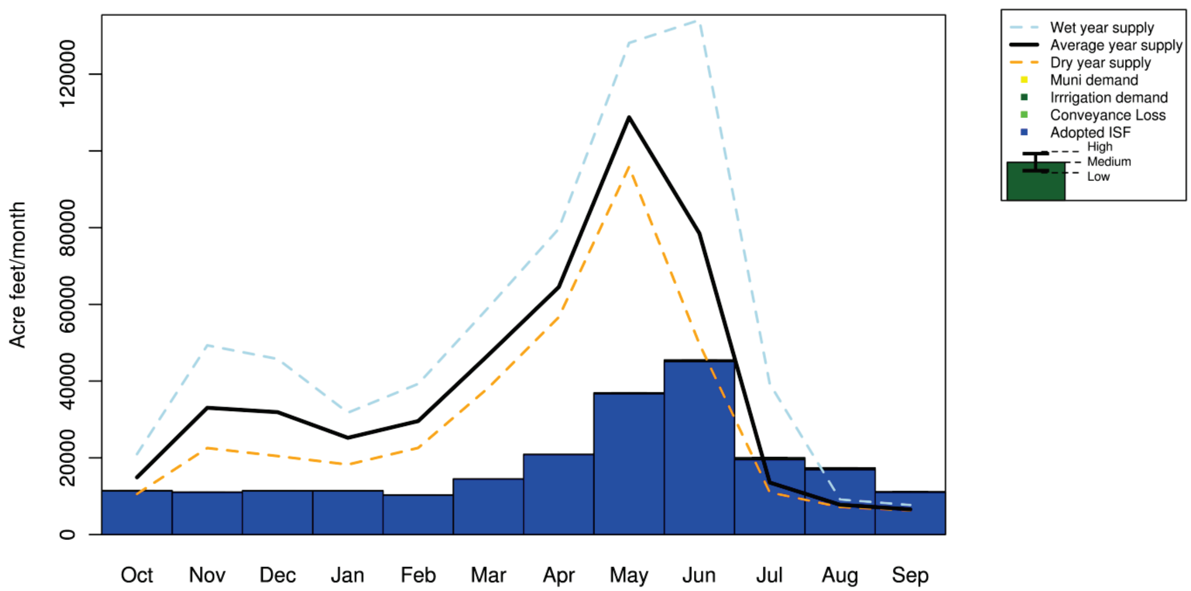


Figure 137. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.21.4.1 WRIA 46 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. Although this WRIA has instream flow targets, there are no interruptible water rights associated with them. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months. There could be insufficient water to meet the instream flow targets in WRIA 46. However data to bias correct the “supply” flows (as described in Section 3.4.6.1) for this WRIA was not available, unmet instream flow estimates were not calculated.

6.21.5 WRIA 46 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 138). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

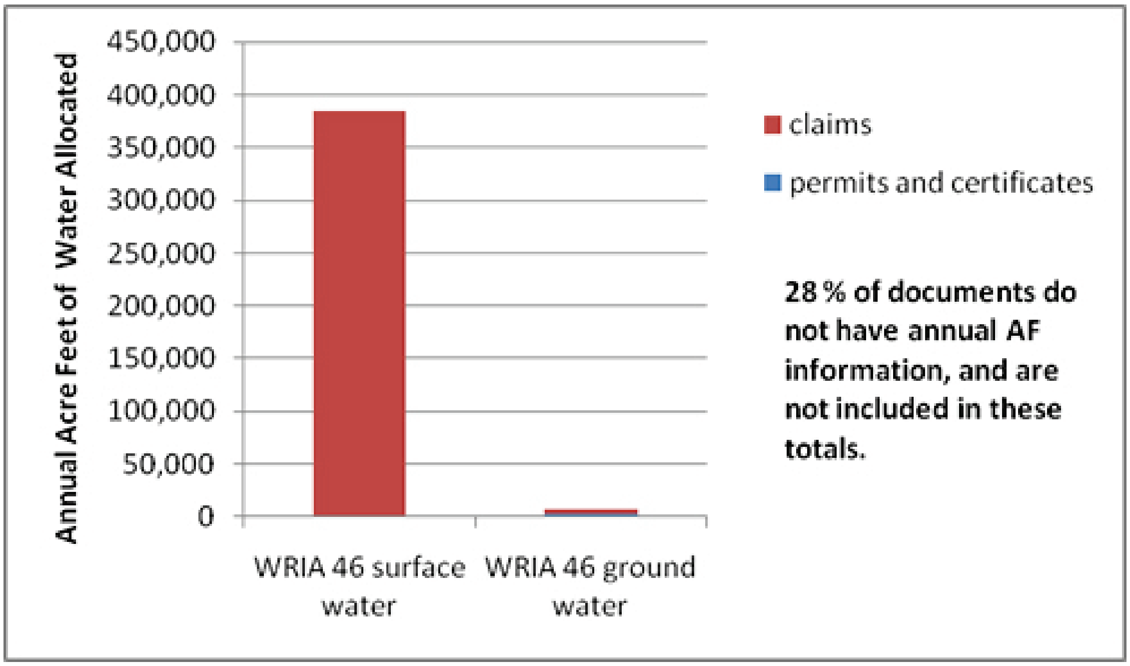


Figure 138. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.21.6 WRIA 46 Management Context

Some major management considerations for WRIA 46 are summarized in Table 48.

Table 48. Major management considerations in WRIA 46.

Management Context	
Adjudicated Areas	Roaring Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-546 WAC)
Fish Listed Under the Endangered Species Act[1]	Upper Columbia River Bull Trout Upper Columbia River Spring Run Chinook
	Upper Columbia Steelhead
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.22 WRIA 47, Chelan

Supplies and demands are defined as described in Section 1.3 “Definitions of Water Supply and Water Demand Used in the 2011 Forecast.” The tributary surface water supply forecast for Chelan is characterized mostly by increases from late fall through mid-spring and decreases in summer and early fall.

Irrigation is the primary demand in Chelan, with much smaller municipal demands. Assuming no change in irrigated acreage, irrigation demand is forecasted to increase most future months but decrease in others, with some variation in impacts in other months when alternate future economic scenarios were considered. Municipal demand projected to grow by roughly 32% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River “medium” scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is projected to be sufficient to meet combined municipal and surface water irrigation demands at the watershed scale. Additional water supplies from the Columbia River are available in some areas of the WRIA, and a separate analysis indicates that roughly a third of agricultural demand is within a mile of the Columbia River (results shown in “Washington’s Columbia River Mainstem: Tier 3 Results”). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed, but the Columbia River mainstem in this area is a migratory corridor for ESA-listed fish.

6.22.1 WRIA 47 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 139 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

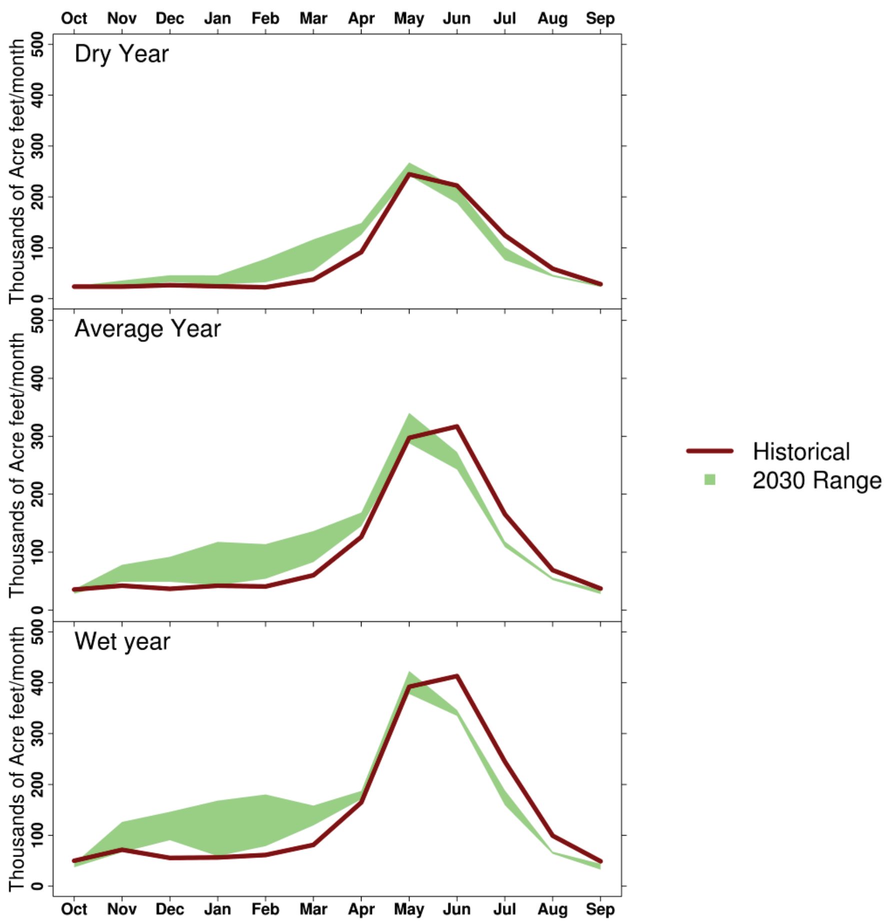


Figure 139. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.22.2 WRIA 47 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 140. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

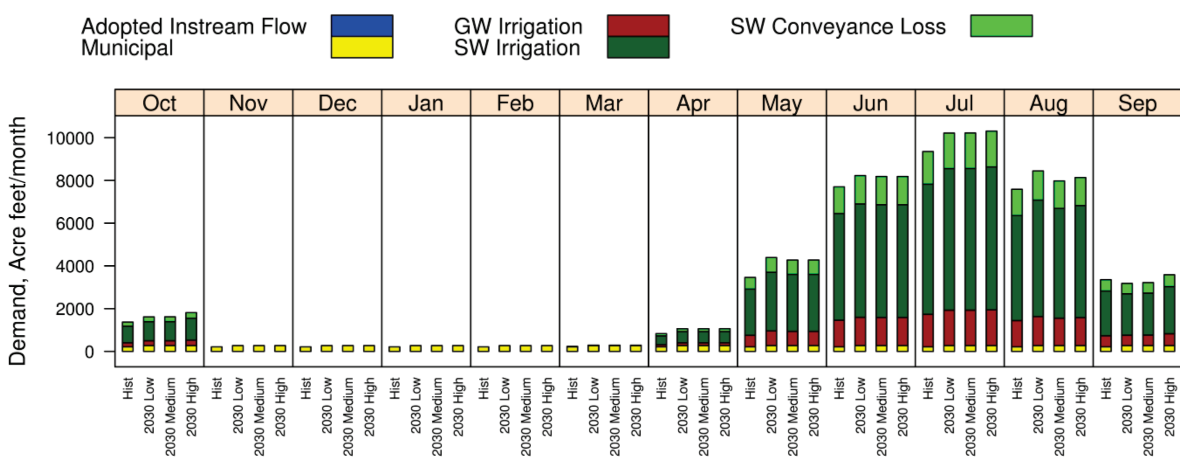


Figure 140. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.22.3 WRIA 47 Demand under Additional Water Capacity Scenarios

Figure 141 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as “2030 Medium” in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

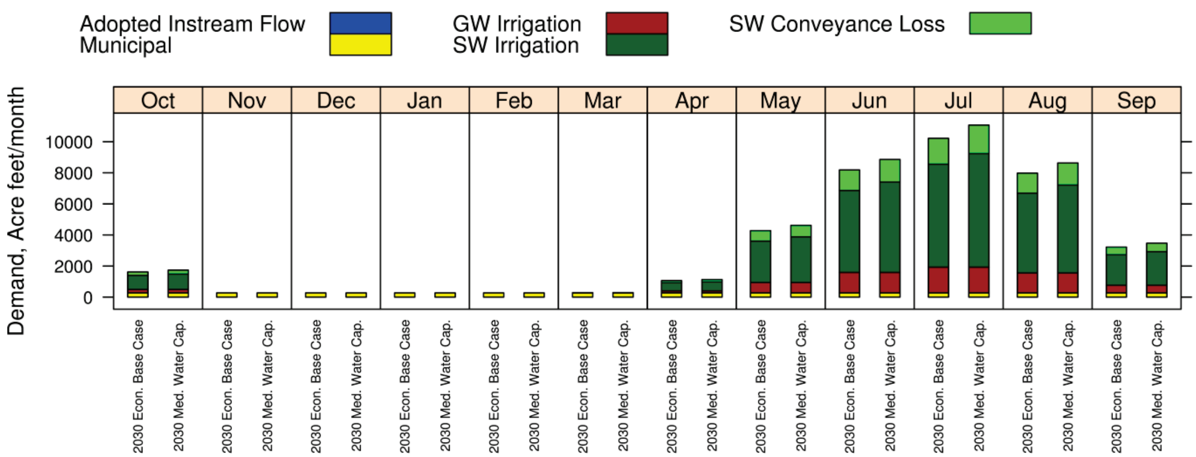


Figure 141. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.22.4 WRIA 47 Supply versus Demand Comparison

Figure 142 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

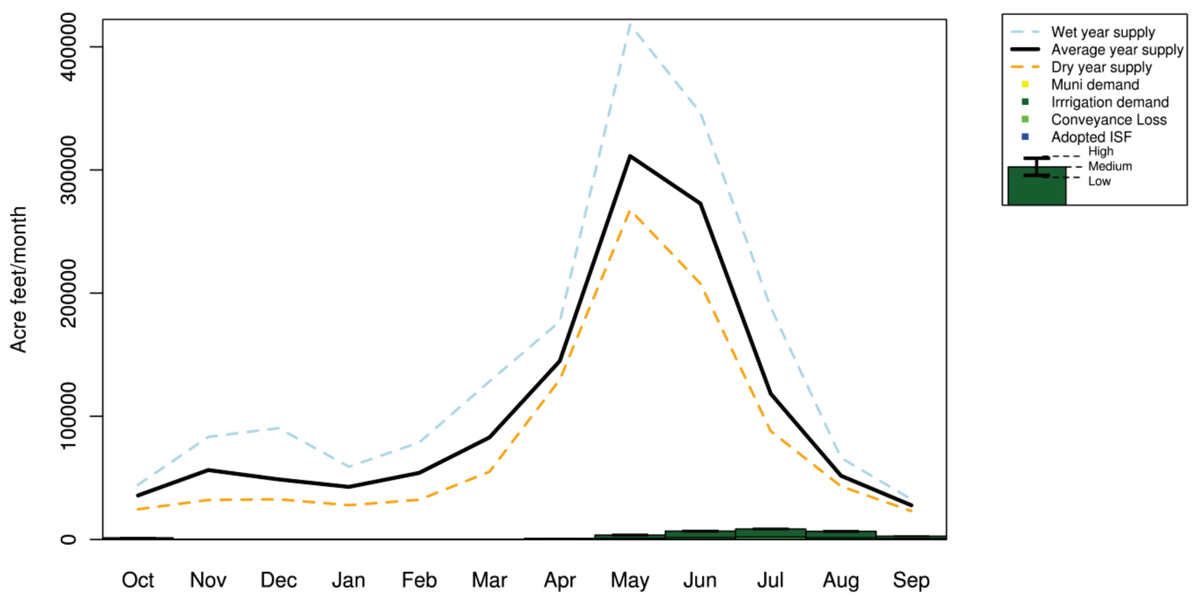


Figure 142. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.22.4.1 WRIA 47 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.22.5 WRIA 47 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 143). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

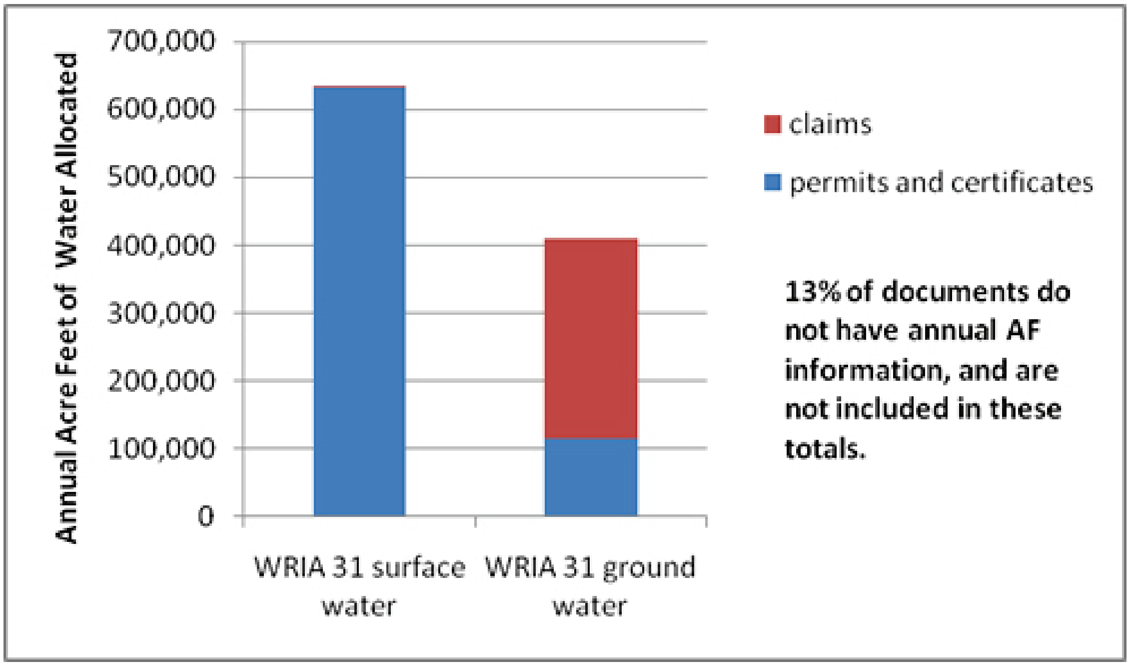


Figure 143. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.22.6 WRIA 47 Management Context

Some major management considerations for WRIA 47 are summarized in Table 49.

Table 49. Major management considerations in WRIA 47.

Management Context	
Adjudicated Areas	Antoine Creek
	Joe Creek
	Safety Harbor Creek
	Johnson Creek
Watershed Planning	Phase 2 (Assessment)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.23 WRIA 48, Methow

Supplies and demands are defined as described in Section 1.3 “Definitions of Water Supply and Water Demand Used in the 2011 Forecast.” The tributary surface water supply forecast for Methow is characterized mostly by increases in the late winter through late spring and slight decreases in late spring and summer.

WRIA 48 has much larger instream flow requirements than irrigation demands, and even smaller municipal demands. Because the instream flows specified in Chapter 173-548 WAC are sometimes higher for the middle Methow River near Twisp than for the lower Methow River near Pateros, instream requirements are shown as the higher of these two instream flow requirements for each month, for both the historical and future period. Assuming no change in irrigated acreage, irrigation demand is projected to increase in future summers under all economic scenarios that were considered, with small variations in impact when alternate economic scenarios are considered. Municipal demands are forecasted to grow by 20% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River “medium” scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, at the watershed scale, combined municipal and surface water irrigation demands and adopted instream flows are projected to outstrip unregulated tributary supply generated within the Washington portion of the watershed during many years from July through November, and in some years from December through February. Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands. Additional water supplies from the Columbia River are available to meet demands in some areas of the WRIA, and a separate analysis indicates that a bit more than a third of agricultural demand is within a mile of the Columbia River (results shown in “Washington’s Columbia River Mainstem: Tier 3 Results”). Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in 80% of years between 1977 and 2006. The resulting unmet demand ranged from 14 to 2,217 ac-ft per year depending on yearly flow conditions, with an average of 622 ac-ft per year. Simulation of future curtailment occurred in 93% of years for the middle climate scenario. The resulting unmet demand per year ranged from 12 to 2,594 with an average of 1,465 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet adopted instream flows are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Methow spring Chinook are a key component of the ESA-Endangered Upper Columbia Spring Chinook run. Adults spawn from late July through October, and most juveniles outmigrate in April-May. Juvenile salmon rearing occurs year-round. Bull trout in the Methow are part of the ESA-Threatened Upper Columbia Bull Trout listing unit.

6.23.1 WRIA 48 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 144 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

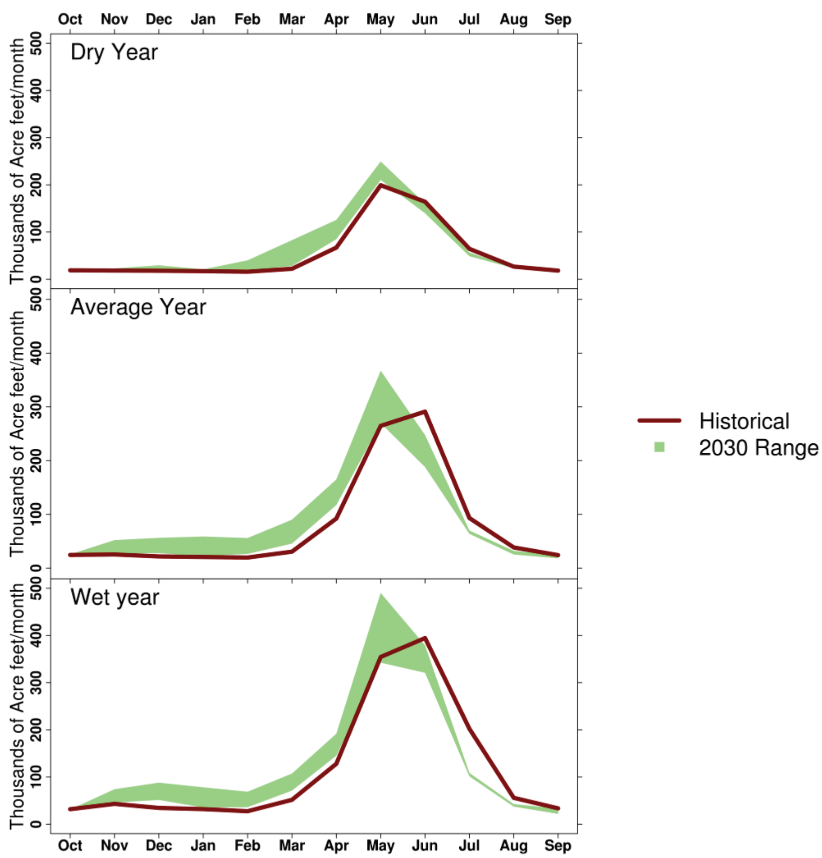


Figure 144. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.23.2 WRIA 48 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 145. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

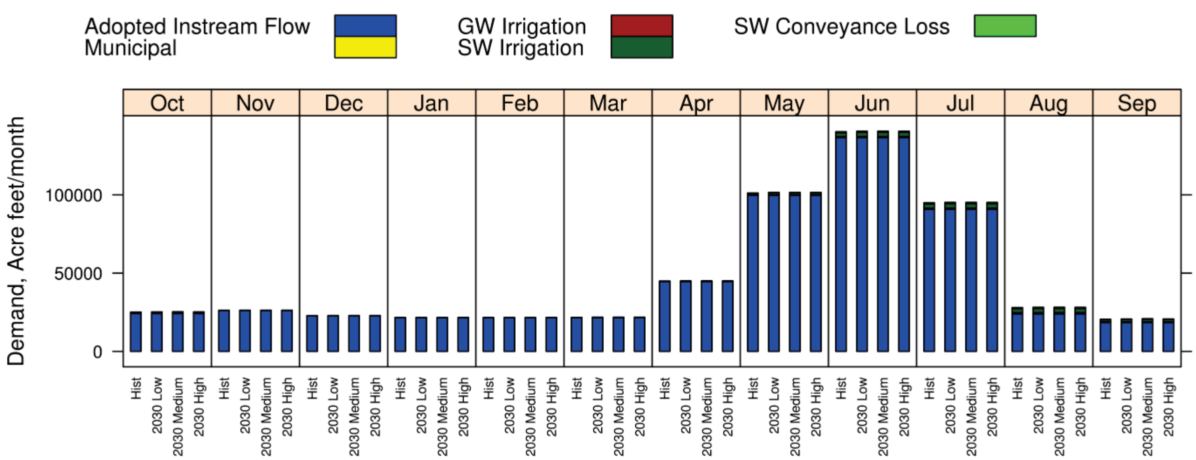


Figure 145. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.23.3 WRIA 48 Demand under Additional Water Capacity Scenarios

Figure 146 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

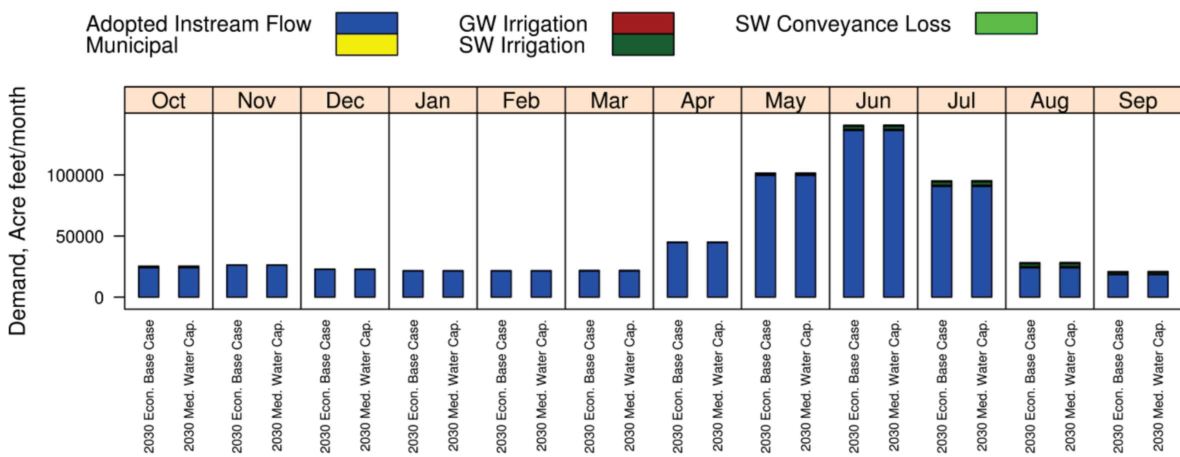


Figure 146. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.23.4 WRIA 48 Supply versus Demand Comparison

Figure 147 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

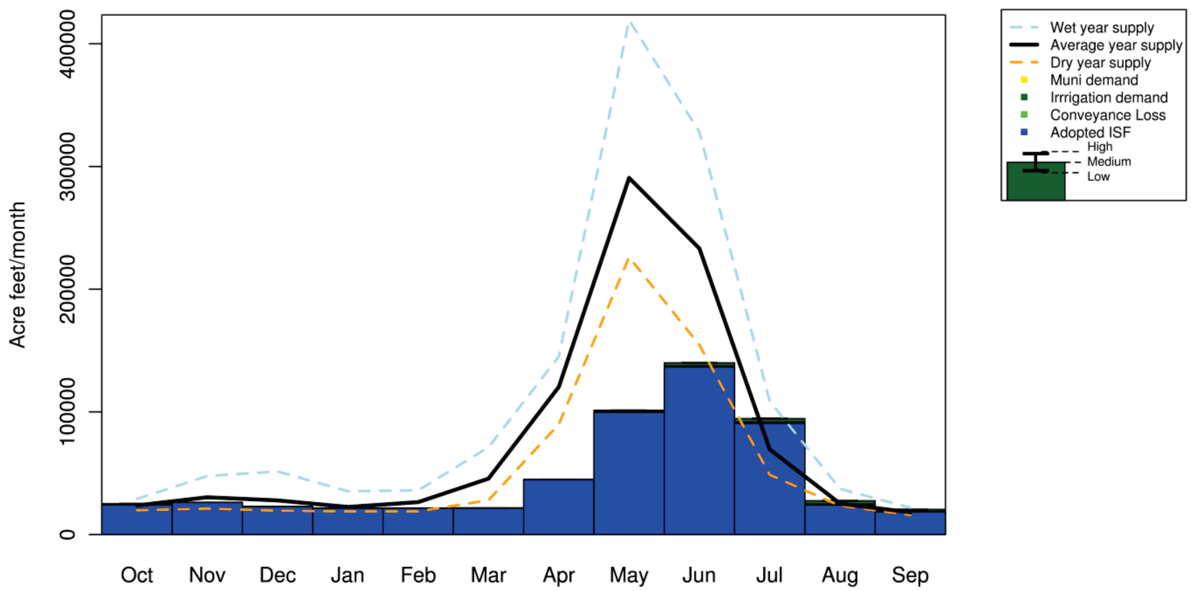


Figure 147. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.23.4.1 WRIA 48 Curtailment Analysis (for applicable WRIAs)

Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in 80% of years between 1977 and 2006. The resulting unmet demand ranged from 14 to 2,217 ac-ft per year depending on yearly flow conditions, with an average of 622 ac-ft per year. Simulation of future curtailment occurred in 93% of years for the middle climate scenario. The resulting unmet demand per year ranged from 12 to 2,594 with an average of 1,465 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

Modeling also indicated that at the WRIA level there was insufficient water to meet the instream flow targets in every year between 1977 and 2006. The resulting unmet instream flow ranged from 89,565 to 350,906 with an average of 122,093 ac-ft per year. Simulation of future insufficient water occurred in all the years for the middle climate scenario. The resulting unmet flow per year ranged from 98,150 to 305,806 with an average of 190,467 ac-ft per year.

6.23.5 WRIA 48 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 148). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

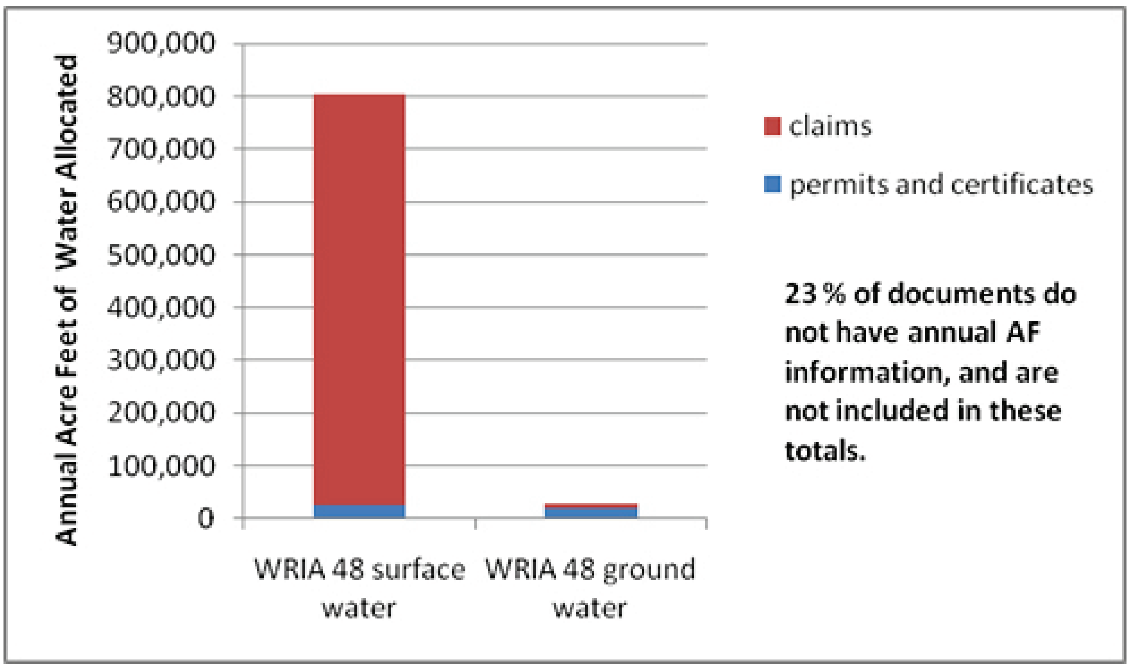


Figure 148. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.23.6 WRIA 48 Management Context

Some major management considerations for WRIA 48 are summarized in Table 50.

Table 50. Major management considerations in WRIA 48.

Management Context	
Adjudicated Areas	Beaver Creek
	Bear Creek & Davis Lake
	Libby Creek
	Gold Creek
	McFarland Creek
	Black Canyon Creek
	Wolf Creek
	Thompson Creek (incomplete)
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-548 WAC)
	(interruptible users curtailed annually)
Fish Listed Under the Endangered Species Act[1]	Upper Columbia River Bull Trout Upper Columbia River Spring Run Chinook
	Upper Columbia Steelhead
	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.24 WRIA 49, Okanogan

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Okanogan is characterized mostly by increases from mid-fall through winter and decreases under most flow conditions from late spring through early fall.

The largest demands in WRIA 49 are from instream demands, though irrigation demands are also important. Municipal demands are much smaller. Because the instream flows specified in Chapter 173-549 WAC are higher for some time periods for the middle Okanogan River near Tonaskett than for lower Okanogan River at Malott, instream requirements are shown as the higher of these two instream flow requirements for each month, for both the historical and future period. Assuming no change in irrigated acreage, irrigation demand is projected to increase in most months but decrease in others under all future economic scenarios that were considered. Municipal demands are forecasted to grow by 22% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, at the watershed scale, combined municipal and surface water irrigation demands and adopted instream flows are projected to outstrip unregulated tributary supply generated within the Washington portion of the watershed during most years for May through February. Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands. Additional water supplies from the Columbia River are available to meet demands in a few areas of the WRIA, and a separate analysis indicates that roughly one sixth of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in every year between 1977 and 2006. The resulting unmet demand ranged from 144 to 11,388 ac-ft per year depending on yearly flow conditions, with an average of 4,426 ac-ft per year. Simulation of future curtailment occurred in 97% of years for the middle climate scenario. The resulting unmet demand per year ranged from 263 to 21,292 with an average of 10,464 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet adopted instream flows are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

The Okanogan summer steelhead stock is a component of the ESA-Threatened Upper Columbia steelhead listing unit. These fish spawn from March through June, juveniles overwinter, and juvenile outmigration generally occurs in April and May. Okanogan sockeye are returning to, rearing in, and migrating from lakes along the U.S. -- Canada border and in British Columbia.

6.24.1 WRIA 49 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 149 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

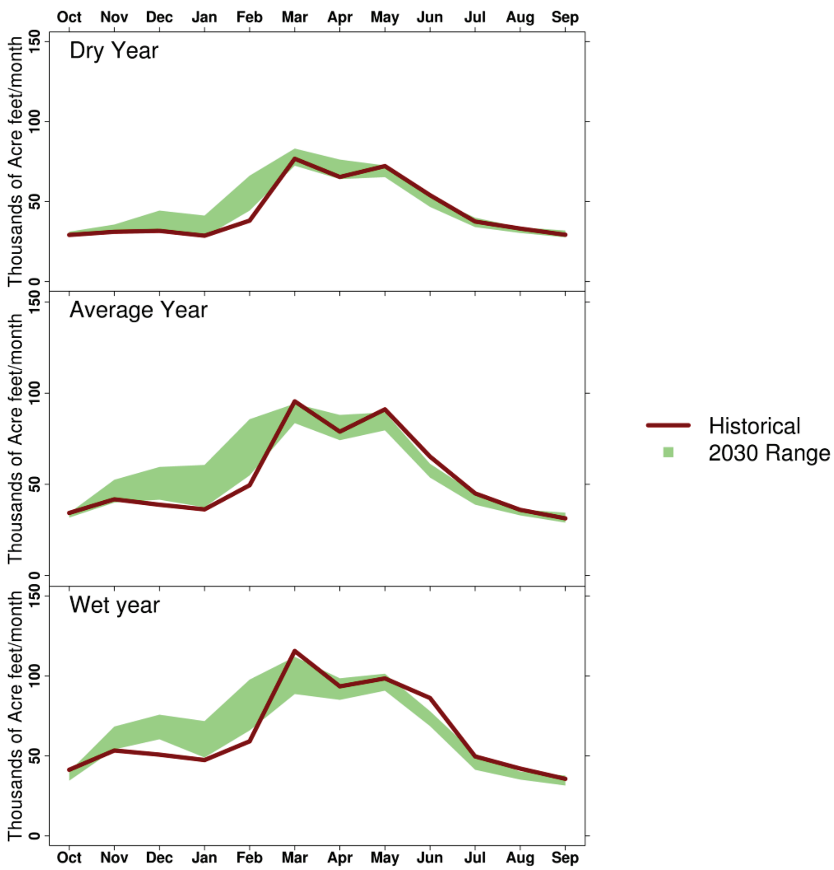


Figure 149. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.24.2 WRIA 49 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 150. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

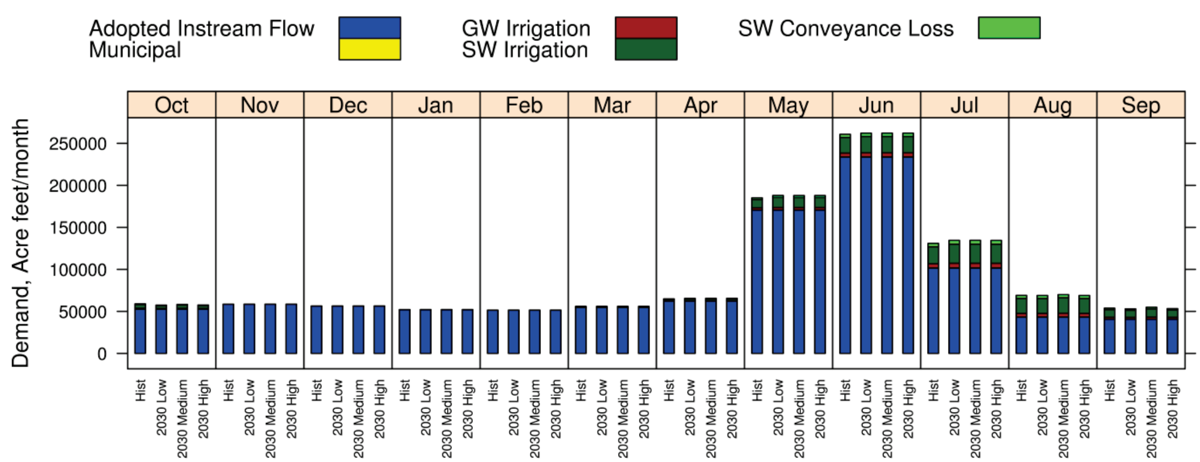


Figure 150. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.24.3 WRIA 49 Demand under Additional Water Capacity Scenarios

Figure 151 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

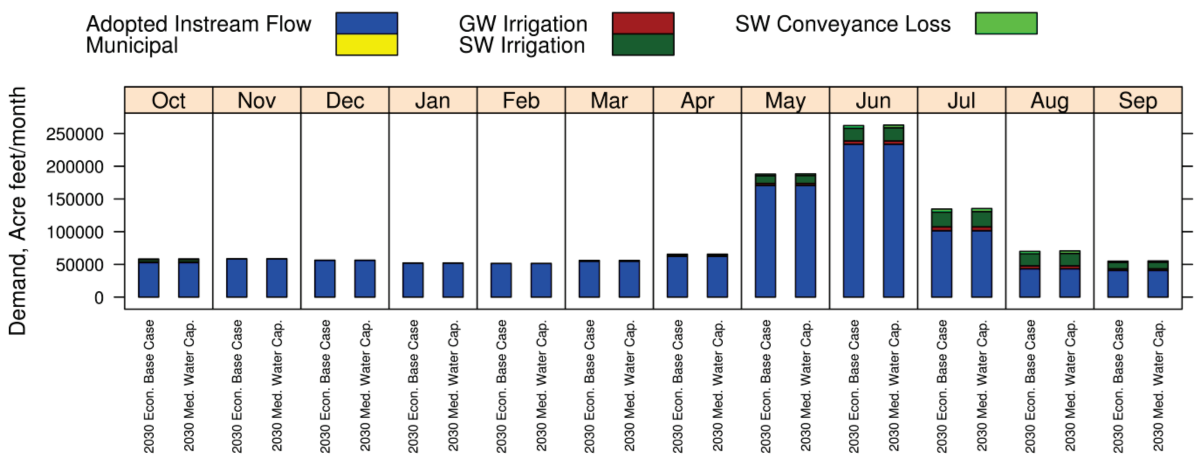


Figure 151. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.24.4 WRIA 49 Supply versus Demand Comparison

Figure 152 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

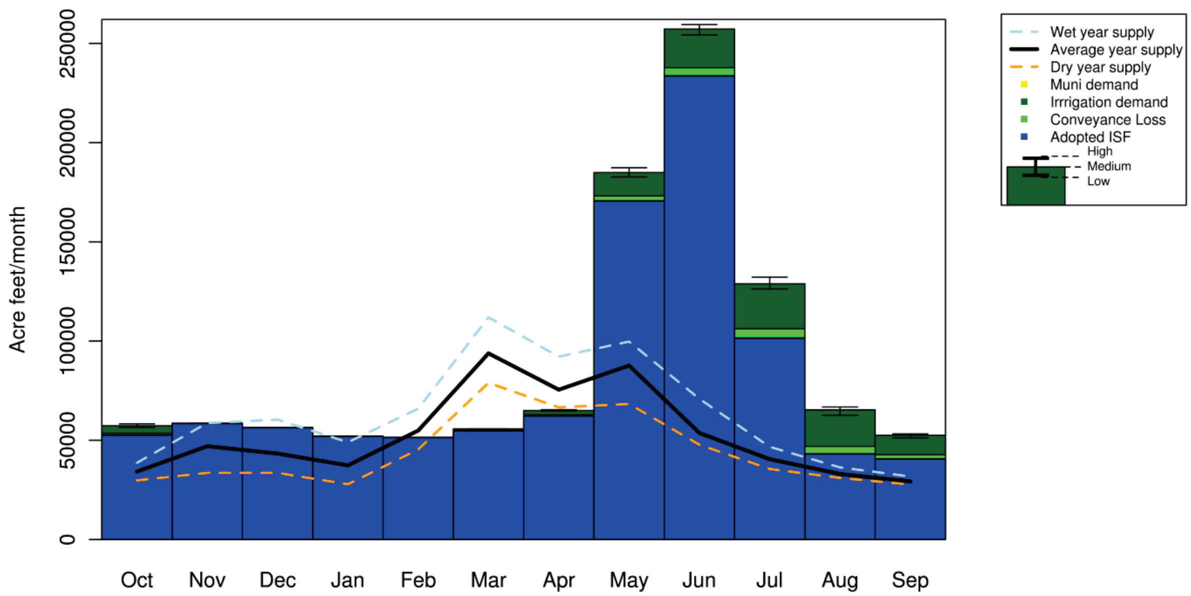


Figure 152. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.24.4.1 WRIA 49 Curtailment Analysis (for applicable WRIAs)

Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in every year between 1977 and 2006. The resulting unmet demand ranged from 144 to 11,388 ac-ft per year depending on yearly flow conditions, with an average of 4,426 ac-ft per year. Simulation of future curtailment occurred in 97% of years for the middle climate scenario. The resulting unmet demand per year ranged from 263 to 21,292 with an average of 10,464 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

Modeling also indicated that at the WRIA level there was insufficient water to meet the instream flow targets in every year between 1977 and 2006. The resulting unmet instream flow ranged from 412,874 to 1,303,441 with an average of 859,762 ac-ft per year. Simulation of future insufficient water occurred in every year for the middle climate scenario. The resulting unmet flow per year ranged from 293,542 to 1,351,308 with an average of 797,773 ac-ft per year.

6.24.5 WRIA 49 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 153). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

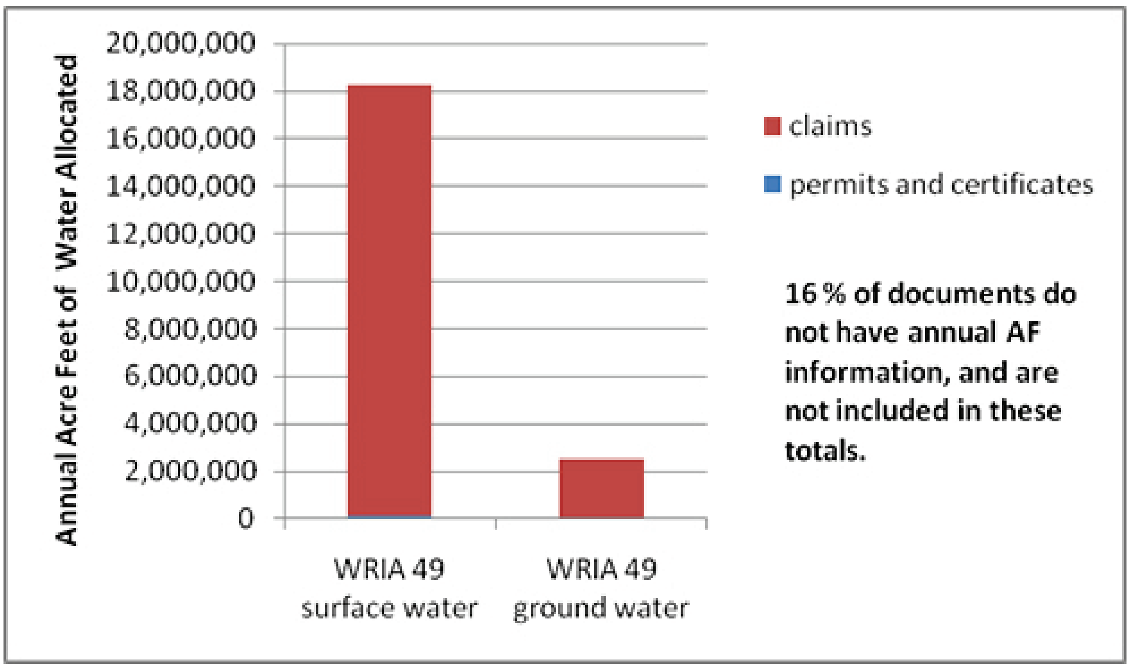


Figure 153. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.24.6 WRIA 49 Management Context

Some major management considerations for WRIA 49 are summarized in Table 51.

Table 51. Major management considerations in WRIA 49.

Management Context	
Adjudicated Areas	Similkameen River
	Sinlahekin Creek
	Whitestone Lake
	Bonaparte Creek & Lake
	Lower Antoine Creek
	Johnson Creek
	Duck Lake Groundwater Subarea
	Chiliwist Creek
	Salmon Creek, Lr & WF & tributaries
	Omak Creek (incomplete)
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-549 WAC)
	(interruptible users curtailed annually)
Fish Listed Under the Endangered Species Act[1]	Okanogan River Sockeye
	Upper Columbia Steelhead
	[Columbia mainstem migratory corridor]
Groundwater Management Area	YES (Duck Lake subarea)
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.25 WRIA 51, Nespelem

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The supply forecast for Nespelem is characterized mostly by very slight increases from mid-fall through winter.

Municipal/domestic demands are quite small in this watershed compared to other watersheds in eastern Washington, and there were no modeled irrigation demands in either the historical or the future period. Municipal demands are forecasted to grow 13% by 2030, a smaller increase than in many other watersheds of eastern Washington.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is not anticipated to create any agricultural irrigation water demand in this WRIA. Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is projected to be sufficient to meet combined municipal and surface water irrigation demands at the watershed scale. Additional water supplies may be available from the Columbia River in a localized area of the watershed. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of Nespelem, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.25.1 WRIA 51 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 154 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River Mainstem.

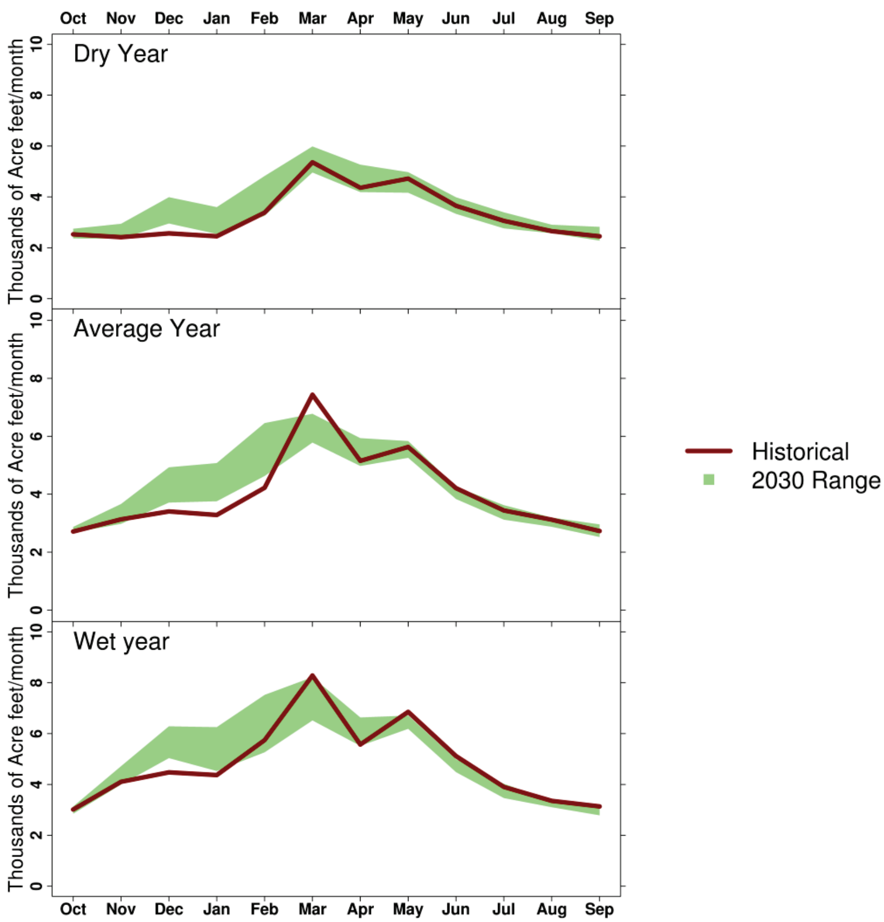


Figure 154. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.25.2 WRIA 51 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 155. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the “top of crop” and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

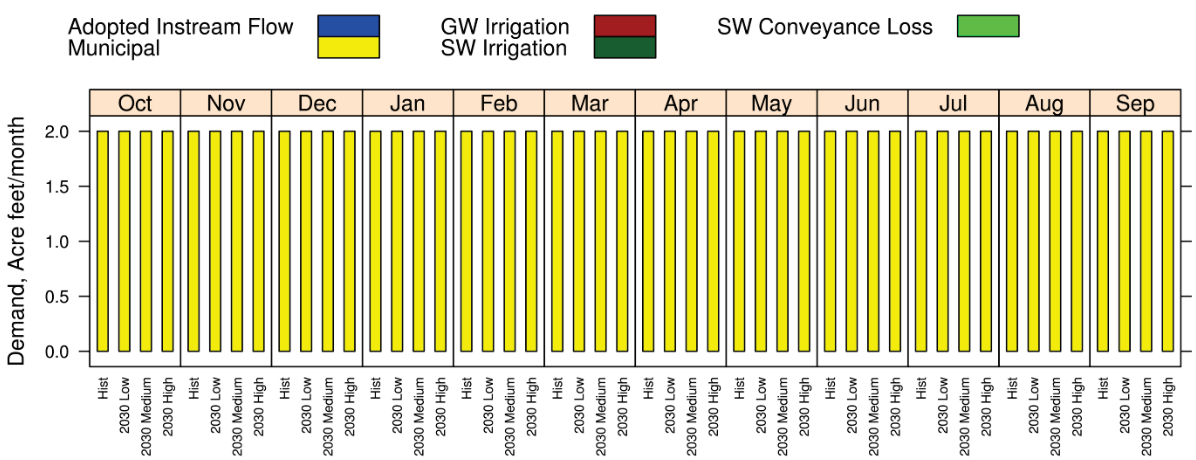


Figure 155. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.25.3 WRIA 51 Demand under Additional Water Capacity Scenarios

Figure 156 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

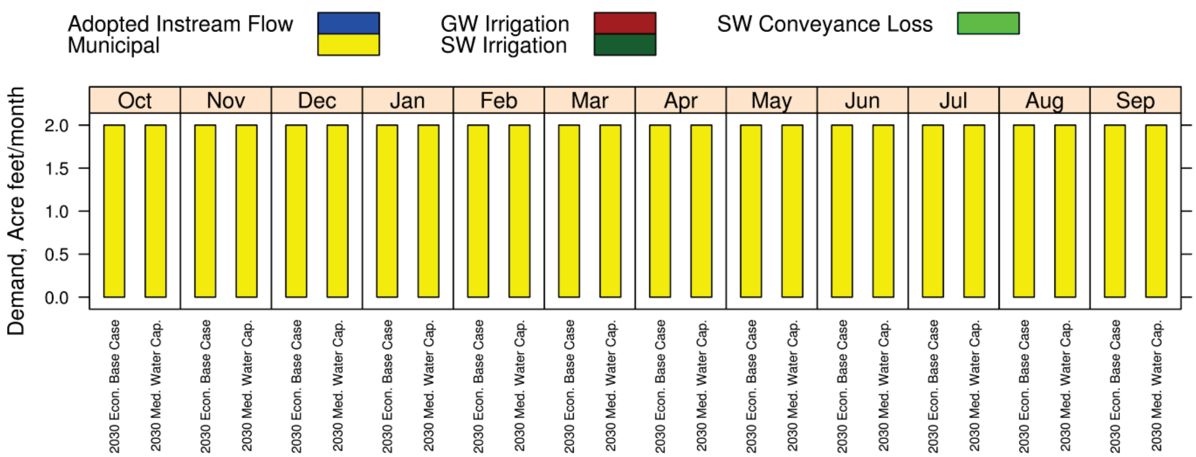


Figure 156. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.25.4 WRIA 51 Supply versus Demand Comparison

Figure 157 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

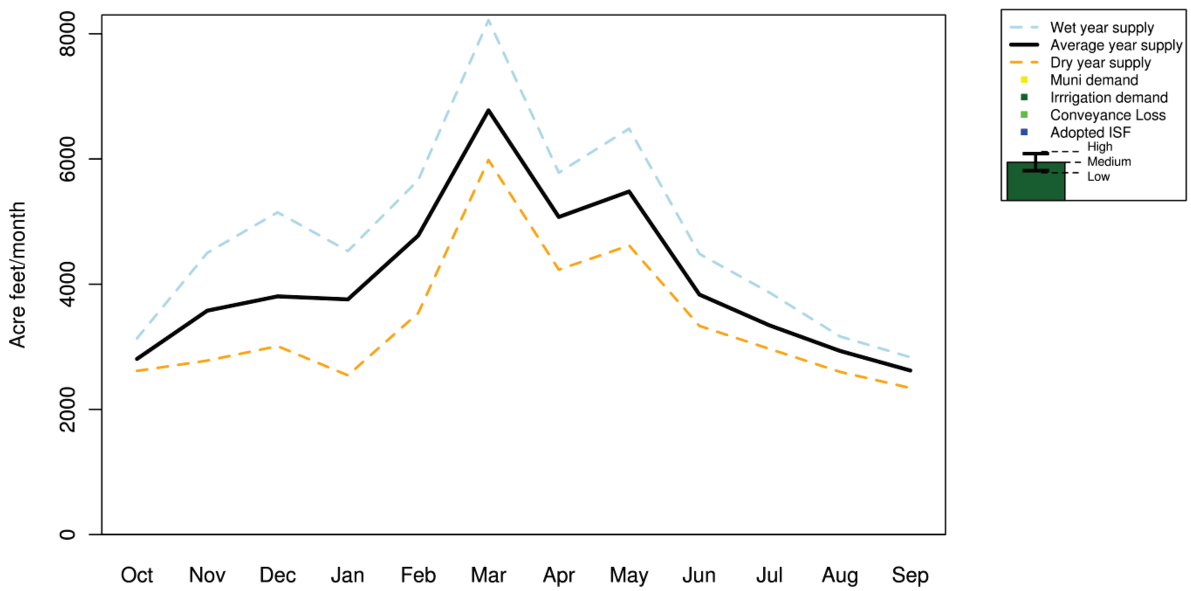


Figure 157. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.25.4.1 WRIA 51 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.25.5 WRIA 31 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 158). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

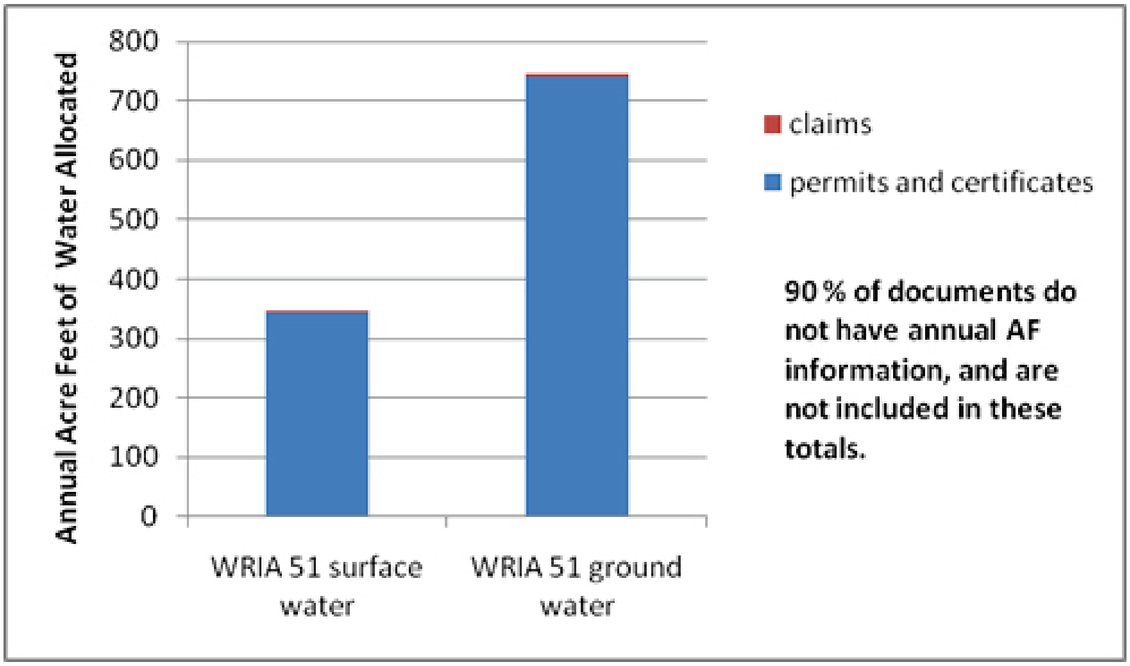


Figure 158. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.25.6 WRIA 51 Management Context

Some major management considerations for WRIA 51 are summarized in Table 52.

Table 52. Major management considerations in WRIA 51.

Management Context	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	None found

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.26 WRIA 52, Sanpoil

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Sanpoil is characterized mostly by increases from mid-fall through winter and slight decreases in average and wet years in late spring through early fall.

Both irrigation and municipal/domestic demands are quite small in this watershed. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in some months and decrease in others, with little change in impacts when alternate future economic scenarios are considered. Municipal demands are forecasted to grow 25% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is projected to be sufficient to meet combined municipal and surface water irrigation demands at the watershed scale. Additional water supplies may be available from the Columbia River in a localized area of the watershed. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of Sanpoil, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.26.1 WRIA 52 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 159 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

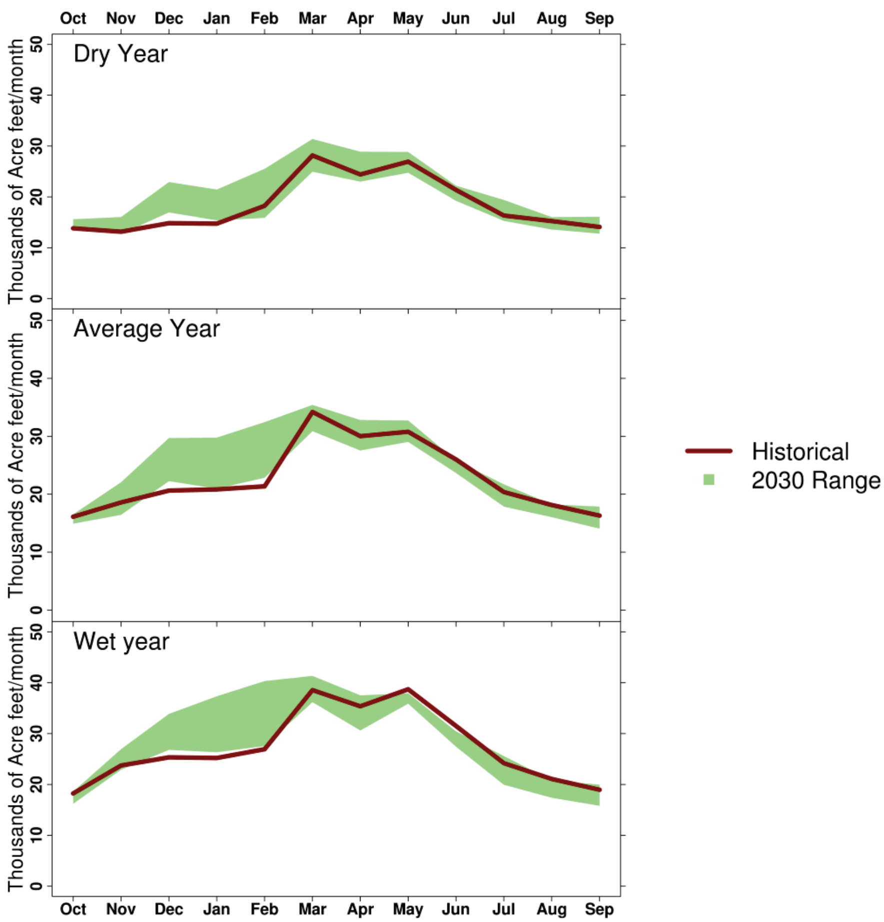


Figure 159. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.26.2 WRIA 52 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 160. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

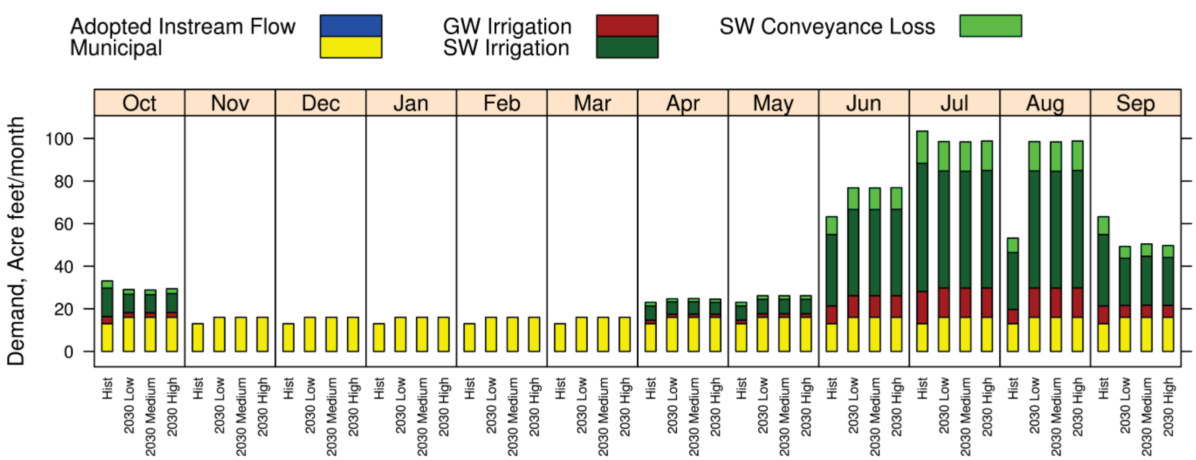


Figure 160. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.26.3 WRIA 52 Demand under Additional Water Capacity Scenarios

Figure 161 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

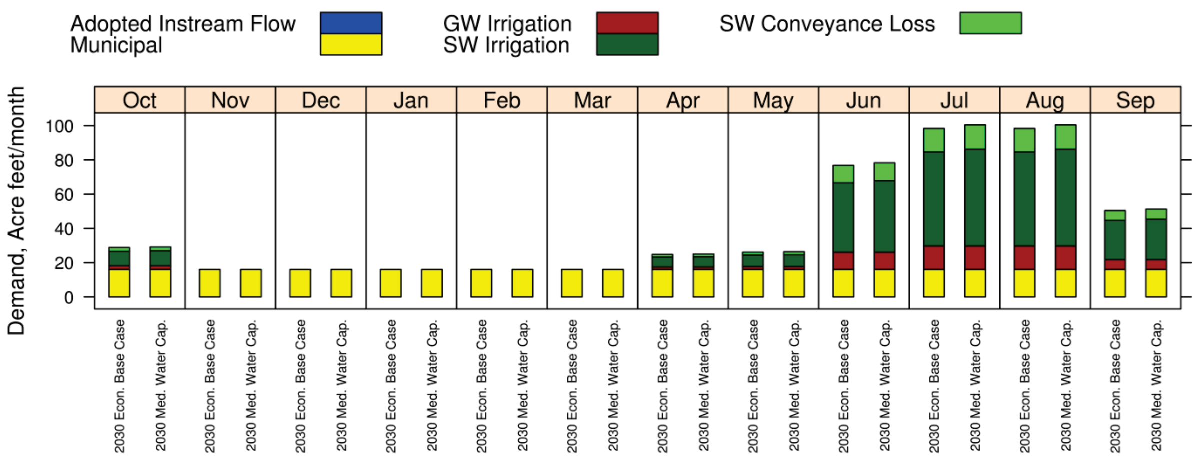


Figure 161. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.26.4 WRIA 52 Supply versus Demand Comparison

Figure 162 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

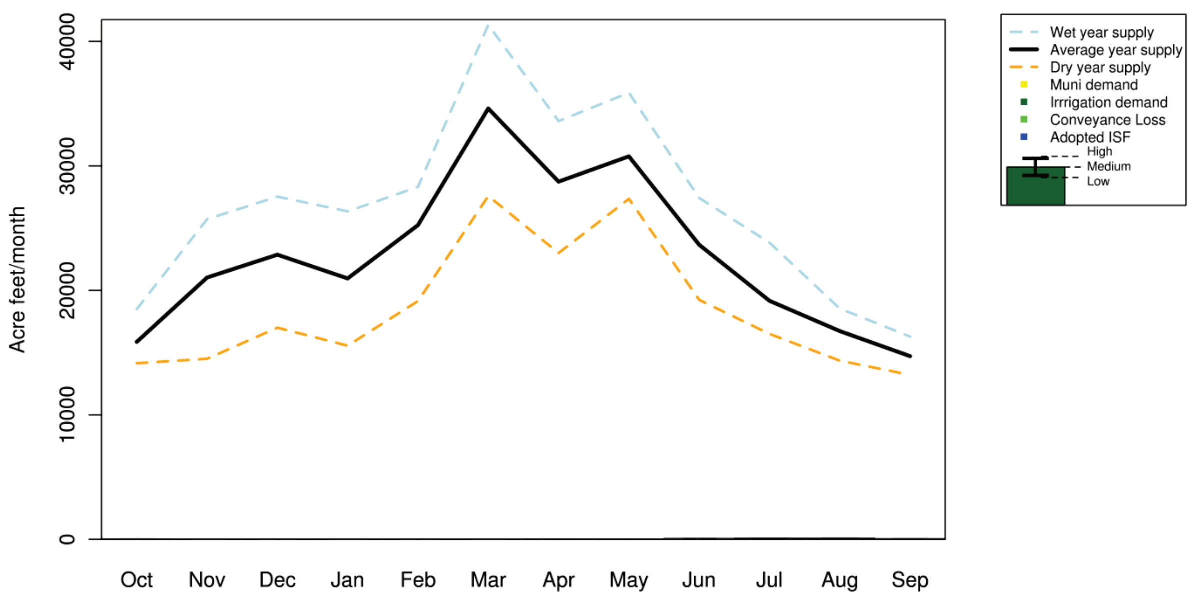


Figure 162. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.26.4.1 WRIA 52 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.26.5 WRIA 52 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 163). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

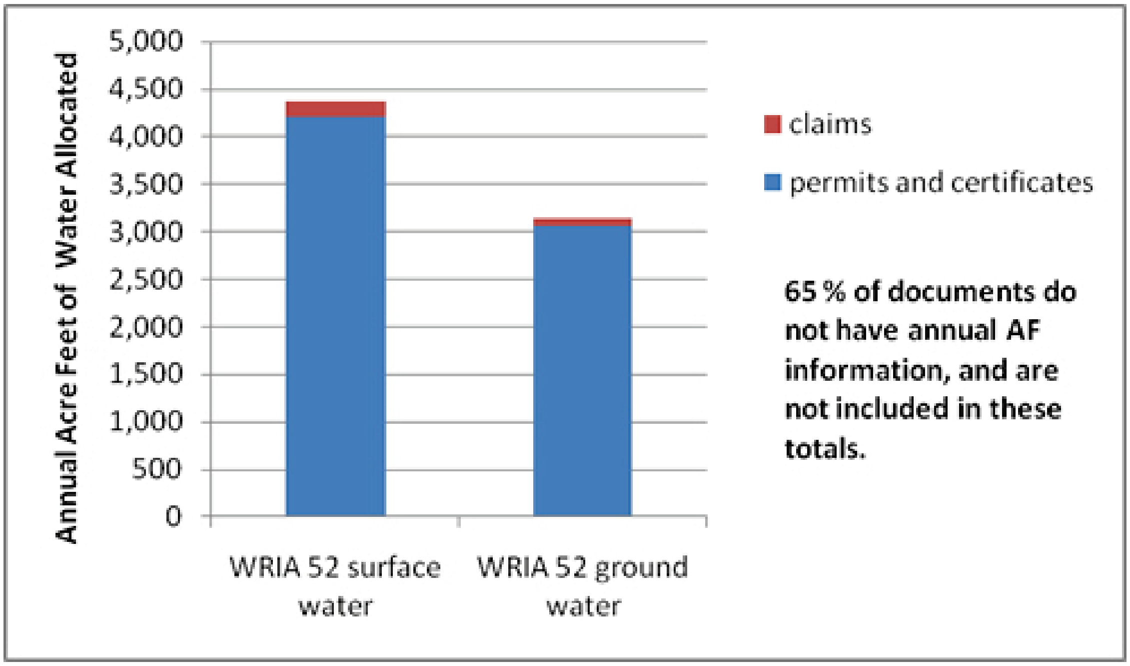


Figure 163. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.26.6 WRIA 52 Management Context

Some major management considerations for WRIA 52 are summarized in Table 53.

Table 53. Major management considerations in WRIA 52.

Management Context	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	None found

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.27 WRIA 53, Lower Lake Roosevelt

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Lower Lake Roosevelt is characterized mostly by small increases from late fall through winter.

Irrigation is the primary source of demand, though overall demands are modest in comparison to other watersheds within eastern Washington. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase for some months by 2030, with modest differences in the magnitude of changes when alternate future economic scenarios are considered. Municipal demands are forecasted to grow 24% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply would be sufficient on its own to meet combined municipal and surface water irrigation demands at the watershed scale. Additional water supplies from the Columbia River are available to meet demands in some areas of the WRIA, and a separate analysis indicates that more than half of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

The Northeast Washington Bull Trout, listed under the Endangered Species Act, spawn or rears in tributary waters of this watershed.

6.27.1 WRIA 53 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 164 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

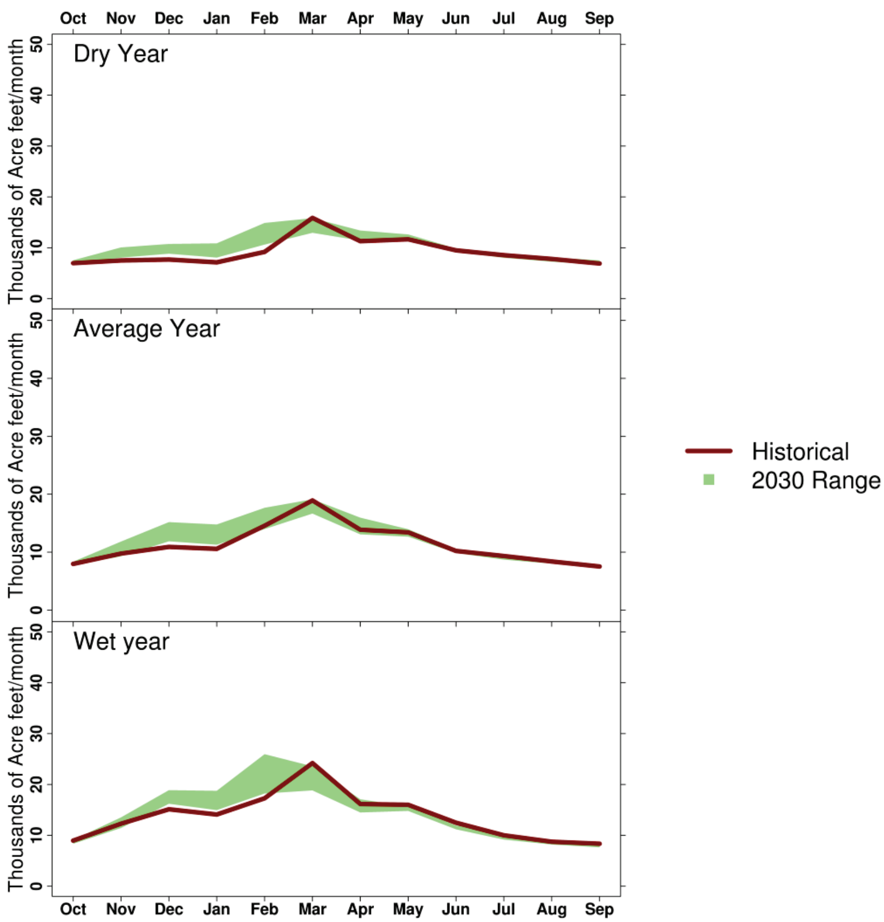


Figure 164. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.27.2 WRIA 53 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 165. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

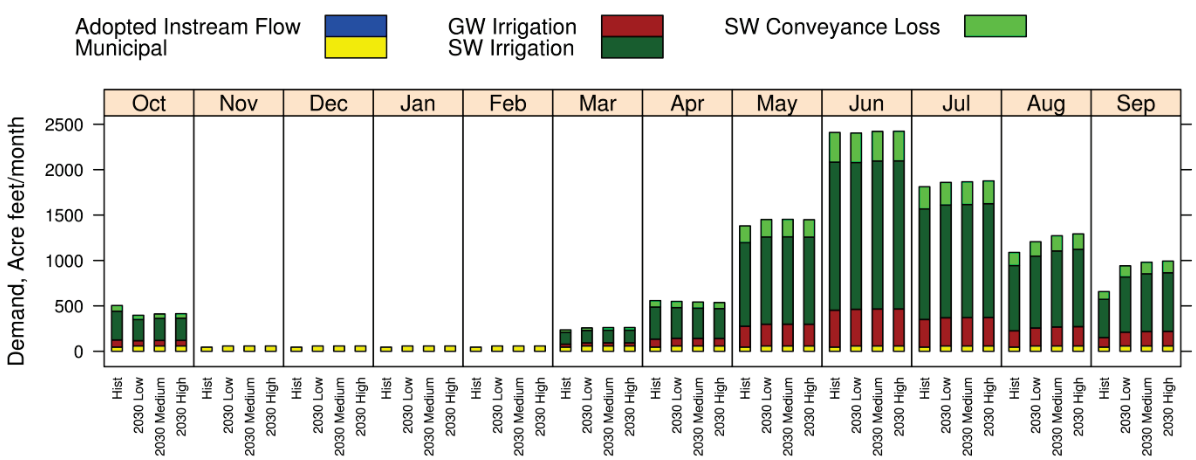


Figure 165. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.27.3 WRIA 53 Demand under Additional Water Capacity Scenarios

Figure 166 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

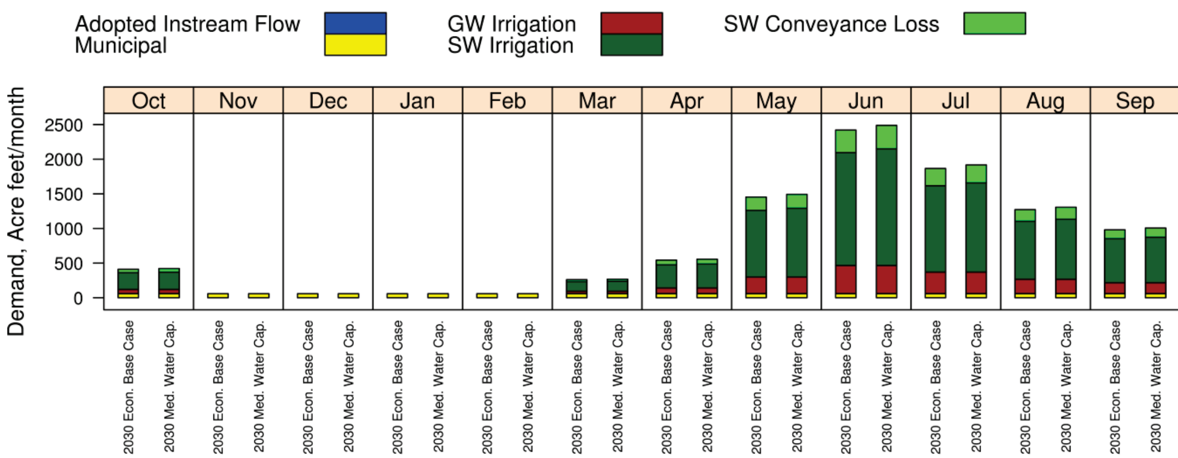


Figure 166. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.27.4 WRIA 53 Supply versus Demand Comparison

Figure 167 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

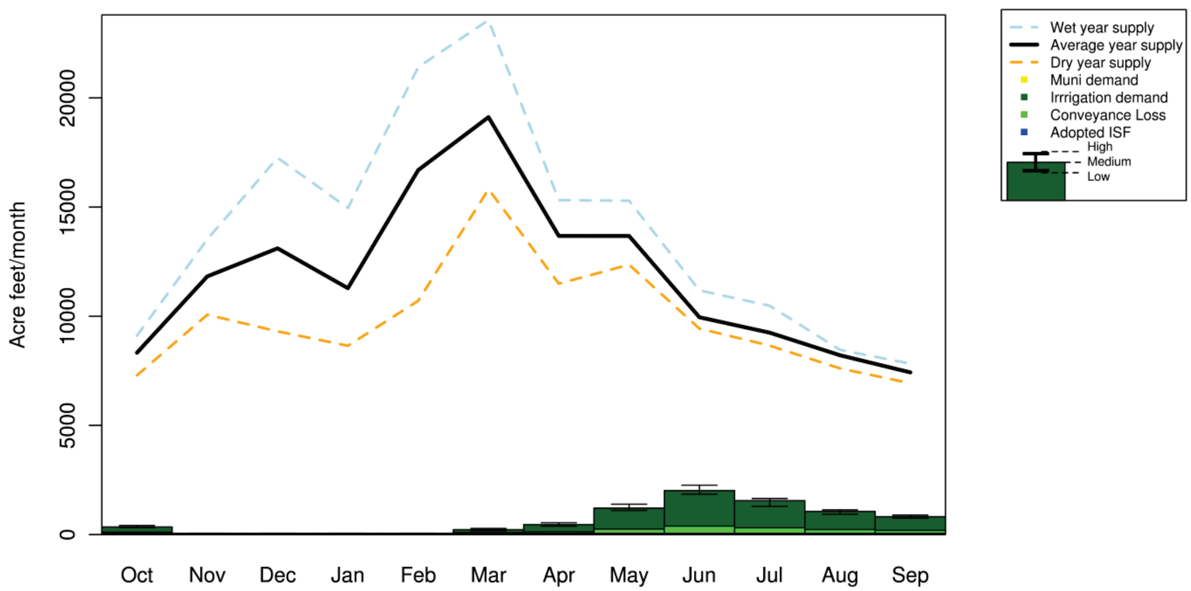


Figure 167. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.27.4.1 WRIA 53 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.27.5 WRIA 53 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 168). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

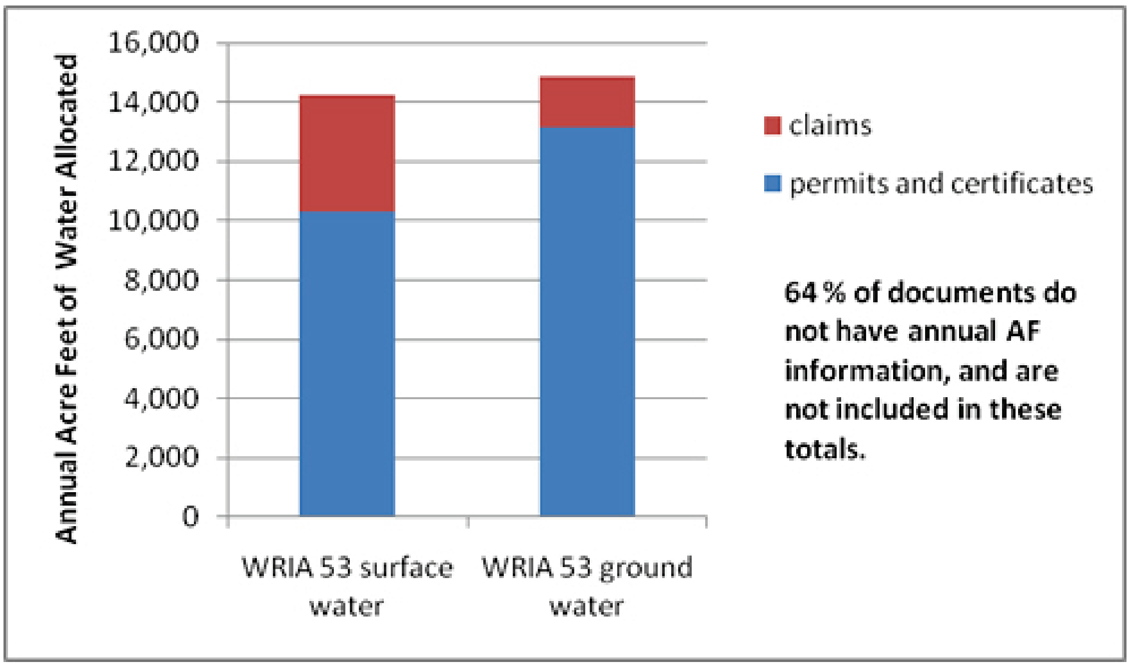


Figure 168. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.27.6 WRIA 53 Management Context

Some major management considerations for WRIA 53 are summarized in Table 54.

Table 54. Major management considerations in WRIA 53.

Management Context	
Adjudicated Areas	Hawkes Creek (incomplete)
Watershed Planning	Phase 2 (Assessment)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Northeast Washington Bull Trout
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.28 WRIA 54, Lower Spokane

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Lower Spokane is characterized mostly by increases from late fall through early spring.

Irrigation demands are larger than municipal demands in this watershed, though they are relatively modest overall. Assuming no change in irrigated acreage, irrigation demand is projected to increase in many months in the future, but decrease in others. The magnitude of change is similar across all future economic scenarios. Municipal demand is forecasted to increase 32% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply is projected to be sufficient to meet combined municipal and surface water irrigation demands at the watershed scale. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of the Lower Spokane, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.28.1 WRIA 54 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 169 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River Mainstem.

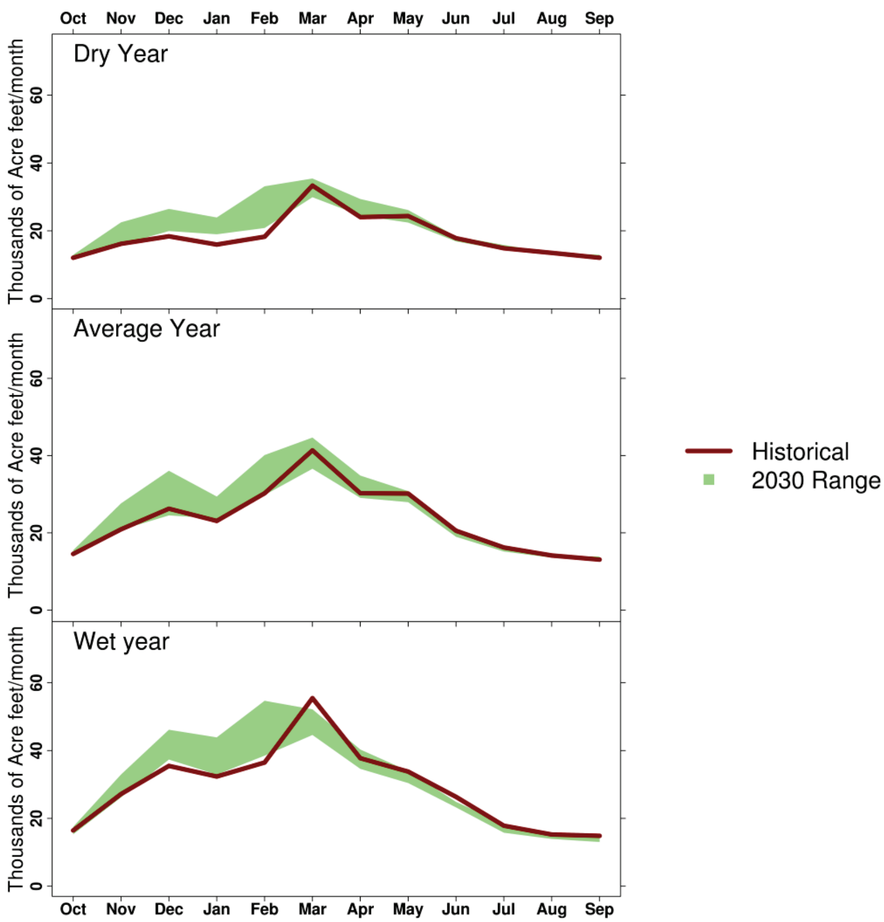


Figure 169. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.28.2 WRIA 54 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 170. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

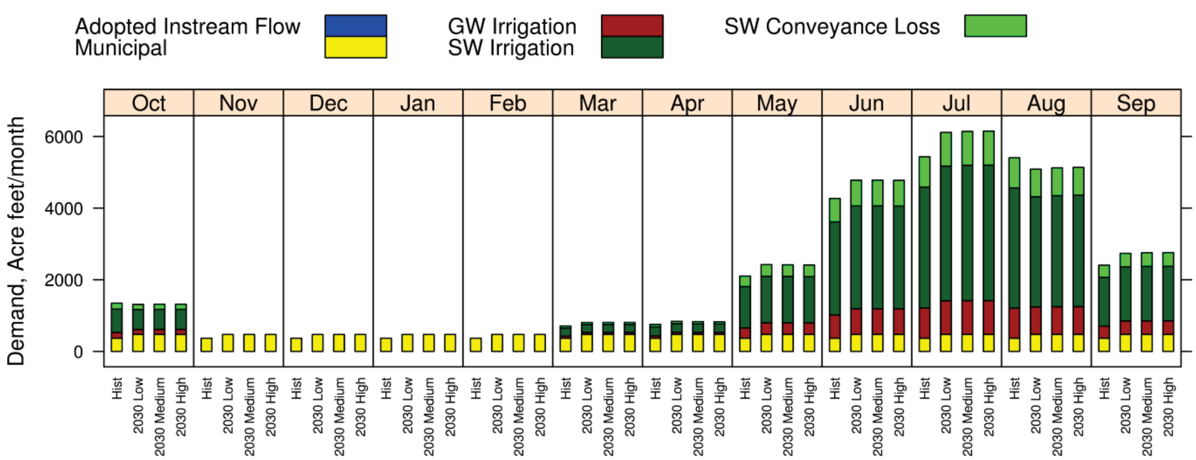


Figure 170. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.28.3 WRIA 54 Demand under Additional Water Capacity Scenarios

Figure 171 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

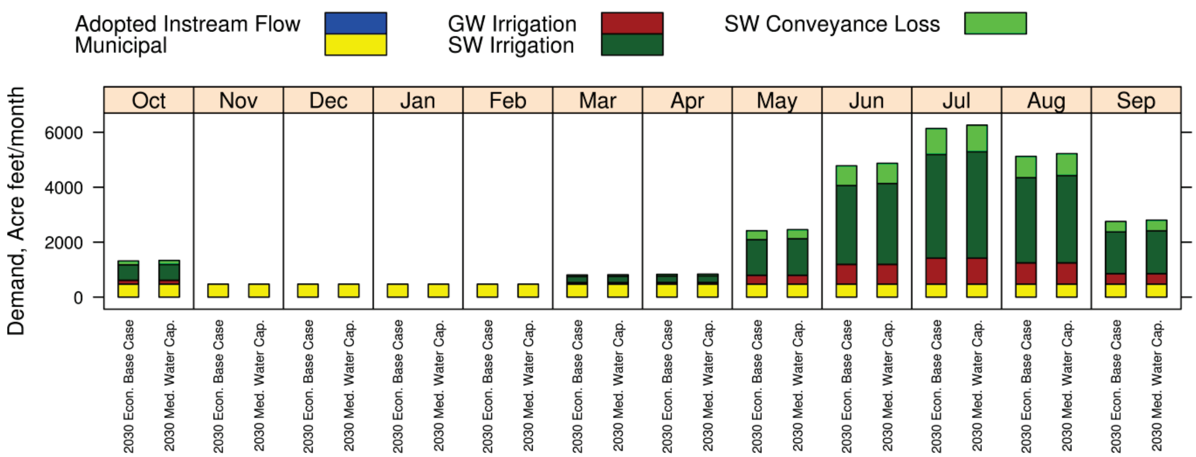


Figure 171. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.28.4 WRIA 54 Supply versus Demand Comparison

Figure 172 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

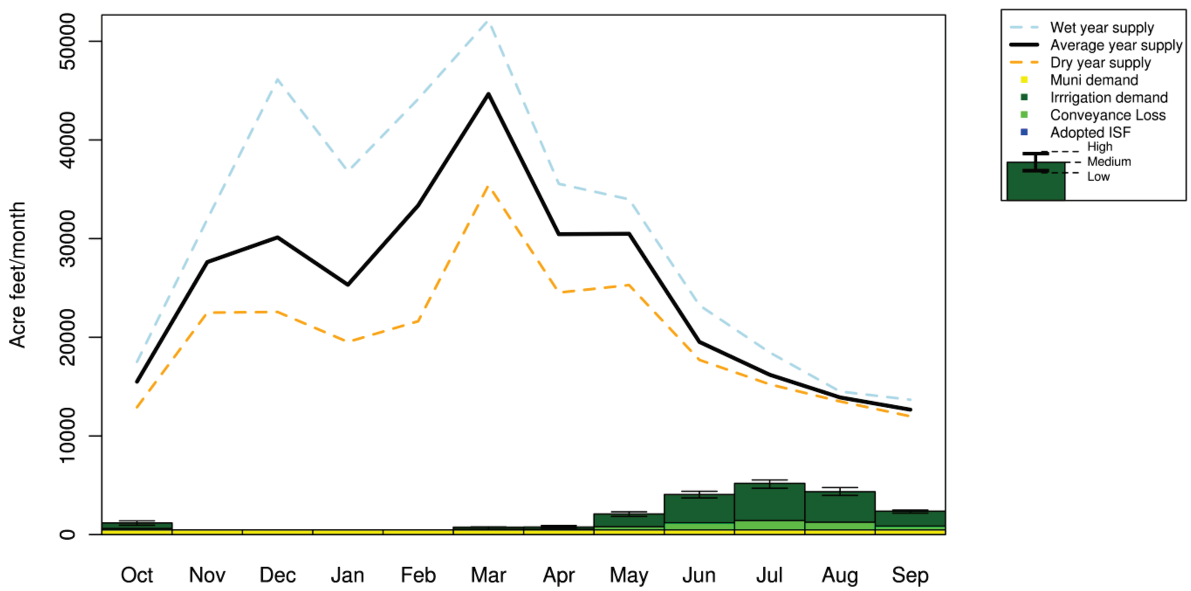


Figure 172. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.28.4.1 WRIA 54 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.28.5 WRIA 54 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 173). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

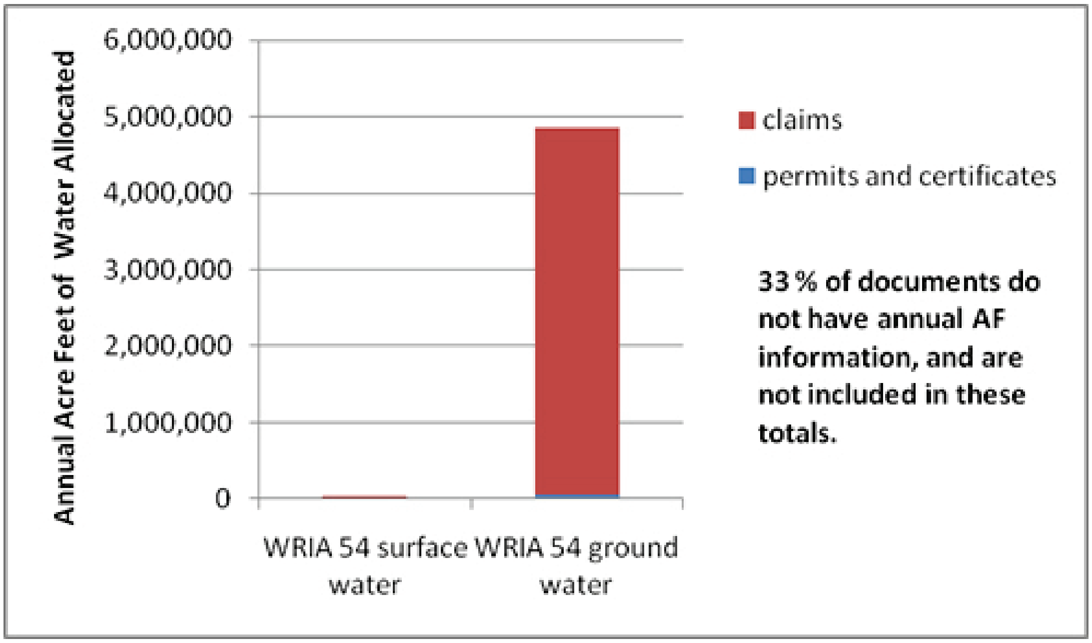


Figure 173. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.28.6 WRIA 54 Management Context

Some major management considerations for WRIA 54 are summarized in Table 55.

Table 55. Major management considerations in WRIA 54.

Management Context	
Adjudicated Areas	Chamokane Creek (incomplete)
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.29 WRIA 55, Little Spokane

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Little Spokane is characterized mostly by increases from the fall through early spring, and smaller decreases in summer and early fall under average and wet flow conditions.

Instream flow requirements are the largest water demands in Little Spokane. Municipal demands are larger than in many other watersheds of eastern Washington, exceeding irrigation demand. Adopted instream flows are shown by the instream flow requirements for the Little Spokane confluence, as specified in Chapter 173-555 WAC, for both the historical and future period. Municipal demand is projected to increase 13% by 2030. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase modestly in many months in the future, with impacts that varied only slightly in magnitude between the alternate future economic scenarios considered.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, at the watershed scale, combined municipal and surface water irrigation demands and adopted instream flows are projected to outstrip unregulated tributary supply generated within the Washington portion of the watersheds during most years for May through February and year-round under low flow conditions. Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in every year between 1977 and 2005. The resulting unmet demand ranged from 1,130 to 3,541 ac-ft per year depending on yearly flow conditions, with an average of 2,503 ac-ft per year. Simulation of future curtailment occurred in all the years for the middle climate scenario. The resulting unmet demand per year ranged from 1,512 to 3,870 with an average of 1,512 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet adopted instream flows are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of these watersheds, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.29.1 WRIA 55 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 174 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

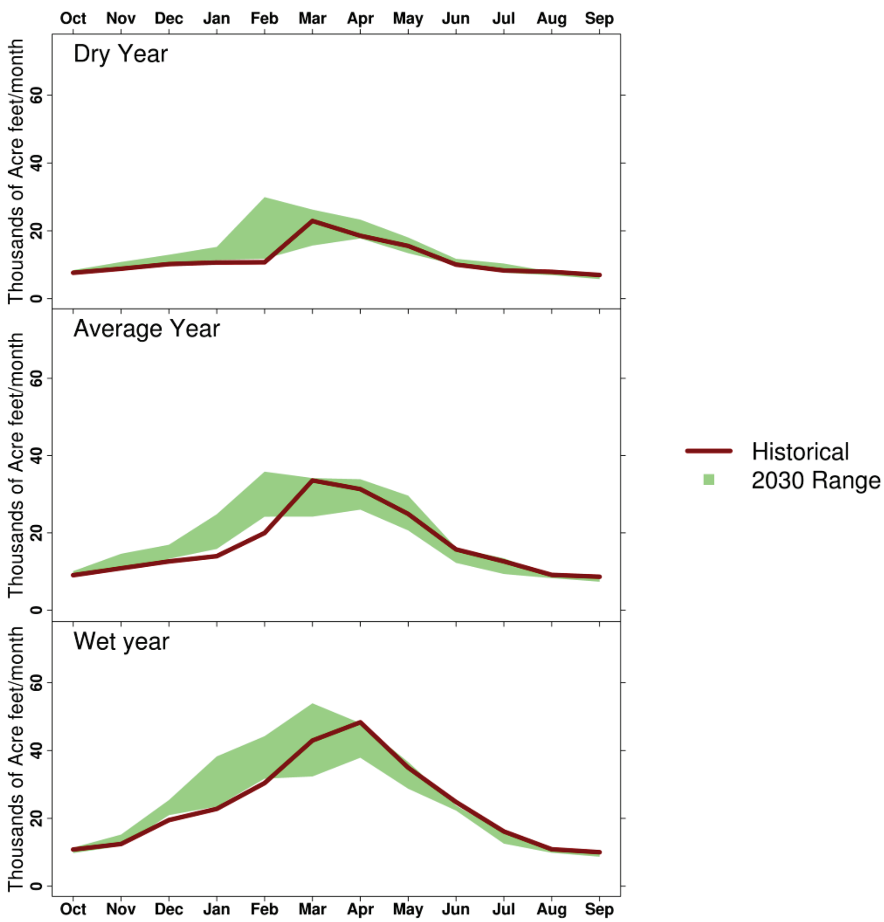


Figure 174. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.29.2 WRIA 55 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 175. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

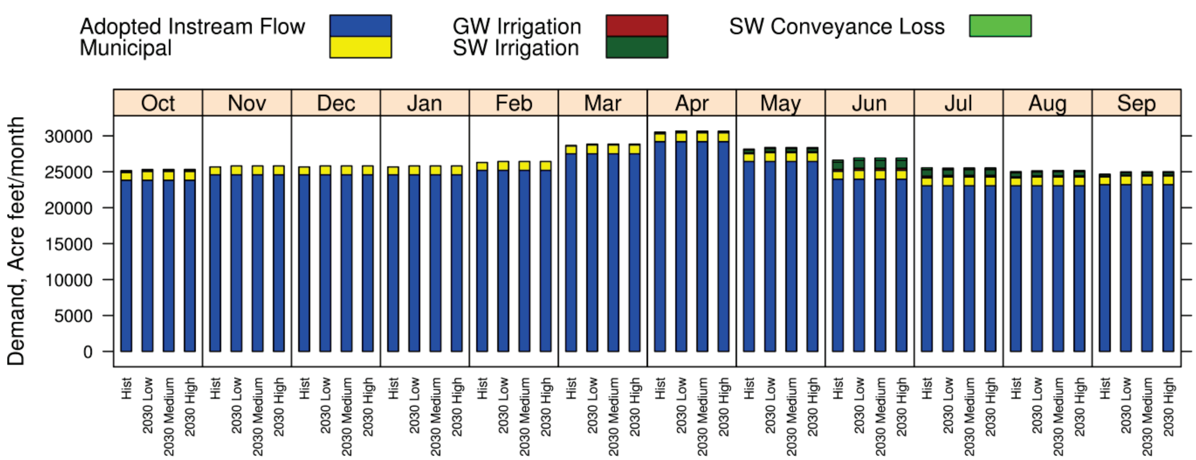


Figure 175. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.29.3 WRIA 55 Demand under Additional Water Capacity Scenarios

Figure 176 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

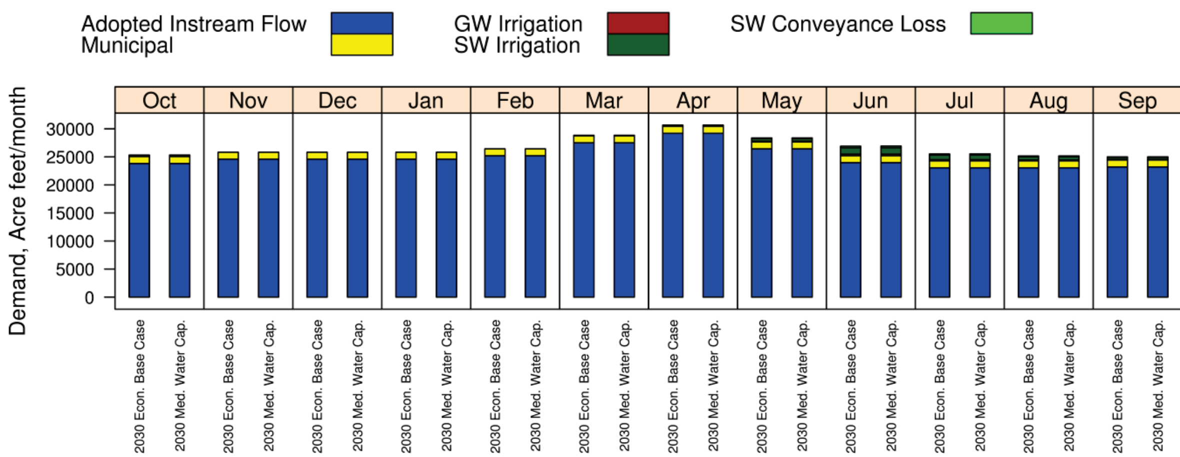


Figure 176. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.29.4 WRIA 55 Supply versus Demand Comparison

Figure 177 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

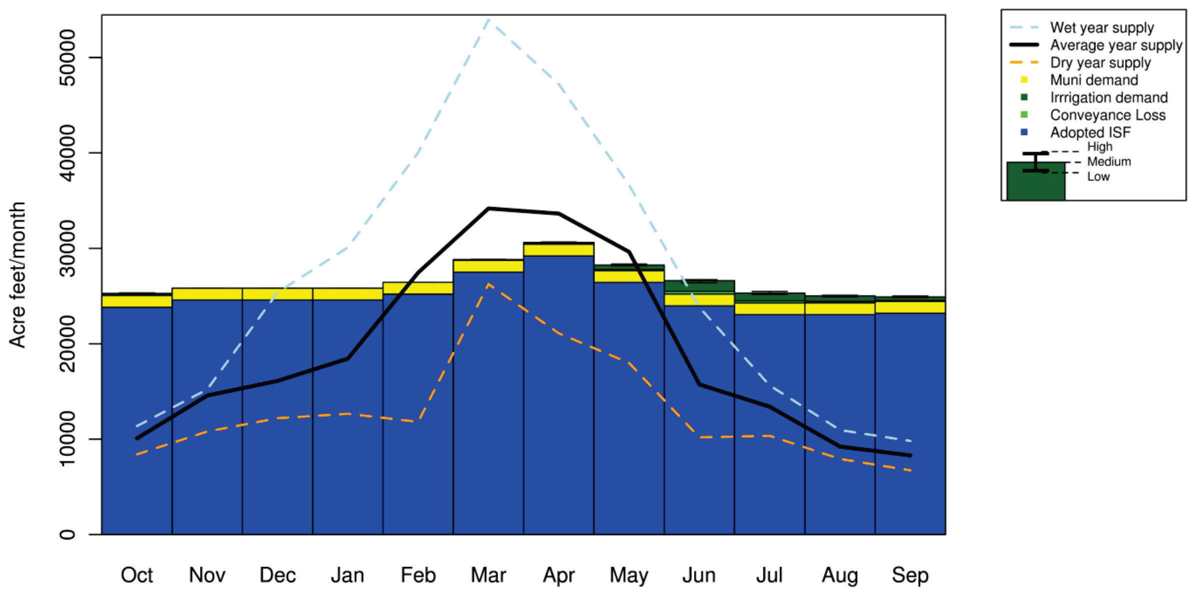


Figure 177. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.29.4.1 WRIA 55 Curtailment Analysis (for applicable WRIAs)

Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in every year between 1977 and 2005. The resulting unmet demand ranged from 1,130 to 3,541 ac-ft per year depending on yearly flow conditions, with an average of 2,503 ac-ft per year. Simulation of future curtailment occurred in all the years for the middle climate scenario. The resulting unmet demand per year ranged from 1,512 to 3,870 with an average of 1,512 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

Modeling also indicated that at the WRIA level there was insufficient water to meet the instream flow targets in every year between 1977 and 2006. The resulting unmet instream flow ranged from 59,463 to 225,247 with an average of 122,093 ac-ft per year. Simulation of future insufficient water occurred in all the years for the middle climate scenario. The resulting unmet flow per year ranged from 41,469 to 183,923 with an average of 102,607 ac-ft per year.

6.29.5 WRIA 55 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 178). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

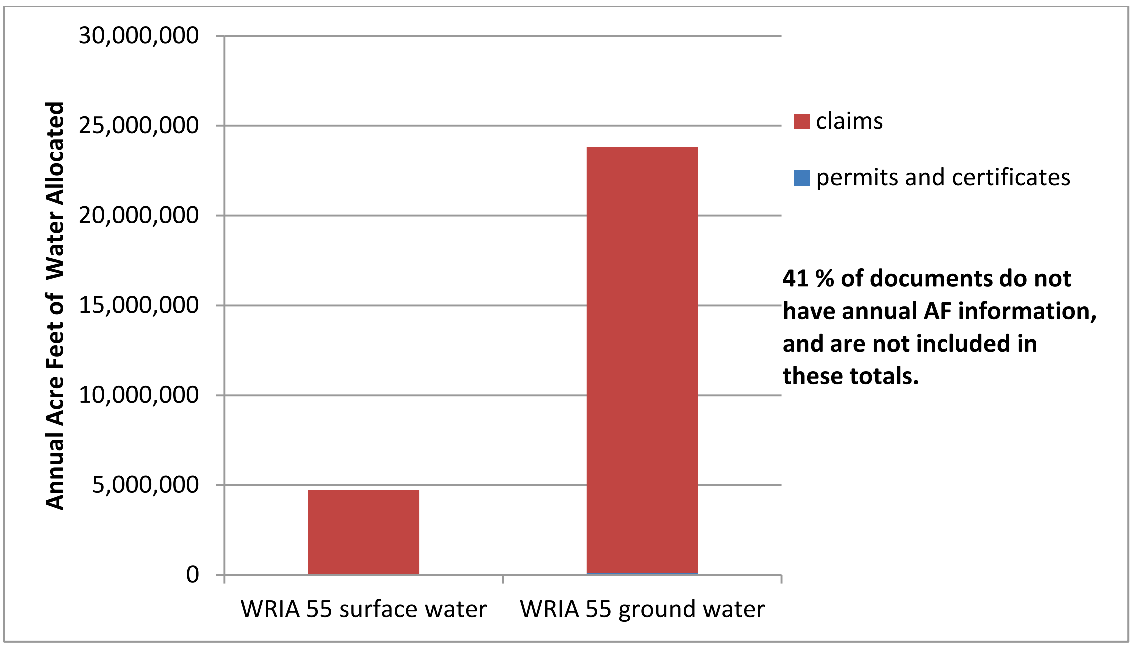


Figure 178. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.29.6 WRIA 55 Management Context

Some major management considerations for WRIA 55 are summarized in Table 56.

Table 56. Major management considerations in WRIA 55.

Management Context	
Adjudicated Areas	Deadman Creek
	Bigelow Gulch Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-555 WAC)
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.30 WRIA 56, Hangman

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Hangman is characterized mostly by substantial increases in late fall and winter.

Unlike many other watersheds in eastern Washington, municipal demands are larger than irrigation demands in Hangman watershed. Municipal demand is forecasted to grow 9% by 2030. Assuming no change in irrigated acreage, irrigation demand is forecasted to increase in most months (May through July and Sept), with little difference in the magnitude of impacts from the consideration of alternate future economic scenarios.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is not anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, at the watershed scale, combined municipal and surface water irrigation demand is projected to outstrip unregulated tributary supply generated within the Washington portion of the watershed during most years for August and September, as well as July and October under some flow conditions. Upstream portions of WRIA 56 outside of Washington provide additional supplies, but may also have additional demands. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

No fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.30.1 WRIA 56 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 179 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

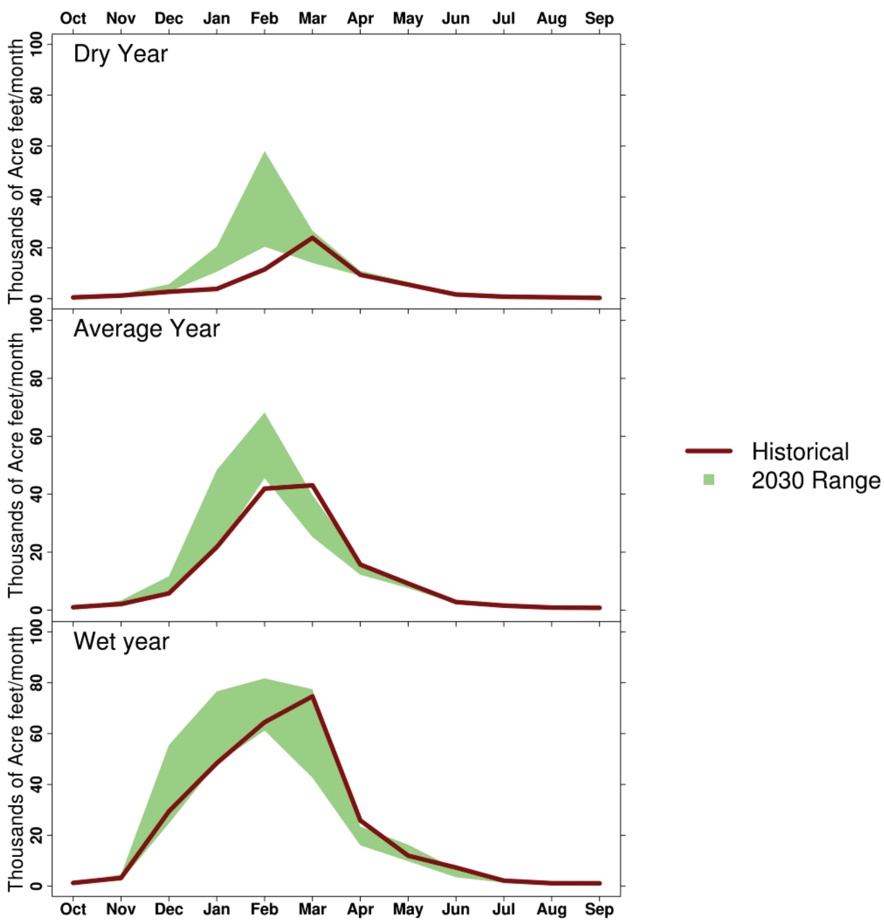


Figure 179. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.30.2 WRIA 56 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 180. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

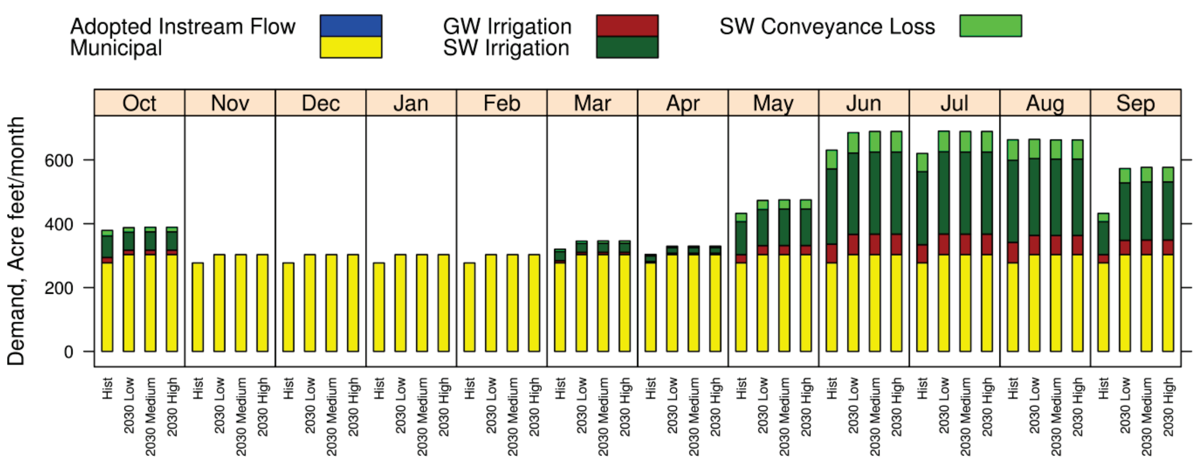


Figure 180. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.30.3 WRIA 56 Demand under Additional Water Capacity Scenarios

Figure 181 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

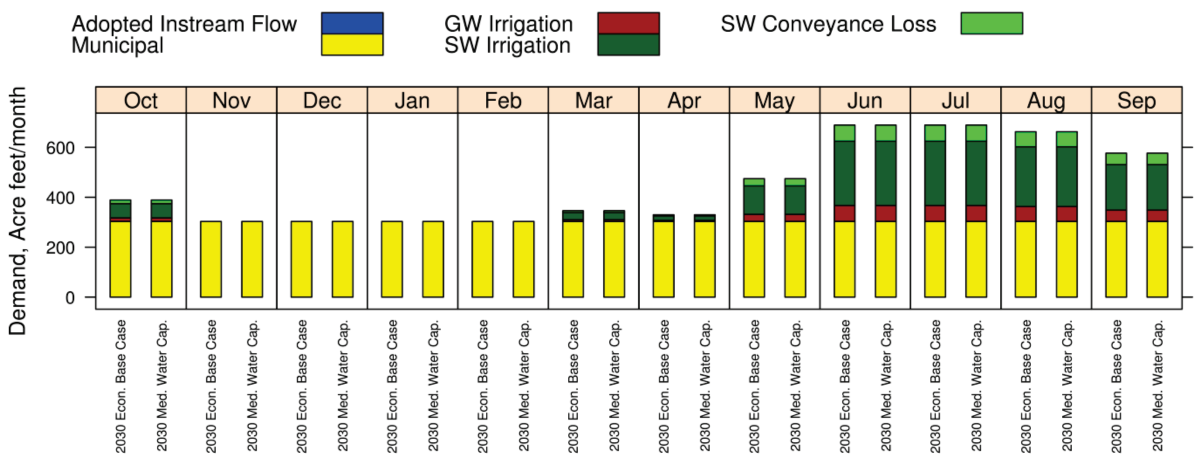


Figure 181. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.30.4 WRIA 56 Supply versus Demand Comparison

Figure 182 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

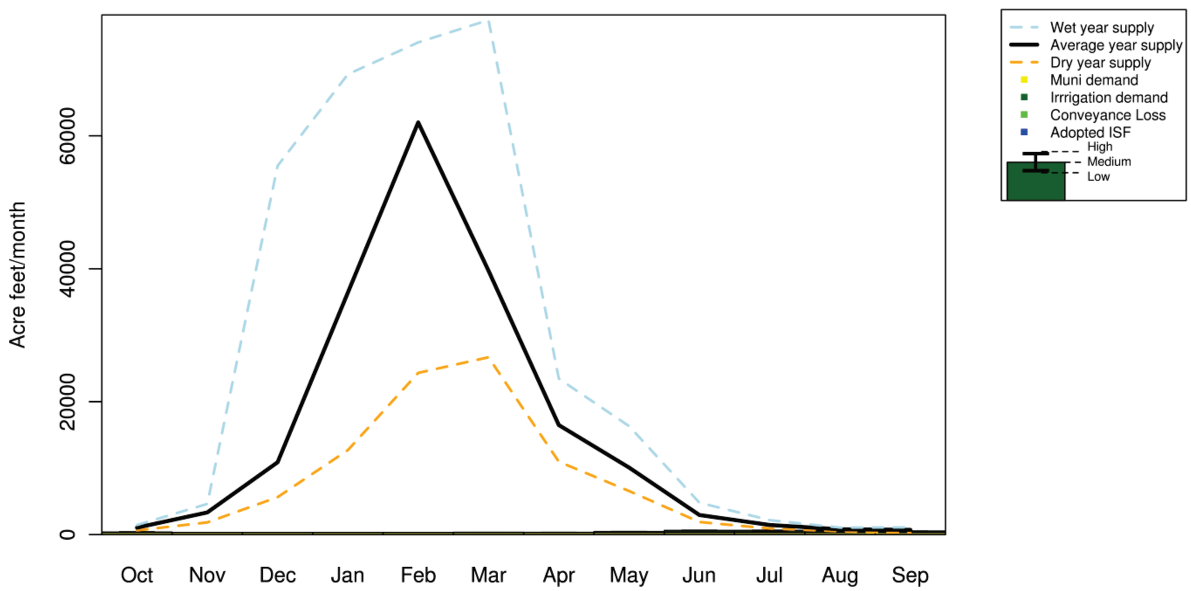


Figure 182. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.30.4.1 WRIA 56 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.30.5 WRIA 56 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 183). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

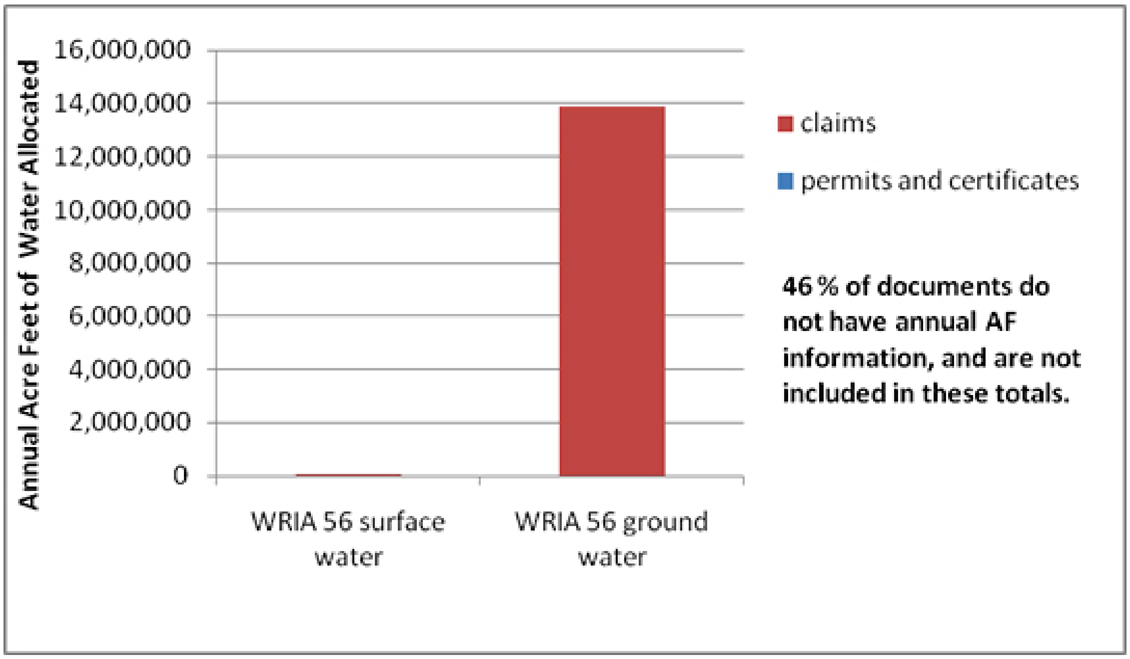


Figure 183. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.30.6 WRIA 56 Management Context

Some major management considerations for WRIA 56 are summarized in Table 57.

Table 57. Major management considerations in WRIA 56.

Management Context	
Adjudicated Areas	Crystal Springs
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.31 WRIA 57, Middle Lake Roosevelt

Supplies and demands are defined as described in Section 1.3 “Definitions of Water Supply and Water Demand Used in the 2011 Forecast.” The tributary surface water supply forecast for Middle Spokane is characterized mostly by increases from late fall through early spring, and smaller decreases in summer and early fall.

Municipal demands are the largest source of water demand in this watershed, and are also larger than in any other WRIA of eastern Washington. Municipal demand is projected to increase 34% by 2030. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase slightly in the fall, with little impact on the magnitude of change when alternate future economic scenarios were considered.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River “medium” scenario is not anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply generated within the Washington portion of the watershed is forecasted to be sufficient to meet combined municipal and surface water irrigation demand at the watershed scale. Upstream portions of WRIA 57 outside of Washington provide additional supplies, but may also have additional demands. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of these watersheds, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.31.1 WRIA 57 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 184 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

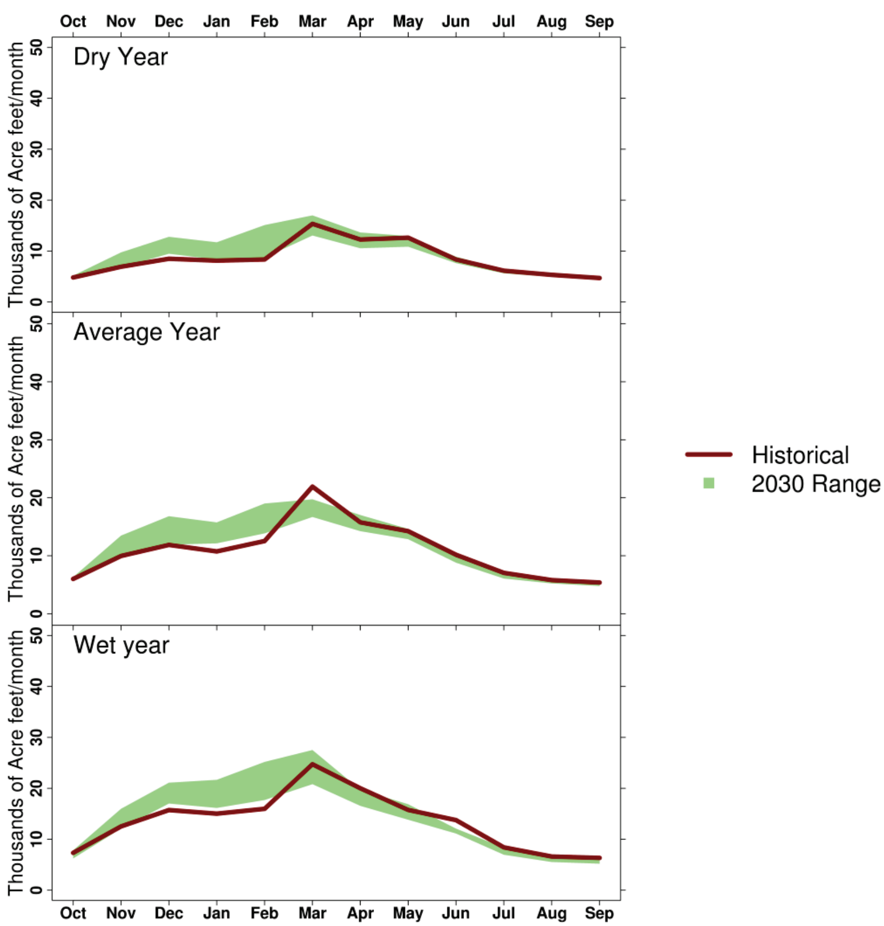


Figure 184. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.31.2 WRIA 57 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 185. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

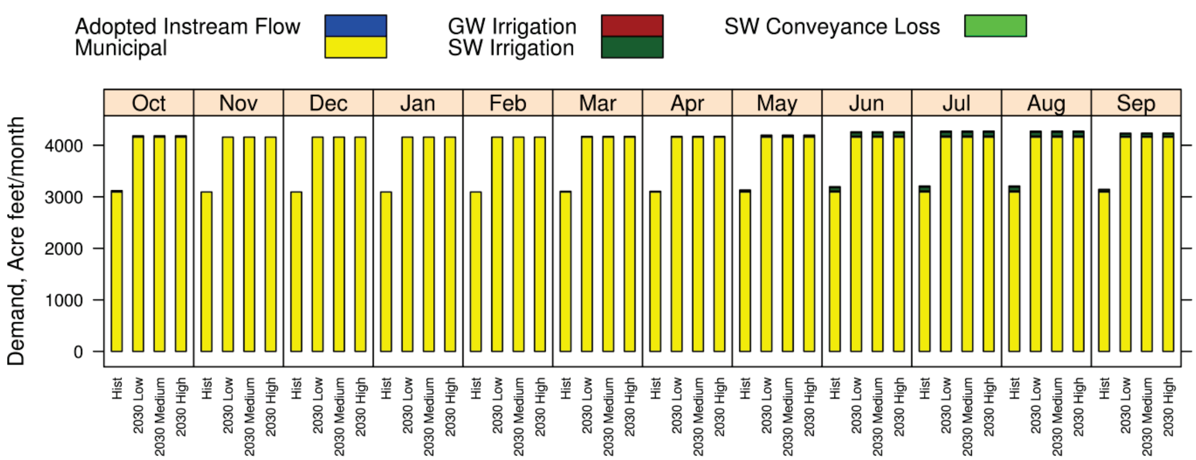


Figure 185. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.31.3 WRIA 57 Demand under Additional Water Capacity Scenarios

Figure 186 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

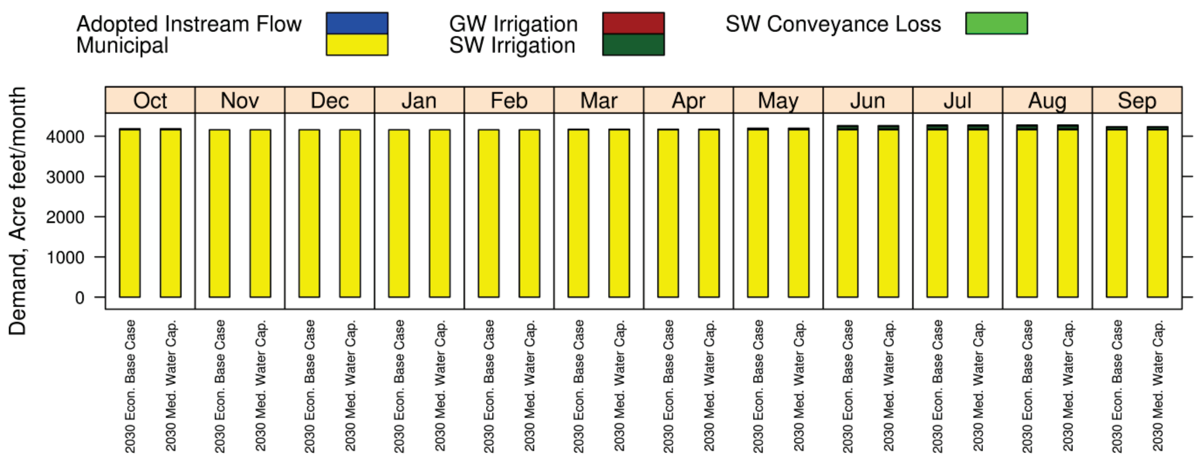


Figure 186. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.31.4 WRIA 57 Supply versus Demand Comparison

Figure 187 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

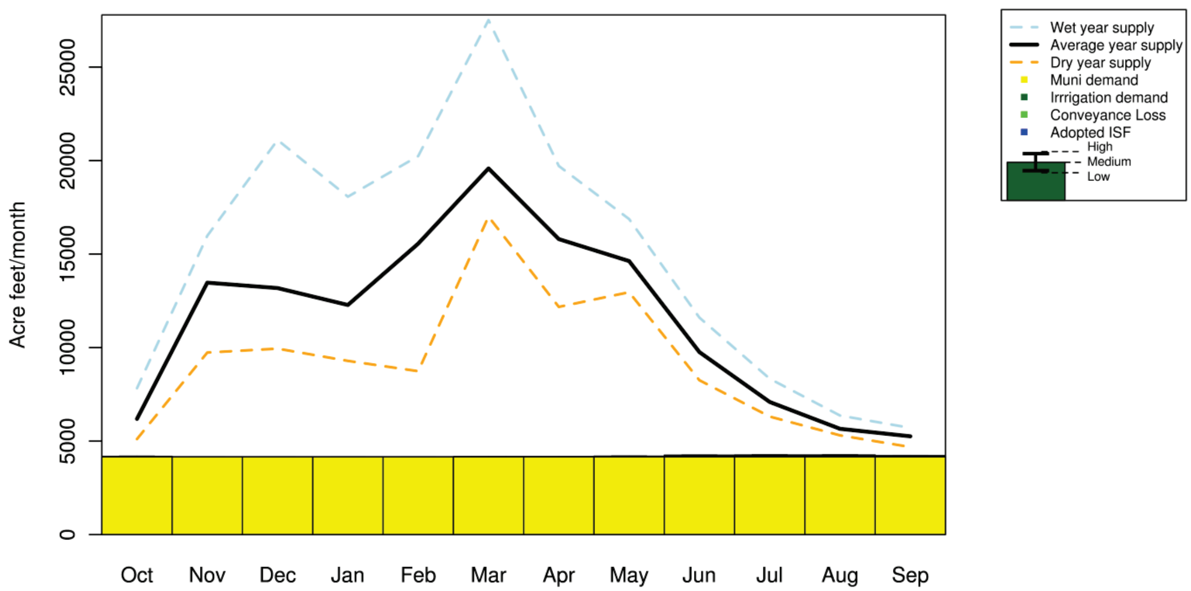


Figure 187. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.31.4.1 WRIA 57 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.31.5 WRIA 57 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 188). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

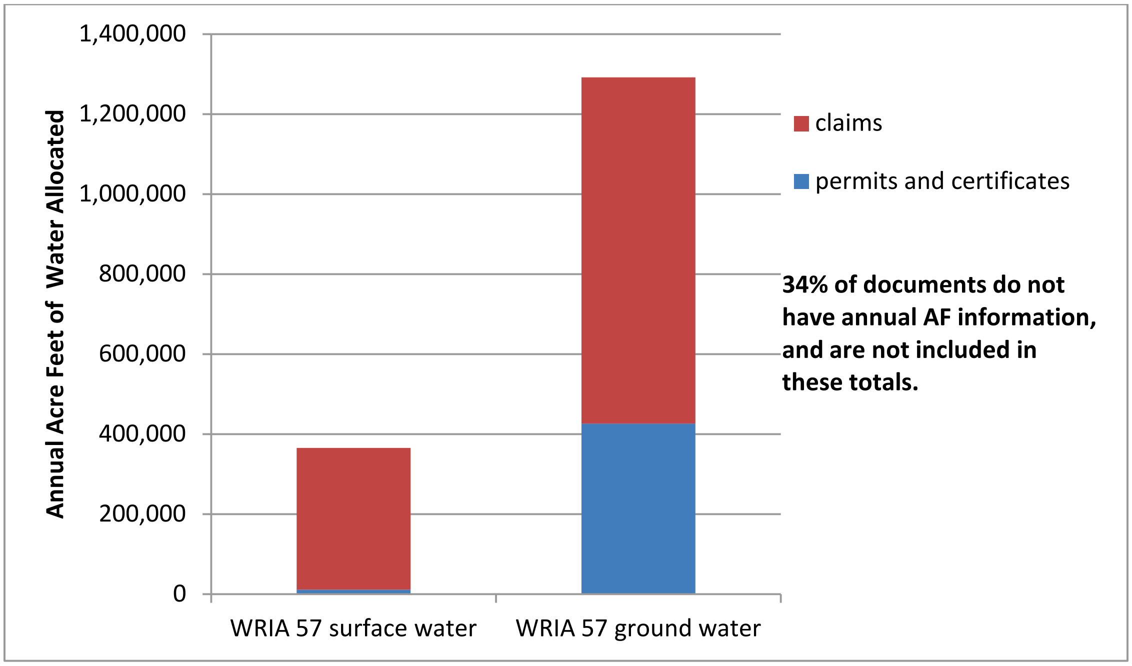


Figure 188. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.31.6 WRIA 57 Management Context

Some major management considerations for WRIA 57 are summarized in Table 58.

Table 58. Major management considerations in WRIA 57.

Management Context	
Adjudicated Areas	NONE
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.32 WRIA 58, Middle Lake Roosevelt

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Middle Lake Roosevelt is characterized mostly by increases from late fall through winter, and smaller decreases in the spring and summer under average and wet flow conditions.

Irrigation is a larger source of demand than municipal demand, though both demands are modest in comparison to other watersheds within eastern Washington. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase somewhat in most months of the summer and fall by 2030, with little impact on the magnitude of change from consideration of alternate future economic scenarios. Municipal demand is forecasted to grow 55% by 2030, though the total municipal demand will still be fairly small.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply would be sufficient to meet combined municipal and surface water irrigation demand on its own at the watershed scale, though additional water supplies from the Columbia River are important in this watershed. A separate analysis indicates that roughly 85% of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of these watersheds, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.32.1 WRIA 58 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 189 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

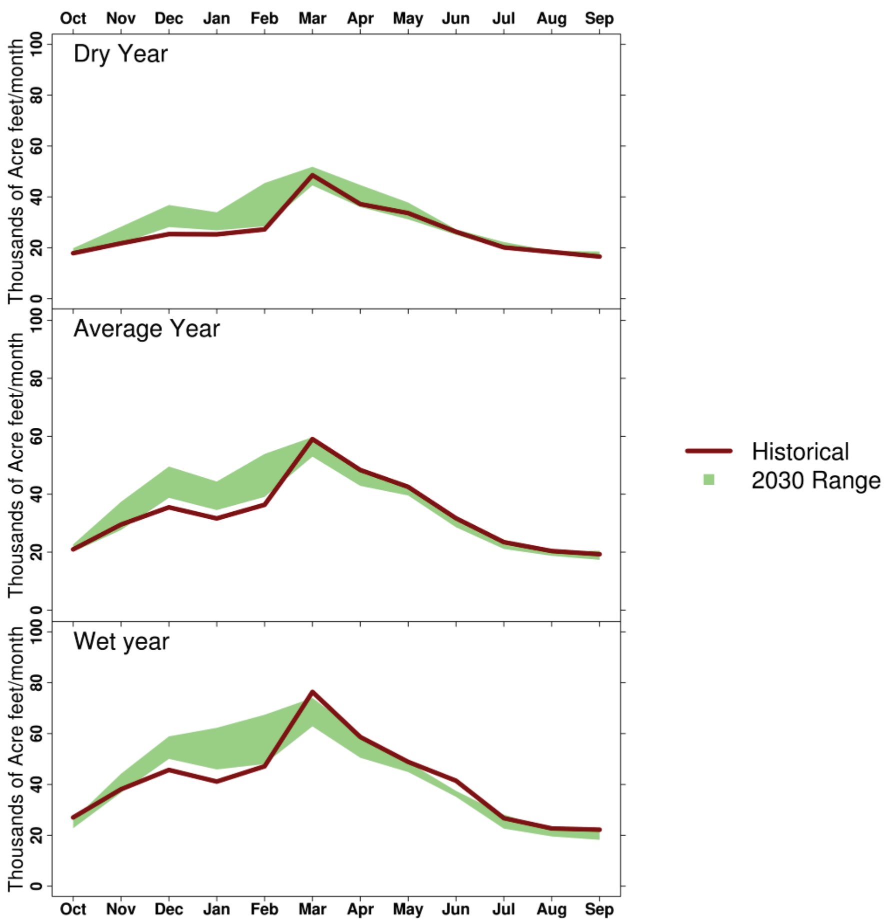


Figure 189. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.32.2 WRIA 58 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 190. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

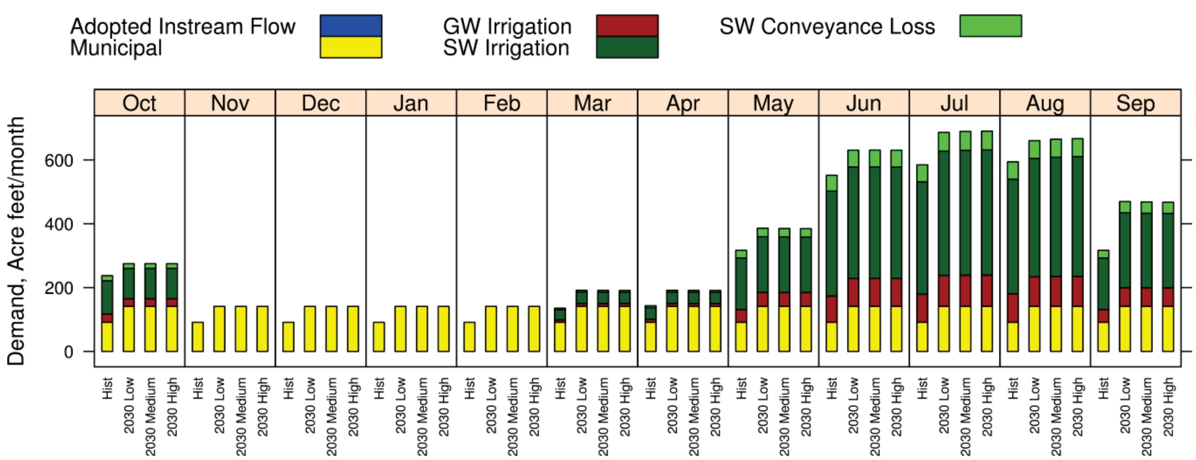


Figure 190. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.32.3 WRIA 58 Demand under Additional Water Capacity Scenarios

Figure 191 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

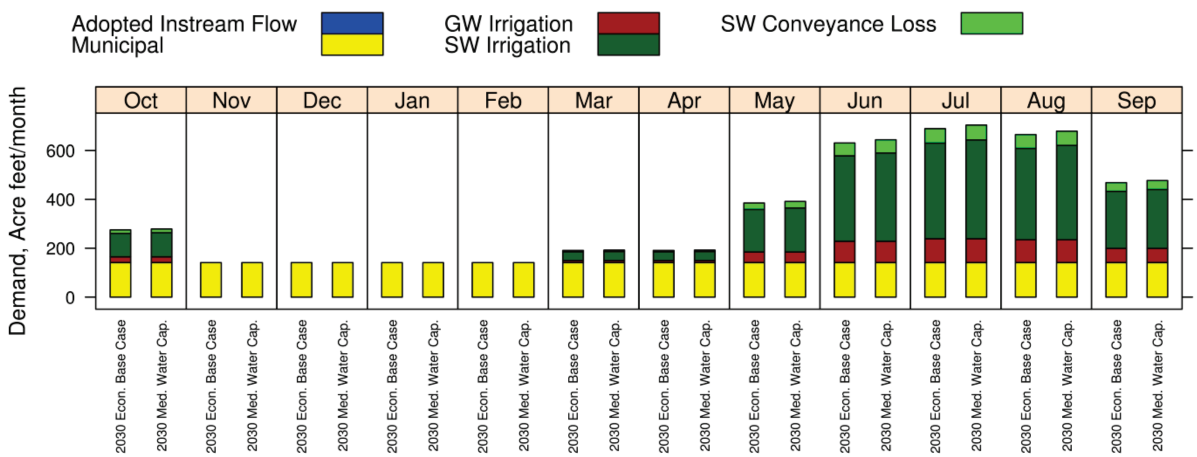


Figure 191. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.32.4 WRIA 58 Supply versus Demand Comparison

Figure 192 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

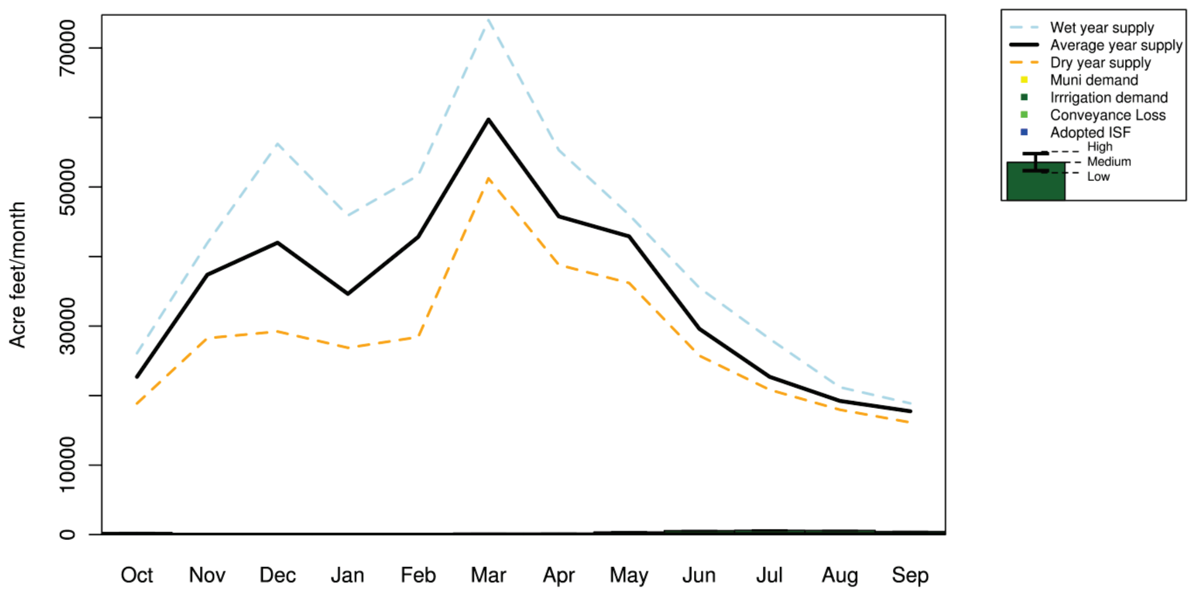


Figure 192. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.32.4.1 WRIA 58 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.32.5 WRIA 58 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 193). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

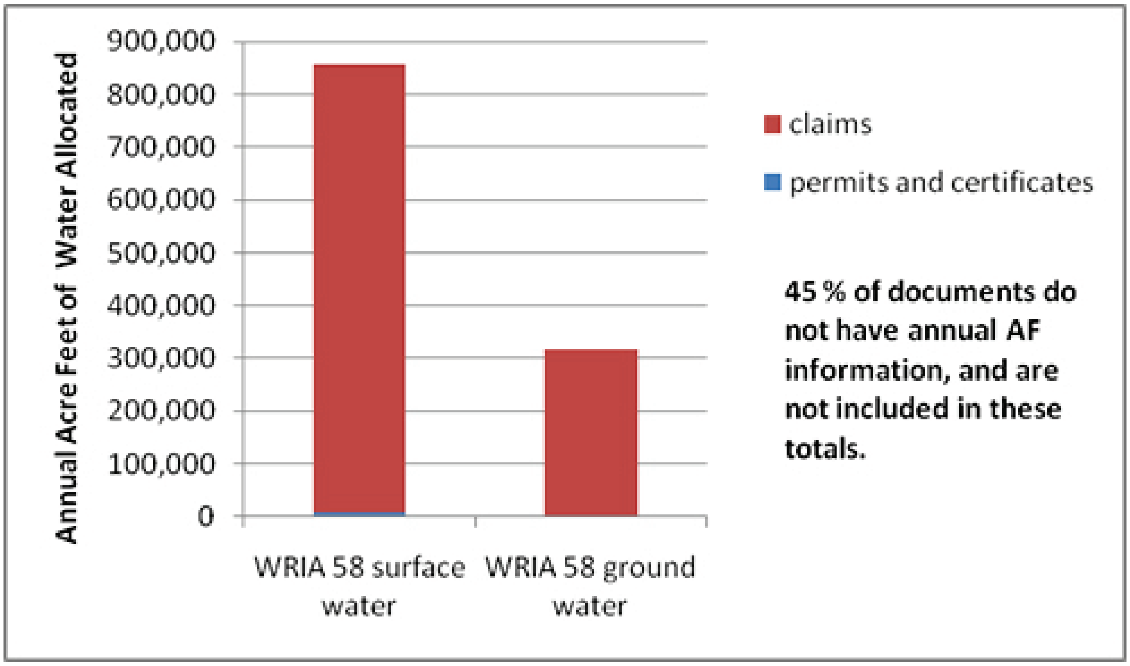


Figure 193. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.32.6 WRIA 58 Management Context

Some major management considerations for WRIA 58 are summarized in Table 59.

Table 59. Major management considerations in WRIA 58.

Management Context	
Adjudicated Areas	Quillisascut Creek
	Cheweka Creek
	Jennings Creek
	Magee Creek
	Stranger Creek
	Harvey Creek
	Alder Creek
	O-Ra-Pak-En Creek
	Corus Creek
	Hunter Creek (incomplete)
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	None found

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.33 WRIA 59, Colville

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Colville is characterized mostly by substantial increases from late fall through mid spring, and small decreases in May and June, extending through the summer and early fall under average and wet conditions.

The primary demands are instream flow requirements and irrigation, with municipal demands that are fairly small. Adopted instream flows are shown by the instream flow requirements for the lower Colville River at river mile 5, as specified in Chapter 173-559 WAC, for both the historical and future period. Assuming no change in irrigated acreage, irrigation demand is projected to increase in most months in the future, with little difference in the magnitude of change between the various future economic scenarios considered. Municipal demands are forecasted to grow roughly 56% by 2030, though the resulting demand will still be modest in comparison to other WRIAs of eastern Washington.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, combined municipal and surface water irrigation demands and adopted instream flows are projected to outstrip unregulated tributary supply at the watershed scale during most years for August and September, and in some years for June, July, and October. Additional water supplies may be available from the Columbia River in a localized area of the watershed. Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in 80% of years between 1977 and 2006. The resulting unmet demand ranged from 233 to 11,187 ac-ft per year depending on yearly flow conditions, with an average of 3,490 ac-ft per year. Simulation of future curtailment occurred in 93% of years for the 2030s middle climate scenario. The resulting unmet demand per year ranged from 738 to 12,829 with an average of 4,807 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Although not shown here, unmet demands due to a failure to meet adopted instream flows are shown in the technical report. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of these watersheds, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.33.1 WRIA 59 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 194 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

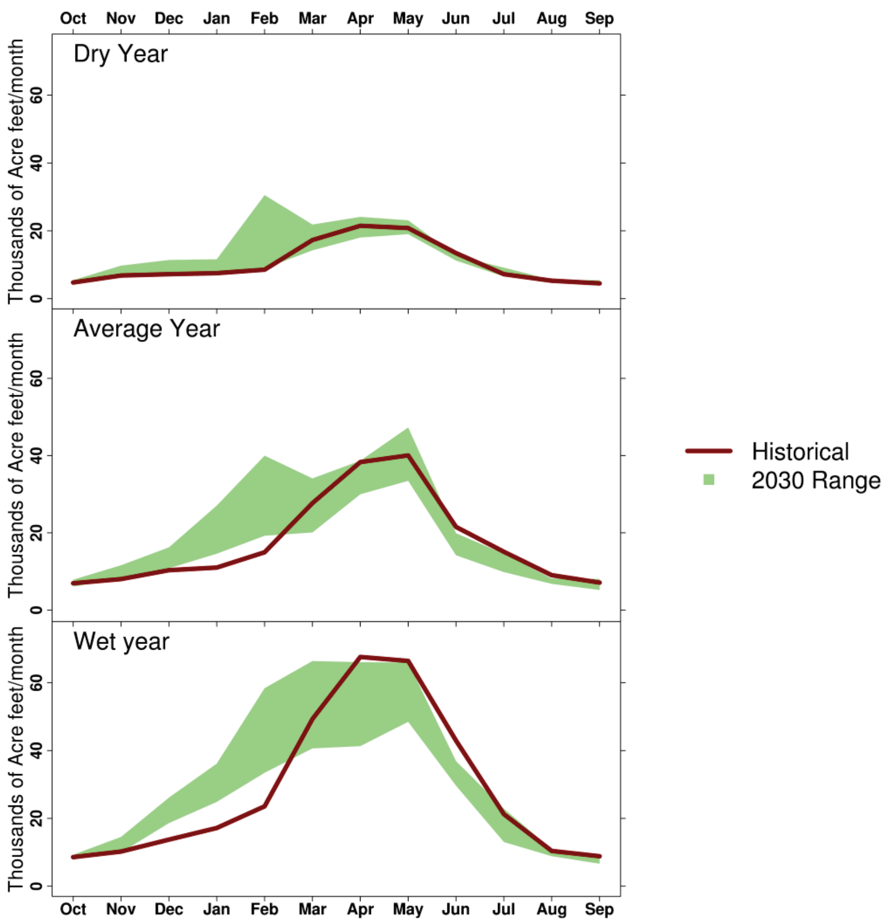


Figure 194. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.33.2 WRIA 59 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 195. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

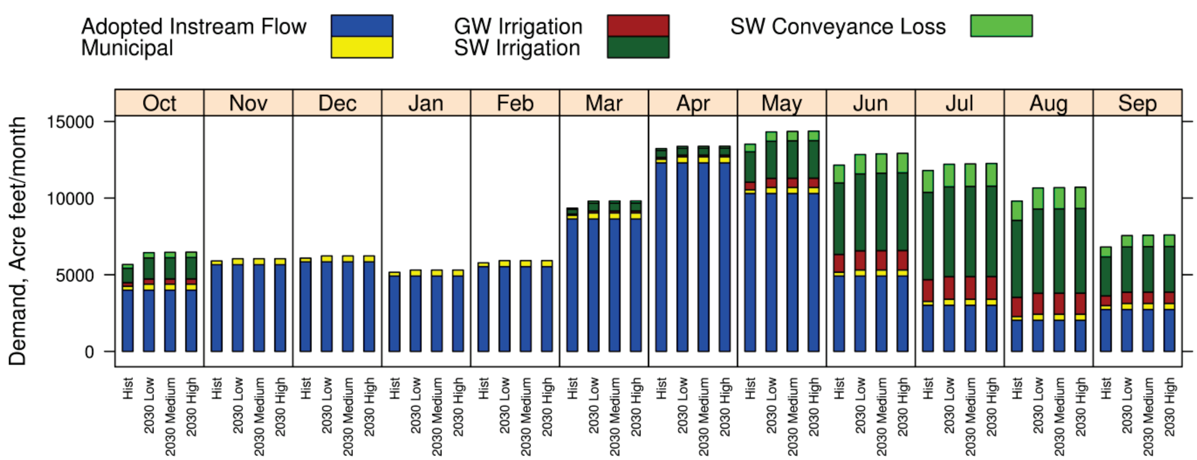


Figure 195. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.33.3 WRIA 59 Demand under Additional Water Capacity Scenarios

Figure 196 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

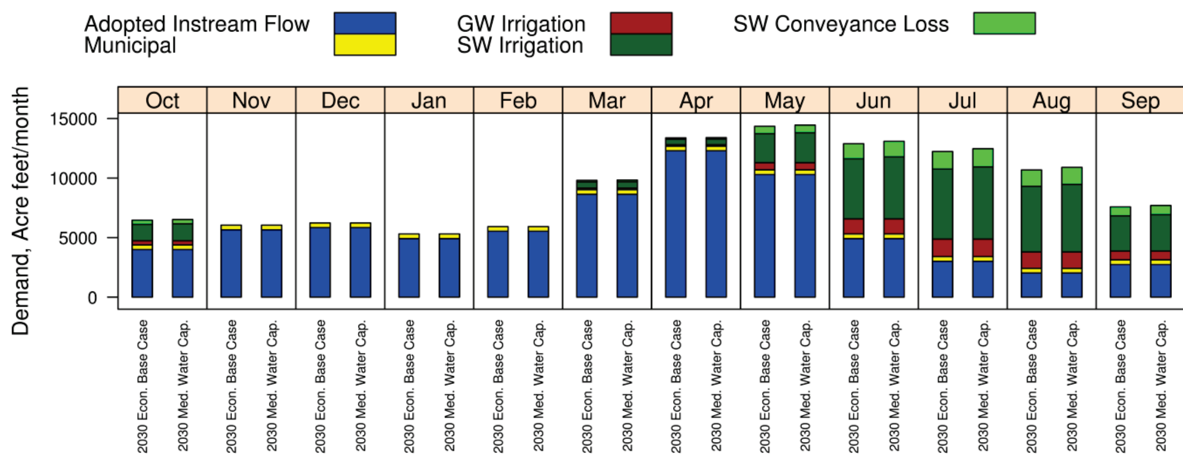


Figure 196. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.33.4 WRIA 59 Supply versus Demand Comparison

Figure 197 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

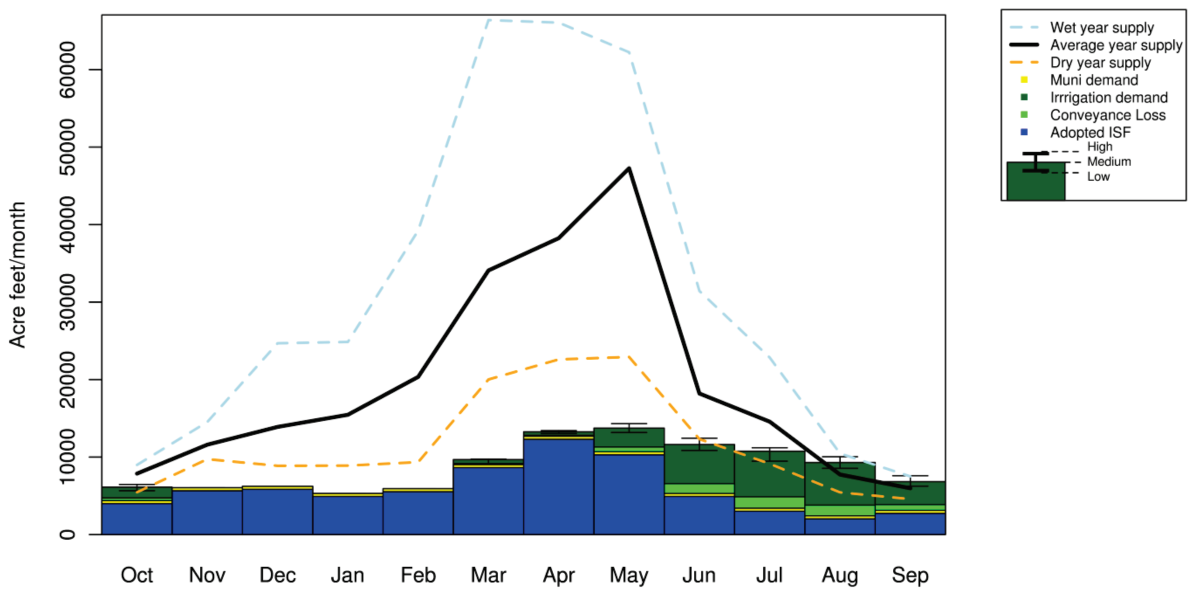


Figure 197. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.33.4.1 WRIA 59 Curtailment Analysis (for applicable WRIAs)

Modeling of curtailment of interruptible irrigation water rights indicated that it occurred in 80% of years between 1977 and 2006. The resulting unmet demand ranged from 233 to 11,187 ac-ft per year depending on yearly flow conditions, with an 06. T average of 3,490 ac-ft per year. Simulation of future curtailment occurred in 93% of years for the 2030s middle climate scenario. The resulting unmet demand per year ranged from 738 to 12,829 with an average of 4,807 ac-ft per year. Due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

Modeling also indicated that at the WRIA level there was insufficient water to meet the instream flow targets in 90% of the years between 1977 and 2006. The resulting unmet instream flow ranged from 233 to 27,501 with an average of 6,909 ac-ft per year. Simulation of future insufficient water occurred in 97% of the years for the middle climate scenario. The resulting unmet flow per year ranged from 541 to 26,183 with an average of 6,420 ac-ft per year.

6.33.5 WRIA 59 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits, and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 198). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

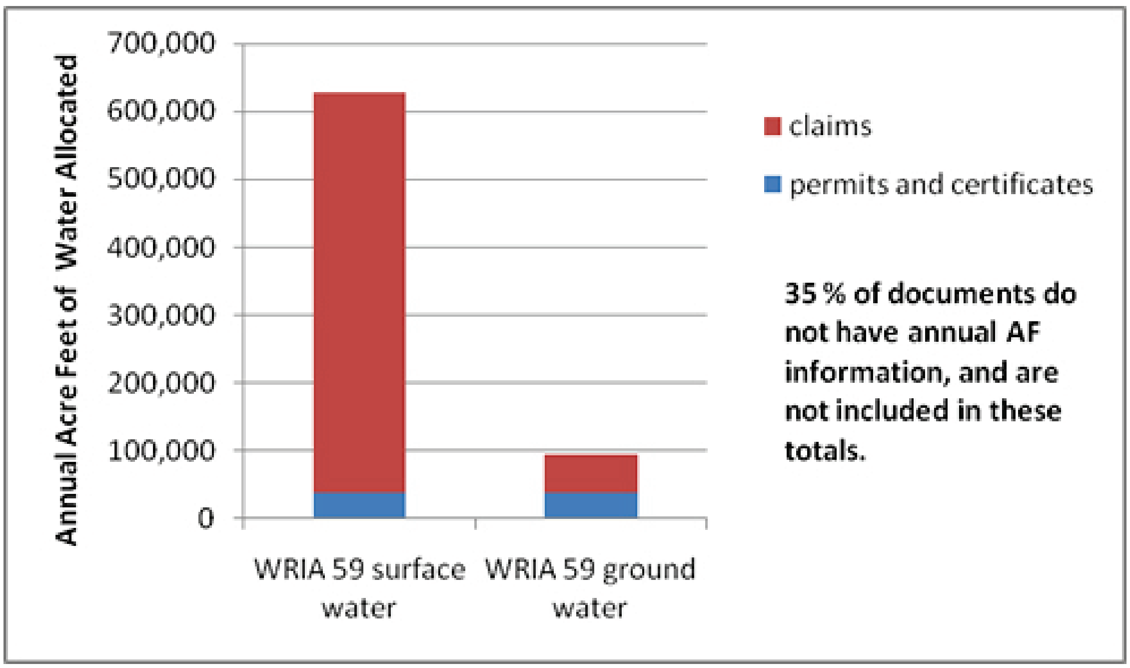


Figure 198. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.33.6 WRIA 59 Management Context

Some major management considerations for WRIA 59 are summarized in Table 60.

Table 60. Major management considerations in WRIA 59.

Management Context	
Adjudicated Areas	Narcisse Creek
	Chewela Creek
	Thomason Creek
	Sherwood Creek
	Grouse Creek & Jumpoff Joe
	Bull Dog Creek
	Deer Creek
	Hoffman Creek
	Clugston Creek (incomplete)
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-559 WAC)
	(In most years, interruptible users not curtailed)
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.34 WRIA 60, Kettle

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Kettle is characterized mostly by increases from late fall through winter and decreases under average and wet flow conditions from spring through early fall.

Both irrigation and municipal/domestic demands are quite small in WRIA 60. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in many months in the future, but decrease in other months. The magnitude of change is similar under all future economic scenarios that were considered. Municipal demand is forecasted to grow roughly 39% by 2030, though total municipal demand will still be modest.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply generated within the Washington portion of the watershed would be sufficient to meet combined municipal and surface water irrigation demand at the watershed scale. Additional water supplies may be available from the Columbia River in a localized area of the watershed. Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of these watersheds, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.34.1 WRIA 60 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 199 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

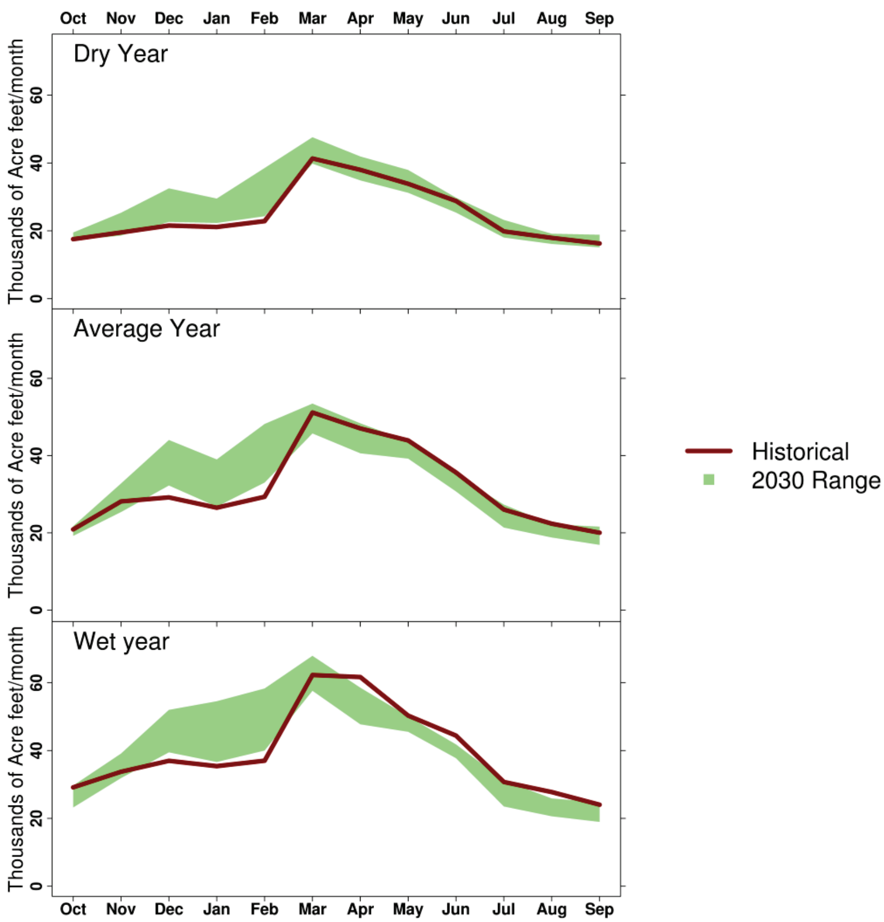


Figure 199. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.34.2 WRIA 60 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 200. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

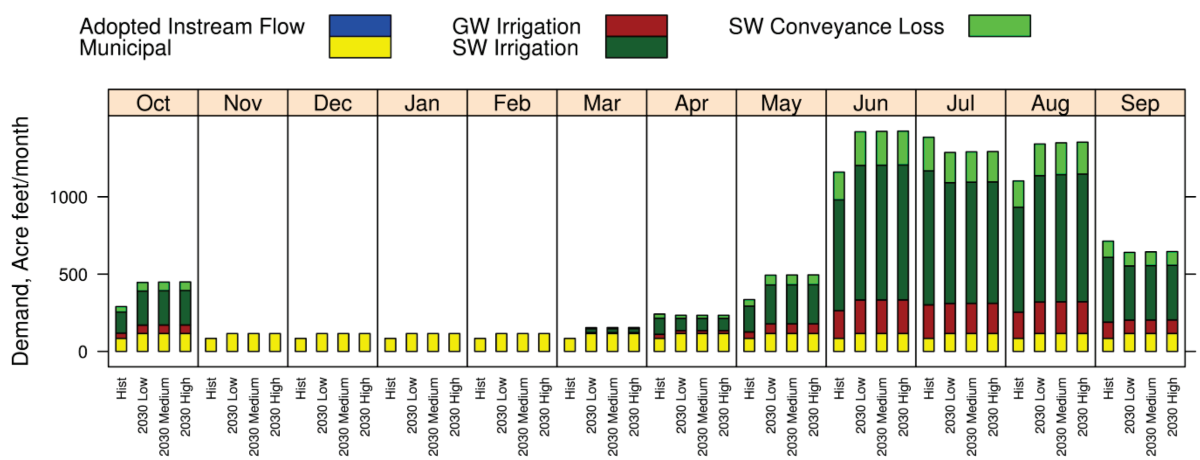


Figure 200. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.34.3 WRIA 60 Demand under Additional Water Capacity Scenarios

Figure 201 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

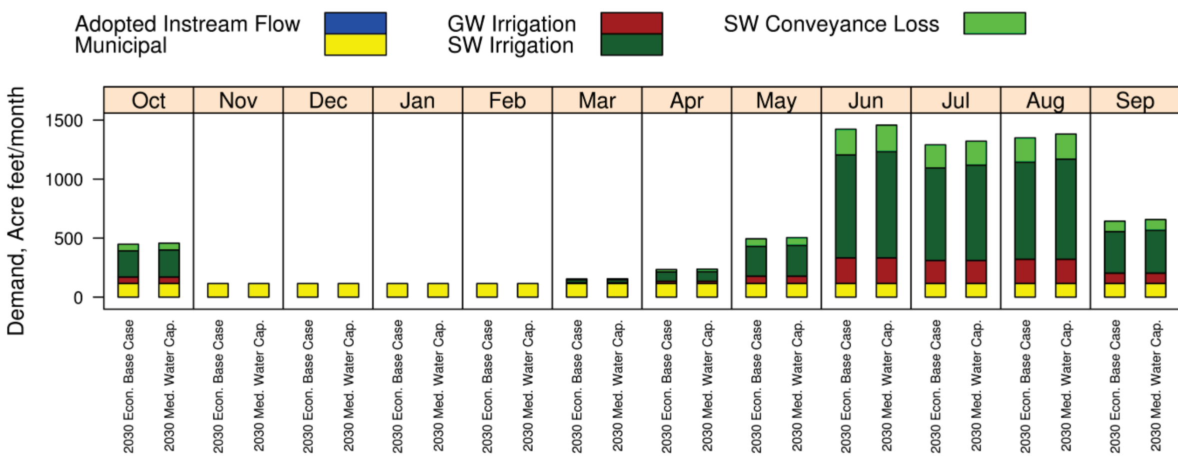


Figure 201. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.34.4 WRIA 60 Supply versus Demand Comparison

Figure 202 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

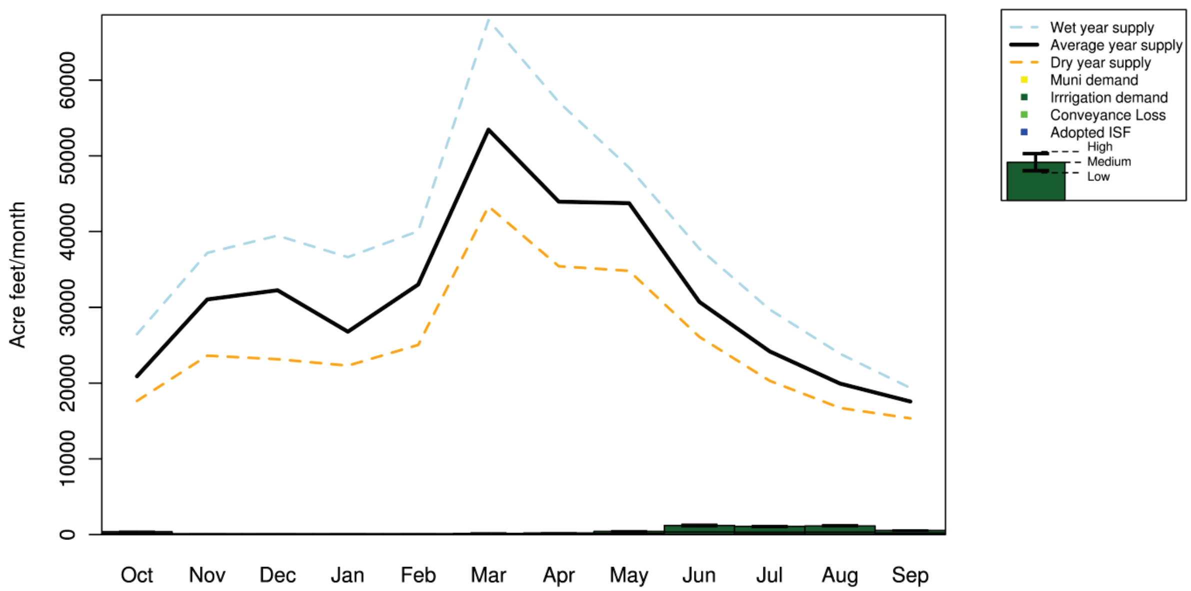


Figure 202. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.34.4.1 WRIA 60 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.34.5 WRIA 60 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 203). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

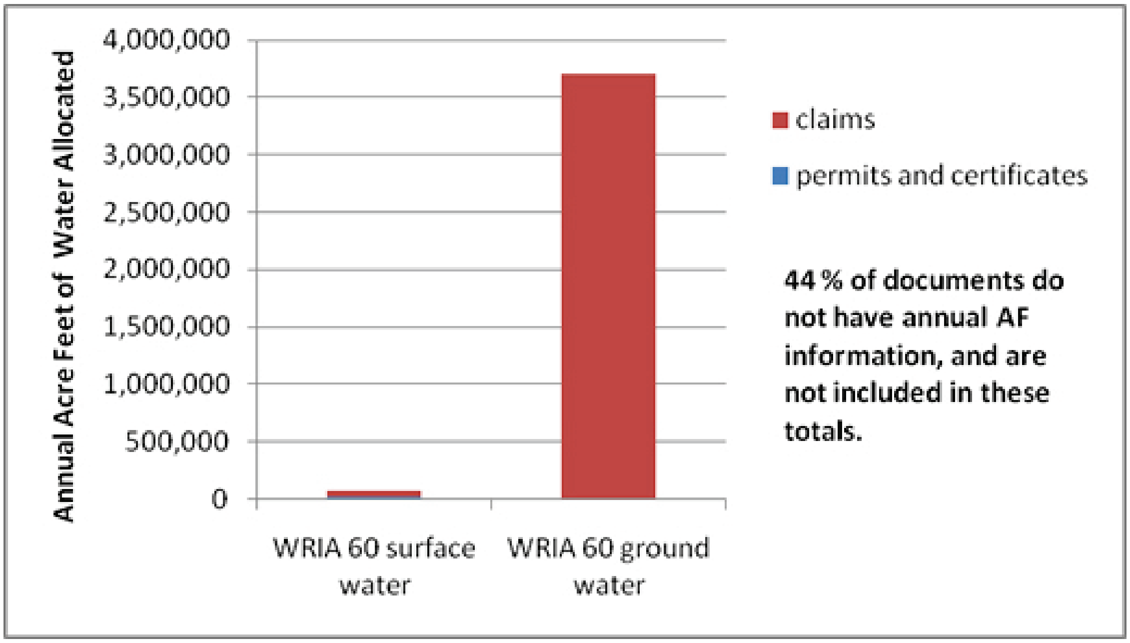


Figure 203. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.34.6 WRIA 60 Management Context

Some major management considerations for WRIA 60 are summarized in Table 61.

Table 61. Major management considerations in WRIA 60.

Management Context	
Adjudicated Areas	Myers Creek
	Twin Creeks
Watershed Planning	NO (planning terminated at the end of phase 2)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.35 WRIA 61, Upper Lake Roosevelt

Supplies and demands are defined as described in Section 1.3 "Definitions of Water Supply and Water Demand Used in the 2011 Forecast." The tributary surface water supply forecast for Upper Lake Roosevelt is characterized mostly by increases from late fall through winter and decreases in most years from spring through early fall.

Both municipal/domestic and irrigation demands are fairly small in WRIA 61. Municipal demand is forecasted to grow roughly 61% by 2030, though total municipal demand will still be modest. Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in some months in the future and decrease in others, with an overall increase. There is little impact on the magnitude of these results from the consideration of alternate future economic scenarios.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River "medium" scenario is anticipated to increase agricultural irrigation water demand in this WRIA compared to 2030 irrigation water demand under the economic base case (a scenario of no additional capacity). Additional capacity will increase demand in all WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply generated within the Washington portion of the watershed would be sufficient to meet combined municipal and surface water irrigation demand at the watershed scale. Additional water supplies from the Columbia River are important to meeting demands in some areas of the watershed and analysis indicates that almost half of agricultural demand is within a mile of the Columbia River (results shown in "Washington's Columbia River Mainstem: Tier 3 Results"). Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

It is not known whether bull trout spawn or rear in the tributary waters of these watersheds, and no other fish listed under the Endangered Species Act spawn or rear in tributary waters of this watershed.

6.35.1 WRIA 61 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 204 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported **prior to** accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

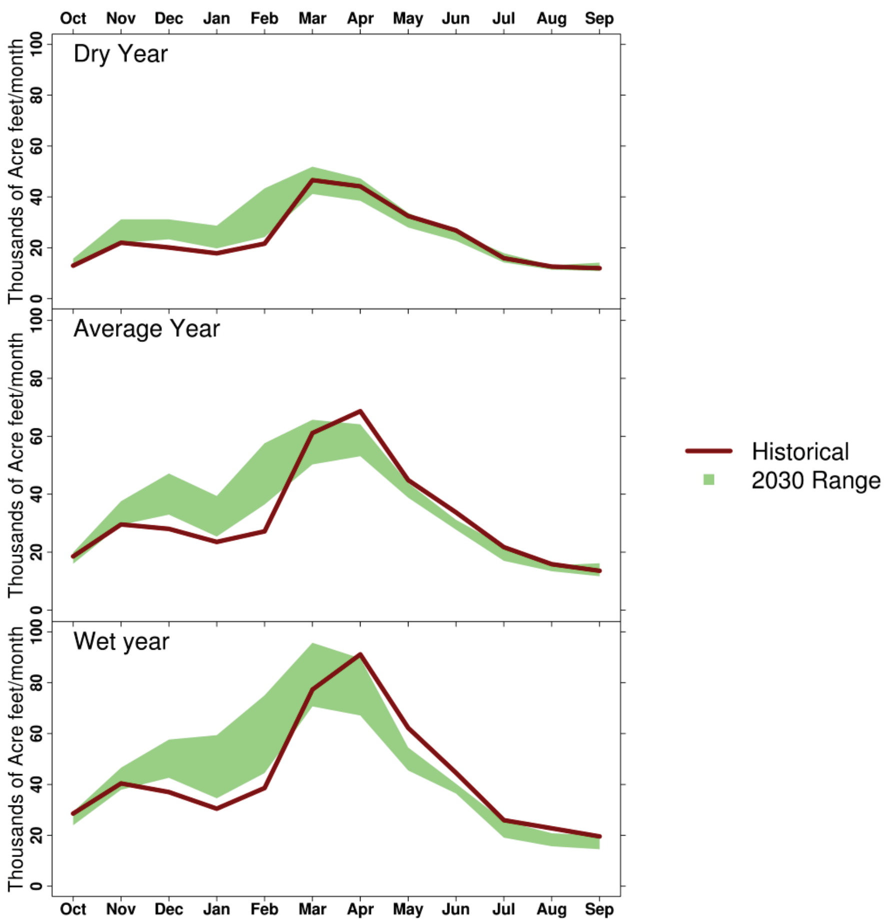


Figure 204. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.35.2 WRIA 61 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 205. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the “top of crop” and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

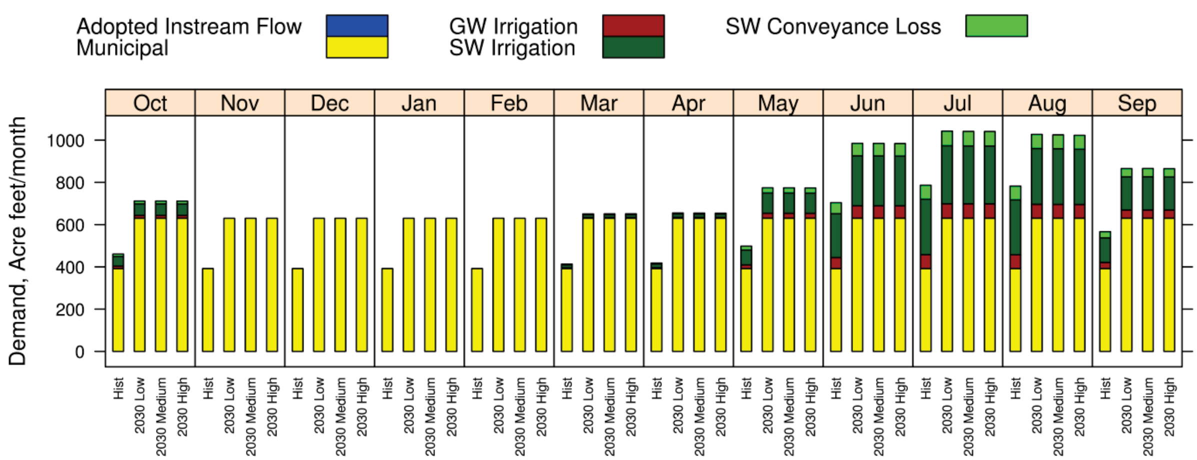


Figure 205. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.35.3 WRIA 61 Demand under Additional Water Capacity Scenarios

Figure 206 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as “2030 Medium” in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

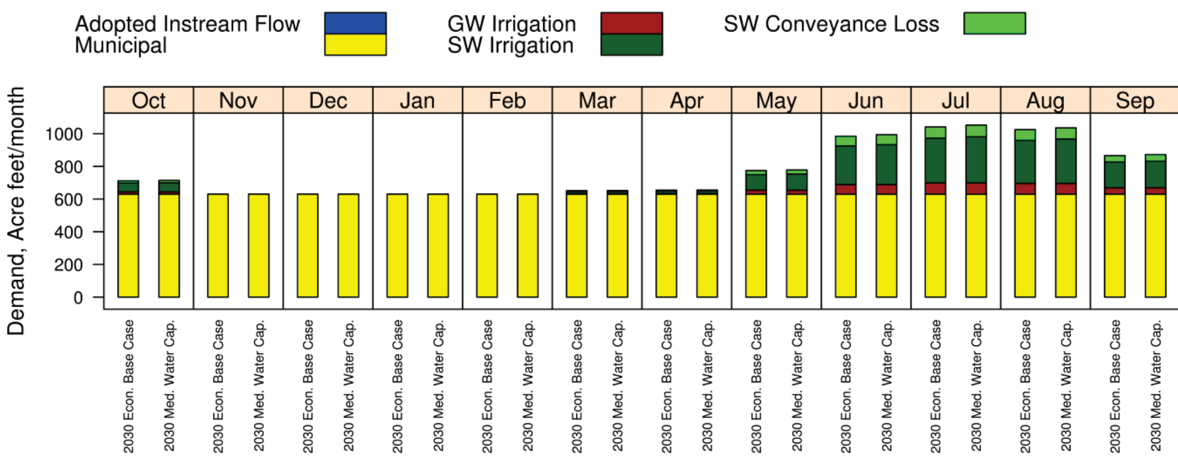


Figure 206. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.35.4 WRIA 61 Supply versus Demand Comparison

Figure 207 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

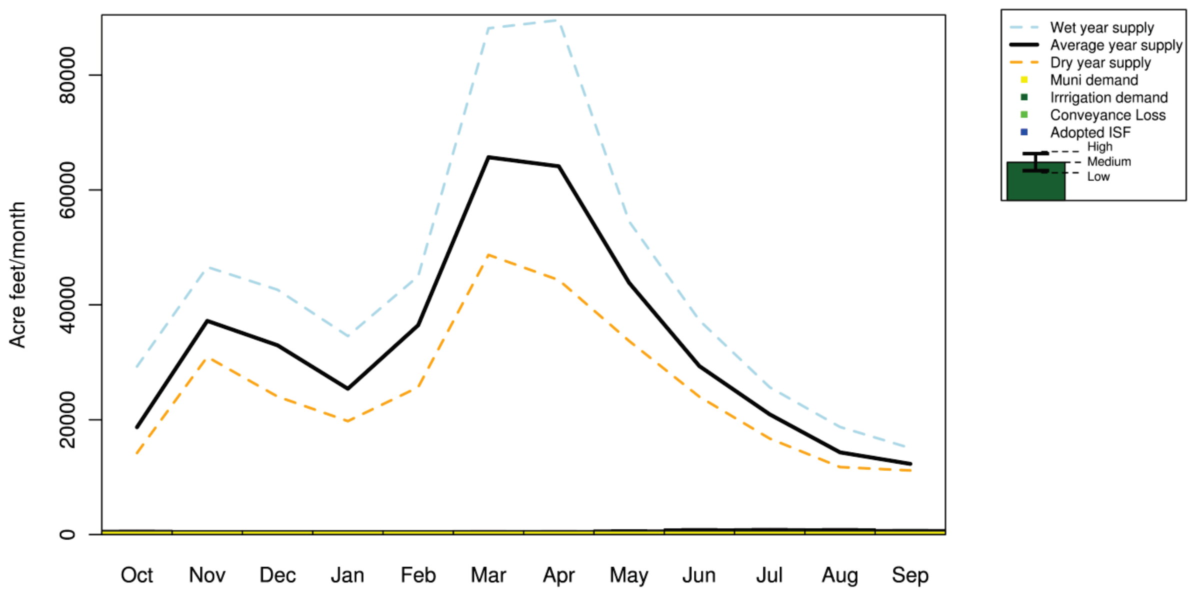


Figure 207. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.35.4.1 WRIA 61 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.35.5 WRIA 61 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 208). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

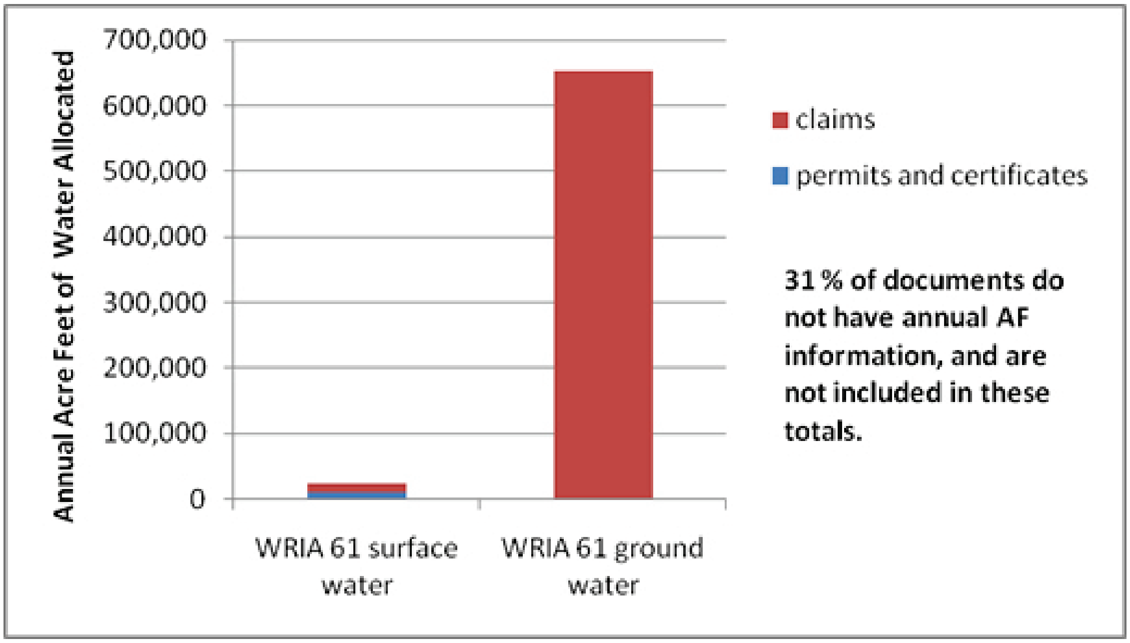


Figure 208. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.35.6 WRIA 61 Management Context

Some major management considerations for WRIA 61 are summarized in Table 62.

Table 62. Major management considerations in WRIA 61.

Management Context	
Adjudicated Areas	Pingston Creek
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO
Groundwater Studies	None found

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

6.36 WRIA 62, Pend Oreille

Supplies and demands are defined as described in Section 1.3 “Definitions of Water Supply and Water Demand Used in the 2011 Forecast.” The tributary surface water supply forecast for Pend Oreille is characterized mostly by increases from late fall through early spring and decreases in most years from spring through early fall.

Municipal demand is the primary source of demand in WRIA 62, though relatively modest in comparison to watersheds with larger population centers. Forecasting did not identify irrigation demands. Municipal demand is forecasted to grow 36% by 2030.

If provided, additional water capacity as specified by the proposed projects in the Office of Columbia River “medium” scenario is not anticipated to create any agricultural irrigation water demand in this WRIA. Additional capacity will only increase demand in WRIAs where water is provided for new irrigated land.

In 2030, unregulated tributary supply generated within the Washington portion of the watershed would be sufficient to meet combined municipal and surface water irrigation demand at the watershed scale. Upstream portions of the watershed outside of Washington provide additional supplies, but may also have additional demands. Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder. Water shortages outside the scope of this analysis may also exist in localized areas, and over time periods within months.

Bull trout, listed under the Endangered Species Act, spawn or rear in tributary waters of this watershed.

6.36.1 WRIA 62 Water Supply Forecast

The spread of 2030 flow conditions shown in Figure 209 is due to the range of climate change scenarios considered. Supply includes current major reservoir operations for Yakima (WRIAs 37, 38, and 39); otherwise it is the unregulated supply, without consideration for reservoirs. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

Surface water supplies include only supplies generated on tributaries within the Washington portion of the watershed. They do not include water supplies that enter the WRIA from upstream portions of the watershed, nor do they include water supplies from the Snake River or Columbia River mainstem.

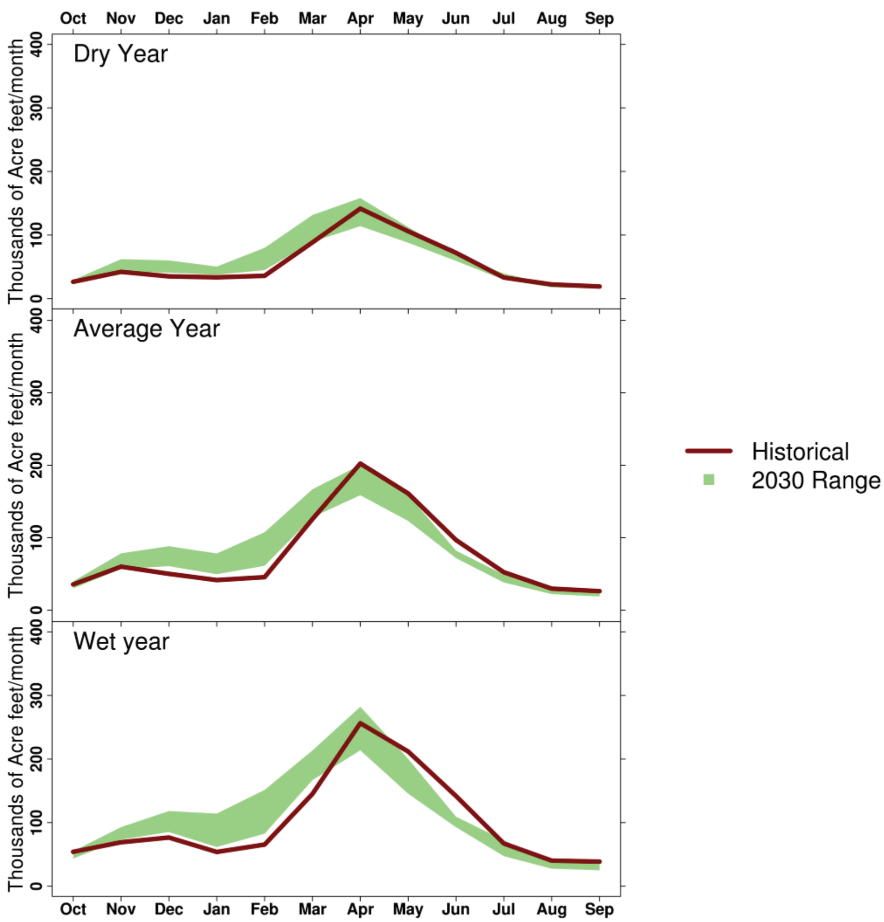


Figure 209. Modeled historical (1977-2006) and 2030 surface water supply generated within the WRIA for dry (20th percentile, top), average (middle), and wet (80th percentile, bottom) flow conditions.

6.36.2 WRIA 62 Water Demand Forecast, including Demand under Alternate Economic Scenarios

Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, are shown in Figure 210. Forecast 2030 water demands are shown for three economic scenarios: low, medium, and high growth in the domestic economy and international trade. Groundwater (GW, brown) and surface water (SW, dark green) irrigation demands are shown at the "top of crop" and include water that will actually be used by plants, as well as on-field losses based on irrigation type. Conveyance losses (light green) are estimated separately. Consumptive municipal demands (yellow) include self-supplied domestic use, but exclude self-supplied industrial use. Instream flows (blue) for both the historical and 2030 forecast are shown using adopted state instream flows or federal flow targets. When more than one instream flow exists at the sub-watershed level for a given month, the largest value (generally also the most downstream) was used to express instream flows at the WRIA level.

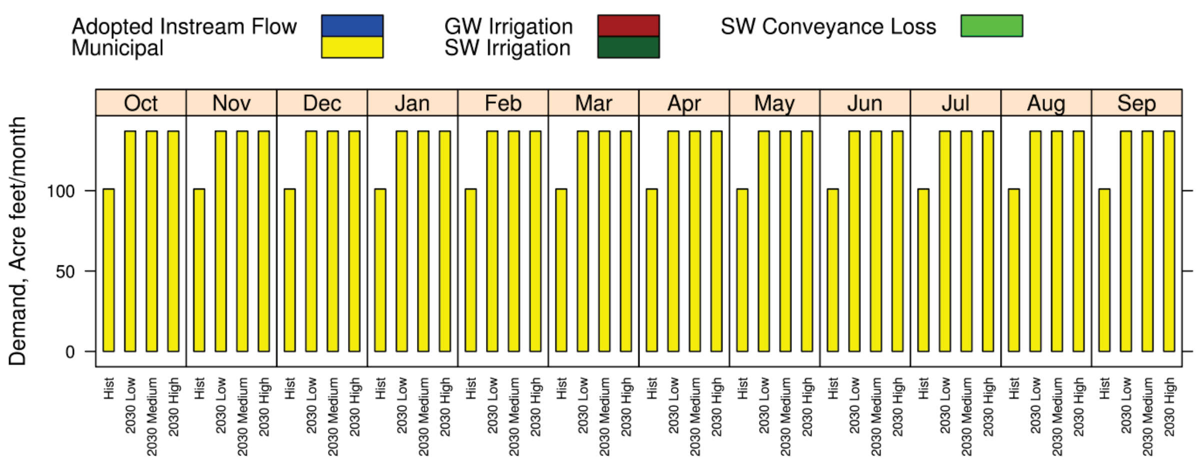


Figure 210. Modeled historical (1977-2006) and 2030 irrigation water, municipal, and instream flow demands under average flow conditions, and under the middle climate change scenario considered, and under three economic scenarios (low, medium, and high).

6.36.3 WRIA 62 Demand under Additional Water Capacity Scenarios

Figure 211 shows 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity, same as "2030 Medium" in the graph above), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity). The medium water capacity scenario examined a specific set of water capacity projects across eastern Washington, and assumed that new surface water supplies would be used for two purposes: as replacement water for acreage in Odessa currently irrigated with groundwater, and to grow crops on land that is not currently irrigated. Irrigation water demand is shown under average flow conditions and for the middle climate change scenario considered. It includes groundwater and surface water demands, as well as conveyance losses, as above.

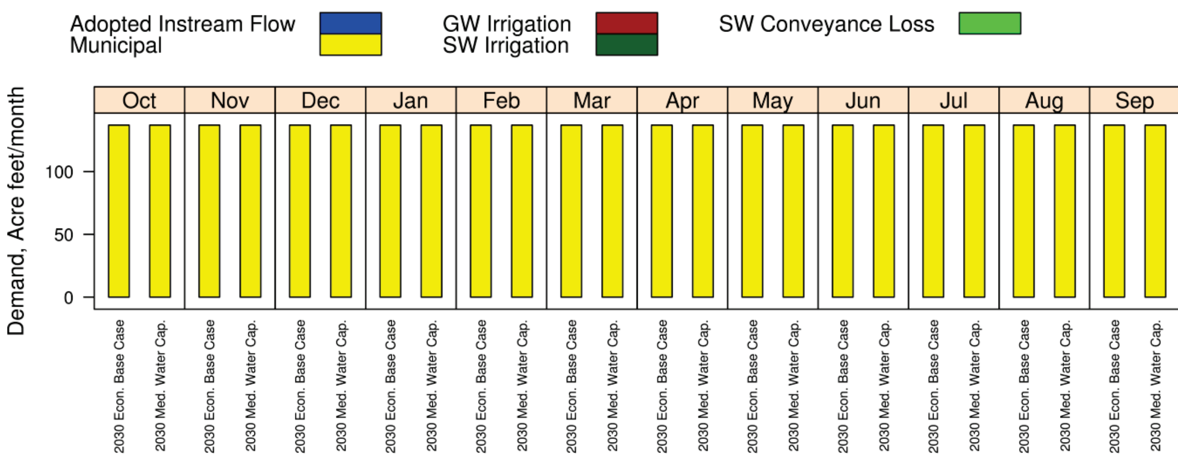


Figure 211. 2030 forecast water demands under the 2030 forecast economic base case (medium economic scenario, no additional water capacity), and under the 2030 medium water capacity scenario (with the addition of 200,000 ac-ft per year of proposed additional capacity).

6.36.4 WRIA 62 Supply versus Demand Comparison

Figure 212 compares surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered. Wet (80th percentile), average, and dry (20th percentile) flow conditions are shown for supply. The 80th, 50th, and 20th percentile conditions are also shown for irrigation demand using error bars. Demands and supplies are defined as above. Water curtailment is not considered.

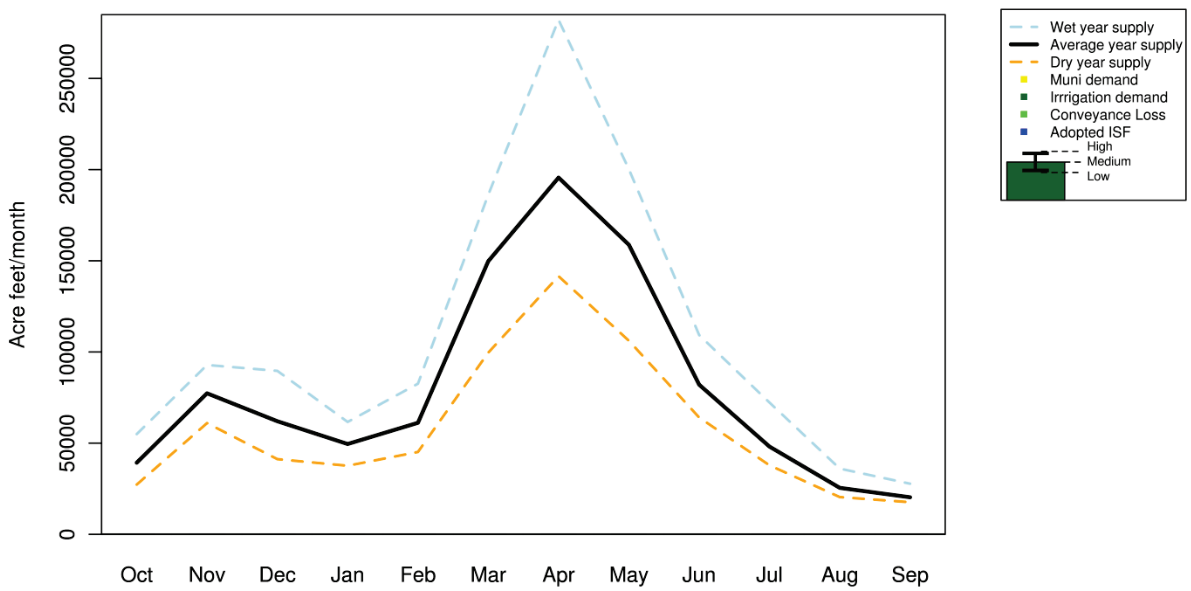


Figure 212. Comparison of surface water supply, surface water irrigation demands, and municipal demand for 2030, using the baseline economic scenario, and the middle value of the range of climate change scenarios considered.

6.36.4.1 WRIA 62 Curtailment Analysis (for applicable WRIAs)

Modeling results suggested no unmet demand for this WRIA resulting from curtailment of interruptible water rights holders in the historical or future period. However, due to data and resource constraints, the modeling of unmet demand did not consider curtailment of one water user in favor of another more senior water right holder, water shortages in localized areas (below the WRIA scale), or over time periods within months.

6.36.5 WRIA 62 Water Allocation Analysis

To give an indication of the amount of uncertainty related to water claims, permits, and certificate data, total annual quantities of water identified under state level water claims, permits,

and certificates in Ecology's Water Rights Tracking System (WRTS) were analyzed (Figure 213). The analysis also indicates the percentage of documents without information. Water documents that could be identified as having exclusively non-consumptive uses (e.g. power, fish propagation) were removed from analysis. WRTS data do not include tribal or federal quantified or unquantified water rights.

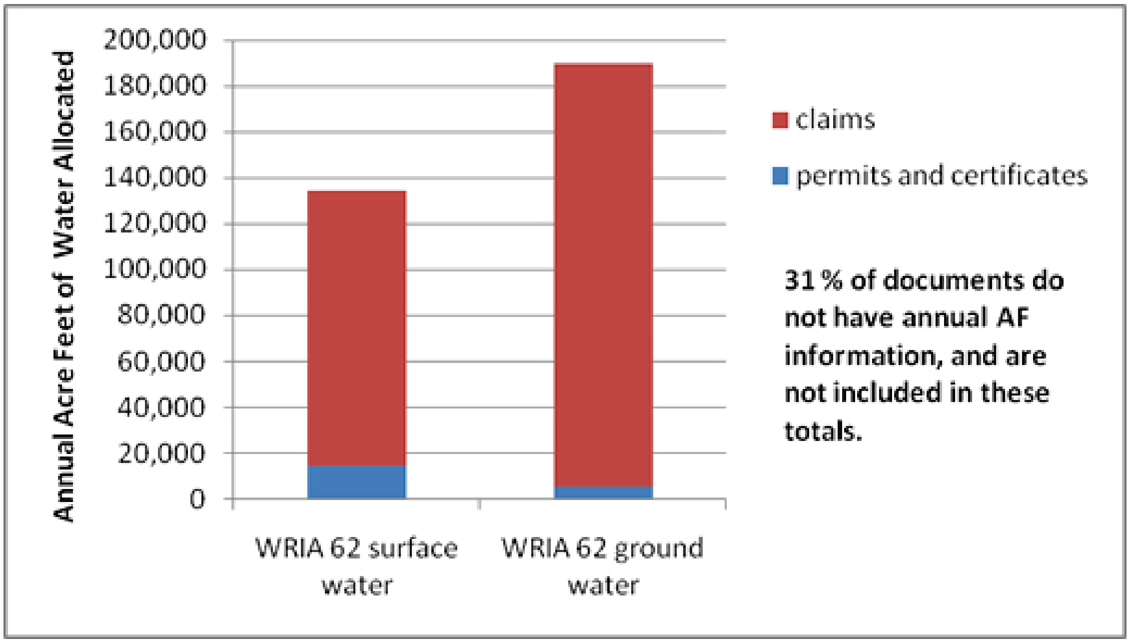


Figure 213. Water documents (claims, permits, and certificates) listing annual amounts of allowable water use in Ecology's Water Rights Tracking System (WRTS).

6.36.6 WRIA 62 Management Context

Some major management considerations for WRIA 62 are summarized in Table 63.

Table 63. Major management considerations in WRIA 62.

Management Context	
Adjudicated Areas	Renshaw Creek
	Little Calispell Creek
	Marshall Lake & Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout
Groundwater Management Area	NO
Groundwater Studies	YES (references listed in Appendix H)

[1] All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

7.0 Tier III Results – Columbia River Mainstem

Flows on the Columbia River mainstem are a reflection of flows in upstream areas of the basin, including areas outside of Washington and tributary areas within Washington. Mainstem water supplies provide instream flows for migrating salmonids, hydroelectricity as part of the federal Columbia River Power System, and water to those in proximity to the river.

Supplies and demands are defined as described in Section 1.3, Definitions of Water Supply and Water Demand Used in the 2011 Forecast. Because all demands exist within a watershed, the bulk of *demand* results are presented in Chapter 5, Tier II Results. However, within the mainstem level, WSU did analyze the proportion of WRIA-level irrigation demand that is within one mile of the Columbia River mainstem.

7.1 Surface Water Supplies Compared to Regulatory and Management Schemes at Key Points along the Columbia River Mainstem

The Forecast compared modeled historical (1977-2006) and 2030 forecast surface water supplies at Priest Rapids, McNary, and Bonneville Dams with Washington State instream flows (WA ISF), and the Federal Columbia River Power System Biological Opinion (FCRPS BiOp) (Figure 214 and Figure 215). These two regulatory schemes were chosen because of their role in regulating interruptible water rights holders (in the case of the WA ISF) and managing federal dams and the Quad Cities[1] water permit (in the case of the FCRPS BiOp[2]).

1 Pasco, Kennewick, Richland, West Richland

2 The FCRPS Biological Opinion governs operations of federal dams on the Columbia and Snake Rivers, specifying flow targets for dam operations and an adaptive management framework. Its purpose is to ensure that dam operations do not impede the recovery of endangered salmon and steelhead. It is required by the Endangered Species Act, and has been the subject of continued litigation.

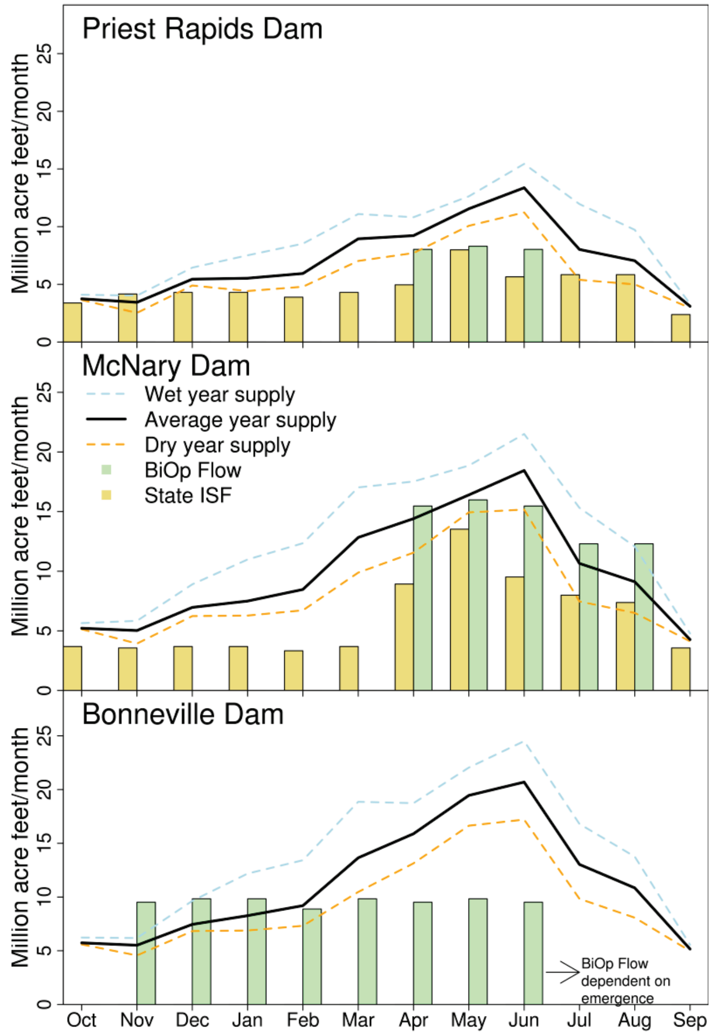


Figure 214. Historical (1977-2006) surface water supply (prior to accounting for demands) at Bonneville, McNary, and Priest Rapids dams for low (20th percentile), average, and high (80th percentile) flow conditions. Also shown are the Washington State instream flow (ISF) and federal BiOp flow targets.

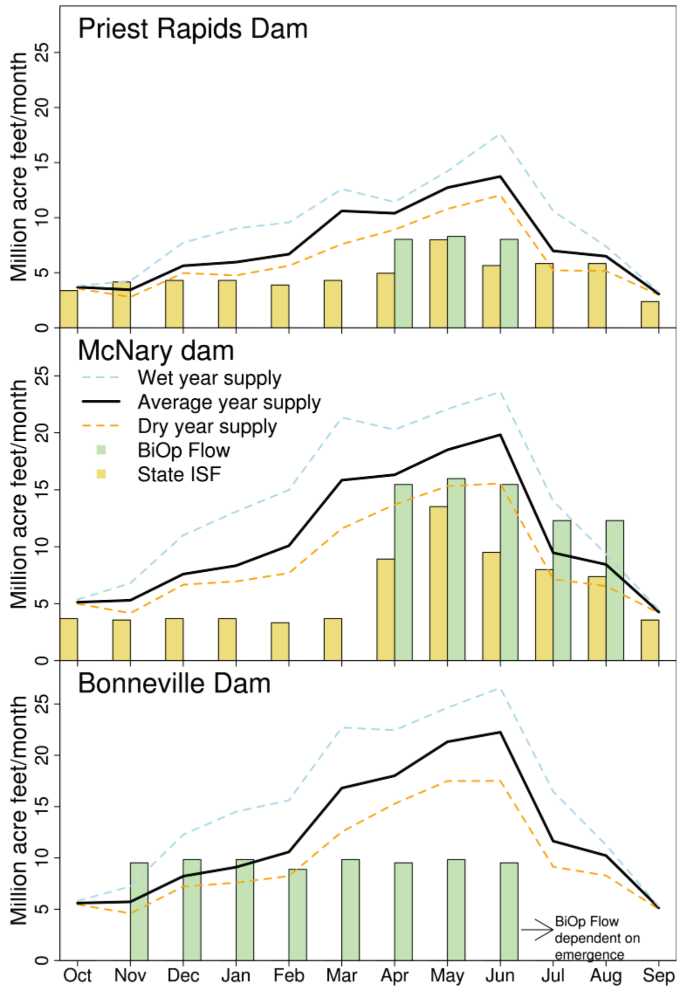


Figure 215. Forecast 2030 surface water supply (prior to accounting for demands) at Bonneville, McNary, and Priest Rapids dams for low (20th percentile), average, and high (80th percentile) flow conditions. Also shown are the Washington State instream flow (State ISF) and federal BiOp flow targets.

Regulation of mainstem water users is not triggered unless the total forecast on March 1st at The Dalles is less than 60 million ac-ft. However, on a month-to-month basis, under all flow conditions, forecasted (regulated) surface water supplies *prior to* meeting demands under average flow conditions were sufficient to meet Washington State instream flow targets in most months at most points along the mainstem. Under average flow conditions, the exception was November water supplies at Priest Rapids Dam, which did not meet State ISF targets.

Under dry flow conditions, in both the historical and 2030 forecast, August surface water supplies failed to meet State ISF targets at Priest Rapids and McNary. November water supplies at Priest Rapids were also below State ISF targets, under both normal and dry flow conditions.

In contrast, water supplies prior to meeting demands were insufficient to meet BiOp flows in more months, in both the historical and 2030 forecast. Under normal flow conditions, at McNary Dam, historical and 2030 forecasted water supplies were below BiOp flow targets for July and August. Historical water supplies were also below BiOp flow targets for April. At Bonneville, both historical and 2030 forecasted water supplies under average flow conditions were below BiOp flow targets from November through January. Imbalances were generally smaller in the 2030 forecast than the historical case for the late winter/spring months, and larger for the late summer months.

Under dry flow conditions, there were even more months when surface water supplies failed to meet BiOp flow targets. Water supplies during dry flow conditions were below BiOp flow targets at McNary Dam from April through August. Under dry flow conditions at Bonneville, water supplies were insufficient to meet BiOp flow targets from November through February in the historical period, and in the 2030 forecast from November through January.

7.2 Proportion of WRIA-level Demand along the Columbia River Mainstem

The Columbia River provides an important source of water supply for many WRIA water users within close proximity to the river. With additional infrastructure investments, mainstem water supplies could potentially meet even more of these WRIA-level demands. To give a sense of what portion of WRIA-level irrigation demand was in proximity to the Columbia River mainstem, a one-mile corridor on each side of the Columbia River was defined identifying all lands bordering the Columbia River. The corridor width was selected by OCR as a surrogate for detailed, project-specific analysis. It is possible that demands outside this corridor could be met by Columbia River supplies under some circumstances; however, evaluating all possible supply options was beyond the scope of the Forecast. Unfortunately, existing water rights data do not provide sufficient accuracy to confidently estimate what proportion of this amount is *already* being met by Columbia River mainstem supplies versus those that could be supplied via new projects. Lastly, the feasibility of serving specific areas with water diverted from the Columbia River was also outside the scope of this Forecast.

Both historically and in the 2030 forecast, more than half of the surface water irrigation demand was within one mile of the Columbia River mainstem for the following WRIAs (Table 64):

- Alkali-Squilchuck (WRIA 40)
- Moses Coulee (44)
- Foster (50)
- Lower Lake Roosevelt (53)
- Middle Lake Roosevelt (58)

In addition, Esquatzel Coulee (36) and Lower Crab (41) each have more than 50,000 ac-ft per year of surface water irrigation demand within one mile of the Columbia River mainstem, although this does not represent a large proportion of WRIA-level irrigation demand, as there are large numbers of irrigated acres in both of these WRIAs.

Table 64. Estimation of the average historical (1977-2006) and forecast 2030 WRIA-level irrigation demand that is within one mile of the Columbia River mainstem.

WRIA	WRIA Name	Total modeled WRIA-level irrigation demand		Modeled WRIA-level irrigation demand within one mile of the Columbia River mainstem			
		ac-ft/year		ac-ft/year		As a percentage of WRIA-level demand	
		Hist	2030	Hist	2030	Hist	2030
29	Wind-White Salmon	6,237	6,600	290	298	5%	5%
30	Klickitat	17,616	18,284	0	0	0%	0%
31	Rock-Glade	401,521	395,150	87,118	87,900	22%	22%
32	Walla Walla	209,049	208,996	7,504	7,445	4%	4%
33	Lower Snake	159,315	163,629	0	0	0%	0%
34	Palouse	28,687	29,548	0	0	0%	0%
35	Middle Snake	1,523	1,579	0	0	0%	0%
36	Esquatzel Coulee	1,166,218	1,185,731	194,190	200,891	17%	17%
37	Lower Yakima	1,435,031	1,476,659	2,840	2,909	0%	0%
38	Naches	94,821	105,019	0	0	0%	0%
39	Upper Yakima	429,379	466,141	0	0	0%	0%
40	Alkali-Squilchuck	41,535	41,916	38,818	39,060	93%	93%
41	Lower Crab	1,824,122	1,829,532	83,342	84,668	5%	5%
42	Grand Coulee	96,813	95,847	0	0	0%	0%
43	Upper Crab-Wilson	84,196	83,931	0	0	0%	0%
44	Moses Coulee	55,869	61,384	36,049	40,707	65%	66%
45	Wenatchee	34,281	36,472	2,289	2,863	7%	8%
46	Entiat	1,726	1,793	0	0	0%	0%
47	Chelan	26,783	28,944	9,737	10,070	36%	35%
48	Methow	13,165	14,600	4,785	5,385	36%	37%
49	Okanogan	102,845	110,050	17,719	18,535	17%	17%
50	Foster	26,314	31,674	26,314	31,674	100%	100%
51	Nespelem	0	0	0	0	0%	0%
52	Sanpoil	230	245	0	0	0%	0%
53	Lower Lake Roosevelt	7,065	7,443	3,947	4,130	56%	55%
54	Lower Spokane	16,522	16,360	0	0	0%	0%
55	Little Spokane	4,449	4,629	0	0	0%	0%
56	Hangman	1,295	1,416	0	0	0%	0%
57	Middle Spokane	371	404	0	0	0%	0%
58	Middle Lake Roosevelt	1,942	2,089	1,674	1,782	86%	85%
59	Colville	26,719	29,970	0	0	0%	0%
60	Kettle	3,737	4,223	0	0	0%	0%
61	Upper Lake Roosevelt	1,220	1,386	549	616	45%	44%
62	Pend Oreille	0	0	0	0	0%	0%
	TOTAL	**6,320,598**	**6,461,645**	**517,167**	**538,932**	**8%**	**8%**

7.3 Curtailment along the Columbia River Mainstem

Water rights holders whose water use can be "interrupted" when flows fall below the levels specified by regulation are vulnerable to potential impacts of water shortages. Along the mainstem, there are 379 interruptible water rights (Figure 216), the majority of which are agricultural surface water rights. When The Dalles flow forecast is below 60 million ac-ft for April through September, these users may be required to stop using water in weeks when flows do not meet requirements. The highest total annual quantity of interruptible water is located in Lower Snake (WRIA 33), while Rock Glade (31), Alkali/Squilchuck (40), Moses Coulee (44), Okanogan (49) and Foster (50) include high numbers of impacted water rights holders.

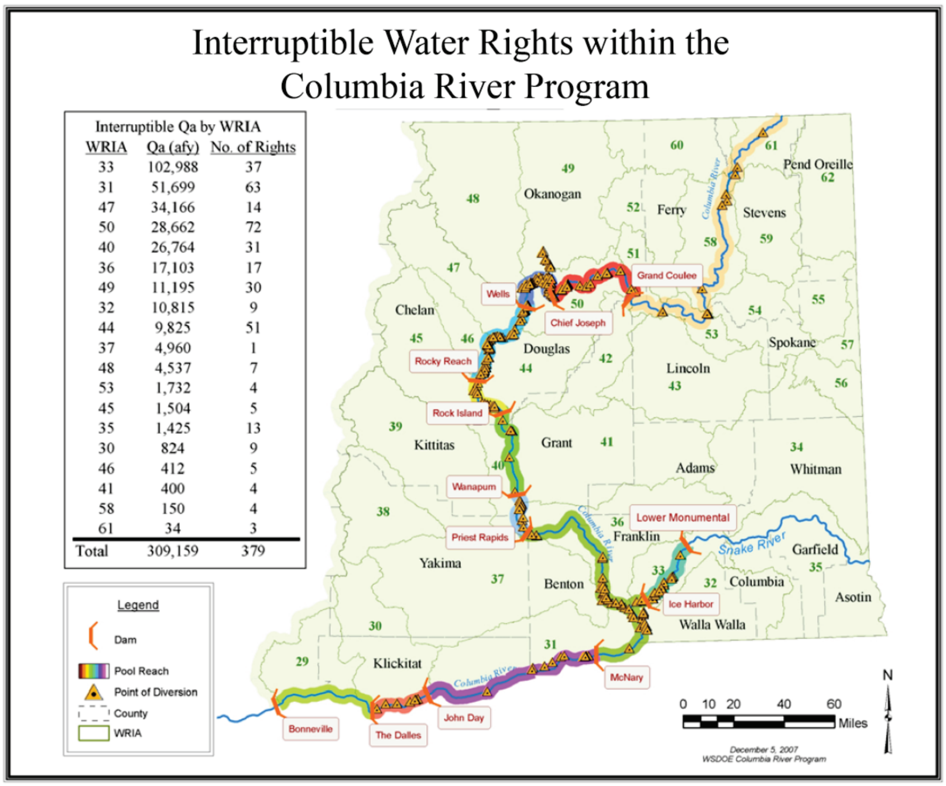


Figure 216. Amount of water associated with interruptible water rights along the 1-mile corridor within the Columbia River Program.

8.0 Limitations and Data Gaps

8.1 Data Gaps

8.1.1 Crop and Irrigation Extent Estimates

The estimation of crop and irrigation extent in the 2011 Forecast has several assumptions which could impact the results.

For the Canadian portion of the Columbia River Basin, WSU did not simulate crops and the modeling relied on the coarser land cover parameterization utilized by the hydrology model, VIC. For the United States portion of the Columbia River Basin, crop and irrigation extent data utilized a combination of the WSDA and USDA cropland data layers. The inconsistency in the naming of crop categories between these two datasets could result in an overestimation of crop extent in certain areas for some crops.

Irrigation extent information was available in the WSDA cropland layer dataset only for Washington State. . Outside of Washington, the modeling based irrigation extent on the type of crop grown from the USDA dataset. For example, crops that are usually irrigated were assumed to be always irrigated in the biophysical models, and vice versa. Pasture extent was not captured by the WSDA cropland layer dataset. Therefore, pasture extent from the USDA cropland layer was used, with the assumption that if more than half of the non pasture cropland in a grid cell was irrigated, than the pasture in that grid cell was also irrigated. This assumption could result in an over or underestimation of pasture extent in different areas.

8.1.2 National Agricultural Statistics Service Statistics for Crop Production Calibration

NASS crop yield statistics were used to calibrate crop production in the United States portion of the Columbia River Basin. These data were not available for all the modeled crops. In some cases, they were available only at a state level of aggregation. Data at a finer resolution (county level) would improve crop production estimates.

8.1.3 Water Rights Data

Water rights data for Washington State were primarily from Ecology's Water Rights Tracking System (WRTS). The data in WRTS were linked to geographic information in Ecology's Geographic Water Information System (GWIS). GWIS associated water rights records in WRTS with points of diversion, and with geographic locations for places of use represented by polygons in a geographic information system. While it was not always possible to identify the parcel of land being irrigated by the water right, GWIS did make it possible to identify with some approximation, at least down to the section, the general location where a water right applied. The extent to which this could be done also depended on the quality of the data in WRTS. Much of the data in WRTS was incomplete, often due to underlying uncertainty in the water rights records and/or lack of information submitted by water users. For example, many records did not include an annual use amount, while another significant group contained neither an annual use amount, nor the number of acres irrigated.

There was significantly more uncertainty associated with claims, and this contributed to uncertainty in calculating the amount of allocated water. The majority of the water right claims have not been confirmed through court adjudications. Some claims seemed to have been entered more than once (whether by the water user, or through data entry errors), while other claims seemed to have dates that were inconsistent with existing water rights law. For the Yakima Basin, the adjudication process is in the final completion stage. Having provisional data from the adjudication created relatively more certainty associated with the data in this watershed than in others. However, since the major claimants have yet to be mapped, they could not geographically be located using GWIS data. .

8.1.4 Interruptible Water Rights

Some water rights are curtailed when specified low flow conditions are not met. Curtailment data could be used to determine 1) which users would potentially have their water use interrupted in the future and 2) the frequency of curtailment.

8.1.5 Water Rights Subject to Low Flows Defined in Washington Administrative Code

The most tractable case of curtailment was with water rights that are subject to low flow provisions defined in WAC. However, even in this case, underlying issues presented challenges for the WSU analysis. For example, it was difficult to tell when these water rights were actually historically curtailed. Lists of curtailable water rights were separate from WRTS, and did not include specific identification of the gage against which users are regulated (though in some cases this could be logically determined). In addition, interviews with Ecology staff indicated that there are some valid regulatory practices that occur within the framework of the Water Code that are different than the regulation described in Washington Administrative Codes (WAC). For example, interviews indicated that, since at least 2000 (and likely significantly before that), the Methow River has been regulated based on the flow at the Pateros gaging station (located several miles upriver from Pateros). This is done because one regulatory gauging station on the Chewuch River washed out after the Instream Flow Rule was adopted, and another regulatory gauging station near Winthrop on the Methow River was moved by the USGS. The USGS has also relocated a gage on the upper Methow River farther upstream than it was a few years ago (Susan Burgdorff-Beery, Ecology, personal communication).

To test the quality of the water rights modeling, it would have been useful to have reliable information about the frequency of historical curtailment. While it was possible to match historical data to the low flows described in WAC (and there was a list from 1992-2004 of the dates on which low flow orders were sent indicating that water rights holders *might* be asked to curtail water use), comprehensive historical information indicating when water users were asked to stop using water by Ecology was unavailable.

8.1.6 Water Rights Subject to Surface Water Source Limitations (SWSLs)

Other water rights have been issued subject to administrative limitations known as surface water source limitations (SWSLs). A list of water rights subject to SWSLs in Ecology's Central Region (including WRIAs 30-31, 37-40, and 45-50, most of WRIAs 44 and 51, and parts of WRIAs 29, 42, 52, 53 and 60) was unavailable. There were lists of water rights subject to SWSL in Ecology's Eastern Region t (including all of WRIAs 32-36, 41, 43, 54-59, and 61-62, most of WRIAs 42 52, 53, 60, and parts of WRIA 51). However, after several interviews, it seemed that many of these water rights were not regulated in practice.

In addition, determining the flows that each water right was subject to would have required looking up the individual water rights documents in Ecology's Water Resources Explorer (http://www.ecy.wa.gov/programs/wr/info/webmap.html). It was decided not to do this because of time and budget constraints and uncertainty on how the data would be used for modeling purposes.

8.1.7 Curtailment of Junior Water Rights Holders in Favor of Senior Water Right Holders

There are watersheds where junior water rights holders have been curtailed with some frequency to ensure that senior water rights holders can exercise their water rights, including Walla Walla, Alkali Squilchuck/Stemilt Squilchuck, Kettle, and adjudicated portions of Methow and Okanogan (Darrell Monroe and Lynn Maser, Ecology, personal communication).

A lack of information about the water rights subject to this type of curtailment and the relationships between them made it impossible to model this. In addition, interviews indicated that the system was complicated. For example, in the Walla Walla, surface water rights have been adjudicated Water rights were grouped into 20-30 classes by priority dates, with Class 1 having the oldest date. Records indicating when Ecology required classes in different portions of the watershed to stop using water were unavailable. Each tributary is managed separately, as curtailment depends on the class status of water rights holders in each reach (Darrell Monroe, Ecology, personal communication).

Within the Yakima River Basin, different classes of water users have also been regulated to ensure that the needs are met for senior water rights holders. Because of the current adjudication data regarding when junior classes of water rights holders have been managed in favor of senior water rights holders was not further investigated.

8.1.8 Identifying Interruptible Grid Cells in VIC-CropSyst

To capture information related to who is curtailed, the WSU modeling effort used the list of interruptible water right holders maintained by the Washington Department of Ecology, and matched it up with the information describing where the water rights could be used in the WRTS/GWIS database to generate a list of grid cells which are interruptible (see Figure 29 in

Chapter 3, Methodology, for definition of a VIC-CropSyst grid cell). However, more than half of these grid cells did not have irrigated crops and hence there was no demand to curtail. Also, the interruptible list was incomplete for this Forecast in that SWSL water right holders in parts of eastern Washington have yet to be incorporated into the list.

In the Yakima River Basin, which follows a system of pro-rationing of water, spatially disaggregated information about the location of the major pro-ratable water rights holders was not available. Hence the 2011 WSU modeling effort assumed that all grid cells in the Yakima River Basin had pro-ratable and non-proratable water rights holders and the water deficit was distributed across all grid cells. This would result in an overestimation of deficit in grid cells that in reality have no proratable water right holders and an underestimation in others. Overall for the Yakima River Basin, the differences should average out.

There was also a lack of spatial information on the locations of supplemental groundwater right holders, and their supplemental water right amounts. These supplemental water rights can be used by the water right holders in the event that their surface water rights are curtailed. Not including this information leads to an overestimation of curtailment amounts.

8.1.9 Sources of Withdrawal and Conveyance Loss Estimates

Spatially disaggregated information related to sources of withdrawal was not available and the WSU modeling assumed that 20% of the total irrigation demand was met by groundwater sources The only exceptions were 1) the Odessa groundwater management subarea where all of the grid cells outside of the area catered to by surface water canals were assumed to use groundwater sources, and 2) the Yakima River Basin where 10% of the irrigation demand was assumed to be met with groundwater sources. (These assumptions were based on data available in Lane 2009 and Vaccaro et al. 2006, as further described in Chapter 3, Methodology). The Department of Ecology water rights database has some information on groundwater and surface water sources of withdrawal that could be used. However, to facilitate this, a process of completing and cleaning the database would need to be undertaken first.

The biophysical framework did not model a system of canals and associated losses and conveyance loss values had to be assumed. The process WSU followed in estimated conveyance losses is explained in Section 3.4.8.4 of Chapter 3, Methodology.

8.2 Modeling Framework Limitations

8.2.1 VIC-CropSyst Limitations

The hydrology model in VIC-CropSyst is a land surface hydrology model and lacks dynamic deep groundwater modeling. The 2011 Forecast only modeled subsurface hydrologic processes to approximately 10 ft below the surface and did not simulate a groundwater table. This feature is important in areas that have a strong aquifer presence or strong surface water-groundwater interactions. Groundwater modeling would help in the understanding of how groundwater withdrawals could help meet demands.

CropSyst can simulate multiple management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, tillage operations, and residue management. However, the implementation of VIC-CropSyst used for the 2011 Forecast had a simplified version of CropSyst that focuses solely on water use and crop productivity. In simulating cropping systems, WSU did not model crop rotations either within a year or for multiple-year rotations. For the historical simulations, cropping patterns in Washington were based on year 2008 information. Similarly, future cropping patterns were determined using the 2008 WSDA data as the baseline case. Other management options were also not considered. Irrigation demand for non-cash crops, such as mustard cover crops, was not modeled.

VIC utilizes coarse data on soils. This is not desirable for modeling crops because the CropSyst model is relatively more sensitive to soil parameters. To address this, the current implementation had CropSyst using soil parameters from a separate source. Efforts are underway to improve the soil data for the VIC-CropSyst model.

Communication of soil water content between VIC and CropSyst was undertaken one time at the beginning of the simulation for each crop being simulated. This was due to computational inconsistencies between soil layers of VIC and the CropSyst model. WSU is in the process of revising this structure so that the models are more closely coupled.

In the implementation used for the 2011 Forecast, the coupled VIC-Cropsyst model was not calibrated as a single unit. Parameter estimates from the individual calibration of VIC and CropSyst separately were used. Improvements to model performance could be expected by calibrating the coupled VIC-CropSyst as a single unit.

VIC is a “macroscale” hydrology model. This means it is best suited to model the hydrologic response of very large river basins and is limited in capturing all the processes in a small watershed scale. Therefore, caution should be exercised in interpreting results at a small watershed scale.

VIC is designed to solve the water balance equations as well as the energy balance equations, in determining the hydrologic response. However, solving both the water and energy balance equations is computationally expensive. Due to computational resource restrictions, modeling ran VIC (as well as VIC-CropSyst) in a “water balance” mode, where the surface temperature is set to air temperature and not iteratively solved for.

8.2.2 Municipal Demand Estimates

There were five significant assumptions made in estimating current and future demands, each of which caused a limitation in the analysis. First, the analysis assumed that Washington OFM’s future population estimates were distributed uniformly across counties and distributed to WRIAs by area. In fact, future populations are often located near existing urban centers rather than scattered throughout the watershed. In the future, the Forecast should examine population patterns and growth and apply growth projections accordingly.

Second, consumptive use estimates were based on the differences between water diversions and waste water treatment plant flows. Leaky pipes, private wells with public sewers, separate irrigation systems, and a mismatch in some areas between water diversion service areas and wastewater treatment service areas, etc. all contribute to uncertainties in the consumptive use estimates. According to the literature, there is currently no adequate means of addressing this limitation.

Third, future use estimates assumed no improvement in existing infrastructure or conservation efforts. Many municipalities have leaks in their infrastructure that could be repaired thereby reducing water demand. It is difficult to determine which of these repairs will be made because of tight budgets and which of the aging pipelines will develop new leaks in the future. However, in general, the assumption made could be expected to be conservative.

Fourth, rural wells were assumed to be shallow and connected to surface water supply. The number of domestic wells drives the magnitude of the limitation caused by the fourth assumption. Without conducting a complete subsurface investigation of shallow groundwater in each WRIA, it would be impossible to get a reliable estimate of surface water impact. This would be cost prohibitive. Therefore, assuming that wells take water from nearby streams in the months of use was a simplifying and needed decision.

Last, per capita urban and rural water use was assumed to be the same, as there was little available information comparing urban and rural water usage for eastern Washington. While municipalities are monitored for water diversion, rural users are largely free of reporting requirements. Individual landscapes vary considerably and no single model would likely capture each circumstance perfectly. Monitoring rural domestic water use would be hugely expensive and unpopular, and future estimates will therefore likely continue to have this assumption built in.

8.2.3 Hydropower Demand Estimates

Power demand estimates were based on projections conducted by NWPPC and individual PUDs in Washington State. While the best available estimates were provided, there are three issues worth discussing that could affect future demand (and which were generally not factored into these projections):

- Potential impact of Columbia River Treaty negotiations.
- Implementation of the 2010 BiOp.
- Integration of renewable energy.

The 2011 Forecast assumes historic operation will continue at least into the 2030s. However, any one of these three issues could dramatically shift hydropower needs and supplies, as further discussed in Chapter 5, Tier I Results.

8.2.4 Integrated Biophysical Modeling Limitations

The surface water availability estimates used to calculate the amount of curtailment or deficit irrigation required were based on the first set of VIC-CropSyst runs in which full irrigation was applied to the crops. These runs assumed that all crop irrigation requirements were met. Generally speaking, curtailment at an upstream location will affect instream flows and surface water availability downstream. Ideally, the model should be run iteratively until an equilibrium is reached between surface water availability and curtailment amount. Due to computing resource restrictions, these iterative runs were not performed for this Forecast.

The model assumed that reservoir operation rules in the future would be the same as the historical operation rules. However, the rules may evolve in the future to adjust to changing climate as well as changing hydropower, instream and other demands. Ideally, a set of reservoir operations rules optimized for future conditions should be used.

The modeling of the process of curtailment has some limitations that can impact the results. These limitations affect correctly capturing who is curtailed, when they are curtailed, as well as how much they are curtailed. Section 8.1.4.4 described the data gaps which affect correctly capturing "who to curtail?" and "how much to curtail". The limitations related to "when to curtail?" are related to the fact that curtailment decisions are in reality made at a weekly time step whereas the WSU model was configured to run at a monthly time step. The future 2030s scenario assumed, for the Odessa area, that ground water sources for irrigation were unavailable. Hence the model did not fulfill any irrigation requirements of the crops. However, the model retained the original irrigated crop mix. In reality, the crop mix in the Odessa area could be expected to change to some form of dryland agriculture (eg. dryland wheat).

8.2.5 Biophysical Model Evaluation

In Ecology's Central Region, an estimated 92% of water users along the Columbia River mainstem had meters installed as of 2011 (Dan Haller, Ecology, personal communication). While the largest water users had been reporting for several years, older data were of mixed quality. Ecology's Central and Eastern Regions continue to work with users to improve the percentage reporting and quality of data.

Due to a lack of extensive metered data for actual withdrawal estimates, the modeled demand estimates have not been extensively evaluated. The WSU team had three years of withdrawal data from Banks Lake (which supplies the Columbia Basin Project area) and found that the modeled "top of crop" irrigation demand model estimates for the area (which do not include conveyance losses) were within 15% of the withdrawal data from Banks Lake.

8.2.6 Economic Modeling and Biophysical/Economic Integration

Many of the agricultural commodities modeled in this study were described as having regional markets. A commodity has a regional market when price variations across regions and the regional price is a function of regional production. A limitation of the 2011 Forecast was to model Washington as the entire region when the region more realistically should include surrounding states that grow similar crops including Oregon, Montana, Idaho, and California. Importantly, there is a significant amount of production transported between the states to regional processing facilities. As a result, production trends in neighboring states can affect Washington production based on price effects. These interactions were not modeled in this study.

This Forecast also did not account for the availability of land for agriculture that is not currently used for agriculture. There are some isolated areas of Washington such as Chelan County where there is little additional land available for agriculture. In the aggregate this is a relatively unimportant.

This Forecast did not model the impact of technological change on productivity growth nor did it consider the long-run impacts of water curtailment on cropping patterns. Including these aspects would require recalibrating the crop growth model for a large number of crops which was not feasible for this study.

Modeling of on-farm management decisions was limited in this Forecast. This includes all the tradeoffs that agricultural producers make in terms of inputs of fertilizer, labor, irrigation, etc. and cropping decisions in response to changes in prices and growing conditions in order to maintain profitability. This study did prioritize deficit irrigation across crops in response to water curtailments in accordance with economic theory, as further described in Chapter 3, Methodology.

9.0 Recommended Potential Improvements for 2016 Forecast

The model developed and used for this study represents current state-of-the-science technology. However, there are areas that could be improved upon to reduce uncertainty and risk. This section consists of recommendations by the WSU research team on how to improve the 2016 Forecast. The recommendations are based on discussions with stakeholders, Ecology and the WSU research team. This section also includes some initial suggestions on how to achieve the improvements. While Ecology will consider and evaluate the suggestions provided here, ultimately, the breadth and scope of the 2016 Forecast will be influenced by many factors including technology, staffing, data availability, budget, timeline, and overall importance to Ecology's strategic plan and mission.

9.1 Water Management Data Collection and Processing

9.1.1 Expand Water Rights Data

There are two primary areas where additional data are needed: 1) percent of irrigation demands associated with groundwater sources versus surface water sources, and 2) water rights associated with Surface Water Source Limitations. Ecology would need to evaluate the best way to acquire these data.

9.1.2 Collect and Verify Diversion Records

Collection and quality assurance/quality control of metered diversion data at the Columbia River scale as well as the watershed scale would allow WSU to evaluate the performance of the integrated model help calibrate the model to better represent actual conditions. Such evaluations are currently lacking due to a lack of data.

9.2 Data Verification and Model Evaluation

9.2.1 Verify Irrigated Areas

The recently released 2011 WSDA Cropland Data Layer expands coverage of irrigated pasture. This will significantly improve the coverage of irrigated agriculture in future models. However, given the large discrepancies between acreage reported by several of the irrigation districts and WSDA, independent field verification of the data could be conducted to reduce uncertainties. This verification could be carried out in the Walla Walla, Yakima, and Okanagan drainages initially and could be expanded depending on the level of agreement between WSDA estimates and the checked acreages.

9.2.2 Improve Information on Surface/Groundwater Sources to Understand Conservation Implications

Conservation is a complex issue in terms of whether or not it improves water quantities in streams and rivers. Diverting less water through use of improved irrigation efficiencies could actually reduce return flows (via shallow groundwater flows). This may in turn increase total consumptive water use and may adversely impact critical season stream flows currently benefitted by less efficient conveyance and irrigation technology.

An increased understanding is needed on how conservation actions may affect return flows, consumptive use and stream flows. Improved knowledge of the local surface/groundwater interface is also needed to evaluate the potential positive and negative impacts of conservation efforts. Seepage studies of water quantity, observation wells, and ion analysis can be used along with models of the Spokane, Yakima, and Walla Walla to improve understanding of the implications of conservation programs.

9.2.3 Field Verify and Expand Irrigation Practice Information

WSDA information was used to determine irrigation efficiencies throughout the State of Washington. This information needs to be field verified (in collaboration with validation of crop types and irrigated acreage). In addition, the database of irrigation efficiencies needs to be expanded to include information from Canada and larger water diversions in Idaho, Oregon, and Montana. This would facilitate the evaluation of conservation practice impacts.

9.2.4 Use Evapotranspiration Remote Sensing Application of Consumptive Use Requirements

The University of Idaho and the Idaho Water Resources Department have been using remote sensing images from LandSat (Thermatic Mapper) to determine evapotranspiration from agricultural areas primarily in southern Idaho. The procedure called "Mapping Evapotranspiration at high Resolution and with Internalized Calibration" (METRIC) is a modified version of the European approach known as SEBAL. A similar version for Washington crops, soils, and climate with field information on soil moisture, precipitation, temperature, and relative humidity at several key locations throughout the watershed could be developed. This information, along with a database of GIS layers of remotely sensed images could be combined with data collection efforts already occurring at AgMet stations throughout the region. In combination with water right diversion records, VIC-CropSyst water demands, and WIG estimates, this information would enable significantly improved evaluation of crop water demand, current groundwater recharge, conservation potentials, and long-term cost savings as ultimately metering of water diversions may not be necessary.

9.2.5 Expand Model Evaluation

Model evaluation could be improved in subsequent Forecasts. The 2011 Forecast has uncertainty in off- and on- farm water use efficiency as well as population expansion patterns. Differences between competing model estimates are difficult to resolve without improved measurement of *in situ* processes at relatively large scales. Even small discrepancies can amount to significant quantities of water over a watershed and provide some degree of overall uncertainty. For example, the Washington Irrigation Guidelines (based on ASCE) and CropSyst (based on United Nations Food and Agriculture Organization) compute evapotranspiration somewhat differently. As illustrated in Figure 217, when alfalfa harvest events (clipping) are considered, crop evapotranspiration evolution throughout the growing season between the two methods are clearly different. Additional information is needed to resolve parameter issues such as these as well as to verify the entire VIC-CropSyst model. This information can be collected through extensive data monitoring of on-farm practices, subsurface return flows, irrigation ditch diversions and losses, streamflows, and climate drivers or from remote sensing with some in-field verification.

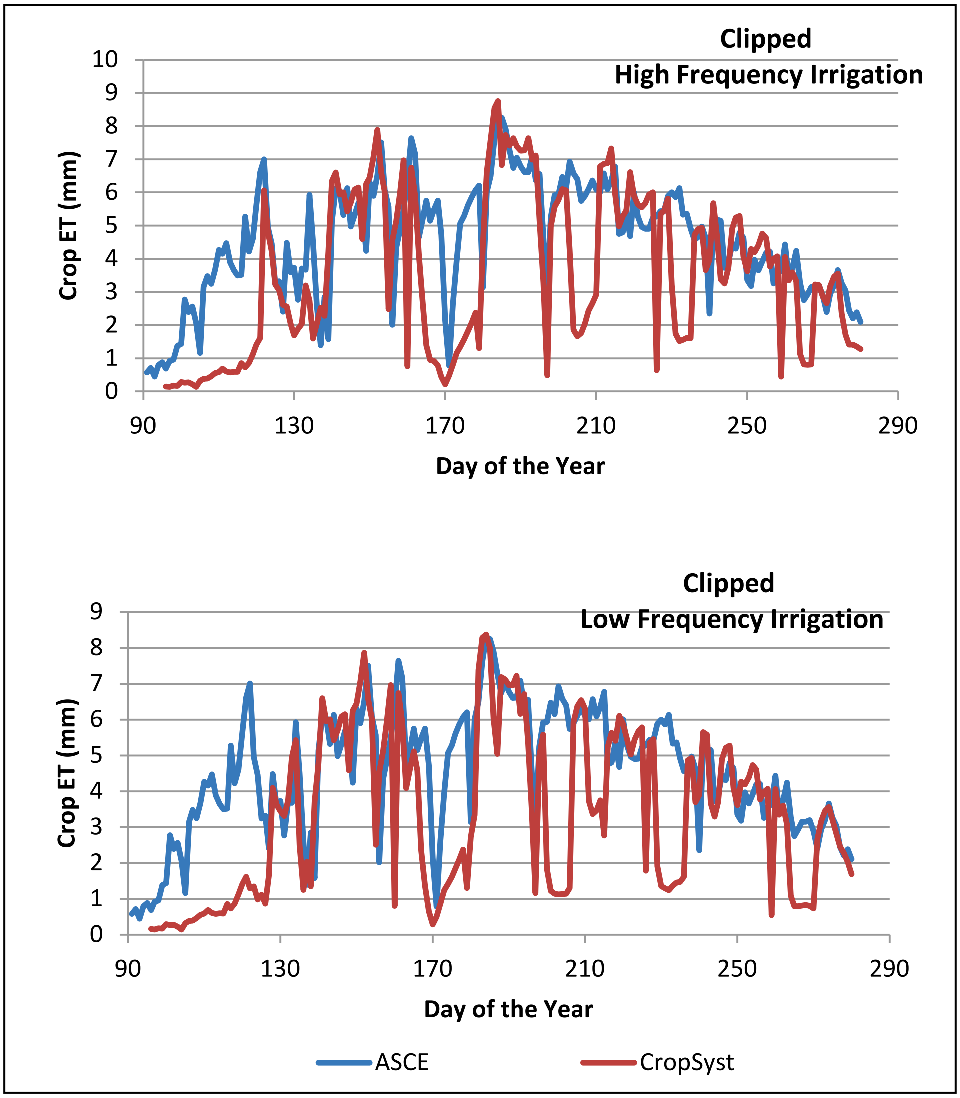


Figure 217. Comparison of estimates of evapotranspiration for alfalfa from the Washington Irrigation Guidelines (based on ASCE) and CropSyst (based on United Nations Food and Agriculture Organization).

9.3 Improvement of Biophysical Modeling

9.3.1 Incorporate Deep Groundwater Dynamics

Several watersheds rely substantially on groundwater pumping to support domestic and agricultural demands. Other areas rely on supplemental groundwater to augment surface supplies. A USGS study showed that these supplemental wells are in some areas now used every year rather than for drought mitigation purposes (Vaccaro and Sumioka 2006). Pumping of groundwater also ultimately reduces return flows back into streams in many instances although the timing may be considerably different. The current VIC-CropSyst model does not incorporate this information. To address this, the model would be expanded to include 3 or 4 areas where sufficient information on groundwater is known. GWATER or MODFLOW would be linked with VIC-CropSyst primarily through the spatially-explicit recharge layer.

9.3.2 Expand Water Right Modeling

To demonstrate types of management strategies that could yield improved asset allocation, a water right priority allocation model could be applied to the Yakima River Basin. This would create a framework for analyzing other watersheds in the future. With the completion of the current adjudication of the Yakima River Basin, a comprehensive list of surface water right information will be available on which to build a model of the watershed. This model would be linked with demand and return flow information from VIC-CropSyst to evaluate yield changes due to specific watershed strategies, new reservoirs, changes in current operations, and allow assessment of curtailment of individual rights. This tool could also form the basis for water marketing exchanges in the future. It would also enable addressing finer scale questions.

9.3.3 Evaluate a Variety of Reservoir Management Scenarios

The 2011 Forecast assumed historical reservoir operations to carry into the future. In fact, future operations are likely to evolve, adapting to changing climate and changing demands. For the 2016 Forecast modeling can create an optimization based reservoir management model that can evaluate multiple sets of operation rules.

In addition, the 2011 Forecast had a simplified reservoir model for Yakima that treated the entire system of reservoirs as a group and did not include specific operations for individual reservoirs. The US Bureau of Reclamation has a detailed reservoir model for Yakima which can be used for the 2016 Forecast by purchasing the required software.

Lastly, all the reservoir models could also be implemented at a weekly or daily time step instead of the monthly time step that was used for the 2011 Forecast. This will allow the model to match the time scale in which curtailment decisions are made.

9.3.4 Include Effects of Crop Rotation

The 2011 Forecast used a single snapshot of crop mix as a data layer for base case conditions. Actual farm practices often involve rotation of crops from year to year and the increasing use of alternative management strategies, such as cover cropping. Each of these could impact the demand and the economics of future crop selection. Factoring in crop rotation would give better long-term soil moisture conditions, improve water budgets, and allow more accurate assessment of economic impacts.

9.3.5 Account for Sensitivity of Forests under Climate Change

The next version of VIC-CropSyst could include improved modeling of the forest hydrology implications of climate change. There is a growing body of evidence indicating significant changes in runoff is occurring due to large-scale infestation of pine bark beetles. Parts of BC are reportedly seeing road and bridge flooding due to rising groundwater tables and reduced evapotranspiration from land surfaces.

9.3.6 Improve Population Growth Projections

On the biophysical side, estimates of population growth projections could be improved by evaluating twenty year trends of population growth locations within the county rather than assuming uniform distributions across each region. The latter approach tended to move people surrounding the city limits to parts of the country not necessary likely to experience the same growth. A more thorough review of water system plans to separate those systems that have separate irrigation feeds could also be conducted in order to more accurately assess total per capita water demand.

Lastly, the 2016 Forecast could carry out municipal demand forecasting in other states' portions of watersheds that extend outside of Washington's borders (e.g. Oregon, Idaho, Montana). This would make the Forecast's Tier II results more relevant by including other states' municipal demands.

9.4 Improvement of Economic Modeling

9.4.1 Include Land Assessments for Expanded Agriculture

Utilization of GIS maps that show potentially viable areas for irrigated agriculture would enable Ecology to better estimate where future demand for new water would likely be the greatest.

Land availability is an important factor because it informs model specification, shaping how land use can change within and across sectors. This is key for understanding the productivity of non-irrigated land that may become irrigated, or land moving from irrigated to dryland agriculture. It will also inform where there is little land available to move into agriculture, such as is the case in parts of Chelan County. Characterizing the entire land base is also significant for capturing the impacts of urban expansion. Incorporation of city ordinances, zoning laws, and other land use regulations such as protected forest land, urban growth boundaries, and development easements that restrict land use change could similarly be important.

9.4.2 Provide a Richer Representation of Factors that Influence Agricultural Productivity

There are two categories of factors influencing agricultural productivity that could be included in future Forecasts. The first is to forecast changes in productivity that are due to technological change that happens as a result of factors such as improved plant breeding. The second is farm level responses that model how producers can substitute between inputs in response to changes in factor prices and resource constraints. This is critical for many reasons including the ability to more accurately determine the impact of water curtailments that occur during drought conditions. This could be achieved by using a multi-input multi-output optimization model to represent the agriculture sector.

9.4.3 Expand Economic Model of Agricultural Production to Include the Entire CRB

Many of the agricultural commodities modeled in this study were described as having regional markets. A limitation of the 2011 Forecast was to model Washington as the entire region when the region more realistically includes surrounding states with similar growing regions including Oregon, Montana, Idaho, and California. The next Forecast could be improved by representing production in this entire multi-state region.

9.4.4 Incorporate Municipal Demand into Economic Modeling

Economic analysis could be extended to include a component for modeling municipal demand. This would include a historical analysis of population migration and urban development. By accounting for the demand for non-agricultural land and water it will be possible to estimate a willingness to pay for additional water resources for various municipalities.

9.5 Improvement of Integration between Biophysical and Economic Modeling

The 2011 Forecast's version of the model relied on sequential integration of economics and biophysical modeling where output from one model was used as inputs into the other model. Model results that were taken out of one model were exogenous in the model they were fed into. This was necessary because of the complexity of developing an integrated modeling framework that allows economic variables to be endogenously determined in the biophysical modeling and vice versa. For example, changes in the land base derived from economic factors are exogenous in the biophysical modeling. This means that crop cover does not change in the biophysical modeling in response to changes in water supply or the influence of climate on crop growth. At the same time, total physical supply of water is exogenous in the economic model and cannot change as a result of producer behavior.

The 2016 Forecast could more directly integrate the biophysical and economic modeling, to address these limitations, and to better account for the impacts of future deficits on future cropping patterns and irrigation technologies.

9.6 Improvement of Modeling Scenarios

9.6.1 Update Climate Data

In the 2016 Forecast, for future climate information, a 4-km gridded product that is based on downscaling methodology outlined by Abatzoglou and Brown (2011), the Multivariate Adapted

Constructed Analogs (MACA) methodology could be utilized. The authors are currently using MACA to downscale GCM results from the Coupled Model Intercomparison Project 5 (CMIP5) as they become available. They have done this for 3 Representative Concentration Pathways (RCPs): RCP 4.5, RCP 6.0, and RCP 8.5 (Moss et al. 2010). For historical weather information (daily maximum and minimum temperatures, relative humidity, precipitation, and wind speed), the 4-km gridded product developed by Abatzoglou (2011) for the period of 1979-2010, which is a combination of *in situ* observations and reanalysis data could be utilized.

9.6.2 Evaluate Conservation Impacts

There is considerable interest across the region in promoting agricultural and municipal conservation efforts as a mechanism for demand management. Overall effectiveness of conservation approaches in terms of improving low-flow discharges will likely be very watershed specific. Existing water demands for individual municipal systems as well as current irrigation technologies for agricultural parcels need to be factored into evaluation efforts. Quantifying overall WRIA impact will require refinement of return flow patterns, development of economic evaluations of possible conservation strategies, and evaluation of the degree of willingness to adopt conservation practices.

9.6.3 Incorporate Water Marketing in the Economic Analysis

There is evidence that water trading has been occurring at the local level but the 2011 Forecast applies deficit irrigation uniformly across low-value crops. A survey could be conducted of water users to more fully understand how water users view water markets. This will enhance the economic modeling particularly related to water shortages and local versus state-wide economic impacts.

9.6.4 Evaluate Potential Impacts of Columbia River Treaty

The Columbia River Treaty could dramatically change reservoir operations and flow timing in Washington. This could lead to changes in spill and fish requirements that will impact hydroelectric generation. Operating rules for ColSim could be updated to account for changes in flow without benefit of Canadian storage capacity.

9.6.5 Fisheries Requirements

WSU's modeling effort for the 2011 Forecast used established instream flow requirements for curtailment rules. However, as part of the Forecast, WDFW developed the "Columbia River Instream Atlas (Atlas, Ecology Publication 11-12-015) which includes instream flow conditions for eight of Washington's fish and low flow critical basins. The 2016 modeling effort could use the Atlas to determine implications for water availability at the WRIA level.

9.7 Additional Integrated Modeling Applications to Improve Forecast

9.7.1 Assess Columbia River Treaty Impacts on Supply

Managing water resources effectively and equitably among competing interests across the multitude of international, federal, state, tribal and local jurisdictional boundaries continues to represent a tremendous challenge for policy makers and scientists despite decades of collaborative efforts. Severe flooding in the U.S. and Canada combined with a growing need for hydropower prompted both countries to ratify a Columbia River Treaty (CRT) in 1964 that required construction of three large storage projects in the upper watershed in Canada (Duncan, Keenleyside, and Mica) and allowed 1 in the U.S. (Libby) that have resulted in improved water management and substantial shared benefits for both countries. For decades the shared benefit approach of the Columbia River Treaty has been held up as a model for international cooperation world-wide. The possible termination or renegotiation of the treaty in 2024 (notice can be given 10 years prior, so 2014 is the initial decision year) is sparking international debate among stakeholders on all sides as interests in prioritizing beneficial uses beyond flood control and hydropower are becoming increasingly important and provides a unique catalyst for change that often takes generations in other watersheds. In addition, the potential changes in river operation that may affect river management for the rest of the 21st century, combined with climate change and a growing population dependent on the ecological services the basin provides requires a systems approach that goes beyond the Columbia River Treaty's focus on hydropower and flood control.

As competition for scarce water resources increases and the impacts of climate change become intensified, more conflict over water supplies is expected between neighboring states as well as US-Canada interests. Future water management decisions involving the complex interactions and trade-offs between sustainable water supplies, economic development, ecosystem functions, energy, food security, societal values, recreation, navigation, laws, and cultural beliefs must be based on sound interdisciplinary and transdisciplinary science communicated to multiple audiences (Max-Neef 2005). Using the integrated biophysical modeling tool and an improved ColSim model, the potential impacts of reservoir operations on flow availability along the Colombia River mainstem could be examined.

9.7.2 Conduct Fine-Resolution Modeling Studies over Key Watersheds

The VIC model simulates the controls of climate on hydrologic processes at a relatively coarse resolution that is not necessarily fine enough to capture some of the sensitivities of the land surface to changes in climate. Therefore, for key watersheds, we plan to explore the influence of modeling scale on the sensitivity of key hydrologic processes to climate. The Distributed Hydrology Soil Vegetation Model (DHSVM; Wigmosta et al. 1994) can be applied over at least two watersheds of the CRB (the Yakima and the Spokane) at a 150 m spatial resolution to examine the finer controls of climate on snowmelt dynamics, evapotranspiration, streamflow, and soil moisture. Comparison of a full suite of states and fluxes between VIC and the process-scale DHSVM will allow a better understanding of VIC's ability to capture hydrologic variables other than streamflow. Comparison of the sensitivities of DHSVM and VIC runoff production to changes in precipitation, temperature, and land use could be done. Streamflow sensitivity to changes in precipitation can be estimated using the elasticity metric of Sankarasubramanian et al. (2001), whereas streamflow sensitivities to temperature can be estimated using the methods outlined by Elsner et al. (2010) who examined relative climate sensitivities over the Puget Sound basins. Analysis could be expanded to include examining sensitivities over the Yakima and Spokane systems. VIC and DHSVM sensitivities can be compared to each other as well as to observed streamflow elasticities. Sensitivity to land-use change can also be compared between the two models.

9.8 Stakeholder Input

9.8.1 Expand Collaboration with Conservation Districts and other Local Organizations for Targeted Preliminary Data Collection

The working water supply and demand model provided insight into specific information needs that could inform assumptions made within the Forecast (localized or basin-wide), as well as possible future applications of the model. Targeting these identified needs, the 2016 Forecast could include involvement of additional groups of informed stakeholders during the preliminary planning stages and at critical stages throughout the Forecast's development.

For example, Conservation Districts have knowledge regarding farmer practices, crop rotation, and in some cases water rights. They also regularly interact with a wide range of local stakeholders. The Okanogan Conservation District has been working with their stakeholders and evaluating claims in an attempt to better understand water supply and demand in their WRIA, and this information could improve localized modeling assumptions made within this watershed. Increased collaboration with existing local stakeholder groups can thus improve our ability to project realistic assumptions relevant to the modeling process.

9.8.2 Conduct Survey of Farm Community

Based in part on the results of initial conversations with Conservation Districts and other relevant local organizations, a survey of the farm community could be carried out. The ultimate success or failure of water policies will depend on society's willingness to adopt and implement new strategies. Water marketing, crop changes, deficit irrigation, response to incentives for conservation, etc. will all be driven by the farm community's desire and ability to adapt. Yet little is known about probable responses and economic valuation needed to promote change. As the single largest consumptive user in the Columbia River basin, understanding farmers' concerns, biases, and social/economic drivers is essential for Ecology. A survey of a representative sample of the farm community could provide information on these topics. The survey would only be identifiable by zip code so GIS interpretation of the data could be conducted. The survey would get at the heart of conservation and long-term planning goals.

10.0 References

Abatzoglou, J. T., 2011. Development of gridded surface meteorological data for ecological applications and modeling, *International Journal of Climatology,* DOI: 10.1002/joc.3413.

Abatzoglou, J. T., and T. J. Brown. 2011. A Comparison of Statistical Downscaling Methods Suited for Wildfire Applications. *International Journal of Climatology,* DOI:10.1002/joc.2312.

Avista Utilities. 2009. *2009 Electric Integrated Resource Plan*. Avista Corporation, Avista Utilities. http://www.avistautilities.com/inside/resources/irp/electric/Documents/Avista%202009%20IRP.pdf.

Avista Utilities. 2011. http://www.avistautilities.com/community/blog/archive/tags/Clark%20Fork/default.aspx?PageIndex=2 (Accessed October 11, 2011).

Badini, O., C. O. Stockle, J. W. Jones, R. Nelson, A. Kodio and M. Keita. 2007. A simulation-based analysis of productivity and soil carbon in response to time-controlled rotational grazing in the West African Sahel region. *Agricultural Systems*, **94**, 87–96.

Balance of Power. 2011. *Hydroelectric development in southeastern British Columbia*. http://www.virtualmuseum.ca/Exhibitions/Hydro/en/intro/ (Accessed October 6, 2011).

Barber, M. E., M. E. Hossain, C. J. Poor, C. Shelton, L. Garcia and M. McDonald. 2011. *Spokane Valley-Rathdrum Prairie aquifer optimized recharge for summer flow augmentation of the Columbia River*. Washington State University, Pullman, WA.

Barnett T.P., J.C. Adam, and D.P. Lettenmaier, 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* 438: 303-309.

BC Hydro. 2011. Duncan Dam, Project Water Use Plan. December 20, 2007. http://www.bchydro.com/etc/medialib/internet/documents/environment/pdf/wup_duncan_dam_project_water_use_plan_december_2007.Par.0001.File.wup_duncan_dam_project_water_use_plan_december_2007.pdf. (Accessed October 21, 2011).

Benli, B., M. Pala, C. Stockle and T. Oweis. 2007. Assessment of winter wheat production under early sowing with supplemental irrigation in a cold highland environment using CropSyst simulation model. *Agricultural Water Management*, **93**, 45–53.

Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers. 2001. *Columbia River system inside story, second edition: Federal Columbia River Power System*. Bonneville Power Administration, Portland, OR. http://www.bpa.gov/power/pg/columbia_river_inside_story.pdf. (Accessed January 27, 2012).

Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers. 2009. *2010 Water Management Plan*. December 31, 2009.

Borsuk, M., R. Clemen, L. Maguire and K. Reckhow. 2001. Stakeholder values and scientific modeling in the Neuse River watershed. *Group Decision and Negotiation*, **10**, 355–373.

Boyer, D. 2011. British Columbia Ministry of Environment. Personal communication via e-mail, October 19, 2011.

Burke, M., K. Jorde, and J. M Buffington. 2009. Application of a hierarchical framework for assessing environmental impacts of dam operation: changes in hydrology, channel hydraulics, bed mobility and recruitment of riparian trees in a western North American river. *Journal of Environmental Management* 90: S224-S236.

Burns, E. R., D. S. Morgan, R. S. Peavler and S. C. Kahle. 2010. *Three-dimensional model of the geologic framework for the Columbia Plateau regional aquifer system, Idaho, Oregon, and Washington*. U.S. Geological Survey Groundwater Resources Program, Reston, VA. http://pubs.usgs.gov/sir/2010/5246/pdf/sir20105246.pdf (Accessed January 24, 2012).

Canadian and United States Entities. 2010. *Phase 1 Report*. Columbia River Treaty 2014/2024 Review. http://www.crt2014-2024review.gov/Files/Phase1Report_7-28-2010.pdf

Casola, J. H., J. E. Kay, A. K. Snover, R. A. Norheim, L. C. Whitely Binder, and Climate Impacts Group. 2005. *Climate impacts on Washington's hydropower, water supply, forests, fish and agriculture. A report prepared for King County (Washington) by the Climate Impacts Group*. Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, Seattle, WA.

Christensen, N. S., A. W. Wood, N. Voisin, D. P. Lettenmaier and R. N. Palmer. 2004. The effects of climate change on the hydrology and water resources of the Colorado River basin. *Climatic change*, **62**, 337–363.

Columbia River Data Access in Real Time (DART). 2011. Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. http://www.cbr.washington.edu/dart/river.html (Accessed July 12, 2011).

Cooper, R. M. 2002. *Determining surface water availability in Oregon.* Oregon Water Resources Department, Salem, OR. http://www.oregon.gov/OWRD/WR/docs/SW02-002.pdf?ga=t

Department of Ecology. 2012. Columbia River Facts and Maps. *Columbia River Facts and Maps*. http://www.ecy.wa.gov/programs/wr/cwp/cwpfactmap.html (Accessed January 27, 2012).

Department of Natural Resources and Conservation (DNRC). 2004. Clark Fork River Basin water management plan, state water plan section. Water Resources Division, Department of Natural Resources and Conservation, Helena, MT. http://dnrc.mt.gov/wrd/water_mgmt/clarkforkbasin_taskforce/water_mgmt_plan.asp (Accessed February 22, 2012).

Drost, B. W., S. E. Cox and K. M. Schurr. 1997. *Changes in ground-water levels and ground-water budgets, form predevelopment to 1986 in parts of the Pasco Basin, Washington*. Tacoma, WA.

Elsner, M. M. and Coauthors. 2010. Implications of 21st century climate change for the hydrology of Washington State. *Climatic Change*, **102**, 225–260.

Espinoza, G.C. and M.C. Espinoza. 2000. A unified approach to sensitivity analysis in equilibrium displacement models. *American Journal of Agricultural Economics*, **80**, 868-879.

Federal Energy Regulatory Commission (FERC). 2009. 127 FERC, 61,265, Order Issuing New License and Approving Annual Charges for Use of Reservation Lands, United States of America, Issued June 18, 2009.

FERC. 2004. *Handbook for Hydroelectric Project Licensing and 5 MW Exemptions from Licensing.* http://www.ferc.gov/industries/hydropower/geninfo/handbooks/licensing_handbook.pdf (Accessed March 8, 2011).

FERC. 2011. Complete list of issued licenses. Federal Energy Regulatory Commission. http://www.ferc.gov/industries/hydropower.asp. (Accessed March 8, 2011).

Gao, H. and Coauthors. 2010. Water budget record from Variable Infiltration Capacity (VIC) model. *Algorithm Theoretical Basis Document for Terrestrial Water Cycle Data Records*.

Golder and Anchor. 2006. *2006 Columbia River Legislative report: Columbia River water supply inventory and long-term water supply and demand forecast*. Submitted by Golder Associates and Anchor Environmental to Washington State Department of Ecology, Olympia, WA. http://www.ecy.wa.gov/programs/wr/cwp/cr_06legrpt.html. (Accessed March 5, 2012).

Grant County PUD. 2009. *Grant County PUD Integrated Resource Plan – Executive Summary*. http://www.gcpud.org/pudDocuments/energyResourcesDocs/IRPSummary.pdf

Grant County PUD. 2010. *Grant County PUD Integrated Resource Plan Update.* August 23, 2010. PowerPoint Presentation. http://www.gcpud.org/energyResources/renawableResources/newResourceProjects.html (Accessed March 7, 2012).

Hale, E. O. 1993. Successful public involvement. *Journal of Environmental Health*, **55**, 17–19.

Hamlet, A. F., S.Y. Lee, K. E. B. Mickelson and M. M. Elsner. 2010. Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. *Climatic Change*, **102**, 103–128, doi:10.1007/s10584-010-9857-y.

Hamlet, A. F. and D. P. Lettenmaier. 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. *Journal of the American Water Resources Association*, **35**, 1597–1623.

Hamlet, A. F. and D. P. Lettenmaier. 2005. Production of Temporally Consistent Gridded Precipitation and Temperature Fields for the Continental United States. *Journal of Hydrometeorology*, **6**, 330–336.

Hamlet, A. F. and D. P. Lettenmaier. 2007. Effects of 20th century warming on flood risk.pdf. *Water Resources Research*, **43**, 1–17.

Hamlet, A. F., P. Mote, M. P. Clark and D. P. Lettenmaier. 2007. 20th century trends in runoff, evapotranspiration, and soil moisture in the Western U.S. *Journal of Climate*, **20**, 1468–1486.

Hamlet, A. F., A. Snover and D. P. Lettenmaier. 2003. Climate Change Scenarios for Pacific Northwest Water Planning Studies: Motivation, Methodologies, and a User's Guide to Applications.

Hansen, M., R. DeFries, J. R. G. Townshend and R. Sohlberg. 2000. Global land cover classification at 1 km spatial resolution using a classification tree approach. *International Journal of Remote Sensing*, **21**, 1331–1364.

Harmon, Robert. 2011. Oregon instream water rights flowing into Washington. Salem, OR. Oregon Water Resources Department. October 13, 2011.

Harrington, D.H. and R. Dubman. 2008. *Equilibrium displacement mathematical programming models: methodology and a model of the U.S. agricultural sector.* Economic Research Service, U.S. Department of Agriculture, Technical Bulletin No. TB-1918.

Hayhoe, K. and Coauthors. 2007. Past and future changes in climate and hydrological indicators in the US Northeast. *Climate Dynamics*, **28**, 381–407.

HDR. 2005. *Middle Snake River Watershed level 1 assessment*. HDR, Prepared for the WRIA 35 Watershed Planning Unit, Pasco, WA.

Howitt, R.E., J. Medellin-Azuara and D. MacEwan. 2008. Calculating California Cropping Patterns in 2050. Draft Report 11-18-2008.

Hseih, P. A., M. E. Barber, B. A. Contor, M. A. Hossain, G. S. Johnson, J. L. Jones and A. H. Wylie. 2007. *Ground-water flow model for the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho*. Reston, VA.

Hughes, T. C. 1996. *Consumptive use of municipal water supply*. Utah Water Research Laboratory, Logan, UT. http://www.cachecounty.org/docs/waterpolicy/docs//Consumptive%20Use%20of%20Municipal%20Water%20Supply.pdf.

Idaho Department of Water Resources (IDWR). 2005. Recommended water rights acquired under state law. Boise, ID. http://www.idwr.idaho.gov/waterboard/WaterPlanning/nezperce/pdf_files/IWRB%2042-1507%20Recommendations.pdf.

Idaho Department of Water Resources. 2009. *Eastern Snake Plain aquifer comprehensive aquifer management plan. Idaho Water Resource Board*. Boise, ID. http://www.idwr.idaho.gov/waterboard/WaterPlanning/CAMP/ESPA/PDFs/ESPA_CAMP_lowres.pdf.

Idaho Department of Water Resources (IDWR). 2012. State Water Plan – Snake River Policy. http://www.idwr.idaho.gov/waterboard/WaterPlanning/StateWaterPlanning/PDFs/2010/Draft_SRB-Policies.pdf. (Accessed February 14, 2012).

Idaho Power. 2011. *2011 Integrated Resource Plan*. IDACORP, Idaho Power Company. http://www.idahopower.com/AboutUs/PlanningForFuture/irp/2011/default.cfm.

Idaho Strategic Energy Alliance. 2009. *Hydropower Task Force Report.* http://www.energy.idaho.gov/energyalliance/taskforce.htm.

IEAB. 2005. *Economic effects from Columbia River Basin anadromous salmonid fish production*. Independent Economic Analysis Board. http://www.nwcouncil.org/library/ieab/ieab2005-1.pdf. (Accessed January 25, 2012).

IPCC. 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA*, **996**, 2007.

Jara, J. and C. O. Stockle. 1999. Simulation of corn water uptake using models with different levels of process detail. *Agronomy Journal*, **91**, 256–265.

Jerardo, A. 2008. What Share of US Consumed Food is Imported? *Amber Waves*, February 2008. http://www.ers.usda.gov/amberwaves/february08/datafeature. (Accessed March 9, 2012).

Kahle, S. C., R. R. Caldwell and J. R. Bartolino. 2005. *Compilation of geologic, hydrologic, and ground-water flow modeling information for the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho*. U.S. Geological Survey Groundwater Resources Program, Reston, VA. http://pubs.usgs.gov/sir/2005/5227/pdf/sir20055227.pdf. (Accessed January 25, 2012).

Kanbergs, K. 2011. USACE, Reservoir Control Center, Team Lead, Northwestern Division, U.S. Army Corps of Engineers, Portland Oregon. Personal communication, October 21, 2011.

Kalnay, E. and Coauthors. 1996. The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society*, **77**, 437–471.

Kemanian, A. 2003. Radiation-based and transpiration-based modeling of barley and wheat growth. Washington State University.

Kemanian, A. R. and C. O. Stockle. 2010. C-Farm. A simple model to evaluate the carbon balance of soil profiles. *European Journal of Agronomy*, **32**, 22–29.

Kemanian, A. R., C. O. Stöckle, D. R. Huggins, and L. M. Viega. 2007. A simple method to estimate harvest index in grain crops. *Field Crops Research*, **103**, 208–216.

Knitter, K. 2010. *Tapping Irrigation Water Delivery Systems to Produce Hydropower: Columbia Basin Project*. 2010 Harvesting Clean Energy Conference, Kennewick, WA. Feb. 2010. http://harvestcleanenergy.org/2010-conference-resources/2010-harvesting-clean-energy-conference/2010-conference-presentations/knitter-330-pdf.

Ladd, M. 2011. Regional Manager, North Central Region, Oregon Water Resources. Personal communication: e-mail attachment Instream Water Rights and Scenic Waterway Flows for selected rivers in Oregon. October 19, 2011.

Lane, R. C. 2009. *Estimated water use in Washington, 2005*. U.S. Geological Survey, U.S. Department of the Interior, Reston, VA.

Lane, R. C. 2004. *Estimated domestic, irrigation, and industrial water use in Washington, 2000*.

Leung, L. R. and S. J. Ghan. 1998. Parameterizing subgrid orographic precipitation and surface cover in climate models. *Monthly Weather Review*, **126**, 3271–3291.

Liang, X., D. P. Lettenmaier, E. Wood and S. Burgess. 1994. A simple hydrologically based model of land surface water and energy fluxes for general circulation models. *Journal of Geophysical Research 99D7*, 14–415.

Liang, X., E. F. Wood and D. P. Lettenmaier. 1996. Surface soil moisture parameterization of the VIC-2L model: Evaluation and modification. *Global and Planetary Change*, **13**, 195–206.

Lohmann, D., E. Raschke, B. Nijssen and D. Lettenmaier. 1998. Regional scale hydrology: I. Formulation of the VIC-2L model coupled to a routing model. *Hydrological Sciences Journal*, **43**, 131–141.

Lower Columbia Fish Recovery Board. 2004. *Lower Columbia salmon recovery and fish and wildlife subbasin plan: Restoring salmon and steelhead to healthy, harvestable levels.* Lower Columbia Fish Recovery Board. http://www.nwcouncil.org/fw/subbasinplanning/lowercolumbia/plan/RP%20Overview.pdf. (Accessed February 16, 2012).

Mantua, N. J., I. Tohver and A. Hamlet. 2005. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change*, doi:DOI 10.1007/s10584-010-9845-2.

Marcos, J. 2000. Simulation-based assessment of alternative crops in the dryland Pacific Northwest. Washington State University.

Markoff, S. M. and A. C. Cullen. 2008. Impact of climate change on Pacific Northwest hydropower. *Climatic Change*, **87**, 451–469.

Marks, C. 2011. Confederated Tribes of the Umatilla Indian Reservation, Water Rights Policy Analyst. Personal communication, September 30, 2011.

Maurer, E. P., A. W. Wood, J. C. Adam, D. P. Lettenmaier and B. Nijssen. 2002. A long-term hydrologically-based data set of land surface fluxes and states for the conterminous United States. *Journal of Climate*, **15**, 3237–3251.

Maurer, E. P. 2007. Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios. *Climatic Change*, **82**, 309–325.

Max-Neef, M. A. 2005. Foundations of transdisciplinarity. *Ecological Economics*, **53**, 5–16.

McCroskery, J. 2011. Hydraulic Engineer, Reservoir Control Center, Northwestern Division, U.S. Army Corps of Engineers, Portland Oregon. Personal communications, October 10-14, 2011.

Mitchell, K. and Coauthors. 1999. GCIP land data assimilation system (LDAS) project now underway. *Gewex News*, **9**, 3–6.

Mote, P. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. *Northwest Science*, **77**, 271–282.

Mote, P. 2006. Climate-driven variability and trends in mountain snowpack in western North America. *Journal of Climate*, **19**, 6209–6220.

Mote, P. W., A. F. Hamlet, M. P. Clark and D. P. Lettenmaier. 2005a. Declining mountain snowpack in Western North America. *Bulletin of the American Meteorological Society*, **86**, 39–49, doi:10.1175/BAMS-86-1-39.

Mote, P. W. and E. P. Salathe. 2010. Future climate in the Pacific Northwest. *Climatic Change*, **102**, 29–50.

Mote, P. W., E. Salathe and C. Peacock. 2005b. *Scenarios of future climate for the Pacific Northwest*. Climate Impacts Group, Seattle, WA. http://cses.washington.edu/db/pdf/kc05scenarios462.pdf.

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K, Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, et al, 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463:747–756.

Muckleston, K.W. 2003. International Management in Columbia River System. UNESCO/IHP/WWAP, Technical Documents in Hydrology, PC-CP series #12.

Mutondo, J.E., B.W. Brorsen and S.R. Henneberry. 2009. Welfare impacts of BSE-driven trade bans. *Agricultural and Resource Economics*, **38**, 324-329.

NOAA. 2008. *Endangered Species Act Section 7(a)(2) Consultation Biological Opinion And Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation*. F/NWR/2005/05883. https://pcts.nmfs.noaa.gov/pls/pcts-pub/sxn7.pcts_upload.download?p_file=F24978/200505883_FCRPS Cover-Ch1-7.pdf.

Northwest Power and Conservation Council. 2010. *6th Northwest Conservation and Electric Power Plan*. Northwest Power and Conservation Council. http://www.nwcouncil.org/energy/powerplan/6/default.htm.

NRC. 2004. *Managing the Columbia River: Instream flows, water withdrawals, and salmon survival*. National Research Council, Committee on Water Resources Management, Instream Flows, and Salmon Survival. The National Academies Press, Washington, D.C. 268 pp. http://www.nap.edu/catalog.php?record_id=10962.

NWPCC. 2010. *6th Northwest Power Plan*. Northwest Power and Conservation Council. http://www.nwcouncil.org/energy/powerplan/6/default.htm.

Oregon Water Resource Department. 2011. Water rights information query. http://apps.wrd.state.or.us/apps/wr/wrinfo. (Accessed October 17, 2011).

Pannkuk, C., C. Stockle and R. Papendick. 1998. Evaluating CropSyst simulations of wheat management in a wheat-fallow region of the US Pacific Northwest. *Agricultural Systems*, **57**, 121–134.

Payne, J. T., A. W. Wood, A. F. Hamlet, R. N. Palmer and D. P. Lettenmaier. 2004. Mitigating the effects of climate change on the water resources of the Columbia River basin. *Climatic Change*, **62**, 233–256.

Peralta, J. M. and C. O. Stockle. 2002. Dynamics of nitrate leaching under irrigated potato rotation in Washington State: a long-term simulation study. *Agriculture, ecosystems & environment*, **88**, 23–34.

Porcello, J., T. Tolan and K. Lindsey. 2009. *Groundwater level declines in the Columbia River basalt group and their relationship to mechanisms for groundwater recharge*. GSI Water Solutions, Kennewick, WA.

Portland General Electric (PGE). 2009. *2009 Integrated Resource Plan*. Portland General Electric Co. http://www.portlandgeneral.com/our_company/news_issues/current_issues/energy_strategy/default.aspx.

Powers, Kyna. 2003. Benefit-Cost Analysis and the Discount Rate for the Corps of Engineers' Water Resource Projects: Theory and Practice. CRS Report for Congress. Order Code RL31976. June 23, 2003.

Rogers, P., R. Bhatia, and A. Huber. 1998. *Water as a social and economic good: how to put the principle into practice*. TAC Background Papers No. 2. Global Water Partnership Technical Advisory Committee, Swedish International Development Cooperation Agency. http://info.worldbank.org/etools/docs/library/80637/IWRM4_TEC02-WaterAsSocialEconGood-Rogers.pdf. (Accessed March 9, 2012).

Rushton, C. 2000: *Instream flows in Washington State of Washington past, present and future. Draft report.* Water Resources Program, Department of Ecology, Olympia, WA. http://home.olympus.net/~dungenesswc/InstreamFlowversion12.PDF. (Accessed February 16, 2012).

Sadras, V. O. 2004. Yield and water-use efficiency of water-and nitrogen-stressed wheat crops increase with degree of co-limitation. *European journal of agronomy*, **21**, 455–464.

Salmon Recovery. 2009. *FCRPS Adaptive Management Implementation Plan*, 2008-2018 Federal Columbia River Power System, Biological Opinion. http://www.salmonrecovery.gov/Files/BiologicalOpinions/AMIP_09%2010%2009.pdf.

Sankarasubramanian, A., R.M. Vogel, J.F. Limbrunner, 2001. Climate elasticity of streamflow in the United States. *Water Resources Research* 37(6):1771–1781.

Scheierling, S.M., J.B. Loomis and R.A. Young. 2005. Irrigation water demand: a meta-analysis of price elasticities. *Water Resources Research*, **42**.

Schwarz, C. V. and B. Y. White. 2005. Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction*, **23**, 165–205.

Shaff, D. 2006. Managing an adjudication: outcomes and accountability. Adjudication Bureau Chief Idaho Department of Water Resources, Western States Adjudication Conference, Seattle, Washington October 9 – 11, 2006. http://www.ecy.wa.gov/programs/wr/rights/Images/pdf/conference/idaho_maoa.pdf. (Accessed October 7, 2011).

Snake River Basin Adjudication: Agreement Summary. May 2004. http://www.fws.gov/dworshak/pdf/srba_agreementsummary.pdf. (Accessed October 6, 2011).

Snake River Basin Adjudication: Informational Brochure. http://www.srba.state.id.us/DOC/BROCH1.HTM. (Accessed February 22, 2012).

Somerville, R. and S. Hassol. 2011. Communicating the science of climate change. *Physics Today*, **64**, doi:doi:10.1063/PT.3.1296.

State Water Plan: Snake River Policy. 2010 08. Draft River Basin Overarching Policies. http://www.idwr.idaho.gov/waterboard/WaterPlanning/StateWaterPlanning/PDFs/2010/Draft_SRB-Policies.pdf. (Accessed October 22, 2011).

Stave, K. A. 2002. Using system dynamics to improve public participation in environmental decisions. *System Dynamics Review*, **18**, 139–167, doi:10.1002/sdr.237.

Stewart, I. T., D. R. Cayan and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a "business as usual" climate change scenario. *Climatic Change*, **62**, 217–232.

Stewart, I. T., D. R. Cayan and M. D. Dettinger. 2005. Changes toward earlier streamflow timing across Western North America. *Journal of Climate*, **18**, 1136–1155.

Stockle, C. O., M. Donatelli and R. Nelson. 2003. CropSyst, a cropping systems simulation model. *European Journal of Agronomy*, **18**, 289–307.

Stöckle, C. O., S. Higgins, A.R. Kemanian, R. Nelson, D. Huggins, J. Marcos and H. Collins. 2010a. A simulation study of the effect of tillage and rotation on the potential for carbon sequestration of cropping systems in eastern Washington. *Agricultural Systems* (in review).

Stockle, C. and J. Jara. 1998. Modeling transpiration and soil water content from a corn (Zea Maize L.) field: 20 min vs. daytime integration step. *Agricultural and forest meteorology*, **92**, 119–130.

Stöckle, C. O., R. L. Nelson, S. Higgins, J. Brunner, G. Grove, R. Boydston, M. Whiting and C.Kruger. 2010b. Assessment of climate change impact on Eastern Washington agriculture. *Climatic Change*, **102**, 77–102.

Stockle, C. O., S. A. Martin and G. S. Campbell. 1994. CropSyst, a cropping systems simulation model: water/nitrogen budgets and crop yield. *Agricultural Systems*, **46**, 335–359.

Sumner, D.A. 2005. *Boxed in: Conflicts between U.S. farm policies and WTO obligations*. Trade Policy Analysis No. 32, CATO Institute, Washington, DC.

Symonds, B. 2011. Director of Environmental Stewardship for the British Columbia Ministry of Environment. Personal communication, October 19, 2011.

Todorovic, M., R. Albrizio, L. Zivotic, M. T. A. Saab, C. Stockle and P. Steduto, 2009. Assessment of AquaCrop, CropSyst, and WOFOST models in the simulation of sunflower growth under different water regimes. *Agronomy Journal*, **101**, 509–521.

Tri-County Water Resource Agency. 2003. *Yakima Basin watershed plan*. Tri-County Water Resource Agency.

U.S. Army Corps of Engineers. 1989. *Columbia River and tributaries review study: Project data and operating limits*. U.S. Army Corps of Engineers, North Pacific Division.

U.S. Army Corps of Engineers. 2009. Map of the Columbia Basin showing major dams. *U.S. Army Corps of Engineers*. http://www.nwd.usace.army.mil/ps/colbsnmap.asp. (Accessed March 6, 2012).

U.S. Army Corps of Engineers. 2011a. Dworshak Dam and Reservoir pertinent data. http://www.nww.usace.army.mil/html/pub/pertdata/dwapert.htm. (Accessed January 31, 2012).

U.S. Army Corps of Engineers. 2011b. Walla Walla District. http://www.nww.usace.army.mil/html/pub/pi/flood/dworshak.htm. (Accessed October 11, 2011).

U.S. Army Corps of Engineers (USACE). 2011c. Dam public information, Albeni Falls Dam. http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=albeni&pagename=DamInformation. (Accessed October 11. 2011).

U. S. Bureau of Reclamation. 2002. Interim Comprehensive Basin Operating Plan for the Yakima Project, Washington. *US Department of the Interior, US Bureau of Reclamation*.

U.S. Bureau of Reclamation. 2008. Upper Columbia alternative flood control and fish operations. http://www.usbr.gov/pn/programs/fcrps/varq/usace-rod-UCEIS-june2008.pdf. (Accessed February 21, 2012).

U.S. Department of Agriculture. 2011. *Long-term Projections Report OCE-2011-1.* Prepared by the Interagency Agricultural Projections Committee. Office of the Chief Economist, World Agricultural Outlook Board, U.S. Department of Agriculture. http://www.usda.gov/oce/commodity/archive_projections/USDAAgriculturalProjections2020.pdf. (Accessed March 9, 2012).

U.S. Department of Agriculture National Agricultural Statistical Service. 2009. Trade and Agriculture. What's at Stake for Washington? U.S. Department of Agriculture Foreign Agricultural Service. http://www.fas.usda.gov/info/factsheets/wto/states/wa.pdf. (Accessed March 9, 2012).

U.S. Department of the Interior. 2011. Bureau of Reclamation, Hungry Horse Project. http://www.usbr.gov/projects/ProjecT. Jsp?proj_Name=Hungry%20Horse%20Project. (Accessed October 10, 2011).

United States Entity. 2010. *United States Entity Supplemental Report*. Columbia River Treaty 2014/2024 Review. http://www.crt2014-2024review.gov/Files/SupplementalReportAndExecutiveSummary.pdf.

U.S. Environmental Protection Agency (USEPA). 2011. Learn About the Columbia River. http://yosemite.epa.gov/r10/ECOCOMM.NSF/Columbia/Columbia+Learn. (Retrieved October 3, 2011).

U.S. Geological Survey. 2004. *Estimated use of water in the United States in 2000*. U.S. Geological Survey. http://water.usgs.gov/watuse/data/2000/index.html.

U.S. Geological Survey. 2012. U.S.G.S. Annual Water Statistics for USGS 14105700 Columbia River at The Dalles, OR. 1880-2010. *U.S. Surface Water Annual Statistics for Oregon.* http://waterdata.usgs.gov/or/nwis/uv?site_no=14105700.

Upper Columbia Alternative Flood Control and Fish Operations: Record of Decision for Libby Dam Flood Control and Fish Operations, U.S. Army Corps of Engineers. http://www.usbr.gov/pn/programs/fcrps/varq/usace-rod-UCEIS-june2008.pdf. (Accessed October 10, 2011).

UW/NOAA JISAO, CSES. 2011a. Pacific Northwest Climate. *University of Washington-National Oceanic and Atmospheric Administration, Joint Institute for the Study of the Atmosphere and Ocean, Center for Science in the Earth System*. http://cses.washington.edu/cig/pnwc/pnwc.shtml. (Accessed March 6, 2012).

UW/NOAA JISAO, CSES. 2011b. Climate change. *University of Washington- National Oceanic and Atmospheric Administration, Joint Institute for the Study of the Atmosphere and Ocean, Center for Science in the Earth System*. http://cses.washington.edu/cig/pnwc/cc.shtml#figure3. (Accessed March 6, 2012).

Vaccaro, J. J. and Sumioka. 2006. *Estimates of ground water pumpage from the Yakima River basin aquifer system, Washington, 1960-2000*. U.S. Geological Survey, U.S. Department of the Interior.

VanRheenen, N. T., A. W. Wood, R. N. Palmer and D. P. Lettenmaier. 2004. Potential implications of PCM climate change scenarios for Sacramento-San Joaquin River Basin hydrology and water resources. *Climatic Change*, **62**, 257–281.

Wandschneider, P., J. Yoder, A. Benson and A. Ohler. 2006. *Crop production and water use forecasts for the State of Washington based on econometric estimation and expert opinion. A report to the Department of Ecology, Washington State.* School of Economic Sciences, Washington State University, Pullman, WA.

Washington Department of Fish and Wildlife. 2011. *Columbia River Instream Atlas*. http://www.ecy.wa.gov/pubs/1112015.pdf. (Accessed January 31, 2012).

Whitehead, R. L. 1994. *Ground Water Atlas of the United States: Idaho, Oregon, and Washington HA 730-H*. U.S. Geological Survey.

Wigmosta, M.S., L. Vail, and D. P. Lettenmaier, 1994. A distributed hydrology-vegetation model for complex terrain, *Wat. Resour. Res.,* 30, 1665-1679.

World Commission on Dams. 2000. *Dams and Development – A New Framework for Decision-Making*. The Report of the World Commission on Dams, pp 55.

Zaher, U., C.O. Stöckle, K. Painter and S. Higgins. 2010. Life-cycle assessment of the potential carbon credit from no- and reduced-tillage winter wheat cropping systems in the dryland region of the U.S. Pacific Northwest. *Agricultural Systems* (in preparation).