Columbia River Basin Long-Term Water Supply and Demand Forecast: Technical Report for the Work Conducted by Washington State University

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.

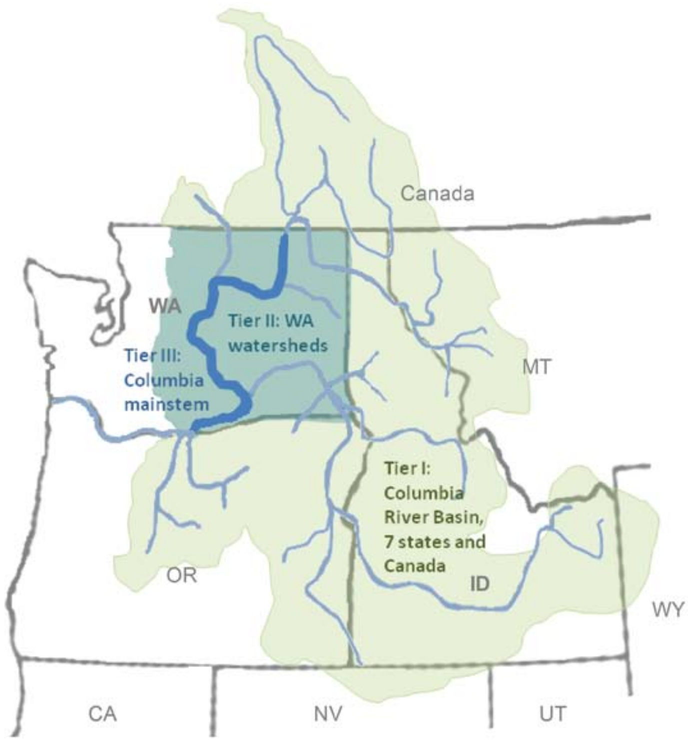

Figure 1. Long-term water supply and demand was forecasted at three tiers. Tier I: the entire basin-wide scale; Tier II: the WRIA scale; and Tier III: the Columbia River mainstem within Washington State upstream of Bonneville Dam.

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.

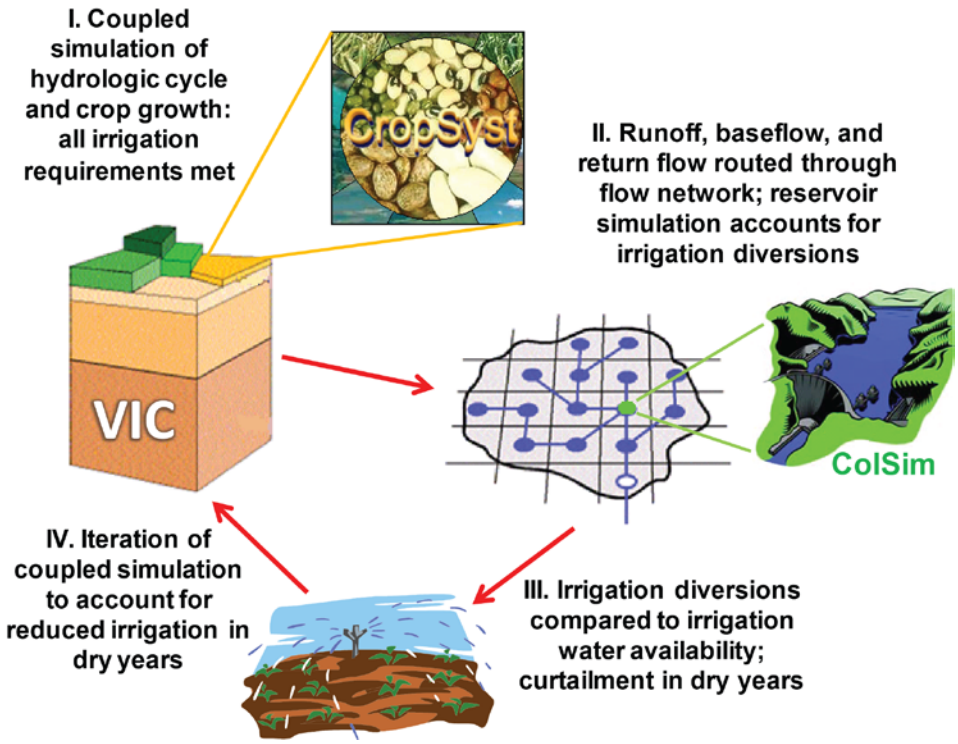

Figure 2. Biophysical modeling framework for forecasting surface water supply and irrigation water demand.

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.

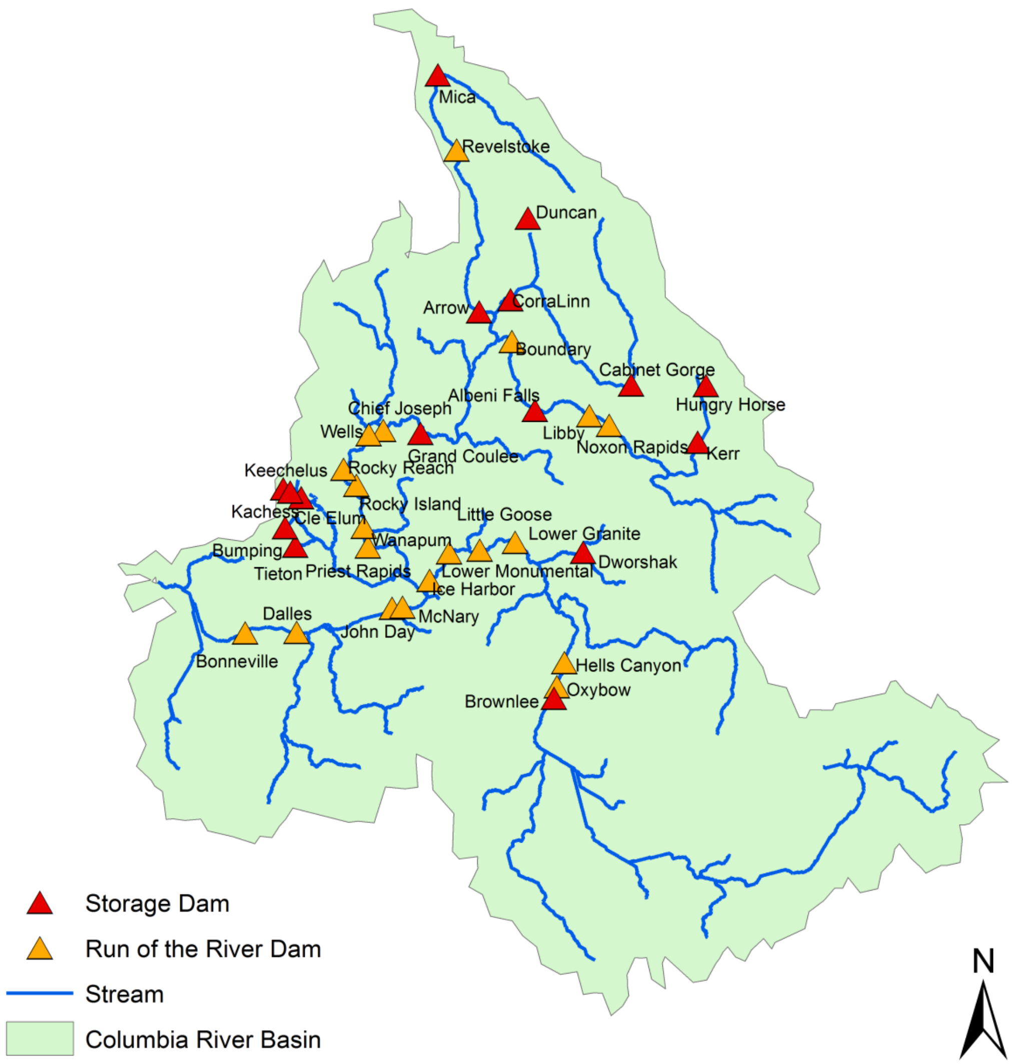

Figure 3. Dams incorporated in reservoir modeling.

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.

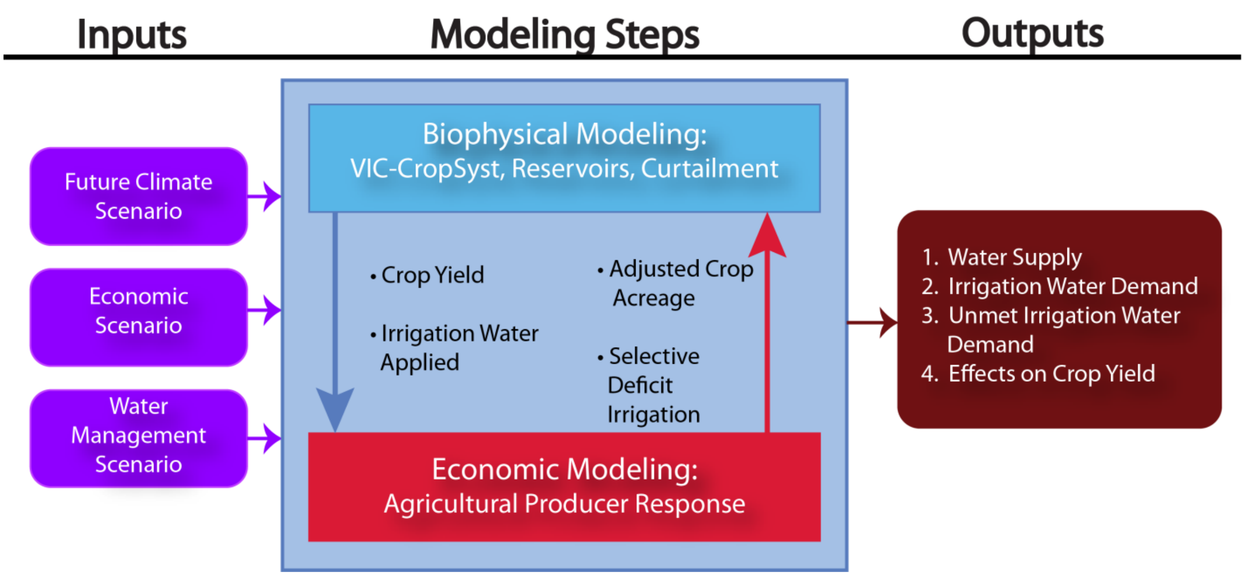

Figure 4. Integration of biophysical modeling (surface water supply, crop dynamics and climate) with economic and policy (human decision-making) modeling.

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.