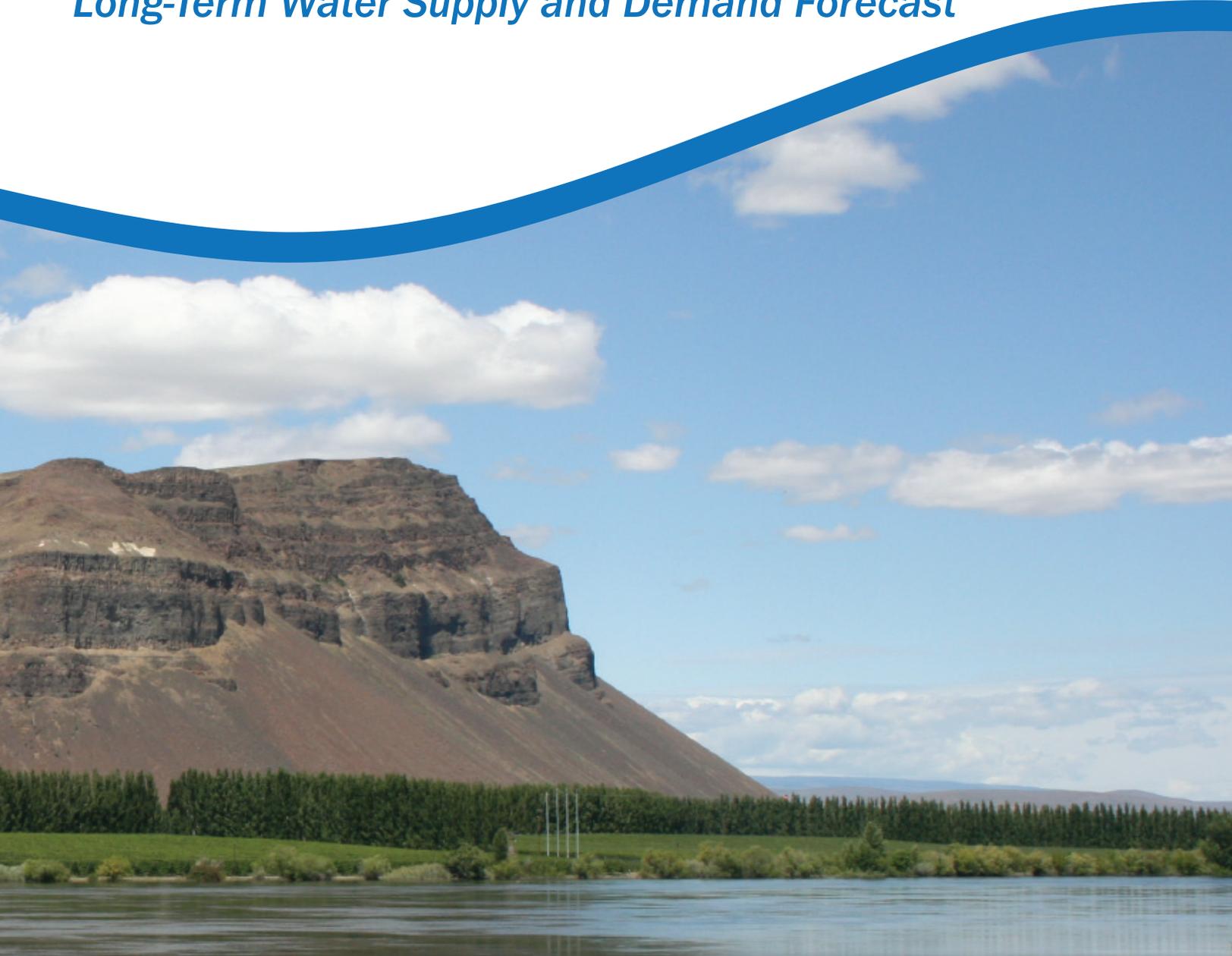


2016 Washington State Legislative Report

# Columbia River Basin

## Long-Term Water Supply and Demand Forecast



Publication No. 16-12-001

Submitted December 2016 Pursuant to RCW 90.90.040 by:



DEPARTMENT OF  
**ECOLOGY**  
State of Washington

in collaboration with

WASHINGTON STATE  
 UNIVERSITY

 STATE OF WASHINGTON  
WATER RESEARCH CENTER

  
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Washington Department of  
**FISH and WILDLIFE**

This publication is available on the Department of Ecology website at:  
<http://www.ecy.wa.gov/programs/wr/cwp/2016Forecast.html>

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# **Columbia River Basin Long-Term Water Supply and Demand Forecast**

## **2016 Legislative Report**

Submitted to Washington State Department of Ecology by:

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# DEFINITIONS OF WATER SUPPLY AND WATER DEMAND TERMS

## Water Supply

**Surface Water Supplies** reflect the total amount of surface water generated in a watershed, quantifying the water available for in-stream and out-of-stream uses. Supplies reflect water availability 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 (see the **Stream Flows** definition, below). Supplies were estimated using an integrated modeling framework that incorporates the impacts of operations of major reservoirs on the Columbia and Snake Rivers, as well as the major reservoirs in the Yakima Basin. Regulated supplies represent water that has been stored and released from reservoirs, whereas unregulated supplies have not. Water supplies at the watershed (Water Resource Inventory Area, or WRIA) level are “natural supplies”, without consideration for reservoirs, with the exception of the Yakima watershed (WRIsAs 37, 38, and 39).

**Groundwater Supplies** reflect the amount of groundwater (from aquifers) available to meet different water demands. Groundwater supplies were not modeled or quantified in the 2016 Forecast. Certain assumptions about existing groundwater supplies were made, described in the Groundwater Irrigation Demand definition, below. To address groundwater supply limitations in future Forecasts, an inventory of areas within the state where groundwater levels are known to be declining was created (see the *Integrating Declining Groundwater Areas into Supply and Demand Forecasting* module).

**Historical Supplies** indicate surface water supplies modeled for 1981-2011, based on historical climate data. To characterize variability in supplies, historical supply curves are provided for low, median, and high supply conditions. As supply cannot be straightforwardly measured, these different conditions were based on flow measurements. Low, median, and high flow conditions were determined as the 20th, 50th, and 80th percentile flows in the historical record, respectively.

**Forecast Supplies** indicate forecasted supplies for the year 2035. Models to quantify supply were run using projected climate information from the global Coupled Model Intercomparison Project Phase 5 (CMIP5) as inputs. These projections include results from five global climate models, obtained using two different assumptions as to how greenhouse gases in the atmosphere are expected to increase, leading to ten different future climate scenarios. Major reservoir rules were assumed not to change in response to changes in forecasted (2035) water supply.

## Water Demand

**Agricultural Water Demand** represents the water needed to fulfill the needs of crops, often referred to as “top of crop” water use. This includes water that will be used consumptively by the crops, as well as irrigation application inefficiencies (such as evaporation, drift from sprinklers, or runoff from fields), but does not include conveyance losses (see the Conveyance Losses definition, below). This demand can be met by groundwater or surface water. In the case of surface water, it is considered an out-of-stream use, as water is diverted from rivers to croplands.

**Conveyance Losses** denote water that is lost as it travels through conveyance systems, which can occur to varying degrees in everything from unlined ditches to fully covered pipes. These losses vary widely and are difficult to assess, but have been estimated to average about 20% across the whole Columbia River Basin. Because of the greater uncertainty associated with these estimates, conveyance losses have been treated and shown separately from “top of crop” demands.

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

**Groundwater Irrigation Demand** represents the agricultural water demand that was met by groundwater supplies. Because this Forecast did not model groundwater supplies, the assumption was made that groundwater supplies would be sufficient to meet a fixed percentage of agricultural water demand, and that percentage would remain constant through 2035. The exception to this assumption was for the Odessa Subarea, where future groundwater supply was forecasted to decrease to zero. There is a recognition that these assumptions are not realistic everywhere, as watersheds with closed or regulated surface water bodies

likely have limited groundwater supplies not available for new appropriation. The inventory of areas with declining groundwater levels (see the *Integrating Declining Groundwater Areas into Supply and Demand Forecasting* module) is a first step towards better incorporating groundwater into future forecasts.

**Unmet Irrigation Requirements** represent the difference between agricultural water needed for crops planted in a typical year to achieve maximum yield, and the water supply available for agricultural irrigation. In watersheds with adopted instream flow rules, curtailment of agricultural water use will occur when agricultural requirements exceed available water. The frequency and magnitude of such curtailments in historical and forecast time periods were quantified for those WRIs with adopted instream flow rules (see the *Curtailments for WRIs with Adopted Instream Flow Rules* section). In addition, a method for quantifying the economic impacts of curtailment was developed, and an example of its application is provided (see the *Exploring the Economic Benefits of More Water for Agriculture* section).

**Municipal Demand** includes estimates of water delivered through municipal systems, as well as self-supplied sources. Municipal demand was only estimated within Washington State. For each county in a WRI, estimates of municipal demand were computed as the sum of water for domestic, commercial and industrial demands, as reported by the U.S. Geological Survey. The source of water can be surface or groundwater. Municipal demand also has a consumptive portion and a non-consumptive portion. The non-consumptive portion includes water that is lost through system leakages and water that returns for wastewater treatment. Together, the consumptive and the non-consumptive portion represent municipal demand.

**Instream Water Demand** was incorporated into water management modeling through state and federal instream flow targets. Within Washington's watersheds, 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 forecasted instream demands. State and federal instream flows along the Columbia River mainstem were also compared to historical and future supplies.

**Hydropower Water Demand** represents the total amount of water that needs to flow through the dams to generate the electricity needed by the entities managing those dams to fulfill their clients' needs. This demand is not estimated with the integrated model, and accurate data to estimate hydropower demand is lacking.

**Total Water Demand** is the water needed for different instream and out-of-stream uses, including agricultural demand, conveyance losses, groundwater demand, municipal demand, and instream flow requirements. For purposes of this report, Total Water Demand does not include all existing demands for water. For example, it does not quantify water needed for hydropower, recreation, and navigation.

**Historical Water Demands** indicate demands modeled for 1981-2011, based on historical climate data. Low, average, and high demand conditions were determined as the 20th, 50th, and 80th percentile demands in the historical record, respectively.

**Forecast Demands** indicate demands projected for the 2020-2050 time period, evaluating year-to-year variability expected by 2035. These demands are expected to be strongly affected by climate change impacts on crops' water requirements, by trends in agricultural production, and by water management policies. The climate change effects were explored by modeling demands under ten climate change scenarios (described in the **Forecast Supplies** definition, above). The effects of trends in agricultural production were explored by modeling two additional scenarios: 1) assuming the current crop mix remains unchanged, and 2) under a projected crop mix that was developed by using a statistical model to extend recent trends in crop mix into the future. In both these scenarios the irrigated land base in agriculture is assumed to remain 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. Finally, the effects of water management policies were explored by quantifying the economic benefits of more water for agriculture (see the *Forecasting Water Supply and Agricultural Demand – Exploring Water Management Scenarios* section).

**Stream Flows** represent streamflow conditions at specific locations in a watershed, as would be observed by a streamflow gauge. Flows at a particular location reflect the balance between supply and demand in the watershed upstream of that location. Whereas supply is the total amount of surface water generated in a watershed and does not account for the impacts of water use and withdrawals (see **Surface Water Supplies** definition, above), flows do account for consumptive use of water upstream of the specified location.





STATE OF WASHINGTON  
DEPARTMENT OF ECOLOGY  
Central Regional Office - Office of Columbia River  
1250 West Alder Street • Union Gap, Washington 98903 • (509) 575-2490

December 22, 2016

The Honorable Jay Inslee, Governor  
and Honorable Members of the Washington State Legislature  
Olympia, Washington

RE: 2016 Columbia River Basin Long-Term Water Supply and Demand Forecast

Since its creation in 2006, Washington Department of Ecology's Office of Columbia River (OCR) has been charged with a mission to aggressively pursue water supply development for both instream and out-of-stream uses to meet Eastern Washington's economic and environmental needs. To support this mission, every five years OCR prepares and submits to the state legislature a water supply and demand forecast. On our 10-year anniversary, I am pleased to submit to you, the third "Columbia River Basin Long-Term Water Supply and Demand Forecast" (Forecast).

OCR partnered with Washington State University (WSU) and the State of Washington Water Research Center; with additional contributions from the Department of Fish and Wildlife, the University of Utah and Aspect Consulting to provide this state-of-the-science forecasting of water supplies and demands 20 years into the future. This 2016 Forecast builds upon the previous two Forecasts by providing a system-wide assessment that combined field measurements, state-of-the-science economic, crop, climate, and water right modeling techniques.

This Forecast tells the story of Washington's water future; where current demand for water exists, the relative magnitude of instream versus out-of-stream demands, and how future environmental and economic conditions are likely to change water supply and demand by 2035. The Columbia River Policy Advisory Group, watershed planning units, sister state agencies, tribes, local governments and the general public provided valuable input that helped the researchers refine methodologies to conduct the agricultural, municipal and industrial, and hydropower components of the forecast.

In Washington State, mountain snowpack is the engine that makes the crops, habitat, and communities thrive – storing valuable winter water and then releasing it into streams and canals when farms, fish, and domestic supply needs are at a peak. This year's forecast confirms overall seasonal shifts in timing of water supply, and how this effects future demand and will be a dominant issue that will likely require area-specific management and adaptation strategies in the future. The droughts of today are likely the average water conditions we will face in the future.

Some of the recommendations outlined in the 2016 Forecast will require additional funding to implement, which OCR will consider as it prepares its future biennial budget requests, while others are policy or legislative in nature. The outcome of the Columbia River Treaty negotiations could also significantly alter how OCR directs its resources, manages its portfolio of water supply projects, and invests in new projects moving forward.

Over the past decade, OCR has invested in a variety of water supply projects to meet competing water management objectives. This has resulted in over 410,000 acre-feet of new water supplies in central and eastern Washington, with more water under long-term development tied to future demand projections. OCR will continue to utilize the 2016 Forecast as a capital investment planning tool, maintaining and enhancing the region's economic, environmental and cultural prosperity through development of future water supply projects.

Sincerely,

A handwritten signature in black ink, appearing to read "G. Thomas Tebb".

G. Thomas Tebb, Director  
Office of Columbia River

# EXECUTIVE SUMMARY

## THE 2016 WATER SUPPLY AND DEMAND FORECAST

The Washington State Legislature recognized the complexities in the water supplies and needs of people and fish across the Columbia River Basin (Basin) in Washington, and identified the development of new water supplies as a water resource management priority. In 2006, it passed Chapter 90.90 RCW, directing the Department of Ecology to aggressively develop water supplies for instream and out-of-stream uses in the Basin. The Office of the Columbia River must develop a long-term water supply and demand forecast every five years, pursuant to RCW 90.90.040 *Columbia river water supply inventory—Long-term water supply and demand forecast*<sup>1</sup>:

*RCW 90.90.040(1) To support the development of new water supplies in the Columbia river and to protect instream flow, the department of ecology shall work with all interested parties, including interested county legislative authorities and watershed planning groups in the Columbia river basin, and affected tribal governments, to develop a Columbia river water supply inventory and a long-term water supply and demand forecast.*

*RCW 90.90.040(3) The department of ecology shall complete the first Columbia river long-term water supply and demand forecast by November 15, 2006, and shall update the report every five years thereafter.*

This 2016 Columbia River Basin Long-Term Water Supply and Demand Forecast is the third forecast submitted to the Washington State Legislature since 2006.

### Meeting Eastern Washington's Water Needs

The Columbia River Basin, the fourth largest watershed in North America in terms of average annual flow, is intensively managed to meet a range of competing demands for water, including hydropower generation, irrigation, navigation, flood control, protection of salmonid species, municipal and industrial use, tribal treaty commitments, and recreation. Reliable access to water is essential for existing and future regional economic growth and environmental and cultural enhancement. Variations in water supply and demand across the Basin are increasingly

leading to localized water shortages as populations grow, the climate changes, and regulatory flow requirements increase. Managing these multiple demands for fresh water requires understanding how future conditions will alter water supply and demand, and strategically investing in projects that meet competing water management objectives.

The water supply systems within the Columbia River Basin were built to reliably deliver water under historical conditions. Future changes in water supply and demand, therefore, have the potential to stress the system. This 2016 Long-Term Water Supply and Demand Forecast provides information that will help legislators, water managers, industry, and agency professionals plan for future conditions that will likely be quite different from those we have experienced in the past.

Many factors that influence water supply and demand—agricultural market conditions, input costs, production decisions, global trade conditions, temperature and precipitation patterns, water management policies, water storage capacity—need to be projected into the future. This 2016 Forecast explores three broad types of changes that are expected to occur:

- **Climatic:** Changes in precipitation and temperature affect water availability, agricultural growing conditions, and the season during which crops require water. The Pacific Northwest is expected to experience increasing temperatures and shifts in precipitation, leading to wetter winters and springs, drier summers, declining snowpack, earlier snowmelt and peak flows, and longer periods of low summer flows. Increasing temperatures also result in an earlier shift in the irrigation season. Increased concentrations in carbon dioxide also directly affect crops' water requirements. These climatic changes were explored using the results of global climate models downscaled to a regional level to represent the projected climate for 2035.
- **Economic:** Water demand depends on the mix of crops in the region, which in turn is responsive to consumer tastes, domestic food demand, export and import trends, and production technologies, among other factors. While some crop groups have seen relatively large changes within existing cropland, the relative acreage share for the region is expected to remain stable, with forage covering the most acreage. Changes in crop mix were explored using a statistical model to project to 2035 the trends in crop mix that are currently being observed.

<sup>1</sup> The full text of RCW 90.90.040 (available at <https://app.leg.wa.gov/rcw/default.aspx?cite=90.90.040>) includes additional detail on the water supply inventory

- **Water management:** Changes in water availability, storage capacity, and programs that pass the cost of water supply development along to users affect water use. Increases in water storage capacity from planned projects can reduce the current users' vulnerability to drought, or can supply water to new uses, including the development of new irrigated acreage. Such water management changes were explored using estimates of the economic benefits of making additional water available for agriculture.

Other types of changes were beyond the scope of this Forecast, often because available data were not sufficient to develop feasible scenarios. By exploring these three dominant types of changes, however, this Forecast quantifies the likely range of water supply and demand across the Columbia River Basin in 2035, paying particular attention to the portion of the Basin in eastern Washington State.

## Overview of the 2016 Forecast

Surface water supplies reflect the total amount of surface water generated in a watershed. Water demand is the total amount of water needed for total instream uses—including hydropower and instream flow requirements—and out-of-stream uses, including agricultural demand (the dominant out-of-stream use), conveyance losses, and municipal and domestic demand (hereafter called municipal demand; see details in the *Definitions of Water Supply and Water Demand Terms* section).

Water supply and demand impact each other. Out-of-stream diversions reduce supply downstream, while water that is diverted but not consumptively used—such as water that is lost through leaks in municipal systems or return flows from irrigated fields—may return to the system and provide water supply downstream.

The 2016 Forecast simulated surface water supply and agricultural irrigation demands with an integrated computer model that captures the relationships between climate, hydrology, water supply, irrigation water demand, crop productivity, economics, municipal water demand, and water management for three different geographic scopes (Figure ES-1):

- **Columbia River Basin**, upstream of Bonneville Dam, across seven U.S. States and one Canadian Province.

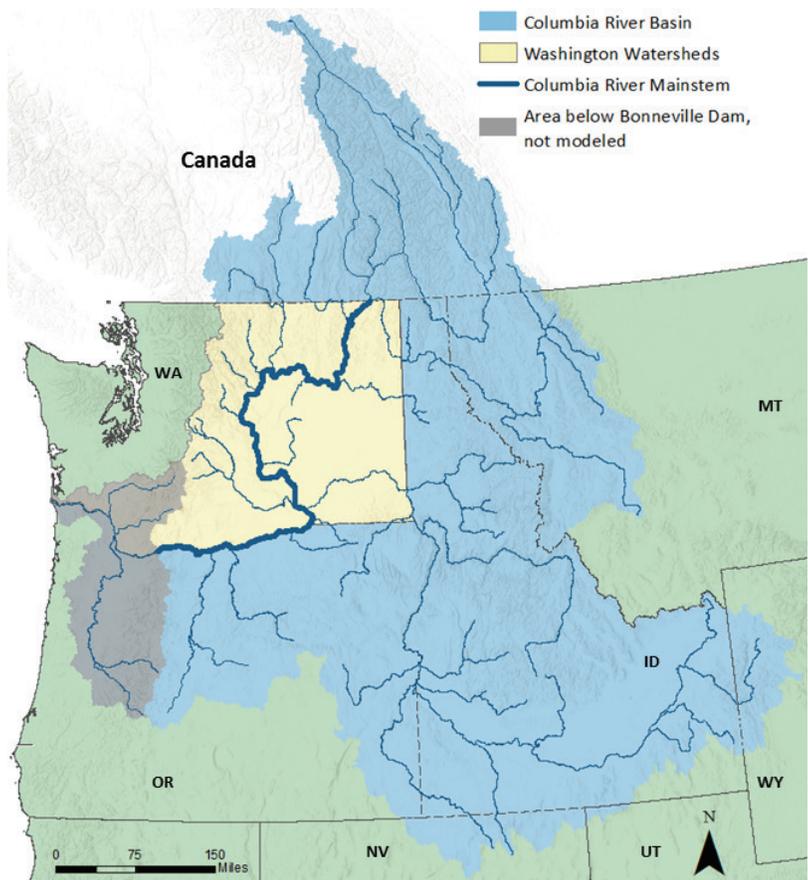


Figure ES-1. The 2016 Forecast results are provided for three different geographic scopes: Columbia River Basin, Washington's Watersheds, and the Columbia River Mainstem.

- **Washington Watersheds**, as delineated by eastern Washington's 34 Water Resource Inventory Areas (WRIAs).
- **Mainstem**, from the Canadian border to Bonneville Dam.

The model used in the 2011 and 2016 Forecasts integrates and builds upon three existing models—VIC, CropSyst, and ColSim—that have been used independently in various published studies to simulate conditions in the Columbia River Basin. What distinguishes this 2016 Forecast from previous efforts is that:

- The hydrological (VIC) and crop production (CropSyst) models are more tightly integrated, so that the interactions between the hydrological cycle and crop growth processes are better captured. This improves the simulation of crop water requirements, particularly during drought conditions.
- Newer climate change projections (CMIP5) and improved downscaling methods were used, so that future climate scenarios are more appropriate for

# EXECUTIVE SUMMARY

the region, and are better able to capture changes in temperature and precipitation extremes, in addition to changes in average temperatures and precipitation.

- Improved historical climate and crop data were available, reducing the number of assumptions that were needed to model historical supply and demand across the region.
- Only one 2035 crop mix was projected, simplifying the assumptions made about future domestic economic growth and international trade. The 2011 Forecast demonstrated that scenarios based on varying economic growth and trade have relatively little effect on the future crop mix.
- In an attempt to improve curtailment modeling, a survey of watershed water masters was conducted by Ecology. While this process provided useful information it was only adequate for direct use in the curtailment modeling for the Yakima Basin, where Yakima RiverWare was used to better simulate prorating.
- A method for using the value of water to explore responses to water shortages was developed and used



Columbia River at Hanford Reach

to quantify upper and lower bounds of the negative impacts of reduced water availability on production and profitability. The upper-bound estimate was based on all crops suffering curtailment equally. For the lower-bound estimate, farmers were expected to fallow lower value crops first.

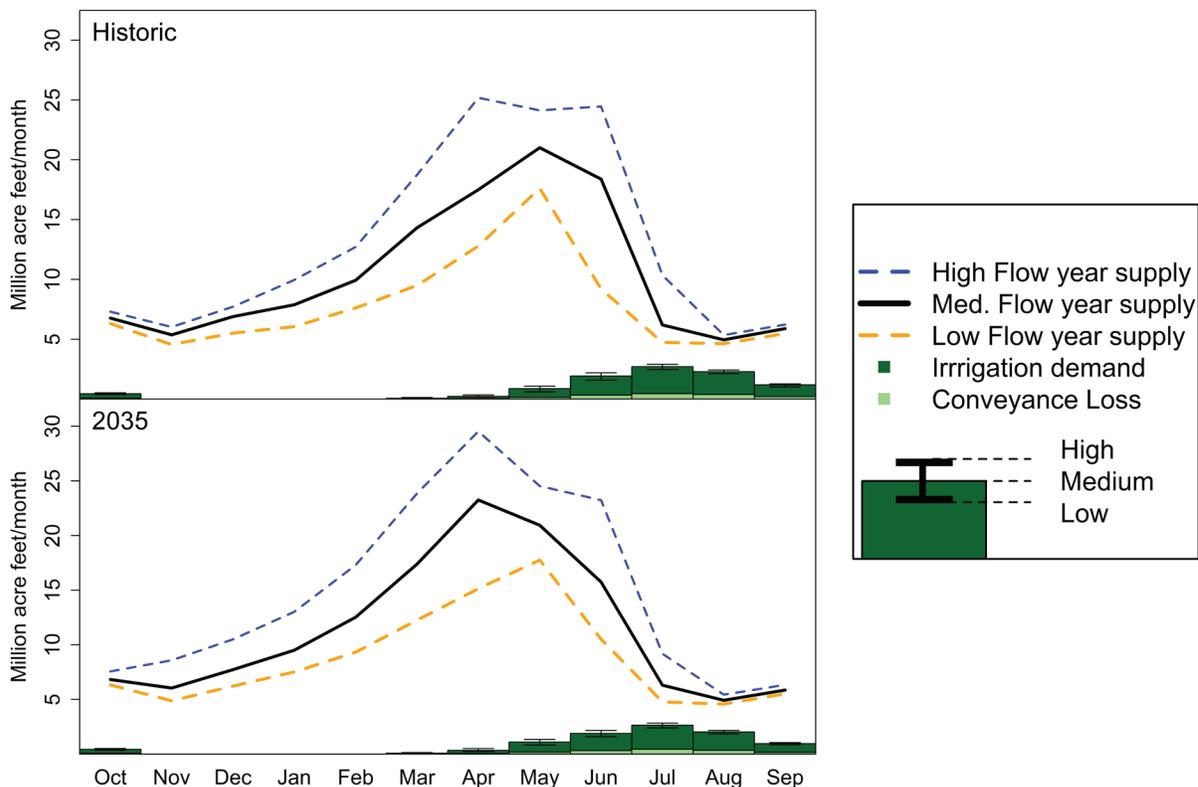


Figure ES-2. Comparison of regulated surface water supply and agricultural water demands for the historical (1981-2011; top panel) and forecast (2035; bottom panel) periods across the entire Columbia River Basin. Interannual variability is shown for both supply (dotted lines) and demand (error bars) (for details see Box 9 in the full Legislative Report). For detailed explanation of this figure, see the Columbia River Basin Surface Water Supply and Columbia River Basin Agricultural Water Demand sections in the full Legislative Report.



In addition to the abovementioned improvements, five complementary modules were produced, focusing on key policy issues whose prominence is expected to increase in the next five years. These modules are:

1. *Integrating Declining Groundwater Areas into Supply and Demand Forecasting:* In some areas of the State, basins are being closed to further groundwater withdrawals due to declining water levels. Where is it critical to integrate groundwater supply modeling into future Forecasts? Is there sufficient data available in those areas to do so?
2. *Pilot Application of METRIC Crop Demand Modeling in Washington State:* Estimating and tracking actual water use by crops may be useful in water right evaluations and adjudications, and to inform future Forecasts. Can agricultural water demands, non-consumptive return flows, and stream discharges be estimated at finer scales, to better assist in those decisions?
3. *Water Banking Trends in Washington and Western States:* Water banking is growing in areas of the State (and beyond) where there is a need to trade water, as no additional water is available—or expected—to support development. What can be learned from water banking across the West, that can help facilitate and increase the efficiency of water banking in Washington State?
4. *Effects of User-Pay Requirements on Water Permitting:* The State Legislature has moved towards an applicant-pays system for processing water rights applications, yet little information exists on how to

effectively design such a system. What impacts do different user-pay systems for water right permitting have on the demands for water?

5. *Western Washington Supply and Demand Forecasting:* Policy issues can have statewide relevance, so consistency in planning and available information across the whole state can inform the need and impacts of proposed policies. Is it feasible to extend the modeling approach to western Washington, as the foundation for a complete Washington State water forecast?

In 2016, the Washington Department of Fish and Wildlife also updated and expanded the Columbia River Instream Atlas (CRIA; Ecology Publication No. 16-12-006), focused on instream water needs and priorities for conserving salmonid species in Washington State.

Feedback received on the previous Forecast (2011) along with interactions with the Columbia River Policy Advisory Group, the Water Resources Advisory Committee, the agriculture, hydropower, and municipal communities, and local, state, federal, and tribal governments in the intervening years were essential for planning for the 2016 Forecast.

## Significant Findings

### *Columbia River Basin Water Supply*

Forecasts for 2035 suggest that there will be an overall increase in annual water supplies across the Columbia River Basin, and a shift in supply timing away from times when demands are the highest. Unregulated surface water supply

# EXECUTIVE SUMMARY

**Table ES-1.** Modeled water supply in the historical (1981-2011) and forecast (2035) periods for the entire Columbia River Basin. Values between parentheses for 2035 represent confidence intervals around the average of future values in median flow years, due to range of supply values obtained under different climate scenarios (for details see Box 9 in the full Legislative Report). The “% Change” reflects the difference from the historical to the forecast values, and is also accompanied by confidence intervals associated with climate uncertainty.

	Historical (million ac-ft per year)	2035 Forecast (million ac-ft per year)	% Change
Entire Columbia River Basin	126.5	145(± 10.48)	14.63% (± 8.29%)

**Table ES-2.** Modeled agricultural water demands excluding conveyance losses (known as “top of crop”), in the historical (1981-2011) and forecast (2035) periods. Values between parentheses for 2035 represent confidence intervals around the average of future values in median demand years, due to the range of demand values obtained under different climate scenarios (for details see Box 9 in the full Legislative Report). The “% Change” reflects the difference from the historical to the forecast values, and is also accompanied by confidence intervals associated with climate uncertainty.

	Historical (1981-2011) (million ac-ft per year)	2035 Forecast (million ac-ft per year)	% Change
Entire Columbia River Basin	10.1	9.6 (± 0.08)	-4.96% (±0.81%)
Washington Portion of the Columbia River Basin	4.2	3.9 (± 0.04)	-6.87% (±0.98%)

between June and October is projected to decrease 10.28% (±7.86%<sup>2</sup>), on average<sup>3</sup>. Meanwhile, an average increase of 30.79% (±9.41%) is expected in unregulated surface water supply between November and May (Figure ES-2). These changes combine to produce an overall increase of approximately 14.63% (±8.29%) in average annual supplies relative to historical (1981-2011) supplies across the entire Columbia River Basin (Table ES-1). This shift in timing is in response to warming temperatures, which will result in a smaller snowpack, with more precipitation falling as rain and less as snow, and an earlier snowmelt peak. Even with an overall increase in annual water supplies, it is possible that this shift in supply away from the season of highest water demand has the potential to cause increased water scarcity in portions of the Columbia River Basin during the irrigation season, which may also shift earlier in the year.

Annual surface water supplies entering Washington will increase approximately 12.65% (±3.03%) by 2035, on average. This includes inflows into Washington along the Similkameen, Kettle, Columbia, Pend Oreille, Spokane,

Clearwater, Snake, John Day, and Deschutes Rivers. Most of the rivers show increases in supply for each climate scenario. However, the direction of change varied across climate scenarios for the Columbia, the Spokane and the Kettle Rivers, particularly when the year-to-year variations were considered. For these three rivers, the supply decreased on average 3.53% (±2.82%), 2.70% (±4.50%), and 3.00% (±4.65%), respectively.

Annual surface water supplies generated within the Washington portion of the Columbia River Basin are expected to increase approximately 14.39% (±3.82%) by 2035, on average. This calculation includes the major watersheds of the Walla Walla, Palouse, Colville, Yakima, Wenatchee, Chelan, Methow, Spokane, and Okanogan Rivers. While most rivers show increases in supply regardless of the climate scenario used, three watersheds—Colville, Spokane, and Okanogan—showed mixed results, ranging from increasing to decreasing supplies, depending on the climate scenario used. The changes in supply for these major rivers in Washington ranged from 3.61% (±4.44%), on average, for the Spokane watershed to 51.4% (±4.00%), on average, for the Methow watershed. As with the supply forecast for the entire Columbia River Basin, these rivers will experience shifts in the timing of stream flow. The rivers experiencing the greatest shift in supply timing are those for which streamflow was predominantly derived from snowmelt during the historical period, such as the Methow River.

2 The values within parentheses reflect uncertainty due to projecting climate 20 years into the future. For details on how climate uncertainty was quantified please see the full Legislative Report.

3 For details on year-to-year variability and how it was quantified please see the full Legislative Report.

### Columbia River Basin Water Demand

Even as water supplies are forecast to increase by 2035, agricultural water demand—which accounts for approximately 79.4% of total out-of-stream demand (agricultural plus municipal)—is forecast to decrease by approximately 4.96% ( $\pm 0.81\%$ ) by 2035, across the entire Columbia River Basin. This decrease is somewhat greater within Washington, where it is forecast to reach 6.87% ( $\pm 0.98\%$ ) (Table ES-2). These decreases in demand are due to a combination of (a) projected changes in climate toward warmer and slightly wetter conditions, leading to an earlier and wetter beginning to the growing season, a shorter irrigation season for most crops; and (b) projected changes in crop mix, where crops with lower water use are expected to replace high-water-use pasture. These results are consistent with current trends in agricultural water demand for non-drought years, which have shown reductions in diversions for irrigation. It is worth noting, however, that current trends may also be responding to changes in irrigation technology, a factor that is not included in the model, and therefore not contributing to the forecasted decrease in agricultural water demand.

Demand for energy generated at hydropower facilities across the Columbia River Basin is anticipated to increase by 2,200 to 4,800 megawatts (MW), on average, by 2035 (accounting for distribution and transmission system losses). Quantifying the demand for instream water at existing dams (or at points where future reservoirs could potentially be built) is challenging, as such a “conversion” of flows to energy produced depends on many factors, including dam design, peak power needs, efficiency, and availability of other energy sources. A preliminary conversion was attempted, with an estimated power-to-water conversion factor of approximately 16 ac-ft/MW, leading to projections of increases in hydropower water demand of as much as 75,000 ac-ft per year by 2035 (Table ES-3).

#### *Demands within Washington State*

Within the Washington State portion of the Columbia River Basin, historical (1981-2011) out-of-stream diversion demands for municipal and agricultural irrigation water (excluding irrigation conveyance losses) were estimated to be in the range of 3.82 million ac-ft. At the watershed scale, shifts in timing of water supply towards the winter and spring months by 2035 are similar to those observed for the entire Columbia River Basin. The details vary by watershed, however. The rivers experiencing the greatest shift in timing of supply are those for which streamflow was predominantly derived from snowmelt. The Forecast

anticipates the following changes in water demand (Table ES-3):

- 291,432 ( $\pm 41,405$ ) ac-ft decrease in total (ground and surface) agricultural water demand annually. This number assumes no change in irrigated acreage. In addition to the demands for both surface and groundwater to be applied to crops, this number accounts for irrigation application inefficiencies. By 2035, surface, out-of-stream water demands across eastern Washington are forecast to increase by 6,644 ( $\pm 34,645$ ) ac-ft per year. This additional surface water would be needed to support current water use practices in the Odessa Subarea into the future, replacing water demand currently being met by declining groundwater.
- Production changes in Washington, such as double cropping, may increase as the climate changes and crops mature earlier in the season. Water development projects planned by the Office of the Columbia River would make “new” water available, leading to increased irrigated acreage. These two factors could, in combination, lead to the overall demand for irrigation water increasing by tens to hundreds of thousands of acre-feet per year by 2035 (Table ES-3).
- 80,000 ac-ft in additional total diversion demands for municipal and domestic water annually, which represents an 18% increase over 2015 (Table ES-3). This increase in municipal and domestic demand is due to a 17% increase in population expected between 2015 and 2035. Although some new municipal demands will likely be met by deep groundwater supplies, others will likely come from shallow groundwater or surface water.

Consistent with the results of the 2011 Forecast, the greatest concentrations of current and future agricultural irrigation and municipal water demand are in south-central Washington<sup>4</sup>. The forecast shift in peak flow to earlier in the spring will decrease future summer season water supply. This shift in timing is dominant in north-central and northeastern Washington watersheds and some southern watersheds. Although annual irrigation demand is forecast to decrease in the future, increases in early season irrigation demand are projected to occur in central Washington watersheds, with associated increased vulnerability to curtailments during droughts. Forecast out-of-stream demand estimates for 2035 do not account for potential water conservation improvements.

<sup>4</sup> For details on each watershed, please see the full Legislative Report.

# EXECUTIVE SUMMARY

**Table ES-3:** Summary of changes in demands in eastern Washington between the historical (1981-2011) and forecast (2035) periods for different uses. Additional information on demands that will need to be met with surface supplies, that are not currently being met from this source, or not reliably, are included to provide context.

Water Use or Need	Estimated Volume (acre-feet)	Source
Projected changes in Agricultural Demand by 2035 <sup>a</sup>	-332,837 to -250,027	WSU Integrated Model
Projected changes in Agricultural Demand by 2035 with 10% Double Cropping <sup>b</sup>	-272,837 to -130,027	WSU Integrated Model + Coarse Estimate of 2nd Crop Water Needs
Projected changes in Agricultural Demand by 2035 with 10% Double Cropping and Planned Water Supply Projects <sup>c</sup>	27,163 to 169,973	WSU Integrated Model + Coarse Estimate of 2nd Crop Water Needs + Planned Water Supply Projects through 2026
Projected changes in Municipal and Domestic Demand (including municipally-supplied commercial) by 2035	80,000	Municipal Demand Projections
Projected changes in Hydropower Demand by 2035 <sup>d</sup>	35,000 to 75,000	Review of Projections by Power Planning Entities
<i>Water Use or Need to be Met with Surface Supplies</i>		
Unmet Columbia River Instream Flows <sup>e</sup>	13,400,000	Ecology data, McNary Dam, 2001 drought year
Unmet Tributary Instream Flows <sup>f</sup>	30,000 to 660,000	Ecology data, tributaries with adopted instream flows, on average, and for a drought year (generally 2001)
Unmet Columbia River Interruptibles	40,000 to 310,000	Ecology Water Right Database (depending on drought year conditions)
Yakima Basin Water Supply (pro-ratables, municipal/domestic and fish) <sup>g</sup>	450,000	Yakima Integrated Water Resource Management Plan (April 2011)
Alternate Supply for Odessa <sup>h</sup>	155,000	Odessa Draft Environmental Impact Statement (October 2010), adjusted based on consultations with the East Columbia Basin Irrigation District
Declining Groundwater Supplies (other than in the Odessa Subarea) <sup>i</sup>	750,000	<i>See Integrating Declining Groundwater Areas into Supply and Demand Forecasting Module</i>

<sup>a</sup> Additional agricultural demands were modeled assuming the land base for irrigated agriculture remains constant, and climate change is moderate (RCP 4.5 scenario). Projected changes in irrigation demand were estimated to decrease 291,432 ac-ft, with a confidence interval (reflecting uncertainty in climate) of  $\pm 32,260$  ac-ft, for median demand years (the decrease is projected to be 251,368  $\pm$  41,224 ac-ft for low demand years, and 239,388  $\pm$  32,299 ac-ft for high demand years; see for details see Box 9 in the full Legislative Report). These decreases in demand were due to the combined impacts of climate change (wetter in the early growing season) and crop mix (projected shift to crops that use less water).

<sup>b</sup> The estimate of additional agricultural demands was increased by the coarse estimate of irrigation demand increases if 10% of eligible land is double cropped by 2035 (see *Potential Impacts of Double-Cropping on Agricultural Demand Estimates* section).

<sup>c</sup> The estimate of additional agricultural demands was increased by the double cropping estimate and by an additional 300,000 ac-ft. The latter reflects an estimated irrigation water supply development goal for the next 10 years (obtained based on the OCR agricultural water supply projects under development, which may include 508.14 Rule Changes, Regional Aquifer Storage and Recovery, Water Banking, and others).

<sup>d</sup> Hydropower projections are based on an average need of 2,200 to 4,800 MW by 2035 for the entire Columbia River Basin. This demand is historically expressed as a nonconsumptive water use. Net power generation and water right data for Grand Coulee, Rocky Reach, Rock Island and Lake Chelan were averaged to develop an approximate power-to-water conversion factor of approximately 16 ac-ft/MW. Because this projection is based on existing dams as opposed to new projects, and because these average numbers do not account for peak power needs, actual demand may be higher. Alternatively, if this demand is met via conservation, efficiency improvements, or non-hydro sources, the demand projections could be lower. Due to the coarse nature of the estimate, it was not possible to allocate a portion of this volume to Washington State at this time.

<sup>e</sup> Unmet Columbia River instream flows are the calculated deficit between instream flows specified in Washington Administrative Code (WAC) and actual flows at McNary Dam in 2001 under drought conditions. 2001 is the only year when Columbia River flows were not met and interruptible water users were curtailed.

<sup>f</sup> Unmet tributary instream flows in tributaries to the Columbia River are the combined deficits between current instream flows specified in WAC and actual flows, estimated as a range by comparing the 50% (average) exceedance curve, and the worst drought on record from 1981 to 2011, to adopted instream flow rules. Unquantified instream flow demand also exists in tributaries without adopted instream flow rules, but will be added in the future, as in the case of the Spokane Rule, which was adopted between the 2011 and 2016 Forecasts. These values include data from the following locations: Walla Walla River at East Detour Road, Wenatchee River at Monitor, Entiat River near Entiat, Methow River near Pateros, Okanogan River at Malott, Little Spokane River at Dartford, Spokane River at Spokane, Colville River at Kettle Falls. All drought year deficits are for 2001, with the exception of the Little Spokane and Colville Rivers, where the greatest unmet flows were in 1992, and the Walla Walla River, where data collection started in 2007.

<sup>g</sup> Range includes both the experienced curtailment from the 2001 drought, and the full water right value at risk of curtailment.

*Table footnotes continued on bottom of next page.*

The forecasted changes for supply and out-of-stream water demands can be expected to lead to changes in instream conditions by 2035, including:

- Almost 660,000 ac-ft per year of unmet tributary instream flow water demand, and 13.4 million ac-ft per year of unmet Columbia River mainstem instream flow water demand, based on observed deficits during the 2001 drought year.
- In many rivers in eastern Washington, including the mainstem Columbia River, 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 summer and early fall tributary streamflow may lead to longer periods with instream flows deficiencies by 2035. This may result in more frequent and potentially more severe curtailment of interruptible water right holders in basins with adopted instream flow rules.
- An evaluation of fish, flows, and habitat in twelve fish-critical subbasins (*Columbia River Instream Atlas*, Ecology Publication No. 16-12-006), will help target investments to maximize the positive impact on fish populations.

These changes in supply and demand are also projected to impact agricultural production, the main use of out-of-stream water in Washington State. A new insight from the 2016 Forecast is a trend in some areas toward increasing frequency and magnitude of irrigation curtailment in the spring, followed by a decrease in curtailments later in the irrigation season. These modeling results suggest that the shift toward increased spring irrigation water demand is projected to occur faster than the shift toward increased spring water supply. These projections vary across watersheds, were modeled under current dam operation schedules, and did not include potential increases in double-cropping, nor did they account for potential water conservation investments. Changes in these and other decisions would affect actual future curtailment patterns.

The economic impact of future curtailments could be significant. The 2016 Forecast quantified these economic impacts for one example: curtailment in the order of

100,000 ac-ft in the Walla Walla watershed could lead to losses ranging from \$2 to \$178 million in one year, depending on producers' ability to focus their use of available water on the highest-value crops grown in the watershed.

## Conclusion

Seasonal shifts in timing of water supply and demand are expected to be a dominant issue as the climate changes, and will likely require area-specific management and adaptation strategies. However, irrigation demand was forecast to decrease on average, which could help to alleviate a reduction in summer water supply, at least in non-drought years.

Two important considerations that highlight the complexity of water management in the region are:

- Producers with existing water rights may respond to decreased crop irrigation demand by more frequently double-cropping or growing cover crops, which could offset the demand decreases projected in this Forecast. However, preliminary results suggest that double-cropping would need to occur over much more than 10% of the eligible acreage by 2035 to lead to an overall increase in irrigation demand.
- Agricultural production remains vulnerable to future changes in climate. Droughts are generally expected to occur more frequently and become more severe as the climate changes. And forecast results present a trend towards increasing frequency and intensity of curtailment in the spring.

This Forecast improves our understanding of future surface water supplies and instream and out-of-stream demands. Though it cannot answer all questions related to water supply and demand in the Columbia River Basin, it does provide projections 20 years into the future, and highlights the main changes that can be expected. It can therefore be a useful tool for water management as climate and water availability change, informing OCR's efforts so that they contribute to maintaining and enhancing eastern Washington's economic, environmental, and cultural prosperity in the future.

<sup>h</sup> Multiple water projects planned in the Yakima River Basin, as part of the Yakima Integrated Water Resource Management Plan, are expected to lead to decreases in the estimated volume needed by the 2021 Forecast. Examples include: Yakima Aquifer Storage and Recovery (ASR), Cle Elum Reservoir, and the Kachess Drought Relief Pumping Plant.

<sup>i</sup> Reports of Examination state that 164,000 ac-ft are needed to serve 70,000 acres. The East Columbia Basin Irrigation District is currently serving 3,000 acres of groundwater replacement via the Columbia Basin Project. Assuming these acres are served with an average 3 ac-ft/ac, the volume still needed was estimated. Two additional sources are expected to contribute to this alternate supply, the Odessa Subarea Special Study and the Lake Roosevelt Incremental Storage Releases Program. As the contributions of these two additional sources were not quantified at the time of this report, the volume estimated here should be considered a conservative estimate.

<sup>j</sup> This estimated need was calculated on the following basis: approximately 230,000 irrigated acres within areas affected by unreliable and/or declining groundwater supplies, an assumed average irrigation rate of 3 ac-ft/ac, and an approximate affected population of 200,000 with an average use of 200 gpcd. This estimate does not include the Odessa Subarea. Significant uncertainty exists in this estimate related to the geographic extent of the affected areas and other factors.

## Next Steps—Building Towards the 2021 Forecast

Many of the improvements in the 2016 Forecast methods were made in response to recommendations made by both the Forecast team and the public in response to the 2011 Forecast. These 2016 improvements include steps towards integrating groundwater limitations in our understanding of future water supply and demand. The Legislature's mandate to update the forecast again in 2021 provides an opportunity for OCR to implement several of the recommendations arising from the 2016 Forecast and the public's response.

The OCR has prioritized the following recommendations on Forecast methodology for work over the next 5 years, in cooperation with partners:

### Forecast Methodology:

- Better understanding of double-cropping patterns across the State, now and in the future.
- Better understanding of the frequency of curtailment priority calls, and the water rights that may be at risk of increased curtailment in the future.
- Improved municipal forecasting methodology, to better inform decisions on municipal water use as supplies and demands change.
- Greater input from hydropower providers, to improve understanding of water needs for hydropower production in the face of policy changes.
- Better integration of groundwater dynamics that impact availability of surface water for different uses.
- Better understanding of the effect of the International Columbia River Treaty on reservoir operations and on future water supply.

The OCR has also prioritized work arising from this Forecast's modules<sup>5</sup>, which focused on emerging policy issues. Successfully completing the work embodied in these priorities will help Ecology's Office of the Columbia River fulfill its legislative-designated mandate, and support the science endeavors that provide the foundation for good decisions in the face of a changing climate, year-to-year variability, and the uncertainty inherent in making investments to sustain the region's economic growth and enhance its environmental and cultural resources 20 years into the future and beyond.

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<sup>5</sup> See full details on prioritized recommendations in the Conclusion section of the full Legislative Report.

# MODULES

## INTEGRATING DECLINING GROUNDWATER AREAS INTO SUPPLY AND DEMAND FORECASTING



Drilling near Dallesport Washington, Klickitat County

In both the 2006 and 2011 Water Supply and Demand Forecasts, groundwater supplies were presumed not to be limiting when supplying water rights, mainly due to modeling constraints. As a result, the economic implications of groundwater limitations were also not considered. Groundwater is declining in some areas in Washington, which could result in curtailment of water rights, delayed impacts on surface water sources in hydraulic continuity with groundwater, denial of groundwater right applications, and resulting changes in water right holder uses in response to an interruptible supply.

Ten areas of Washington State with groundwater declines documented by the Department of Ecology and the United States Geologic Survey were evaluated. Study of the groundwater areas included summaries of groundwater declines, geographic extent of the groundwater body, aquifer cross-sections and descriptions, groundwater model information, water right data, and supply-side and demand-side options to reducing groundwater declines.

### *Key findings:*

- Declining groundwater areas should be incorporated into the 2021 Forecast.
- Greater monitoring of the declining groundwater areas is warranted, including aquifer levels, metering data, stream gauges, and pump testing.
- Public outreach to water right holders in declining groundwater areas should be implemented to incentivize demand-side conservation measures.
- State and County government should consider whether existing policies and regulations are sufficient in these areas to protect public water supplies and prevent unintended economic consequences.
- The State should consider water supply projects that could stabilize, reverse, or offset declining groundwater supplies.

Additional groundwater development is already limited in all areas in Washington where there are regulated or closed surface water bodies. The current focus on documented areas of decline is therefore a first step towards identifying the places where it is critical to integrate groundwater supply modeling into future Forecasts.

## PILOT APPLICATION OF METRIC CROP DEMAND MODELING IN WASHINGTON STATE

Agricultural water use largely corresponds to evapotranspiration (ET), which is the sum of evaporation from the ground plus transpiration from plants. The aggregation of ET values across a watershed can be used to calibrate the integrated models used in the 2016 Forecast. Evapotranspiration is usually estimated using data from weather stations and making assumptions on stages of crop growth. Stages of crop growth vary significantly across a watershed, though, due to factors such as soil, management, and topography. To address this problem, a model—METRIC, which stands for Mapping Evapotranspiration at High Resolution and Internalized Calibration—was developed to calculate evapotranspiration using Landsat satellite images. This model has been successfully used in Idaho, California, New Mexico and other regions to monitor water rights, quantify net groundwater pumping and to determine irrigation uniformity. The first objective of this module was to develop and calibrate METRIC to estimate crop water use in three pilot watersheds in eastern Washington: Okanogan, Walla Walla, and Yakima.

A drawback to using Landsat images for METRIC is that the satellite provides images every 16 days, or less frequently if some images are blocked by clouds. The second objective, therefore, was to develop an algorithm to compare crop water use between CropSyst (the crop production model used in this Forecast) and Landsat-derived-METRIC. If the use values are consistent, this would allow the crop model to estimate crop water use between the dates for which images are available. CropSyst could then be used to model scenarios with changes in irrigation practices, crop management, or crop rotations, and to evaluate the effects of changes in water supply (e.g. curtailments) on crop water use during droughts.

### **Key Findings:**

- METRIC was applied to apple orchards in the Roza Irrigation District, Yakima County. A similar analysis will be done for major crops in these three watersheds.
- Apple water use estimates from METRIC in Roza ranged around the value provided by the Washington Irrigation Guidelines (WIG) for apples, as the METRIC estimates capture the range of water use values specific to particular conditions (soil, slope, basin orientation, etc.) (Figure ES-3). For example,

METRIC estimates quantify the difference in water used by apples in the upper Yakima relative to the lower Yakima WRIsAs (Figure ES-3).

- CropSyst, if well-parameterized, can estimate crop growth—estimated using Leaf Area Index (LAI)—quite accurately (Figure ES-4).
- The METRIC model is now developed and calibrated for eastern Washington using freely or generally available software (Python and ESRI ArcGIS functions). Removing the platform dependence of the original model will make it easier and cheaper for users interested in water use in Washington to use this model.
- Automation of various processes involved in METRIC has reduced the necessity of highly trained experts to run this model. It has also made the model easier to use and less time consuming.

Comprehensive modeling of the dominant crops' water use across Washington's WRIsAs using METRIC could help Ecology:

- Identify areas where the best solutions to water scarcity would be to invest in conservation projects, versus areas where additional storage projects would be needed.
- Quantify the amounts of water needed based on where the land is located within the WRIA, and
- Improve model estimates of consumptive use in future long term supply and demand forecasts.

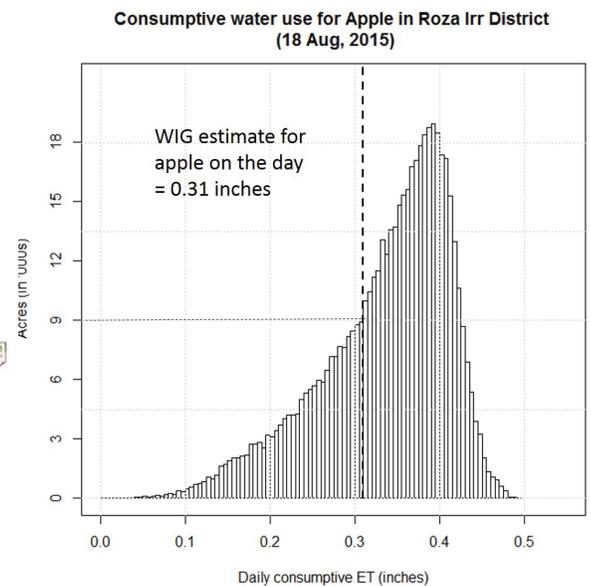
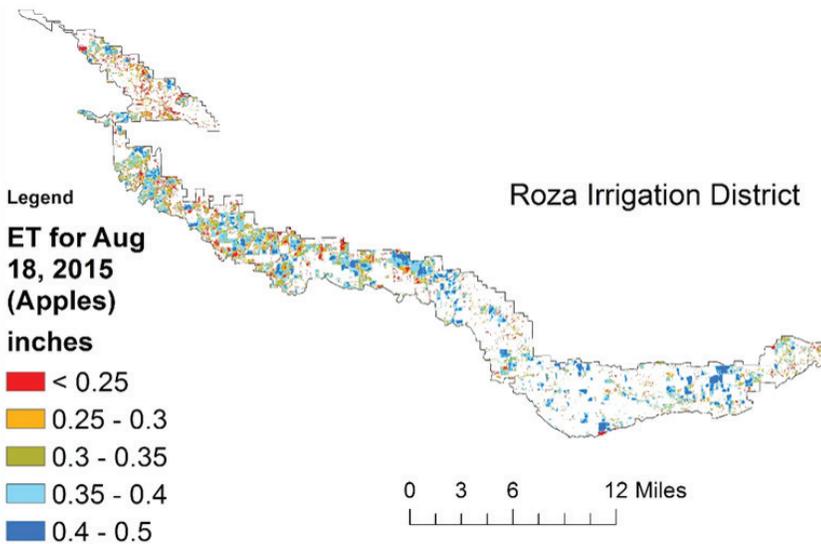
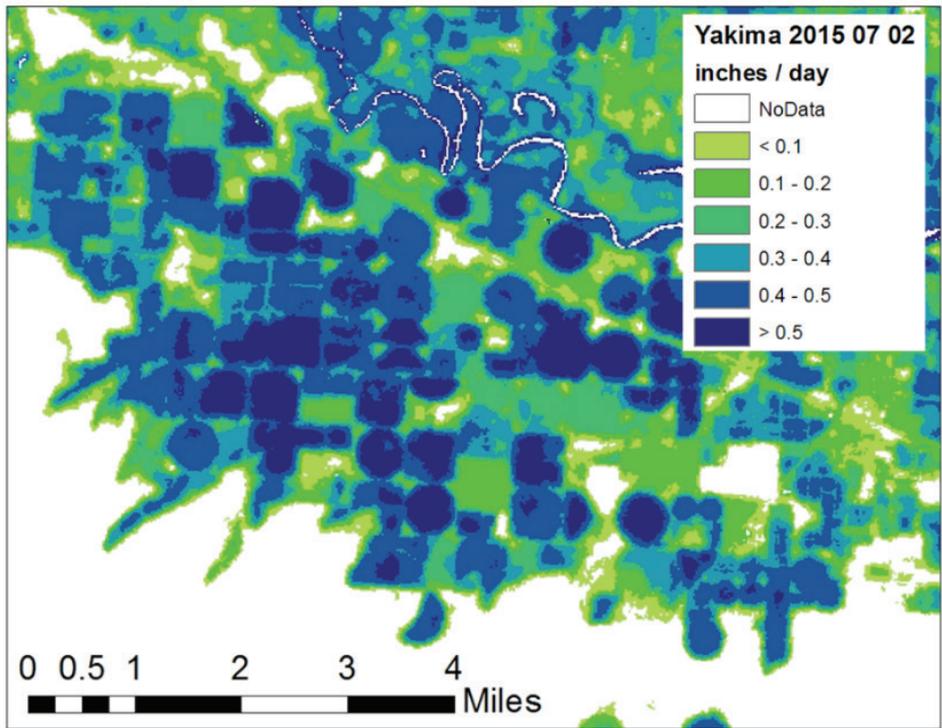


Figure ES-3: Pilot results from using METRIC in an eastern Washington Water Resource Inventory Area (WRIA). (a) METRIC can produce high resolution consumptive use maps, showing areas that use less water (green), and irrigated areas that use more water (dark blue). This is an example showing alfalfa near Prosser (Yakima River Basin). (b) Consumptive water use for apple orchards in Roza Irrigation District. Areas in red show apple orchards that use less water, and areas in blue show apple orchards that use more water per acre. (c) Acres of apple orchards in the Roza Irrigation District using different amounts of water (each bar reflects a different consumptive use). The bars to the right of the dotted line (which add up to about 75% of the total acres of apples) are using more water than recommended by Washington’s Irrigation Guidelines (WIG).

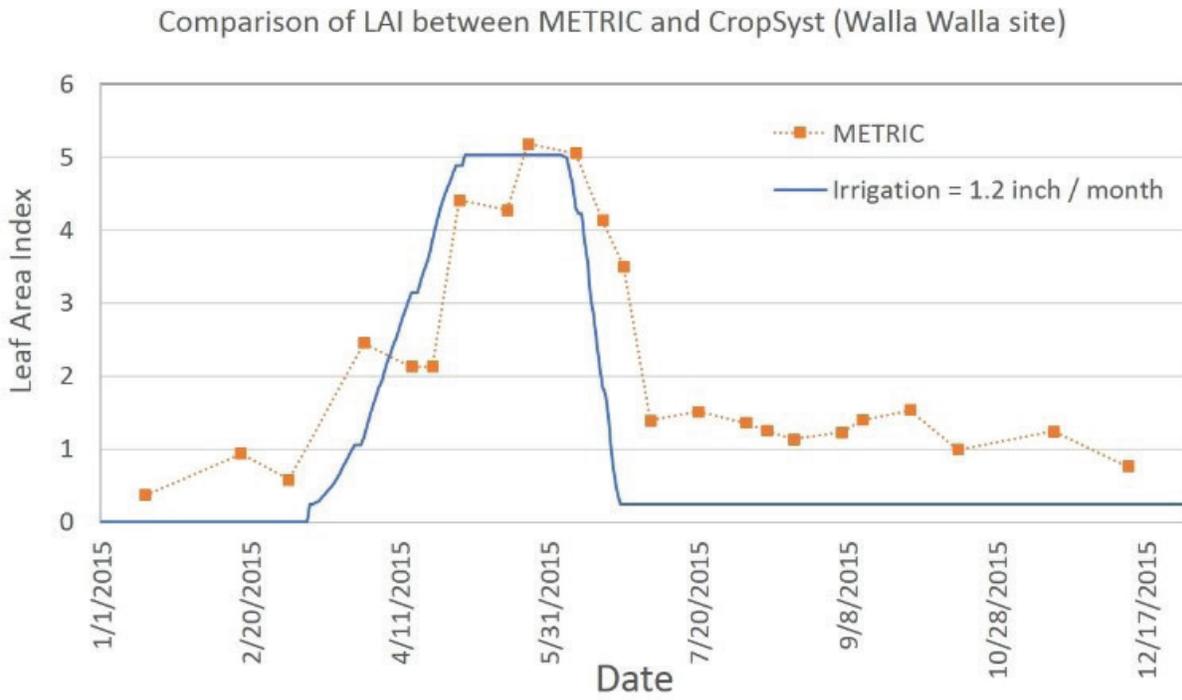


Figure ES-4: Comparison of METRIC's and CropSyst's leaf area index (LAI) estimates for a grape vineyard in Walla Walla.

## WATER BANKING TRENDS IN WASHINGTON AND WESTERN STATES

Water banks and water markets allow people and farms who face water use restrictions to purchase mitigation credits to allow water use. Water banks and markets are among the critical portfolio of tools needed to help address the complexities of water management—including drought risk, surface water-groundwater interactions, and legal and regulatory disputes and restrictions over water markets—thereby allowing scarce water resources to be allocated more efficiently.

Understanding how water markets are working and maturing in Washington can help guide regulatory oversight and function of water banks, and clarify how water rights will move in response to water supply shortages, curtailments, demographic changes, and climate change. These are important elements that still need to be incorporated into the economic forecasting that influences the long-term supply and demand forecast for the Columbia River. This module describes water banking activities in Washington State and across the western United States—including the various administrative forms that water banks take, and the various forms that water transactions take in the context of water banking—and provides recommendations on how to improve and provide incentives for water banking in Washington.

### **Key findings:**

- 24 banks currently operating (including self-mitigating banks), and seven developing water banks.
- Water banking activity across 11 western States has tended to increase in the last 12 years—since the publication of Clifford et al., 2004—in terms of the number of programs, the number of transactions, and the volume of water traded, with a great deal of variation in form, function, and growth across States.
- Water banking grew from two active banks in 2004 to 24 operating banks in 2016, with an additional seven banks in development (Figure ES-5). This expansion is driven primarily by regulatory imperatives such as groundwater closures (e.g. Upper Kittitas) and Supreme Court rulings (e.g. Postema v. Pollution Control Hearings Board), and encouraged by the need to maintain instream flows for fish.
- A number of options to improve water banking and water markets more generally in Washington exist, including:
  - Seek legislative clarity on mitigation criteria for streamlined bank operation. Mitigation criteria are currently in flux due to recent Supreme Court cases (Swinomish v. Ecology, Foster v. Ecology).
  - Clarify public interest criteria necessary for forming a water bank, since Ecology resources would be used to administer it. As currently structured, each new water bank creates new unfunded obligations on Ecology that detract from other legislatively-prioritized work.
  - Identify financing mechanisms appropriate for water banking, to provide Ecology cost-recovery for bank formation and operation.
  - Identify criteria for banks whose operation depends on water rights originating outside the watershed, to prevent unintended economic impacts.
  - Explore alternatives to conventional operations and monitoring for very small uses that drive bank costs up, including for metering and certified water right examinations.
  - Explore alternative contracting options, such as computer-aided transactions and options contracts for water.

This analysis provides a broad perspective on water bank and water market developments, which can provide ideas for future developments and improvements for the State of Washington.

### *Reference:*

*Clifford, P., C. Landry and A. Larsen-Hayden. 2004. Analysis of Water Banks in the Western States. Washington Department of Ecology. Publication number 04-11-011.*

# EXECUTIVE SUMMARY

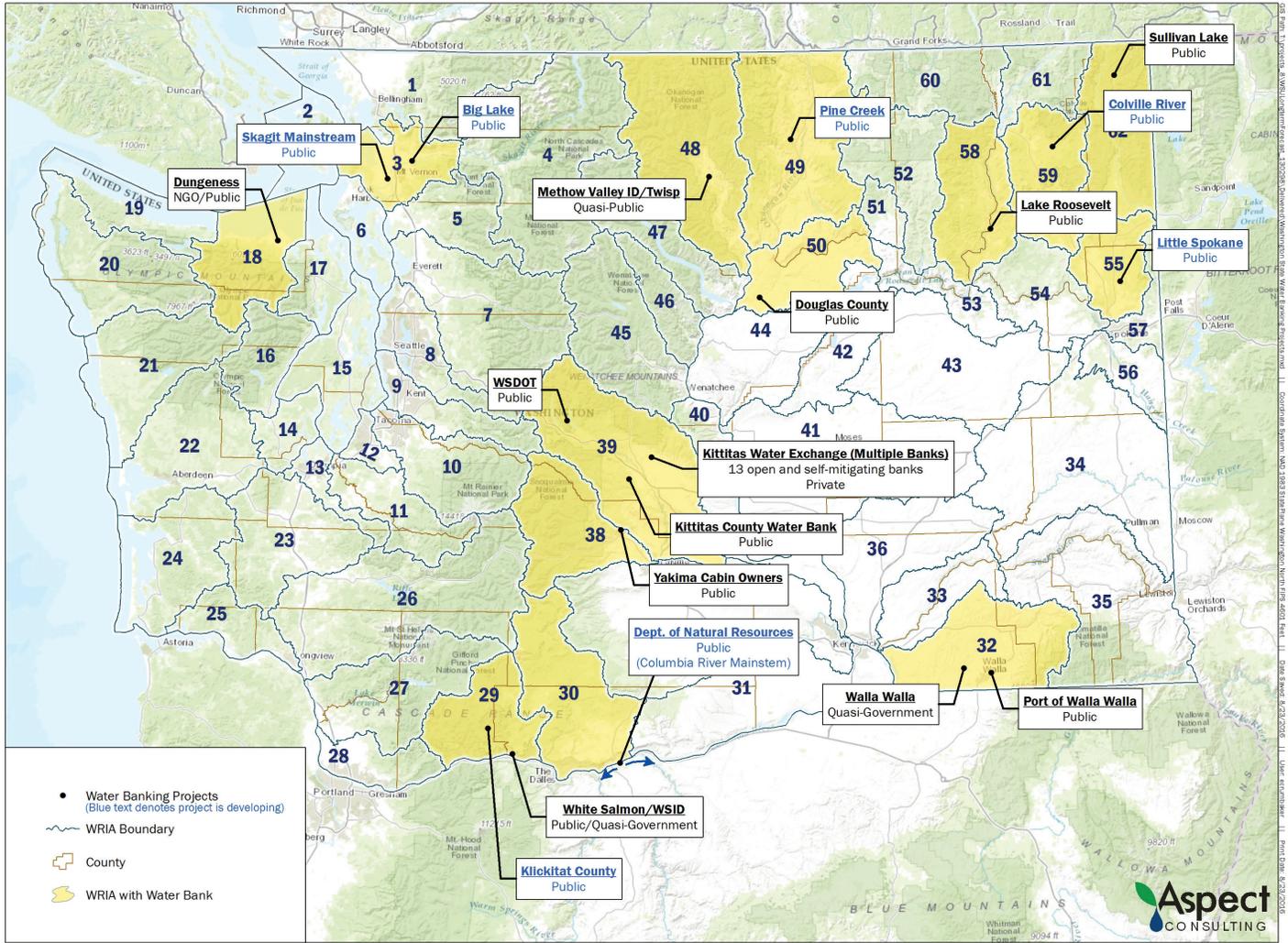


Figure ES-5. Location and extent of existing water banking projects across Washington State in 2016.

## EFFECTS OF USER-PAY REQUIREMENTS ON WATER PERMITTING

Participation of applicants in water supply development cost-recovery programs affects both the extent of service provided by Ecology's projects, and Ecology's ability to recover the costs of providing these services. Water rights applicants seem more frequently to be declining the opportunity to have their applications processed and receive water through these programs when made available. These negative responses are adversely affecting Ecology's ability to reduce its backlog of water right applications in the face of Legislative mandates to meet annual permit processing targets.

Over the last 10 years, Ecology and OCR have offered six programs that included different kinds of cost-recovery user-pay responsibilities. These programs offer an opportunity to compare and contrast different business models and their relative successes in terms of program participation. Fee structure variants include:

- a. A one-time processing fee for water supply development and administration,
- b. Annualized payments for water service,
- c. Specified program fees, and
- d. Individualized mitigation without program fees.

The objective of this module was to better understand the importance of program characteristics, including fee structure, on program participation decisions. A survey was delivered to individuals who chose to or declined to participate in the different target programs, obtained from Ecology's water right application database. 192 of 678 initial survey requests were completed, for a response rate of 28.3%. This magnitude of response rate is not uncommon in social science surveys such as this. The survey data were evaluated statistically to identify the most important determinants of program participation, and to estimate the price-responsiveness of potential participants.

### **Key findings:**

Although there are many possible reasons why individuals may choose not to participate, the analysis provided evidence of three primary reasons for program participation decisions in the Ecology programs examined:

1. *Time:* Many applications were submitted many years ago (Figure ES-6), and applicant circumstances have in many cases changed to the point that the water

rights application itself is of relatively less value to the applicant.

2. *Cost:* Potential program participants respond to cost (Figure ES-7), and some potential participants opt out of the program due to the cost-recovery fees charged by Ecology.
3. *Uncertainty:* Applicants sometimes choose to keep applications on hold due to uncertainty about family or business situations, as well as uncertainty or lack of clarity of program costs or benefits. As there is no cost to keeping an application on file, there is no impetus not to simply leave it there even if it no longer represents a viable project.

These results suggest that waiting times, cost effects, and program uncertainty have impacts on participation rates and hold-times. This understanding can be helpful to Ecology in making policy and administrative decisions. To the extent that permit application backlogs are problematic for Ecology, filtering out likely non-participants from the future applicant pool may help. Some possible approaches include (1) requiring new applicants to submit additional information that is foundational to the application processing, such as a stamped hydrogeological report, or independent 3rd party beneficial use analysis; (2) increasing processing fees under RCW 90.03.470 to close the gap between applicant expectations and actual costs, thereby likely reducing speculative applications; (3) eliminating the opportunity for applicants who are offered water to remain in line with all other backlogged applications if they decline such an opportunity; or (4) modifying the cost-reimbursement application processing statute (RCW 90.03.265) to require applicants to immediately participate in a cost-reimbursement processing program to ensure timely processing and a closer tie to expectations around cost of processing.

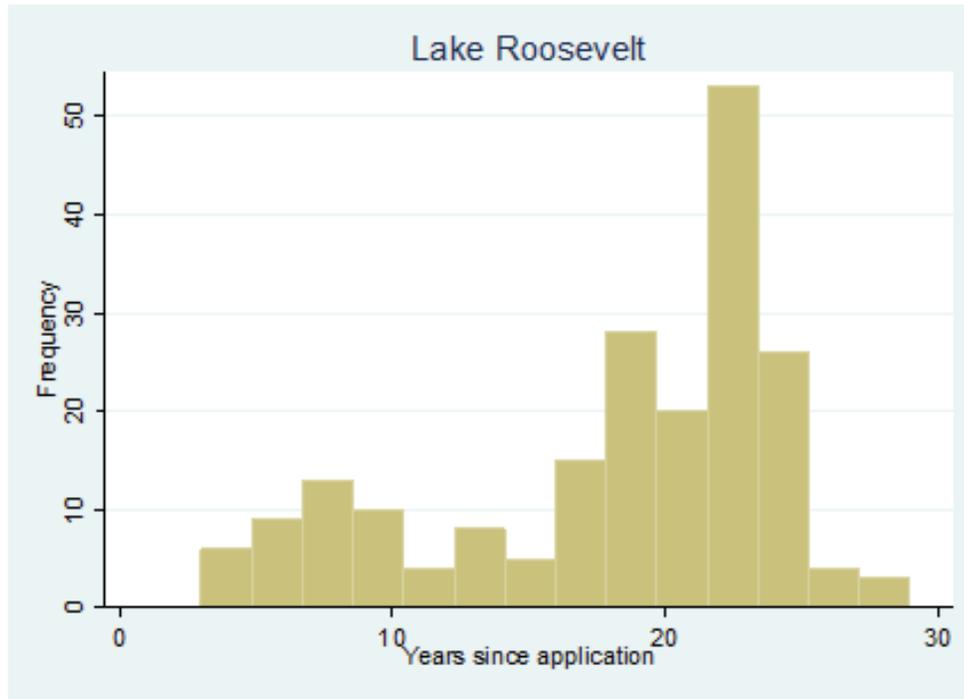


Figure ES-6. Distribution of time since applications were submitted to Ecology for the Lake Roosevelt cost-recovery program.

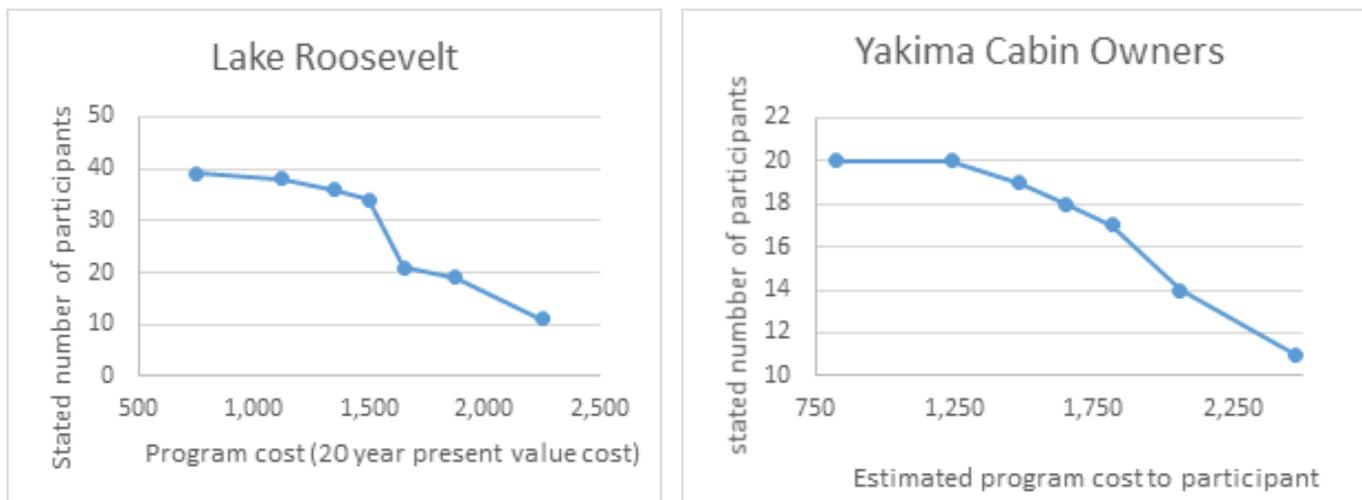


Figure ES-7. Responses to cost from potential participants in the Lake Roosevelt (left panel) and Yakima Cabin Owners (right panel) cost-recovery programs.

## WESTERN WASHINGTON SUPPLY AND DEMAND FORECASTING

Local watershed planning in Washington started in 1997, with varying success. In some watersheds, the plans resulted in stakeholder collaboration and agreement on both out-of-stream needs and adoption of instream flow rules. In other watersheds, the process was less successful in bringing together coalitions and achieving consensus-based supply and demand solutions.

In 2006, the Legislature required the Office of Columbia River to integrate water supply and demand forecasting for eastern Washington and the entire Columbia River Basin, and harmonize it with local watershed planning efforts. The resulting forecasts provide coverage for watersheds without a plan, extend the momentum of successful plans, and inform water supply development. However, increasing demands on water are not limited to eastern Washington. The purpose of this module was to assemble information on available data, studies, and plans in western Washington, and evaluate the potential for a statewide Water Supply and Demand Forecast in 2021.

### **Key Findings:**

- The primary datasets used as inputs to the integrated models used in eastern Washington extend to western Washington.
- The existing modeling framework developed for eastern Washington could be used to forecast water supply and agricultural demand across Washington State, and a process similar to that used in eastern Washington can be used to forecast municipal and hydropower demands.
- The existing modeling framework may not be ideal for all western Washington WRIAs, because of the existence of:
  - Smaller WRIAs than in eastern Washington,
  - Tidal effects in coastal WRIAs, not accounted for in this framework,
  - WRIA-specific groundwater–surface water interactions, as groundwater accounts for a higher proportion of water withdrawals,
  - Non-trivial small farm acreage missing in the WSDA land cover data, and
  - Livestock consumptive use, not accounted for in this framework, is a large fraction of agricultural water demands in certain WRIAs.
- Stakeholder input and local documents collected as part of this scoping effort should be used to evaluate the appropriateness of model results in western Washington WRIAs, and to identify WRIAs where additional modeling and data are needed.
- Western Washington has fewer interruptible water rights than eastern Washington, primarily because eastern Washington has several basins (e.g. Yakima, Walla Walla) where junior water rights are routinely called to curtail in favor of ensuring that the water needs of senior water rights are fully met. In comparison, Western Washington water right curtailment is instead focused on interruptible water users that are subject to instream flow provisions. Western Washington has a greater number of these kinds of interruptible users than eastern Washington (1373 and 909 interruptibles, respectively). This simplifies curtailment modeling for future Western Washington forecasting efforts if the modeling framework is able to provide realistic supply and demand estimates.
- For WRIAs with regulated supply, if the reservoir capacity is above a certain threshold, simple reservoir models that simulate the reservoir operation rules can be created.

In conclusion, it appears possible to extend the methods of the 2016 Forecast to provide a statewide long-term supply and demand forecast in 2021, though additional stakeholder input, modeling and data collection is likely needed to ensure results are accurate at the scale of Washington’s watersheds. Providing a statewide Water Supply and Demand Forecast in 2021 would allow Washington to:

1. Fill in data gaps in non-planning jurisdictions,
2. Take a holistic look at policies of statewide significance (e.g. declining groundwater and water banking), and
3. Achieve some parity with the other 33 states doing statewide water planning, which can be a factor (along with adjudications) when cross-state conflicts or issues arise.

# MEETING EASTERN WASHINGTON'S WATER NEEDS

The Columbia River Basin, the fourth largest watershed in North America in terms of average annual flow, is intensively managed to meet a range of competing demands. These include hydropower generation, irrigation, navigation, flood control, protection of salmonid species, municipal and industrial water needs, tribal treaty commitments, and recreation. Reliable access to water is essential for existing and future regional economic growth and environmental and cultural enhancement. Variations in water supply and demand across the Basin are increasingly leading to localized shortages as populations grow, the climate changes, and regulatory flow requirements increase. Managing these increasing and competing demands for fresh water requires understanding how future conditions will alter supply and demand, and strategically investing in projects that meet competing water management objectives.

## Climate Change Impacts

Surface water flows in the Columbia River Basin are dominated by the temperature-sensitive cycle of snow accumulation and melting. During the winter, when the majority of precipitation occurs, snow accumulates in upper elevations of the Basin, forming a “natural reservoir” that stores water during times when demands are relatively low. Melting snow subsequently provides peak yearly flows in the spring and early summer, with nearly 60% of the unregulated surface water availability occurring during May, June, and July. This is generally followed by a low-flow period in the late summer and early fall, until late fall flows increase once again due to rainfall. Operations of major reservoirs have shifted a significant amount of water availability from the winter months to the drier summer months.

The climate in the Pacific Northwest is already changing. Average temperatures are about 1.3° F higher than they were a century ago. Regional climate change projections suggest that these trends will intensify, with projected temperature changes in the range of 2 to 8.5° F by the middle of the 21st century, with more intense warming in the summer months<sup>1</sup>. Precipitation on the other hand is not projected to change much on average, though summers are projected to be drier and the other seasons somewhat wetter than historically<sup>2</sup>. These projected climate changes could fundamentally change the patterns of rain and snowfall in the Columbia River Basin, leading to reduced snowpack, earlier snowmelt and peak flows, with longer periods of lower flows during the summer, when out-of-stream demands are highest and instream demands for hydroelectricity generation and fish are important. Reservoir management can compensate for some timing changes in areas of the Basin with storage, though 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 United States.

Simultaneously, higher summer temperatures under climate change could change out-of-stream demands for water in complex ways. While the atmospheric demand for water is greater with higher temperatures, increases in atmospheric carbon dioxide concentration increases the water-use efficiencies of most crops. Therefore, models are required to understand how evaporation and plant transpiration rates will respond to climate change. Decreases in summer precipitation could also increase demand for irrigation to supplement rainfall (though summer precipitation is currently very low), but early season precipitation increases will reduce irrigation demand. Some crops may be planted and reach maturity earlier, which could change the seasonality of demand, moving the irrigation season earlier in the year when precipitation is more plentiful. Meanwhile, higher summer temperatures could also increase domestic water demands.



*Aerial photo of Columbia River by William Durham.*

1 Dalton, M.M., Mote, P., Snover, A.K. (Editors) 2013. *Climate Change in the Northwest: Implications for our Landscapes, Waters, and Communities*. Island Press. Washington, DC

2 Ibid.

## Trends in Agricultural Production

Irrigated agriculture accounts for a large portion of the demand for water in the Columbia River Basin. The mix of irrigated crops grown in eastern Washington is constantly adjusting over time due to a number of factors, including consumer tastes, export and import trends, and production technologies, to name a few. Water demand—both in hydrological and economic terms—depends on the mix of crops in the region, as different crops require differing amounts of water per acre. For example, expansion in acreage of wine grapes, that use relatively little water, would reduce the amount of water consumptively used (all other factors being equal).

Over the last twenty years, irrigated agricultural production trends in the Columbia River Basin show that hay crops (such as alfalfa and Timothy), tree fruit, and herb crops (such as mint and hops) have remained relatively constant. Crops that have expanded include wine grapes and vegetables. Irrigated grains have seen the largest decline. Detailed analysis of these trends allows projections of crop mix in the future. While some of the crop groups have seen relatively large percentage changes, the relative acreage share for the region has remained stable, with hay crops covering by far the most acreage.

In addition to adjusting the mix of irrigated crops grown, producers' and policymakers' decisions and investments affect a number of other variables that, in turn, may affect consumptive use of water for agriculture. Examples include irrigation technology, which affects the efficiency of water use; cropping practices such as double-cropping, which affects total use of water in a season and extends the irrigation season; or water appropriation or water storage projects, which affects the total water available, and therefore the acreage under irrigation.

### BOX 1

#### Economic value of fish- and wildlife-dependent activities in Washington State

Spending associated with recreational fishing, hunting and wildlife viewing across Washington State was estimated to be over \$4.5 billion in 2011, a 67.6% increase from 2006 (USFWS and USCB, 2008, 2014). The Washington Department of Fish and Wildlife estimated that the 2006 activities supported some 46,250 jobs in the state (WDFW, 2010).

The census data used to develop these estimates is not available at a county or regional scale within the state, so numbers for eastern Washington are not available.

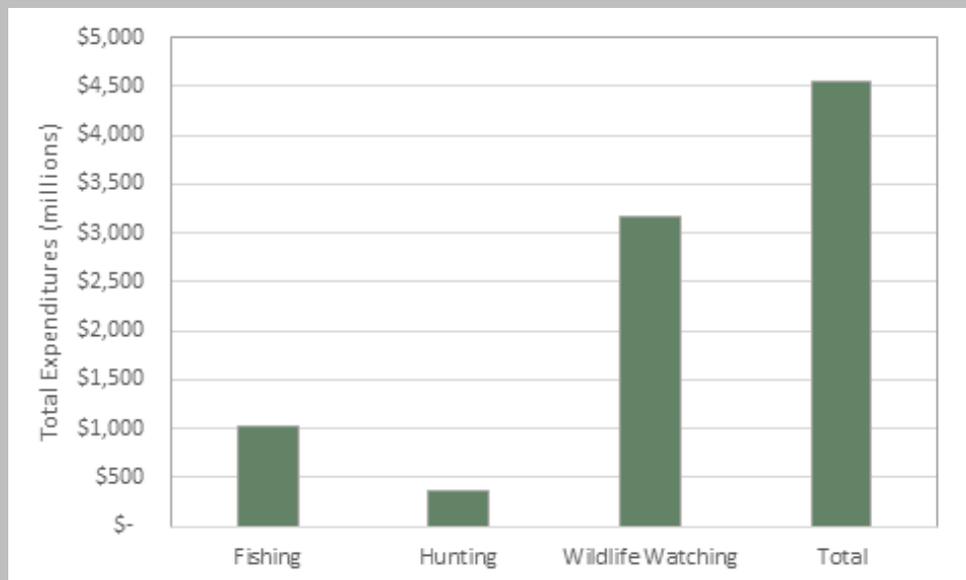
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## Fish Instream Needs

The waters of the Columbia River Basin support a variety of fish and other wildlife important to maintaining cultural, environmental, and recreational values, including several fish stocks listed as threatened and endangered under the Endangered Species Act (ESA). All these 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 (Box 1). While the Washington Department of Ecology (Ecology) recognizes the value of all fish and wildlife, Chapter 90.90 RCW directs Ecology's Office of the Columbia River (OCR) to focus on salmonids.

## The Columbia River Treaty and Tribal Water Rights

One important issue that could dramatically alter the surface water supplies entering Washington State is the re-negotiation of the Columbia River Treaty between the United States and Canada. The 1964 Treaty provided for the construction of four dams in the upper Columbia River Basin that more than doubled the amount of reservoir storage in the Basin: Libby in Montana, and Duncan, Keenleyside (also known as the High Arrow Dam), and Mica in Canada. These four dams are operated to benefit downstream hydropower generation and flood control. According to the U.S. Army Corps of Engineers, the dams provide billions of dollars of benefits to the two countries. The Treaty has an opt-out clause as of 2014, that allows either country to notify the other that they intend to terminate the Treaty 10 years from the date of that notification.

Since the Treaty was originally ratified, the emergence of complex issues in addition to power and flood control, such as future needs for anadromous and resident fish, irrigation, recreation, and municipal water supply, has both countries examining whether or not new operating rules would provide additional benefits. Though no notification to terminate has yet been given by either side, both sides are evaluating termination and re-negotiation alternatives. These could radically change the context in which OCR is working to meet water demands in the Columbia River Basin.

Tribal water rights may also have the potential to substantially alter how water supplies are allocated in the region, particularly those available for meeting instream demands. Tribes residing in eastern Washington reserve the right to fish, hunt, and gather their traditional foods across usual, accustomed, and ceded areas beyond their reservations, that encompass large stretches of the Columbia River and its tributaries. The water rights associated with these fishing rights have not yet been quantified. The implications of quantifying the tribal water rights are difficult to predict.

# LONG TERM WATER SUPPLY AND DEMAND FORECASTING

The water supply systems in the Columbia River Basin were built to reliably deliver water under historical conditions. Changes in water supply and demand due to population growth and climate change have the potential to stress those systems. This 2016 Long-Term Water Supply and Demand Forecast provides information that will help legislators, water managers, and agency professionals plan for future conditions that will likely be quite different from those we have experienced in the past.

## The Office of the Columbia River

The Washington State Legislature recognized the complexities in the water supplies and needs of people and fish across the Columbia River Basin in Washington, and identified the development of new water supplies as a water resource management priority. In 2006, it passed Chapter 90.90 RCW, directing the Department of Ecology (Ecology) to aggressively develop water supplies for instream (one-third of the supply developed through new storage projects) and out-of-stream (the remaining two-thirds of the developed supply) uses. With approximately 395,000 acre-feet (ac-ft) of water supply already developed since 2006 and another 320,000 ac-ft under development (Figure 1), OCR has met the challenge of rapidly improving water supply for eastern Washington, consistent with its legislative directives (Box 2).

Since OCR's inception, the pursuit of developing new water supply has provided insight that now shapes the way OCR allocates funds and prioritizes water supply projects. The 2015 drought was a recent reminder of the fragile nature of the state's water resources and the need to build and maintain innovative partnerships that focus on resilient and integrated water resource management. Understanding where additional water supply is most critically needed will continue to assist OCR in making smart investments that help improve water supplies for our growing communities, rural economies, and instream flow needs throughout the Columbia River Basin.

## Past Water Supply and Demand Forecasts

Pursuant to RCW 90.90.040, OCR develops a long-term water supply and demand forecast (Forecast) every five years, and submits it to the State Legislature. The primary purposes of the Forecast are to provide a generalized, system-wide assessment of:

- How future environmental and economic conditions are likely to change water supply and demand.
- Where OCR can invest in water supply projects that have the greatest chance of meeting new demand and improving flows for fish.

### BOX 2

#### The Office of Columbia River in Washington State

The Office of Columbia River (OCR) was formed in 2006 as a result of Chapter 90.90 RCW. The OCR has a mission to develop water supplies to:

- Provide alternatives to groundwater for the Odessa Subarea.
- Provide water for pending water right applications.
- Secure water for drought relief and interruptible water users.
- Provide water for new municipal, domestic, industrial, and irrigation uses.
- Provide water for instream flows to benefit fish.

# OCR WATER PROJECTS 2016

- **Completed, Developed**
- **Active, Under Development**

Locations are approximate

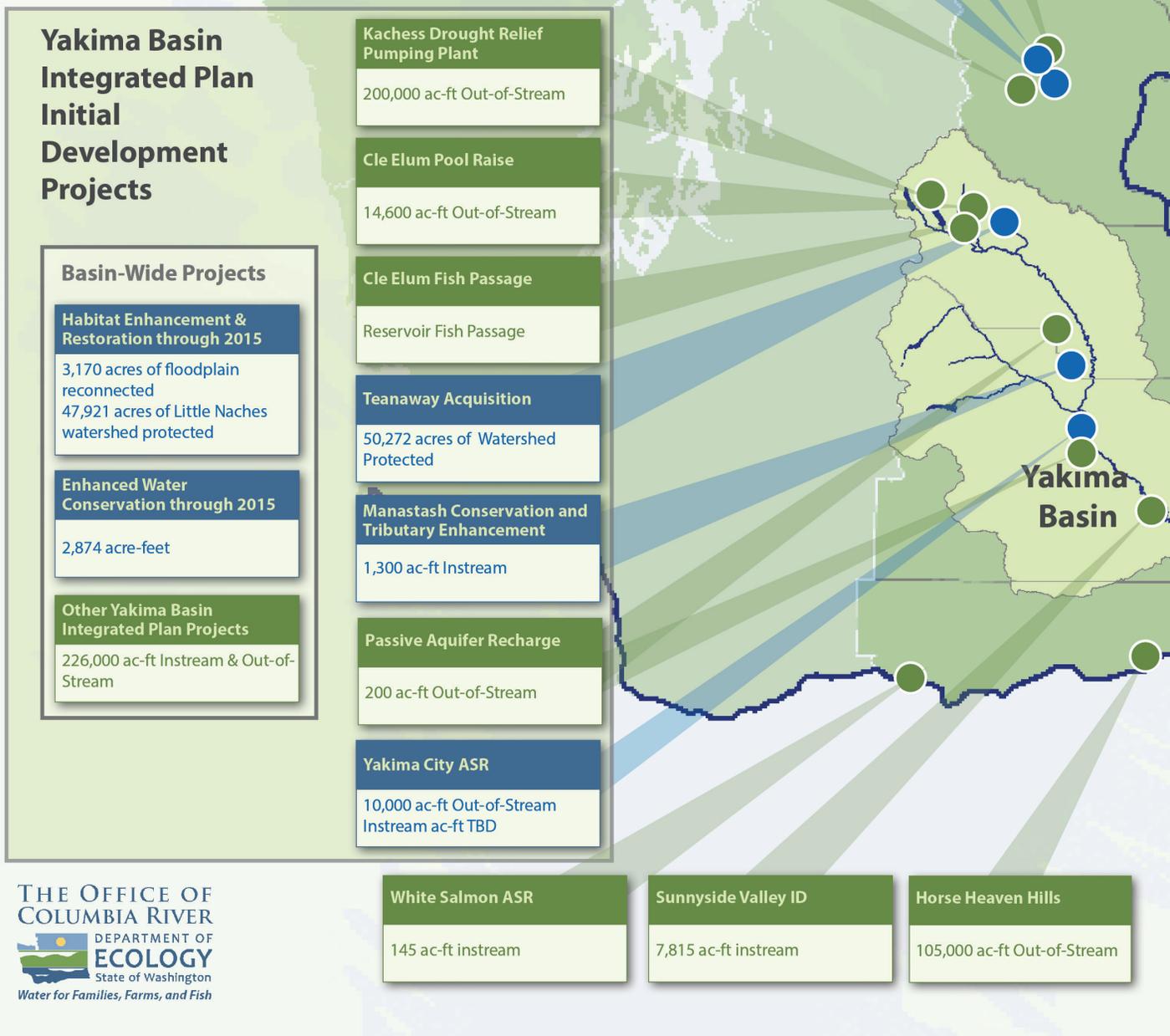
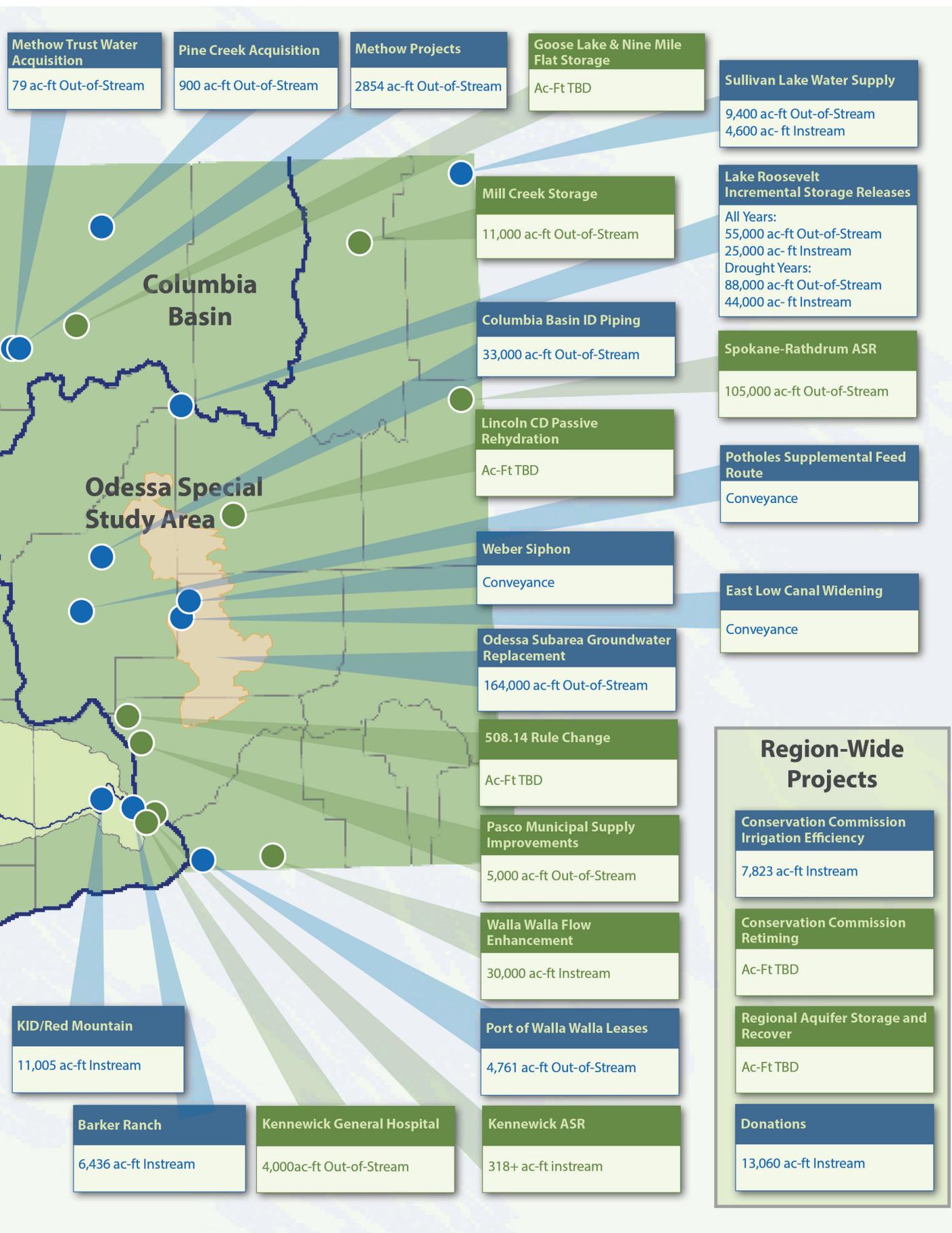


Figure 1. Projects funded by the Office of Columbia River.



The first Forecast, in 2006, used a variety of existing data and methods to estimate water use in eastern Washington in 2000, and to make projections of water use for 2025. One of these methods was using water right applications on file with Ecology as a surrogate for demand, which was generally viewed as inadequate and potentially speculative during the public review process.

A different approach was taken in the 2011 Forecast when, for the first time, a computer-based model was employed to forecast water supply and demand, incorporating the impacts of climate change, future regional and global economic conditions, and state-level water management actions. This Forecast quantified water supply and agricultural, municipal, and hydropower demands for water in 2011, and projected supply and demand in 2030. This represented a major endeavor that laid the foundation for future forecasts.

Meanwhile, the Columbia River Instream Atlas, a part of the Forecast first completed in 2011, evaluated stream flows, the status of fish populations and their use of habitat, and the condition of that habitat along 189 stream reaches in eight fish-critical watersheds in the Columbia River Basin.

## Changes Explored in the 2016 Forecast

There is inherently a great deal of uncertainty in predicting changes in water supply and demand 20 years ahead. Many factors that influence water supply and demand need to be projected, such as agricultural market conditions, input costs, production decisions, global trade conditions, temperature and precipitation patterns, water management policies, and water storage capacity. By exploring different scenarios that address three broad types of changes that may occur, it is possible to represent the likely range of water supply and demand in 2035. The following three types of changes were explored in the 2016 Forecast:

- **Climatic factors:** Increases in greenhouse gas concentrations in the atmosphere are leading to changes in precipitation and temperature, which in turn affect water availability and agricultural growing conditions. The Pacific Northwest is expected to experience increasing temperatures, shifts in precipitation leading to wetter winters and springs and drier summers, declining snowpack, earlier snowmelt and peak flows, and longer periods of low summer flows. In addition, increased concentrations in carbon dioxide also influence crop water requirements through increases in water- and energy-use efficiencies.
- **Economic factors:** Changes in domestic food demand and international trade affect production decisions. Water demand depends on the mix of crops in the region, which in turn is responsive to consumer tastes, export and import trends, and production technologies, among other factors. While some crop groups have seen relatively large changes, the relative acreage share for the region is expected to remain stable, with hay crops covering the most acreage.

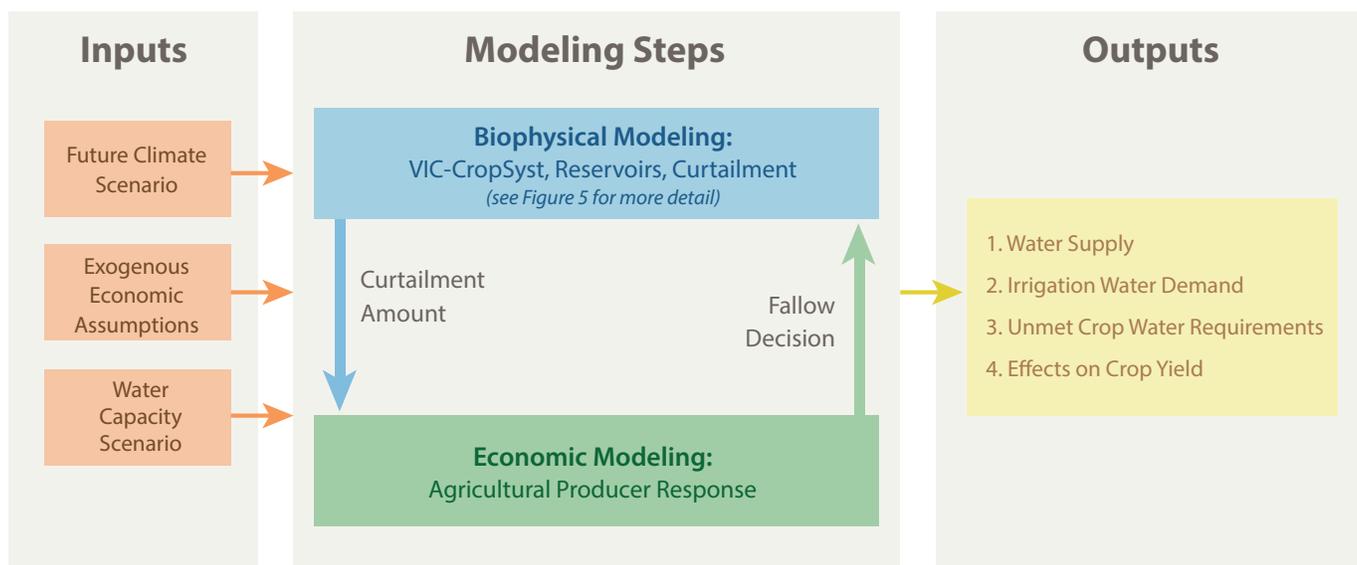


Figure 2. Integration of biophysical modeling (surface water supply, crop dynamics and climate) with economic and policy (human decision-making) modeling.

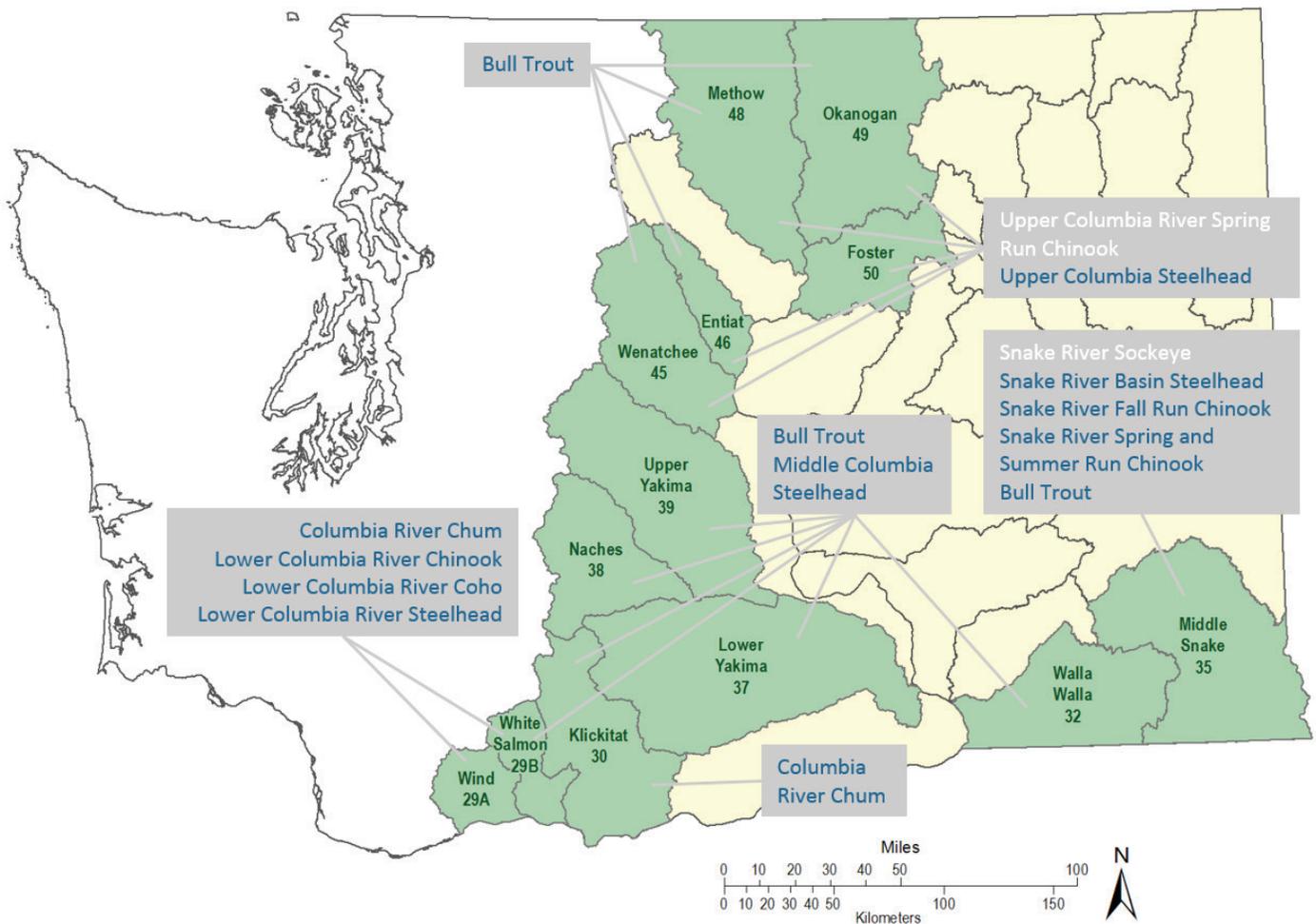


Figure 3. Endangered Species Act (ESA)-listed anadromous salmonid stocks known to occur—though not necessarily spawn—in specific subbasins within the 12 Water Resource Inventory Areas (WRIAs) evaluated in the 2016 Columbia River Instream Atlas (CRIA) update (see Box 8 for details). Threatened stocks in blue, and endangered stocks in white.

- **Water management factors:** Changes in water availability, curtailment of water rights, and water storage capacity affect water use. For example, increases in water storage capacity from planned water storage projects can supply water for new uses, including the development of new irrigated acreage. The response of producers to such changes also impacts water use.

Other types of changes were beyond the scope of this Forecast, because sufficient data were not available to develop feasible scenarios, given the complexity of factors that drive them. The quantification of tribal rights, for example, involves complex legal issues beyond the scope of the Forecast. Similarly, there is no guidance yet from the United States or Canada on what changes might be made—or not—to the Columbia River Treaty.

The 2016 Forecast used an expanded and updated modeling framework that was initially developed for the 2011 Forecast to make projections of water supply and demand in 2035, using integrated biophysical and human decision-making models (Figure 2) (see details of model improvements in the *Integrated Modeling of Supply and Out-Of-Stream Demands* section).

The 2016 Forecast was not meant to provide an in-depth analysis of how to meet the water needs of fish. As in 2011, the Forecast is complemented by the Columbia River Instream Atlas (CRIA), which was also updated in 2016 (see Ecology Publication No. 16-12-006). These updates included:

- Expansion of the CRIA to include four more WRIAs: Wind River/White Salmon (WRIAs 29a and 29b), Klickitat (30), Entiat (46), and Foster (50) (Figure 3).

- Development of an interactive webmap of the 12 flow-critical WRIs within a GIS-based framework that is publicly accessible.

In addition to the improved Forecast and updated CRIA, six complementary tasks (hereafter called modules) were conducted, focusing on key policy issues. These modules focus on issues whose prominence is expected to increase in the next five years, and could affect future water demands (and in turn OCR's future planning), investments and implementation of water supply development projects, or the development of the 2021 Forecast. The policy issues that framed the modules are:

- In some areas of the State, basins are being closed to further groundwater withdrawals due to groundwater declines. Understanding the integrated dynamics of groundwater and surface supplies across eastern Washington is a goal that future Forecasts could fulfill.
- Estimating and tracking actual water use by crops is both necessary to assist in water right evaluations and adjudications, and to inform future Forecasts. A method that provides accurate estimates of actual water use in an effective and cost-efficient manner would improve such evaluations, adjudications, and Forecasts.
- Water banking is growing in areas of the State (and beyond) where there is a need to trade water, as no additional water is available—or expected to become available—to support development and other projects. Identifying bank characteristics, costs, and barriers to their creation could inform both Ecology's and OCR's resource and financial investments, as they fulfill multiple roles in the water banking arena.
- The State Legislature has moved towards an applicant-pays system for processing water rights applications, yet little information exists on how to effectively design such a system.
- Policy issues can have statewide relevance, so consistency in planning and available information across the whole state can inform the need and impacts of proposed policies. Multiple states have developed State Water Plans. A statewide Forecast could provide foundational information in support of such a plan, yet does not exist to date.

# OVERVIEW OF THE 2016 FORECAST

## Forecast for Three Geographic Scopes

Supply and demand was forecasted for the entire Columbia River Basin, and results are provided for three different geographic areas of interest (Figure 4), fulfilling specific objectives:

**Columbia River Basin:** Estimate climate-induced changes in surface water supplies and demands upstream of Bonneville Dam in seven U.S. States and British Columbia, with a particular focus on eastern Washington.

**Washington's Watersheds:** Conduct an in-depth analysis of surface water supply and demand for each of eastern Washington's 34 Water Resource Inventory Areas (WRIAs), from the Canadian border to Bonneville Dam.

**Washington's Columbia River Mainstem:** Estimate changes in supplies with regard to the mainstem's legal, regulatory, and management schemes.

## Instream and Out-of-Stream Elements of the Forecast

Four demand sectors were considered: agricultural, municipal, hydropower, and the needs of listed fish species. Washington State University (WSU) carried out integrated modeling of surface water supply and agricultural water use (the dominant out-of-stream use), estimated projections of municipal water use, and completed a review of hydropower planning projections and instream needs to meet flow regulations. The Washington Department of Fish and Wildlife (WDFW) and Ecology's OCR carried out the analysis focused on instream flow requirements for endangered fish.

## Integrated Modeling of Supply and Agricultural Demand

Water supply and demand impact each other. Out-of-stream diversions reduce supply downstream, while water that is diverted but not consumptively used—such as water that is lost through leaks in municipal systems—may return to the system and provide water supply downstream. Surface water supply and out-of-stream demands were thus simulated with an integrated computer model that quantifies the relationships between climate, hydrology, water supply, irrigation water demand, crop productivity, economics, municipal water demand, and water management. Some of these elements, such as municipal water demand, were simulated in more depth or specificity within Washington State.

The model used in the 2016 Forecast integrates and builds upon three existing models—VIC, CropSyst, and ColSim (Figure 5)—that have been used independently in various studies to simulate conditions in the Columbia River Basin. What distinguishes the Forecast from those independent studies is that VIC and CropSyst exchange hydrologic and crop production information. What distinguishes this 2016 Forecast from the previous 2011 effort is that:

- The hydrological (VIC) and crop production (CropSyst) models are more tightly integrated, so that the interactions between the hydrological cycle and crop growth processes are better captured. This improves the simulation of crop water requirements and irrigation needs, particularly during drought conditions.
- Newer climate change projections (CMIP5) and improved downscaling methods were used, so that future climate scenarios are more appropriate for the region, and are better able to capture changes in temperature and precipitation extremes, in addition to changes in average temperatures and precipitation.
- Improved historical climate and crop data were available, reducing the number of assumptions that were needed to model historical supply and demand across the region.
- Only one 2035 crop mix was projected, simplifying the assumptions made about future domestic economic growth and international trade. The 2011 Forecast demonstrated that scenarios based on varying these assumptions have relatively little effect on the future crop mix.

In addition to the improvements in the core modeling relative to the 2011 Forecast, this 2016 Forecast also includes results and methods that would allow OCR to explore the impacts of water management decisions. The two aspects of water management that were explored are:

- How climate change by 2035 would impact the frequency and magnitude of curtailment of water use under certain types of water rights.
- How to quantify the economic benefits of investments that make more water available for agriculture in eastern Washington, either to reduce the frequency or magnitude of curtailment to existing water users, or to allow for expanding the irrigated acreage across the region.

### Forecasting Water Supply and Agricultural Demand – Framing Principles

VIC-CropSyst v2.0 uses daily precipitation and temperature observations from across the Columbia River Basin (upstream of the Bonneville Dam, including upstream areas in other states and British Columbia) for 1981-2011 to generate baseline simulations of historical conditions for each location. To forecast future conditions, the model used daily weather information from 2020 to 2050 (referred to in this Forecast as 2035, the year at the center of the 31-year range) from ten different climate change scenarios, representing five different climate models run under two alternative greenhouse gas emissions scenarios. These climate change scenarios were adapted for our region by the University of Idaho<sup>3</sup>. Increased carbon dioxide concentrations were also used as inputs to CropSyst, affecting crop growth and water use under future scenarios.

To accurately simulate surface water supply and agricultural demand, the VIC-CropSyst model needs accurate land use information for the entire region. To simulate these variables for 2035, projections in land use—characterized by the mix of crops across the region—are needed. There are two options for forecasting a future crop mix. The first option is to directly model each factor that influences cropping decisions, such as economic growth and export trends. The second option is to simply analyze the historical changes in crop mix statistically, and forecast those trends into the future, based on an understanding that changes in cropping patterns reflect changes in these many factors, so it is not necessary



Figure 4. Long-term water supply and demand was forecasted for the entire Columbia River Basin, and results are provided for three different geographic scopes: Columbia River Basin, Washington’s Watersheds, and the Columbia River Mainstem.

<sup>3</sup> Modeling used downscaled climate projections from the 4.5 (medium greenhouse gas emissions) and 8.5 (high greenhouse gas emissions) Representative Concentration Pathways (RCPs), as developed by the Intergovernmental Panel on Climate Change (IPCC). The downscaling method and data from the University of Idaho are available online at: <http://maca.northwestknowledge.net/>.

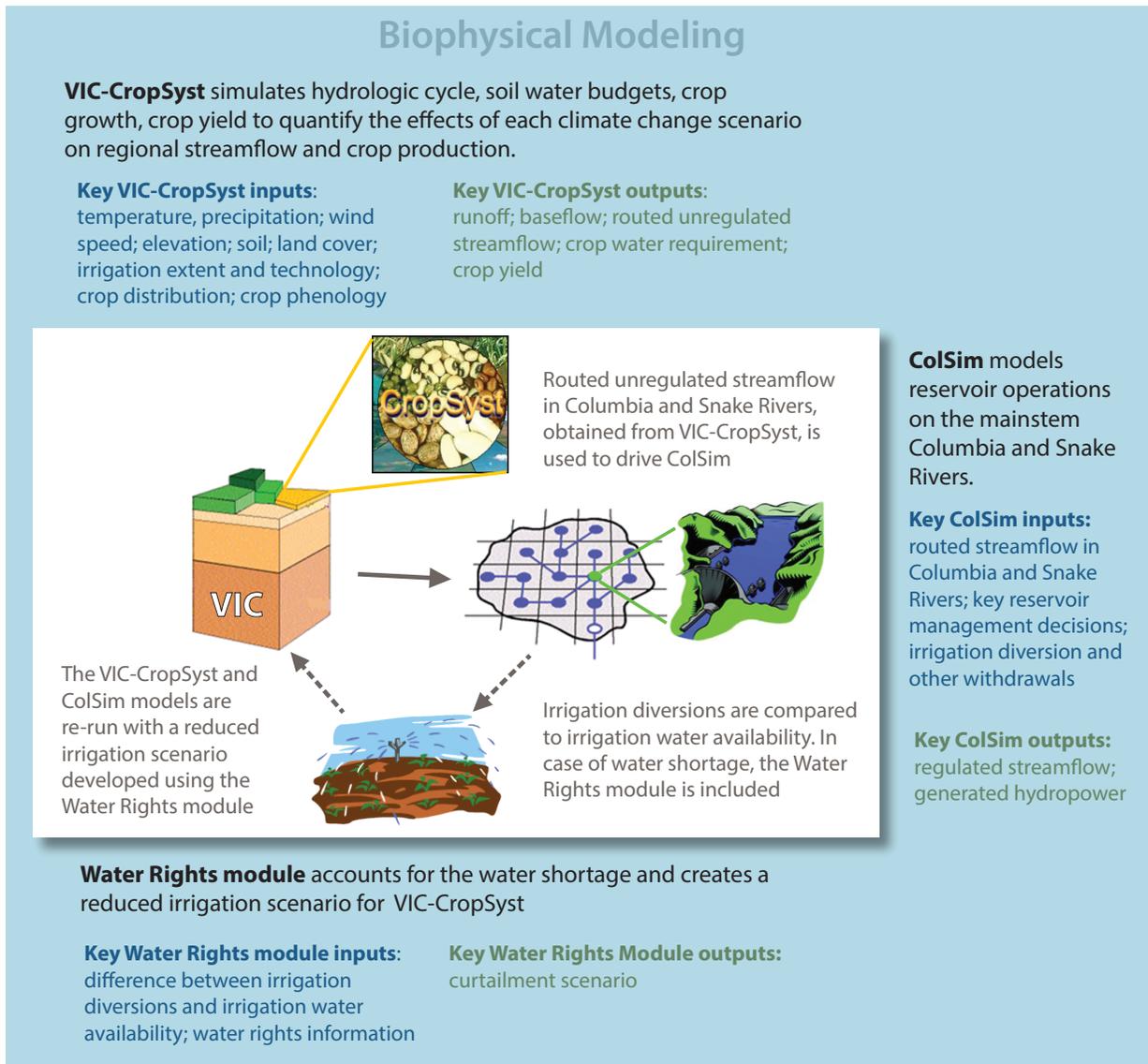


Figure 5. Biophysical modeling framework for forecasting surface water supply and agricultural water demand across the Columbia River Basin.

to model them directly. This approach would have limited utility if changes in the factors that influence crop mix in the future suddenly move in a different direction than in the recent past. However, there is a significant amount of economic research demonstrating that this approach produces more accurate forecasts than trying to model all factors, so this was the approach taken in this 2016 Forecast.

Based on the weather, land use, and other inputs, VIC-CropSyst simulates the hydrologic cycle, soil water budgets, and crop growth to quantify the effects of each climate change scenario on regional streamflow and on crop water requirements (Figure 5).

Key principles that guided the VIC-CropSyst simulations include:

- The Forecast focused on surface waters and shallow subsurface/surface hydrologic interactions. Though deep groundwater supplies play a significant role in many parts of eastern Washington, this Forecast does not analyze deep groundwater dynamics (but see the *Integrating Declining Groundwater Areas into Supply and Demand Forecasting* module).
- Irrigation demands were modeled assuming that the land base for irrigated agriculture remained constant between the historical snapshot (1981-2011) and the future timeframe (2035), based on the understanding that increasing the

irrigated acreage in the region is dependent on additional water development (but see the *Forecasting Water Supply and Agricultural Demand – Exploring Water Management Scenarios* section).

- The historical (1981-2011) simulations used recent crop mix information from the United States Department of Agriculture’s (USDA) Cropland Data Layer (CDL; 2013 dataset) for areas outside of Washington, and used the Washington State Department of Agriculture’s (WSDA; 2013 dataset) more precise data for areas inside the state.
- Each crop within Washington was identified as irrigated or not based on irrigation information in the WSDA dataset. Since the USDA dataset does not include any irrigation information, irrigation methods outside of Washington were assigned based on the most dominant type of irrigation for that crop in the WSDA dataset. High value crops such as corn, fruit crops, and potatoes were considered to be always irrigated.
- The future crop mix was projected based on recent changes in the relative acreage of various types of crops. The future crop mix scenario assumed that historical trends in the relative acreage of crop types—and the relative profitability of each crop, which is the main driver of those changes—will continue into the future (see *Changes Explored in the 2016 Forecast* section).
- The Forecast focused on irrigation, which represents the majority of out-of-stream water use in the Columbia River Basin and supports irrigated agricultural production, a prominent driver of Washington’s economy. While other agricultural uses—such as stock water—are important within some WRIAs, the magnitude of these uses Basin-wide is small relative to consumptive use for crops, so they were not estimated for this Forecast (Box 3).
- Nearly 40 groups of field and pasture crops, tree fruit, and other perennials were simulated (Box 4), capturing the diversity of eastern Washington’s crop mixes.
- As in the 2011 Forecast, all irrigated agriculture in the Odessa Subarea that was served by groundwater in the

### BOX 3

#### Stock water use accounts for a small portion of the agricultural water uses in eastern Washington

Every five years, the U.S. Geological Survey (USGS) estimates the amount of water used in homes, businesses, industries, and farms across Washington State. In 2010, their most recently published estimate, the USGS found that stock water uses represented approximately 0.45% of out-of-stream water use, considering public- and self-supplied domestic use, irrigation, stock water, aquaculture, industrial, and mining.

Stock water use was estimated to increase 4% in eastern Washington between 2005 and 2010, with greater increases coming from groundwater than from surface water. Even given this slight rate of increase in stock water use, the total amount of water this represents continues to be very small, on average, relative to other water uses in eastern Washington.

**Table A.** Water withdrawals in eastern Washington in 2010. Data estimated by the U.S. Geological Survey (Lane and Welch, 2015).

	Millions gallons per day	Percent of All Uses
Public Supply	285	7.56%
Domestic	226	6.00%
Irrigation	3020	80.15%
Livestock	17	0.45%
Aquaculture	63	1.67%
Industrial	152	4.03%
Mining	5	0.13%
<b>All Uses</b>	<b>3768</b>	<b>100%</b>

**Table B.** Percent change in agricultural water withdrawals in eastern Washington between 2005 and 2010. Data estimated by the U.S. Geological Survey (Lane and Welch, 2015).

	Change 2005-2010 (%)
Irrigation	-11%
Livestock	4%

Lane, R.C., and Welch, W.B., 2015, *Estimated freshwater withdrawals in Washington, 2010: U.S. Geological Survey Scientific Investigations Report 2015-5037*, 48 p. Available online at <http://dx.doi.org/10.3133/sir20155037>.

BOX 4

Field, pasture, tree fruit, and other perennial crops simulated in the historical and future crop mixes

Field Crops		Vegetables and Fruits	Pasture Crops	Tree Fruit and Other Perennial Crops	Other Perennial Crops
Winter Wheat	Millet	Sweet Corn	Alfalfa	Apple	Silviculture
Spring Wheat	Sorghum	Green Peas	Pasture	Cherry	Christmas Trees
Durum Wheat	Soybeans	Mint	Pasture Grass	Pear	Poplar
Barley	Spelt	Onions	Grass Hay	Peach or Nectarine	Daffodil
Potato	Canola	Asparagus	Bluegrass Hay	Plum	Tulip
Corn	Chickpea	Carrots	Timothy	Apricots	Sod Grass
Lentils	Mustard	Squash	Rye Grass	Hops	Green Manure
Dry Peas	Camelina	Garlic	Clover Hay	Grapes	Yellow Mustard
Sugar Beet	Safflower	Spinach	Vetch	Grape – Juice	Clover, Wildflowers
Canola	Beet Seed	Green Beans	Barley Hay	Grape – Wine	Sudangrass
Oats	Corn Seed	Herbs	Alfalfa Seed	Caneberry	Nursery Silviculture
Rye	Pea Seed	Turnips	Bluegrass Seed	Blueberry	Nursery Orchard, Vineyard
Dry Beans	Flax Seed	Watermelon	Ryegrass Seed	Cranberry	Nursery Ornamental
Buckwheat	Sugar Beet Seed	Green Beans	Fescue Seed	Strawberries	Walnuts
Triticale	Sunflower Seed	Broccoli	Grass Seed	Other Orchards	Conifer Seed
Sunflower	Rape Seed	Cabbage	Other Hays		
Other Small Grains		Cauliflower			
		Cucumber			
		Lettuce			
		Peas			
		Peppers			
		Potatoes			
		Pumpkin			
		Radish			
		Greens			
		Dill			
		Carrot Seed			
		Spinach Seed			

historical period was assumed to need surface water in 2035.

- The 2016 Forecast utilized only a medium, or “most likely” scenario for economic growth to project the 2035 crop mix. The 2011 Forecast demonstrated that scenarios based on varying assumptions about domestic economic growth and trade have relatively little effect on crop mix in general, likely because the U.S. population spends a relatively small portion of their household budget on food, and because export markets had an effect on only a few crops. Therefore, alternative scenarios are not considered in this 2016 Forecast.
- The Forecast modeled supply using current water management and existing reservoirs. Reservoir modeling captured operations of 36 of the 400 dams in the Columbia River Basin, focusing on the major storage dams on the Columbia and Snake Rivers, and the five major reservoirs in the Yakima Basin (Figure 6). Dam management captured within ColSim included operations for power generation, flood control, instream flow targets, water storage, and stream flow regulation.

Water supply under the different climatic, economic and water management scenarios was obtained from the unregulated streamflow outputs of VIC-CropSyst, and the regulated streamflow outputs of ColSim (Figure 5). Agricultural water demand under those same scenarios were obtained from the crop water requirements outputs (plus conveyance losses) of VIC-CropSyst (Figure 5).

Evaluation of the VIC-CropSyst agricultural water demand simulations was primarily based on observed unmet demand in watersheds where such data were available. In general, model-estimated unmet demand matched reasonably well with unmet demand estimated from observed data during the irrigation season of historical low flow years. Observed unmet demands in 2001 were close to the simulated values for the Methow and Okanogan Rivers (130,757 vs. 138,747 ac-ft in the Methow; 98,069 vs. 112,574 ac-ft in the Okanogan). In 1983 (a low flow year) the observed unmet demand was 39,539 ac-ft, compared to the modeled 56,054 ac-ft in the Wenatchee watershed. In 1989 (low flow year), the Colville watershed had no unmet demand, while the model simulated 15 ac-ft of unmet demand. The Little Spokane River showed a high discrepancy between the observed value (12,289 ac-ft) and the modeled result (0 ac-ft). This is mainly due to the small drainage area of the Little Spokane River, which leads to modeling results with high uncertainty.

### Forecasting Water Supply and Agricultural Demand – Exploring Water Management Scenarios

The water supply and agricultural demand modeling results described above reflect water available on the one hand, and the needs of crops on the other. Irrigation is not limited if supply is sufficient (or sufficient while still leaving enough water in the streams for other uses) – supply and demand need to be compared to each other, within the context of the regulatory environment, to make that determination. Understanding to what extent water supply is sufficient, and whether that is expected to change by 2035, is important additional information for decision-makers.

In addition, an important framing principle that guided—and constrained—the agricultural demand modeling is that the extent of irrigated acres across the region is considered fixed at the current extent through 2035, because increasing that acreage is dependent mainly on there being water available to irrigate additional acres. Criticism about the realism of this

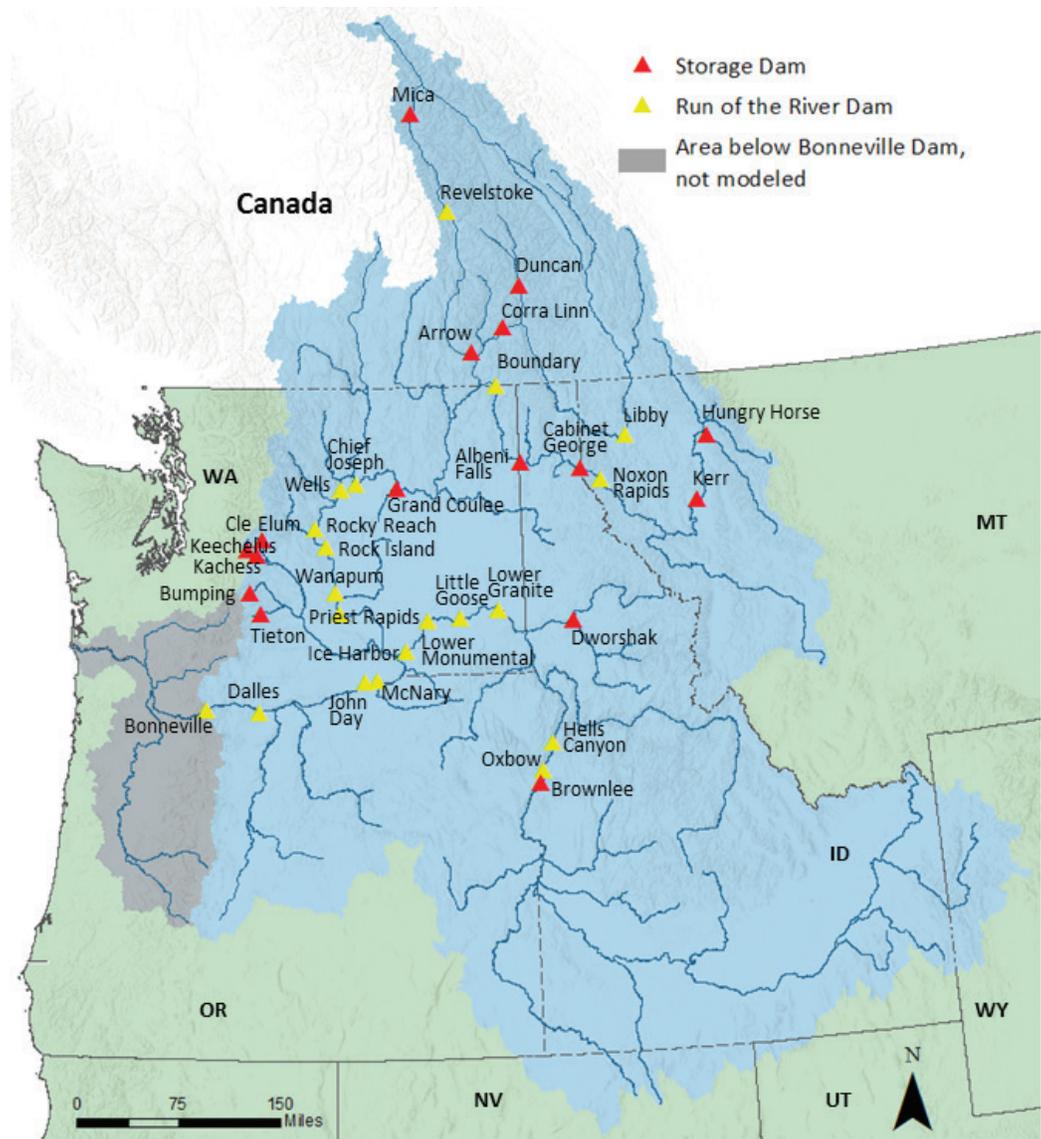


Figure 6. Dams incorporated in modeling of reservoir operations.

## BOX 5

## Types of curtailment in Washington State modeled in the 2016 Forecast

Washington State's water law is described as "first in time, first in right." This means that a particular water right is considered "senior" to all water rights appropriated after it, and "junior" to all those water rights appropriated earlier in time. Instream flow rules function as the stream's water right, and are "senior" to any water right appropriated after the instream flow rule was adopted (though there may be situations where they also affect water rights appropriated earlier).

In drought years, when the available water in streams and rivers in eastern Washington is not sufficient to meet the needs of all water right holders—including instream rights—the Department of Ecology may curtail irrigators' water use because of declining stream flows. There are different types of curtailment in eastern Washington. The main ones considered in the 2016 Forecast are:

**Interruptible water rights curtailment:** A water right that may not be acknowledged during a low water year to make more water available for instream uses is known as interruptible water right. For example, in the Columbia River mainstem, water rights issued after 1980 are designated as interruptible. When this type of water right holder is ordered to stop using water so that enough water stays instream to meet flow requirements, it is known as interruptible curtailment.

**Non-interruptible curtailment:** Water rights that are not subject to instream flow targets are called non-interruptible water rights. These water rights may still be subject to curtailment, given that a senior water right holder can call on individual junior water right holders to cease withdrawals, if and when their water availability is affected. These non-interruptible curtailments were not explored in the 2016 Forecast.

**Prorating:** Water in the Yakima River Basin is managed differently. Water entitlements are divided into three groups based on their priority date. Non-proratable water rights have a priority date prior to May 10, 1905; proratable water rights have a priority date of May 10, 1905; and junior water rights have a priority date after May 10, 1905 (Figure A). Under drought conditions, the non-proratable right holders receive their entitlement in full while the proratable water rights users receive a reduced or prorated portion of their entitlements. This prorating amount (the amount that proratable water rights are curtailed) is determined based on the March 1st forecast of the total water availability for the season, and then adjusted throughout the season. The prorating analysis in the 2016 Forecast, using the model Yakima RiverWare, focused on these proratable water rights. When prorating is in effect, the junior right holders are curtailed in full and receive no water.

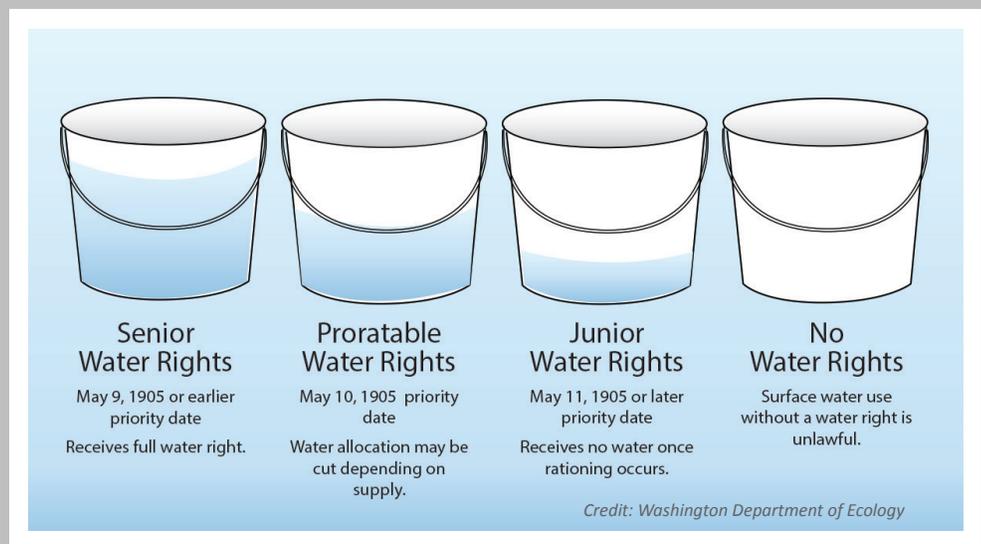


Figure A. Surface water rights in the Yakima Basin.

For more information see Washington Department of Ecology's website at:

[http://www.ecy.wa.gov/programs/wr/comp\\_enforce/curtail.html](http://www.ecy.wa.gov/programs/wr/comp_enforce/curtail.html)

principle is legitimate. However, without robust data to support the development of an alternative, more legitimate set of future conditions, alternative scenarios would just constrain the modeling in a different way. The 2016 Forecast therefore explores the impact of this principle, and provides results (obtained both from the models and additional methods described below) that can be used to relax this constraint in different ways.

### Water Use Curtailment

The 2016 Forecast modeled the frequency and magnitude of curtailments in eastern Washington, on a weekly basis, for the historical period (1981-2011), and forecasted curtailment for the 2020-2035 time period. Modeled water supply (historical or forecast) in the appropriate geography was compared to state or federal instream flow requirements, and the legislated trigger points for curtailment (in accordance with the relevant portions of the Washington Administrative Code, or the federal flow targets and pro-rationing system in the Yakima Basin) were used to estimate how often interruptible and proratable water users (Box 5) would see their water curtailed in those two time periods.

Curtailment of interruptible water right holders at the watershed scale was modeled for the Walla Walla (WRIA 32), Wenatchee (45), Methow (48), Okanogan (49), Little Spokane (55), and Colville (59) watersheds. A curtailment model was used, that identifies when the water supply left over after accounting for agricultural and municipal demands is insufficient to meet instream flow requirements, and estimates the reductions in irrigation by interruptible water right holders necessary to fulfill instream flow requirements. Curtailment of other water rights was not performed due to data and resource constraints.

Curtailment in the Columbia River mainstem was only performed for years when the April through September total unregulated flow volume at The Dalles Dam was projected to be less than 60 million acre-feet, in accordance to the relevant flow targets and curtailment trigger points. In extreme low flow years, the Director of the Department of Ecology can reduce minimum instream flow requirements by up to 25%, if considered to be in the public interest (such reductions, called “critical flow adjustments,” are subject to certain flow conditions along the mainstem). The model did not account for this potential reduction, and hence could overestimate curtailment frequency and magnitude on the Columbia River mainstem.

The water rights system in the Yakima River Basin (WRIAs 37, 38, and 39) is different (Box 5). This prorationing system of water rights was simulated using Yakima RiverWare. This model also compared modeled water supply (historical or forecast) to the Yakima’s flow targets, but has curtailment rules designed around the specifics of the prorationing system that regulates water use in this basin. These unique curtailment rules were applied to estimate curtailment of irrigation by proratable water right holders.

## BOX 6

### Calculating the value of additional water for agriculture

#### Estimating water values

Both to estimate drought impacts or to compare the costs and benefits of additional water to irrigate new acreage it is necessary to estimate the value of water (\$/acre-foot) associated with each crop. From an economic perspective, the **value of water** is the additional revenue (net of production costs) that the farmer accrues from being able to use another acre-foot of water.

Calculating the value of water requires two numbers, both of which are specific to a particular crop at a particular location: (1) estimates of the profit per acre (often taken from enterprise budgets), and (2) water use (in ac-ft) per acre. Dividing (1) by (2) gives an estimate of water value.

**Example:** If the profit obtained from growing potatoes in a particular location is \$300/acre, and say that potatoes use 4 ac-ft of water per acre:

$$\text{Value of water} = \$300/\text{ac} \div 4 \text{ ac-ft/ac} = \$75/\text{acre-foot}$$

## BOX 7

**Hydroelectric power in the Columbia River Basin**

Hydroelectric power is extremely important to economic development in the Pacific Northwest, including Washington State. The first hydropower turbines were installed on Columbia River tributaries in late 1800s, and water power from dams in the Columbia River Basin provided most of the electricity in the Pacific Northwest into the 1960s. As the population became larger and regional economy grew, demand for electricity surpassed the output of the dams, which gave rise to other types of power plants, including thermal plants fueled by coal, nuclear fission and natural gas. However, electricity in the Northwest is still dominated by hydropower, accounting for about two-thirds of the region's supply with most of the region's hydropower generated on the Columbia River and its tributaries.

The Northwest Power and Conservation Council (NWPPC) collects data on energy produced by the major hydroelectric dams in the Columbia River Basin. According to the NWPPC (2016a), 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, which accounts for approximately 55% of the power generating capacity in the Pacific Northwest (about three quarters of the region's electricity). Power entities in the Northwest regularly carry out extensive forecasting of electricity demand and power-generating capacity (NWPPC 2016b).

**References:**

Northwest Power and Conservation Council, 2016a. *Seventh Power Plan*, February 25, 2016. <http://www.nwcouncil.org/energy/powerplan/7/plan/>  
 Northwest Power and Conservation Council, 2016b. *Demand Forecast*, February 25, 2016. [http://www.nwcouncil.org/media/7149913/7thplanfinal\\_appdixe\\_dforecast.pdf](http://www.nwcouncil.org/media/7149913/7thplanfinal_appdixe_dforecast.pdf)

**Quantifying the Economic Benefits of More Water for Agriculture – Drought Mitigation**

Much of the concern over climate change in Washington comes not from changes in average year conditions, but from an increase in the frequency and magnitude of drought. Quantifying the value of making additional water available to reduce curtailments to agriculture during a drought can help decision-makers make smarter decisions. The 2016 Forecast includes a demonstration of methods for estimating the economic losses due to drought for a particular watershed. Two scenarios of responses to water shortages were explored, providing upper- and lower-bound estimates of the negative impacts of reduced water availability on agricultural production and profitability:

- The *upper-bound estimate* assumed that all crops are curtailed in proportion to their water use, which is consistent with the assumption that farms have very little crop diversity and there is little to no short-term leasing of water between farms.
- The *lower-bound estimate* assumed that farmers are able to fallow lower-value crops first. This is consistent with the assumption that at the farm level there is substantial crop diversity or that farms are able to lease water, such that farms with higher-value crops pay those with lower-value crops to fallow.

Crop-specific water values—defined as the dollar value to the producer of using an additional acre-foot of water on that crop—are needed to quantify the impacts of reduced water availability under different scenarios. The two numbers needed to calculate water values for each crop and location are (1) estimates of the profit per acre, which is often taken from enterprise budgets, and (2) water use per acre, obtained from the integrated modeling. Dividing the profit by the water use gives an estimate of water value (see more details and an example in Box 6). The 2016 Forecast provides such values for the main irrigated crops in eastern Washington, allowing the user to calculate the impacts of different curtailment scenarios.

**Quantifying the Economic Benefits of More Water for Agriculture – Expanding Irrigated Lands**

While the most pressing issue for OCR is reducing the vulnerability of existing water right holders to drought in much of eastern Washington, opportunities exist for expanding irrigated acreage. Assessing project feasibility requires a detailed analysis of costs and benefits; however, much can be gained from having a sense in advance of the cost range that would be feasible.

The water-value calculations described above are a first step towards estimating that feasible-cost range. That water value, however, is for a single year. To calculate the total value of using the water in perpetuity, a discount rate needs to be applied, to estimate the value today of that future use of water. This total water value, in perpetuity, allows the user to compare the feasible cost with other price information.

## Other Demands for Water

### *Forecasting Municipal Water Demand – Framing Principles*

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.<sup>4</sup>

Key principles that guided the estimates of municipal water demand include:

- Municipal demand was assessed only within Washington State.
- Values for self- and municipally-supplied domestic, industrial, and commercial water use were obtained from the U.S. Geological Survey's Estimated Use of Water in the United States in 2010 report, and were forecasted and integrated with the modeling.
- Calculations of total WRIA water demand were estimated as the sum of municipal, industrial, and domestic demand for each block of County population residing within a WRIA (obtained from the U.S. Census Bureau).
- It was assumed that growth in rural demand will likely be met by groundwater supplies, but domestic wells are expected to be shallow enough to directly impact surface water flows.
- Consumptive municipal use was estimated by subtracting wastewater returns (reported at the County level) from public supply values for each WRIA. Some adjustments were needed to make these two datasets comparable, which were done by computing the mean per capita wastewater return in each WRIA over the historical periods of 1985, 1990 and 1995 (the most recently reported values). The potential exists for significant discrepancies due to municipal inflow and infiltration.
- Per capita consumptive use values were multiplied by the population estimates for 2015 and 2035 (estimated through a logistic curve model) to gain total consumptive use values for these two years.
- No attempt was made to account for seasonal variations in water use.

Municipal water demands were obtained by equating demand to consumptive municipal use.

### *Forecasting Hydropower Water Demand – Framing Principles*

The Northwest Power and Conservation Council collects data on energy produced by the major hydroelectric dams in the Columbia River Basin (Box 7). Power entities in the Northwest regularly carry out extensive forecasting of electricity demand and power-generating capacity. For this Forecast, researchers reviewed existing projections across the Columbia River Basin with two specific objectives in mind:

- 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.
- Determine the likelihood of any additional hydroelectric storage capacity being built within the Columbia River Basin over the next 20 years.

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<sup>4</sup> The U.S. Geological Survey estimated that domestic uses (including public and self-supplied) represented around 6% of total withdrawals in eastern Washington, considering domestic, irrigation, stock water, aquaculture, industrial, mining, and thermoelectric uses. Irrigation accounted for much of the remaining 94%. Lane, R.C., and Welch, W.B., 2015, Estimated freshwater withdrawals in Washington, 2010: U.S. Geological Survey Scientific Investigations Report 2015-5037, 48 p. Available online at <http://dx.doi.org/10.3133/sir20155037>.

## BOX 8

### Low flow critical subbasins included in Washington Department of Fish and Wildlife's Columbia River Instream Atlas

Subbasin	WRIA	Stream Miles	Number of Reaches
Wind River	29A	74.6	25
White Salmon	29B	84.9	20
Klickitat	30	360.3	46
Walla Walla	32	337.2	36
Middle Snake	35	430.2	32
Lower Yakima	37	233.3	11
Naches	38	119.5	9
Upper Yakima	39	309.1	36
Wenatchee	45	172.6	29
Entiat	46	36.1	7
Methow	48	173.7	35
Okanogan	49	293.6	25
Foster	50	59.4	4
<b>Total</b>		<b>2,684.5</b>	<b>315</b>

Endangered Species Act (ESA)-listed anadromous salmonid species<sup>1</sup> that occur—though do not necessarily spawn—in the 12 Water Resource Inventory Areas (WRIAs) evaluated in the Columbia River Instream Atlas (CRIA) Project are illustrated in Figure 1. All of the WRIAs under study in the CRIA Project are within the geographic area designated by National Oceanic and Atmospheric Agency (NOAA) Fisheries as the “Interior Columbia Domain” for ESA-listed stocks, with the exception of the salmon evolutionarily significant units (ESUs) in WRIA 29, that are within NOAA’s Lower Columbia/Willamette Domain. Bull trout are designated by U.S. Fish and Wildlife Service as “threatened” throughout the Columbia Basin and the contiguous United States. For information about salmonids that spawn within each eastern Washington WRIA, please refer to the appropriate WRIA in the Forecast Results for Individual WRIAs section.

1 The technical terms for “ESA species” are Evolutionarily Significant Unit (ESU) for salmon under the jurisdiction of NOAA Fisheries, or Distinct Population Segment (DPS) for steelhead (under NOAA) and other fishes, e.g., bull trout and sea run cutthroat trout under the jurisdiction of US Fish & Wildlife Service (USFWS and NMFS 1996). These ESA-listed populations are generally geographically and reproductively isolated units of a biological species – that may also be referred to as subspecies or stocks in conventional fisheries nomenclature.

#### References:

Waples, R. S. (1991). “Pacific salmon, *Oncorhynchus* spp., and the definition of “species” under the Endangered Species Act”. *Mar. Fish. Rev.* 53 (3): 11–22.

United States Fish and Wildlife Service, and National Marine Fisheries Service. 1996. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act. *Federal Register* (7 February 1996)61(26):4722-4725.

The effort to forecast water demand for hydropower production, therefore, is based directly on power entities' projections of their expectations.

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), Grant County Public Utility District (PUD), Chelan County PUD, and Douglas County PUD. British Columbia (BC) Hydro documentation was also reviewed, though long-term planning documents were general in nature. In addition, newspaper articles and websites were examined for relevant content. It is important to recognize that some information was difficult to evaluate and market conditions and corporate announcements can quickly render some assumptions obsolete. Nevertheless, attempts were made to ensure the most recent information was included. Reviews were supported with conversations with staff at public utility districts in Washington State and Avista Utilities.

## Forecasting Instream Water Demand

Instream demands were not determined during the integrated modeling described above, but were represented through the adopted state and federal instream flows in the Washington portion of the Columbia River Basin, upstream of the Bonneville Dam:

- Adopted flows were assumed to be the same in the historical and future periods.
- Within WRIAs, the highest adopted state and federal instream flows for each month were used to express current minimum flows for fish in both the historical and the forecast periods.
- Along the Columbia River mainstem, Washington State instream flows (WA ISF), and the Federal Columbia River Power System Biological Opinion instream flows (FCRPS BiOp) were compared to modeled historical and forecasted surface water supplies at Priest Rapids, McNary, and Bonneville Dams, to evaluate if and when water availability—quantified by the supply values—was likely insufficient to meet flow requirements, once water demands were accounted for. These two regulatory schemes were chosen because of their role in regulating interruptible water right holders (in the case of the WA ISF) and managing federal dams and the Quad Cities<sup>5</sup> water permit (in the case of the FCRPS BiOp).

Additional detail on instream water demands was generated through two related efforts. Across the Washington portion of the Columbia River Basin, OCR developed a comprehensive database of available historical flow data for each major tributary to the Columbia River. Using these data, OCR compared historical 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 see their water use curtailed.
- Whether trends exist in the historical 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.

For those WRIAs that have adopted instream flows, this historical flow information is presented in the *Forecast Results for Individual WRIAs* section.

In addition to the comparative work that covered the Washington portion of the Columbia River Basin, OCR contracted with the WDFW to update and expand information on instream water demands for 13 low flow critical subbasins (12 WRIAs) that provide habitat for ESA-listed anadromous salmonids in eastern and central Washington (Box 8). The resulting Columbia River Instream Atlas (CRIA; Ecology Publication No. 16-12-006):

- Presents the WDFW's updated data, quantitative analyses, and best professional knowledge for 316 stream reaches in 12 WRIAs (Box 8) at a finer geographic scale than WSU's modeling analysis.

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5 Kennewick, Pasco, Richland, West Richland.

- Scores each reach on three critical components: (a) fish stock status and habitat utilization, (b) fish habitat condition, and (c) stream flow.
- Allows for comparisons of fish habitat conditions in stream reaches within each of the WRIAs, and thus provides a consistent means for evaluating flow use constraints and opportunities for fish habitat enhancement.

The CRIA empirical data, statistical analyses, and scores based on expert judgment will be incorporated into a spatially explicit, interactive, GIS-based Webmap tool with links to more detailed information, and will be published in a separate report (CRIA; Ecology Publication No. 16-12-006). OCR will use the results summarized in the CRIA Webmap, as well as consultations with WDFW staff, to identify and prioritize projects that benefit stream flows while considering fish use and habitat condition.

## Key Policy Issues – Modules

Each module included in this 2016 Forecast addresses a specific policy issue, and the approach, methods, and resources used are specific to each module. The five modules included in this Forecast are:

1. *Integrating Declining Groundwater Areas into Supply and Demand Forecasting:* A survey of declining levels of groundwater and a review of existing groundwater models were carried out, exploring the eventual inclusion of groundwater supply modeling in future Forecasts.
2. *Pilot Application of METRIC Crop Demand Modeling in Washington State:* METRIC, a satellite-based method to calculate field evapotranspiration, was applied in Washington State, as a potential approach to predicting agricultural crop demands, irrigation return flows, and stream discharges at a watershed scale.
3. *Water Banking Trends in Washington and Western States:* An inventory of water banks across Washington State and of water banking activities across the western United States was conducted, followed by an evaluation of methods for facilitating and increasing the efficiency of water banking in Washington State.
4. *Effects of User-Pay Requirements on Water Permitting:* An evaluation of the impacts of user-pay systems for water right permitting on demand for new water supplies was carried out.
5. *Western Washington Supply and Demand Forecasting:* The data needs and availability for extending the water supply and demand forecast to western Washington were evaluated, as a foundation for a complete Washington State Water Forecast.

The rationale, approach, and findings of each module are described in the *Modules to Inform Key Policy Issues* section. Their findings are meant to inform the 2021 Forecast and OCR's future planning, investment, and permitting horizon as it relates to water supply development. Some of the recommendations outlined in the 2016 Forecast will require additional funding to implement, which OCR will consider as it prepares its biennial budget requests. Other recommendations are policy or legislative in nature, and the OCR Policy Advisory Group will be a sounding board for prioritizing these initiatives.

## Stakeholder Input

Feedback received during the 2011 Forecast process was essential for planning for the 2016 Forecast. So too were responses to the many presentations WSU researchers have given on the Columbia River Long-Term Supply and Demand Forecast to diverse groups in the intervening years. WSU researchers have continued to obtain feedback from the Columbia River Policy Advisory Group (PAG), a group that provided input on the original modeling methods. This group represents a range of stakeholder interests, and helps OCR identify and evaluate policy issues. In addition, WSU carried out targeted outreach to agricultural, municipal, tribal, and federal professionals to identify any relevant datasets not yet incorporated into the modeling and model evaluation.

In the development of the 2016 Forecast, input from stakeholders was received through a series of three public workshops in Richland, Wenatchee and Spokane, in June 2016, where preliminary results were presented and discussed, and actionable feedback was requested from participants. The draft Legislative Report was then available online, and comments accepted during a month-long open public comment period.

## FORECAST FOR THE COLUMBIA RIVER 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 (Figure 7). This Columbia River Basin Forecast therefore provides a broad assessment of the Basin as a whole, giving context to the in-depth analysis of its Washington portion. At the Basin-wide scale, the 2016 Forecast estimated the changes in surface water supplies and demands that can be expected by 2035 under different climatic scenarios. This section of the Forecast also discusses results for the Washington State portion of the Basin.

### Columbia River Basin Surface Water Supply

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, the major water contributors—with Washington—to Columbia River flows.

The comparison of the modeled results for surface water supply for the Columbia River Basin in 2035<sup>6</sup> versus the historical supply (1981-2011) highlighted the following changes:

- An increase of around 14.63% ( $\pm 8.29\%$ ) in annual supplies across the Columbia River Basin, on average<sup>7</sup>, by 2035 (Table 1).
- The timing of supply will shift water away from the times when demands are highest by 2035. An average increase in unregulated surface water supply of 30.79% ( $\pm 9.41\%$ )<sup>8</sup> is expected between November and May, followed by a 10.28% ( $\pm 7.86\%$ ) decrease, on average, between June and October<sup>9</sup> (Figure 8).

The increase in supplies expected by 2035 is mainly due to the fact that the climate is projected to get somewhat wetter. The shift in timing, on the other hand, is in response to warming temperatures. Warming results in a smaller snowpack (as less precipitation falls as snow and more as rain) and an earlier snowmelt peak. It is noteworthy that, even with an overall increase in annual water supplies, this shift in supply away from the season of highest water demand has the potential to cause increased water stress across the Columbia River Basin.

### Modeled Surface Water Supplies Entering Washington

The direction and reason for changes in surface water supply entering Washington projected for 2035 are similar to those estimated for the entire Columbia River Basin:

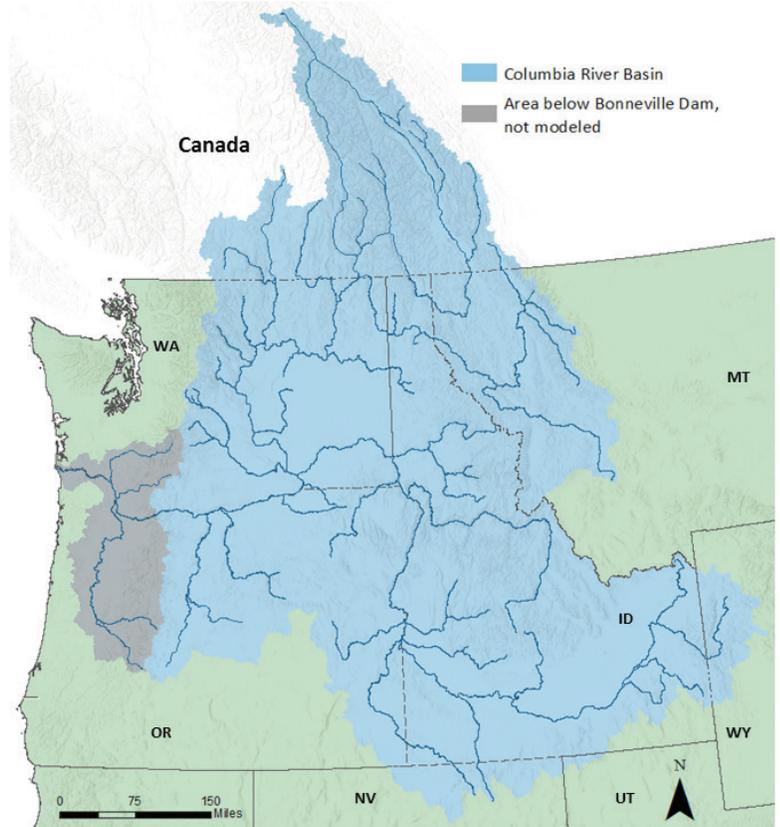


Figure 7. Columbia River Basin geographic scope

<sup>6</sup> Future (2035) projections are based on 10 different climate scenarios, providing climate values for 31 years (2020-2050). These 10 scenarios x 31 years are synthesized to provide average values. See Box 9 for a description of how the values are synthesized.

<sup>7</sup> In low flow years, the increase is 7.07% ( $\pm 8.19\%$ ), and in high flow years, the increase reaches 8.53% ( $\pm 7.19\%$ ).

<sup>8</sup> In low flow years, the increase is 19.44% ( $\pm 8.96\%$ ), and in high flow years, the increase reaches 35.91% ( $\pm 10.76\%$ ).

<sup>9</sup> In low flow years, the decrease is 0.82% ( $\pm 9.39\%$ ), and in high flow years, the decrease reaches 13.03% ( $\pm 7.74\%$ ).

**Table 1:** Modeled water supply in the historical (1981-2011) and forecast (2035) periods for the entire Columbia River Basin. Estimates are presented for low (20th percentile) flow, median (50th percentile) flow, and high (80th percentile) flow years. Values between parentheses represent confidence intervals around the average of future values in median flow years, due to the range of supply values obtained under different climate scenarios (for details see Box 9). The percent change reflects the difference from the historical to the forecast values, and is also accompanied by confidence intervals associated with climate uncertainty.

Entire Columbia River Basin	Historical (million ac-ft per yr)	2035 Forecast (million ac-ft per yr)	% Change
Low supply year (20th percentile)	113	121 (± 9.25)	7.07% (± 8.19%)
<b>Median year (50th percentile)</b>	<b>126.5</b>	<b>145 (± 10.48)</b>	<b>14.63% (± 8.29%)</b>
High supply year (80th percentile)	159.6	173.2 (± 11.47)	8.53% (± 7.19%)

**Table 2:** Modeled agricultural water demands excluding conveyance losses (known as “top of crop”), in the historical (1981-2011) and forecast (2035) periods. Two different futures were explored, first only including climate change projections, and then including projections in both climate change and crop mix. Extent of agricultural acreage was kept constant in all cases. Estimates are presented for low (20th percentile) demand, median (50th percentile) demand, and high (80th percentile) demand years. Values between parentheses represent confidence intervals around the average of future values in median demand years, due to the range of demand values obtained under different climate scenarios (for details see Box 9). The percent change reflects the difference from the historical to the forecast values, and is also accompanied by confidence intervals associated with climate uncertainty.

		Historical (1981-2011)	2035 Forecast				
			Historical climate, historical crop mix (million ac-ft per yr)	Future climate, historical crop mix		Future climate, future crop mix	
				(million ac-ft per yr)	% Change	(million ac-ft per yr)	% Change
Entire Columbia River Basin	Low supply year (20th percentile)	9.2	9.0 (± 0.14)	-2.16% (± 1.48%)	8.9 (± 0.13)	-3.09% (± 1.47%)	
	<b>Median year (50th percentile)</b>	<b>10.1</b>	<b>9.7 (± 0.08)</b>	<b>-3.98% (± 0.83%)</b>	<b>9.6 (± 0.08)</b>	<b>-4.96% (± 0.81%)</b>	
	High supply year (80th percentile)	10.9	10.4 (± 0.12)	-4.56% (± 1.06%)	10.3 (± 0.11)	-5.45% (± 1.02%)	
Washington Portion of the Columbia River Basin	Low supply year (20th percentile)	3.9	3.7 (± 0.04)	-4.41% (± 1.09%)	3.7 (± 0.04)	-6.11% (± 1.06%)	
	<b>Median year (50th percentile)</b>	<b>4.2</b>	<b>4.0 (± 0.04)</b>	<b>-5.12% (± 0.99%)</b>	<b>3.9 (± 0.04)</b>	<b>-6.87% (± 0.98%)</b>	
	High supply year (80th percentile)	4.4	4.2 (± 0.06)	-3.99% (± 1.27%)	4.2 (± 0.05)	-5.7% (± 1.20%)	

- Annual water supplies entering Washington will increase by approximately 12.65% (±3.03%) by 2035, on average<sup>10</sup>. This includes inflows into Washington from the Similkameen, Kettle, Columbia, Pend Oreille, Spokane, Clearwater, Snake, John Day and Deschutes Rivers. The direction of change was unclear for the Columbia, the Spokane and the Kettle Rivers, particularly when the year-to-year variations were considered. For these three rivers, the supply decreased on average: 3.53% (±2.82%), 2.70% (±4.50%), and 3.00% (±4.65%), respectively (Figure 9).
- Surface water supplies entering Washington will generally decrease in the summer and early fall and increase in the late fall, winter and spring, consistent with the patterns observed across the entire Columbia River Basin (Figure 9, inset panels). The exact timing of these shifts vary by watershed (see *Forecast Results for Individual WRIs*).

<sup>10</sup> In low flow years, the increase is 9.82% (± 1.94%), and in high flow years, the increase reaches 11.52% (± 1.53%).

## Columbia River Basin Agricultural Water Demand

Agricultural demand is the largest out-of-stream water demand in the Columbia River Basin. Results modeling the projected changes in climate and in the planted crop mix by 2035 suggest that:

- “Top of crop” demand for agricultural irrigation water across the entire Columbia River Basin is estimated to decrease approximately 0.5 ( $\pm 0.08$ ) million ac-ft by 2035, relative to estimated demands for the historical period (1981-2011), during average (50th percentile) flow conditions<sup>11</sup> (Table 2).

Approximately 0.4 million ( $\pm 83,462$ ) ac-ft out of the 0.5 million ac-ft decrease was due to projected changes in climate and to crops’ responses to those changes (Table 2). The Basin is expected to be wetter by 2035, and the higher concentrations of carbon dioxide expected by 2035 would allow most crops to use water more efficiently (they can take up the carbon dioxide more easily, thereby losing less water in the process). The remaining 0.1 million ac-ft was attributable to how the crop mix is projected to change by 2035 (Table 2), where crops that use less water are expected to replace others with greater demand for water per acre.

These values of projected agricultural water demand provide a relatively conservative estimate of “top of crop” water demand, as they assume no increase in the land base for irrigated agriculture, and no changes in practices such as double cropping. They also assume no changes in irrigation efficiency, which could lead to even lower water demands. Some of

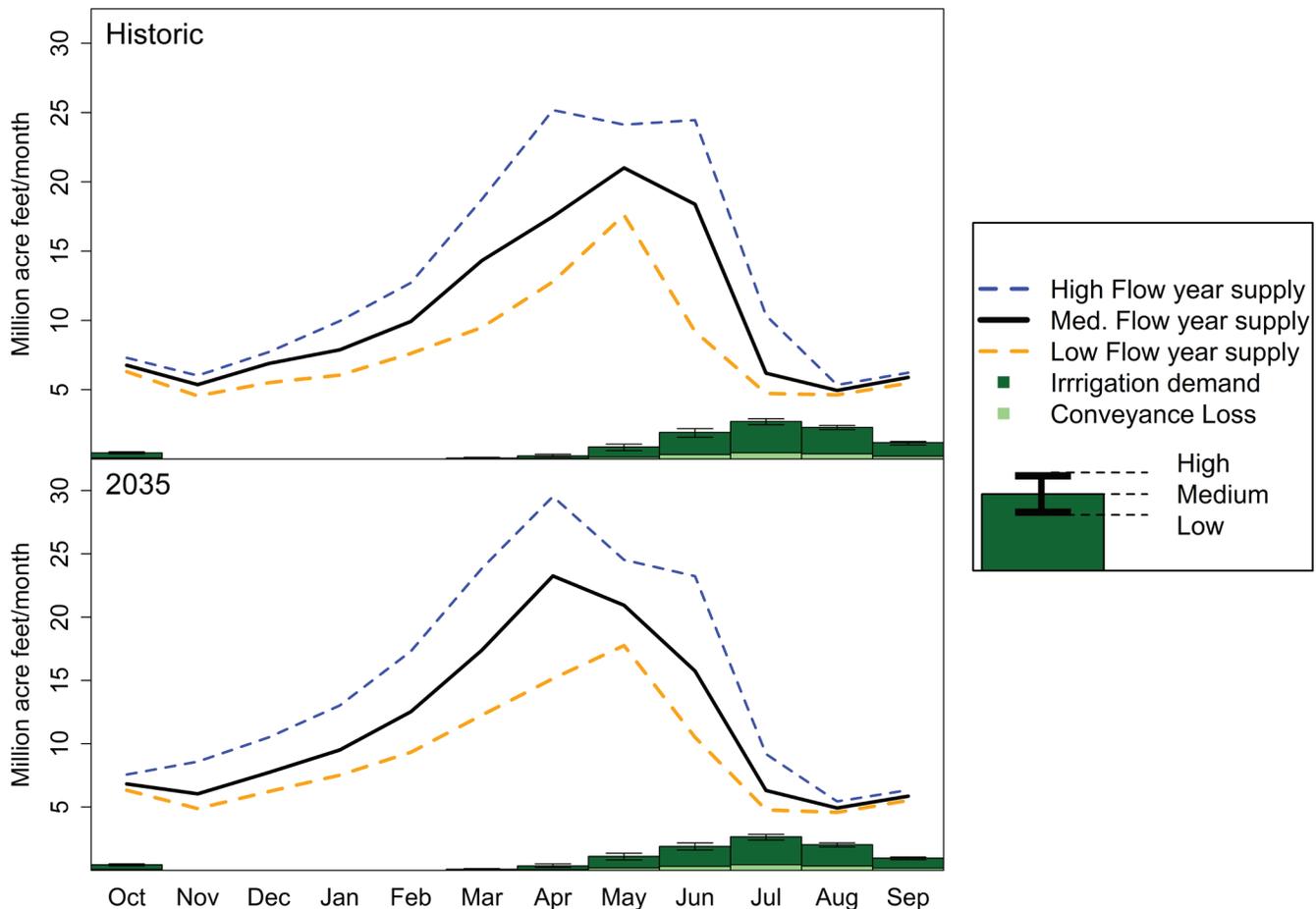


Figure 8. Comparison of regulated surface water supply and agricultural water demands for the historical (1981-2011; top panel) and forecast (2035; bottom panel) periods across the entire Columbia River Basin, including portions of the basin outside of Washington State. Interannual variability (20th and 80th percentile conditions around the median year values) is shown for both supply (dotted lines) and demand (error bars). In the bottom panel, all values represent the average of 10 different climate scenarios (see Box 9 for details).

<sup>11</sup> In low demand years, the decrease is -283,521 ( $\pm 134,394$ ) ac-ft, and in high demand years, the decrease reaches -594,012 ( $\pm 110,940$ ) ac-ft.

these constraints are further explored within the Washington State portion of the Columbia River Basin (see the *Potential Impacts of Double-Cropping on Agricultural Demand Estimates and Using Water Values to Estimate the Benefits of Additional Water for New Irrigated Acreage* sections).

## Columbia River Basin Hydropower Water Demand

The Northwest Power and Conservation Council (NWPCC) forecasts regional electricity demand will grow from 19,400 average megawatts in 2013 to somewhere between 20,600 to 23,600 average megawatts by 2035<sup>12</sup>. In other words, regional demand is expected to increase by anywhere from 1,200 to 3,200 average megawatts over the 2013-2035 timeframe (Table 3), with the possibility of these numbers reaching 2,200 to 4,800 average megawatts considering distribution and transmission system losses. This represents a relatively modest growth rate of 0.5 to 1.0% per year.

A preliminary effort was made to translate the increased regional demand for electricity into flows needed to generate said electricity using hydropower. Net power generation and water right data for Grand Coulee, Rocky Reach, Rock Island and Lake Chelan were averaged to develop an approximate power-to-water conversion factor of approximately 16 ac-ft/MW. Applying this conversion factor to the 2,200 to 4,800 MW that electricity demand is expected to grow by 2035 led to estimated increases in hydropower water demand of approximately 35,000 to 75,000 ac-ft (Table 5). Because this projection is based on existing dams as opposed to new projects, and because these average numbers do not account for peak power needs, actual demand may be higher. Alternatively, if this demand is met via conservation, efficiency improvements, or non-hydro sources, the demand projections could be lower.

Peak demand is perhaps more important than average demand. The regional peak demand for power, which typically occurs in winter, is forecast to grow from 30,000 to 31,000 megawatts in 2015 to 31,600 to 35,600 megawatts by 2035. Summer-peak demand is forecast to grow faster than winter peak, however<sup>13</sup>.

In the Canadian portion of the Columbia River Basin, BC Hydro expects that demands may grow as much as 40% across British Columbia. Conservation and transmission improvements will be essential in meeting this anticipated new demand. Power entities in the Columbia River Basin feel that new storage reservoir projects may be needed to help meet growing future surface water supply demands, which will probably require off-channel storage due to concerns about fish passage. Several power entities also mentioned concerns about the potential for climate variability and possible renegotiation of the international Columbia River Treaty to disrupt or reduce hydropower generation capacity.

**Table 3:** Projected increase in energy demand from hydropower across the entire Columbia River Basin by 2035.

	Historical - 2013 (MW)	2035 Forecast (MW)	% Change
Entire Columbia River Basin	19,400	20,600 to 23,600	6.19 to 21.65%

**Table 4:** Historical (2015) and forecast (2035) municipal diversion demands for the Washington State portion of the Columbia River Basin.

	Historical - 2015 (million ac-ft per year)	2035 Forecast (million ac-ft per year)	% Change
Washington Portion of the Columbia River Basin	433,418	513,141	18.39%

12 Northwest Power and Conservation Council, 2016a. Seventh Power Plan, February 25, 2016. <http://www.nwcouncil.org/energy/powerplan/7/plan/> and Northwest Power and Conservation Council, 2016b. Demand Forecast, February 25, 2016. [http://www.nwcouncil.org/media/7149913/7thplanfinal\\_appdixe\\_dforecast.pdf](http://www.nwcouncil.org/media/7149913/7thplanfinal_appdixe_dforecast.pdf).

13 Ibid.

**Table 5:** Summary of changes in demands in eastern Washington between the historical (1981-2011) and forecast (2035) periods for different uses. Additional information on demands that will need to be met with surface supplies, that are not currently being met from this source, or not reliably, are included to provide context.

Water Use or Need	Estimated Volume (acre-feet)	Source
Projected changes in Agricultural Demand by 2035 <sup>a</sup>	-332,837 to -250,027	WSU Integrated Model
Projected changes in Agricultural Demand by 2035 with 10% Double Cropping <sup>b</sup>	-272,837 to -130,027	WSU Integrated Model + Coarse Estimate of 2nd Crop Water Needs
Projected changes in Agricultural Demand by 2035 with 10% Double Cropping and Planned Water Supply Projects <sup>c</sup>	27,163 to 169,973	WSU Integrated Model + Coarse Estimate of 2nd Crop Water Needs + Planned Water Supply Projects through 2026
Projected changes in Municipal and Domestic Demand (including municipally-supplied commercial) by 2035	80,000	Municipal Demand Projections
Projected changes in Hydropower Demand by 2035 <sup>d</sup>	35,000 to 75,000	Review of Projections by Power Planning Entities
<i>Water Use or Need to be Met with Surface Supplies</i>		
Unmet Columbia River Instream Flows <sup>e</sup>	13,400,000	Ecology data, McNary Dam, 2001 drought year
Unmet Tributary Instream Flows <sup>f</sup>	30,000 to 660,000	Ecology data, tributaries with adopted instream flows, on average, and for a drought year (generally 2001)
Unmet Columbia River Interruptibles <sup>g</sup>	40,000 to 310,000	Ecology Water Right Database (depending on drought year conditions)
Yakima Basin Water Supply (pro-ratables, municipal/domestic and fish) <sup>h</sup>	450,000	Yakima Integrated Water Resource Management Plan (April 2011)
Alternate Supply for Odessa <sup>i</sup>	155,000	Odessa Draft Environmental Impact Statement (October 2010), adjusted based on consultations with the East Columbia Basin Irrigation District
Declining Groundwater Supplies (other than in the Odessa Subarea) <sup>j</sup>	750,000	<i>See Integrating Declining Groundwater Areas into Supply and Demand Forecasting Module</i>

<sup>a</sup> Additional agricultural demands were modeled assuming the land base for irrigated agriculture remains constant, and climate change is moderate (RCP 4.5 scenario). Projected changes in irrigation demand were estimated to decrease 291,432 ac-ft, with a confidence interval (reflecting uncertainty in climate) of  $\pm 32,260$  ac-ft, for median demand years (the decrease is projected to be 251,368  $\pm$  41,224 ac-ft for low demand years, and 239,388  $\pm$  32,299 ac-ft for high demand years; see for details see Box 9 in the full Legislative Report). These decreases in demand were due to the combined impacts of climate change (wetter in the early growing season) and crop mix (projected shift to crops that use less water).

<sup>b</sup> The estimate of additional agricultural demands was increased by the coarse estimate of irrigation demand increases if 10% of eligible land is double cropped by 2035 (see *Potential Impacts of Double-Cropping on Agricultural Demand Estimates* section).

<sup>c</sup> The estimate of additional agricultural demands was increased by the double cropping estimate and by an additional 300,000 ac-ft. The latter reflects an estimated irrigation water supply development goal for the next 10 years (obtained based on the OCR agricultural water supply projects under development, which may include 508.14 Rule Changes, Regional Aquifer Storage and Recovery, Water Banking, and others).

<sup>d</sup> Hydropower projections are based on an average need of 2,200 to 4,800 MW by 2035 for the entire Columbia River Basin. This demand is historically expressed as a nonconsumptive water use. Net power generation and water right data for Grand Coulee, Rocky Reach, Rock Island and Lake Chelan were averaged to develop an approximate power-to-water conversion factor of approximately 16 ac-ft/MW. Because this projection is based on existing dams as opposed to new projects, and because these average numbers do not account for peak power needs, actual demand may be higher. Alternatively, if this demand is met via conservation, efficiency improvements, or non-hydro sources, the demand projections could be lower. Due to the coarse nature of the estimate, it was not possible to allocate a portion of this volume to Washington State at this time.

<sup>e</sup> Unmet Columbia River instream flows are the calculated deficit between instream flows specified in Washington Administrative Code (WAC) and actual flows at McNary Dam in 2001 under drought conditions. 2001 is the only year when Columbia River flows were not met and interruptible water users were curtailed.

<sup>f</sup> Unmet tributary instream flows in tributaries to the Columbia River are the combined deficits between current instream flows specified in WAC and actual flows, estimated as a range by comparing the 50% (average) exceedance curve, and the worst drought on record from 1981 to 2011, to adopted instream flow rules. Unquantified instream flow demand also exists in tributaries without adopted instream flow rules, but will be added in the future, as in the case of the Spokane Rule, which was adopted between the 2011 and 2016 Forecasts. These values include data from the following locations: Walla Walla River at East Detour Road, Wenatchee River at Monitor, Entiat River near Entiat, Methow River near Pateros, Okanogan River at Malott, Little Spokane River at Dartford, Spokane River at Spokane, Colville River at Kettle Falls. All drought year deficits are for 2001, with the exception of the Little Spokane and Colville Rivers, where the greatest unmet flows were in 1992, and the Walla Walla River, where data collection started in 2007.

<sup>g</sup> Range includes both the experienced curtailment from the 2001 drought, and the full water right value at risk of curtailment.

*Table footnotes continued on bottom of next page.*

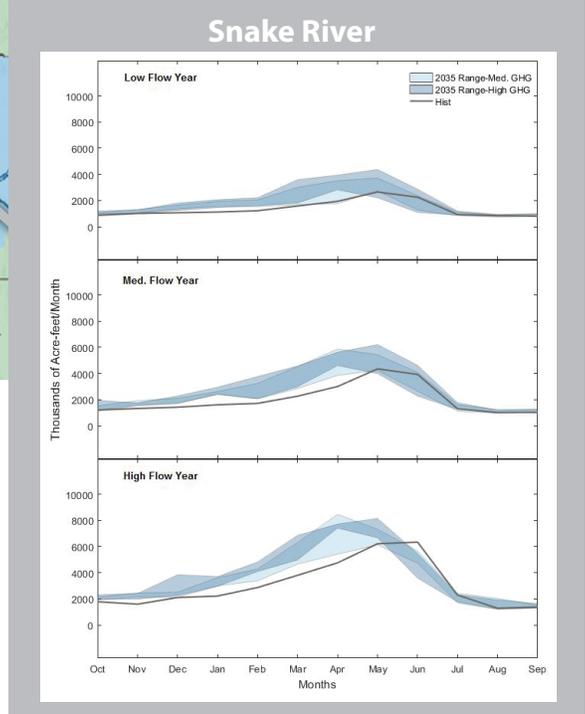
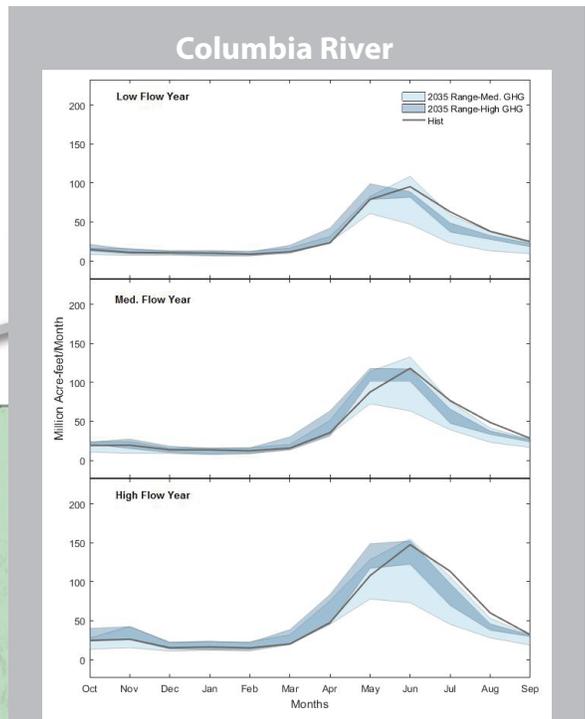
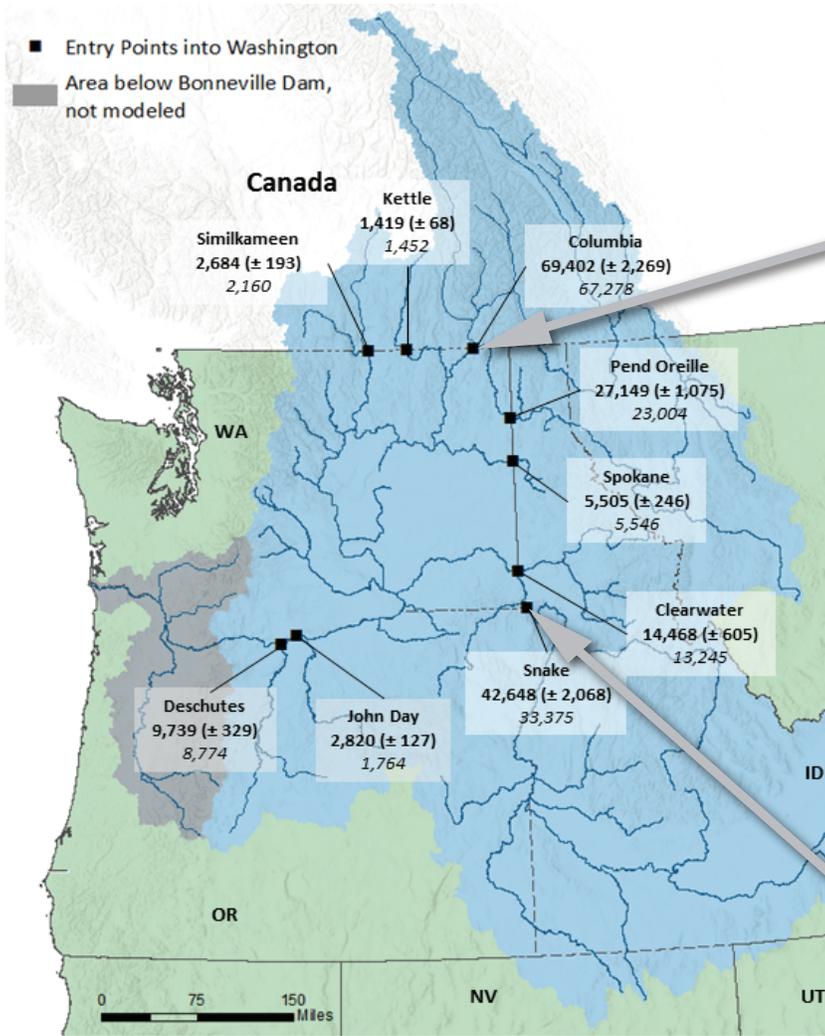


Figure 9. Surface water supplies for major Columbia River tributaries, upstream of the point where the rivers enter Washington State. The top number for each tributary (in bold) refers to forecasted (2035) water supplies, averaged across all climate scenarios' median (50th percentile) flow year values. The confidence interval around the average is in the parentheses. The bottom number (in italics) refers to historical (1981-2011) water supplies in a median flow year. All values are in cubic feet per second. Inset panels show the historical (1981-2011) and forecasted (2035) regulated surface water supplies on the Snake and Columbia Rivers upstream of the point where they enter Washington State for low (20th percentile; top graph in each panel), median (50th percentile; middle graph in each panel), and high (80th percentile; bottom graph in each panel) flow years. The spread of forecast (2035) flow conditions is due to the range of climate change scenarios considered.

<sup>h</sup> Multiple water projects planned in the Yakima River Basin, as part of the Yakima Integrated Water Resource Management Plan, are expected to lead to decreases in the estimated volume needed by the 2021 Forecast. Examples include: Yakima Aquifer Storage and Recovery (ASR), Cle Elum Reservoir, and the Kachess Drought Relief Pumping Plant.

<sup>i</sup> Reports of Examination state that 164,000 ac-ft are needed to serve 70,000 acres. The East Columbia Basin Irrigation District is currently serving 3,000 acres of groundwater replacement via the Columbia Basin Project. Assuming these acres are served with an average 3 ac-ft/ac, the volume still needed was estimated. Two additional sources are expected to contribute to this alternate supply, the Odessa Subarea Special Study and the Lake Roosevelt Incremental Storage Releases Program. As the contributions of these two additional sources were not quantified at the time of this report, the volume estimated here should be considered a conservative estimate.

<sup>j</sup> This estimated need was calculated on the following basis: approximately 230,000 irrigated acres within areas affected by unreliable and/or declining groundwater supplies, an assumed average irrigation rate of 3 ac-ft/ac, and an approximate affected population of 200,000 with an average use of 200 gpcd. This estimate does not include the Odessa Subarea. Significant uncertainty exists in this estimate related to the geographic extent of the affected areas and other factors.

## Columbia River Basin Water Demand for Fish

The Columbia River is home to multiple species of salmonids listed under the Endangered Species Act (ESA) (Figure 10). A comparison of the flow targets defined in the federal Biological Opinion (BiOp) for these species with the historical (1981-2011) and forecast (2035) surface water supplies at Bonneville Dam (Figure 10, inset panels) suggests that:

- From November through May, average forecast supplies are as likely to meet the BiOp targets in 2035 as they have been historically. It is important to note, however, that (a) climate change impacts on water temperatures and on fish directly may lead to changes in requirements not considered in this Forecast, and (b) these results are averages across years, so do not detail changes in frequency of droughts, which could also impact fish.
- From June through October, when supplies across the entire Columbia River Basin are forecast to decrease by approximately 11%, ensuring flows are sufficient to meet the needs of fish are likely to become more challenging. As the BiOp flow targets depend on emergence of the different species, this Forecast was unable to compare flow targets to projected water supplies in detail for these months.

## Water Supply and Demand in Washington State

### *Projected Out-Of-Stream Demands in Washington*

Historical (1981-2011) 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 total, on average, 3.82 million ac-ft (Tables 2 and 4). Forecasted water demand for combined agricultural irrigation and municipal uses in 2035, including both surface water and groundwater demands, were estimated to reach 4.4 million ac-ft by 2035 (Tables 2 and 4; see Box 7). These demand values do not include potential improvements due to water conservation measures, nor do they address areas of unmet water requirements suggested by other studies (Table 5), with the exception of the demand currently supplied by Odessa groundwater, which was assumed would need to be supplied by surface water in the future.

The projected changes in agricultural water demand by 2035 within Washington State include the following:

- “Top of crop” agricultural water demand within Washington State is estimated to decrease by approximately 291,432(±41,405) ac-ft by 2035, relative to historical values (Tables 2 and 5). This decrease includes both ground and surface agricultural irrigation water demand, plus the additional water needed due to irrigation application inefficiencies. This estimate assumes no change in irrigated acreage, and no additional water supply development (but see the *Using Water Values to Estimate the Benefits of Additional Water for New Irrigated Acreage* section).
- It is important to highlight that, though a decrease in overall agricultural demand is projected, 6,644 (±34,654) ac-ft of additional surface water will be needed annually, on average<sup>14</sup>, by 2035, to replace demand currently being met by groundwater in the Odessa Subarea. This number does not change the overall agricultural demand, but does change the amount of water that future surface supplies will need to fulfill.

As with the results for the entire Columbia River Basin, the overall decrease in agricultural water demand within Washington State by 2035 is due to a combination of two factors: climate change—which leads to a 5.12% (± 0.99%) decrease in demand—and forecasted changes in crop mix, which further enhances the decrease in demand to 6.87% (±0.98%) (Table 2). The climatically driven portion of this decrease is due to the projected wetter spring conditions by 2035, the warmer temperatures that reduce the length of and shift the irrigation season earlier in the year, as well as the fact that most of the crops grown regionally will be able to more efficiently use their water when atmospheric carbon dioxide concentrations are higher. The additional decrease attributable to changes in crop mix are due to the projected increase in acreage under crops with lower water demands.

The Forecast anticipates the following changes in water use by the municipal sector:

- Per capita municipal water demands varied considerably throughout eastern Washington, with an average (including

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<sup>14</sup> In low demand years, the increase is 42,155 (± 35,275) ac-ft, and in high demand years, the increase reaches 53,892 (±43,808) ac-ft.

system losses) of approximately 242 gpcd<sup>15</sup>. These results are in line with a 2015 U.S. Geological Survey study of domestic water use, which estimated 285 gpcd<sup>16</sup>. These per capita values add up to 80,000 ac-ft in additional total diversion demands for municipal and domestic water annually by 2035 (Tables 4 and 5), which represents an 18% increase over 2015. This increase in municipal and domestic demand is due to an increase in population. Although some new municipal demands will likely be met by deep groundwater supplies, others will likely come from shallow groundwater or surface water.

- Total municipal consumptive demands for eastern Washington were estimated to be 210,000 ac-ft per year in 2035, compared to 177,000 ac-ft per year in 2015. This represents approximately 41% of the total municipal diversion quantity.

It is important to note that these estimates do not address seasonality in municipal use. Municipal use increases in the drier summer months (for example, due to lawn irrigation within city limits). This is one limitation of these estimates.

### Potential Impacts of Double-Cropping on Agricultural Demand Estimates

The modeled decrease in agricultural demand by 2035 appears to contradict a concern voiced by many in the public workshops that climate change would lead to increased demand for water by agriculture, even in the absence of any new water rights. This concern arose, however, from anticipation that double cropping (growing two crops within a cropping season) could become more frequent as the climate changes, and as crops mature earlier in the season. This in turn could lead to increases in irrigation demand later in the season not accounted for in the model results. Though data on the extent of double cropping in the region is lacking, the issues and questions raised about double cropping need to be addressed. This section provides a

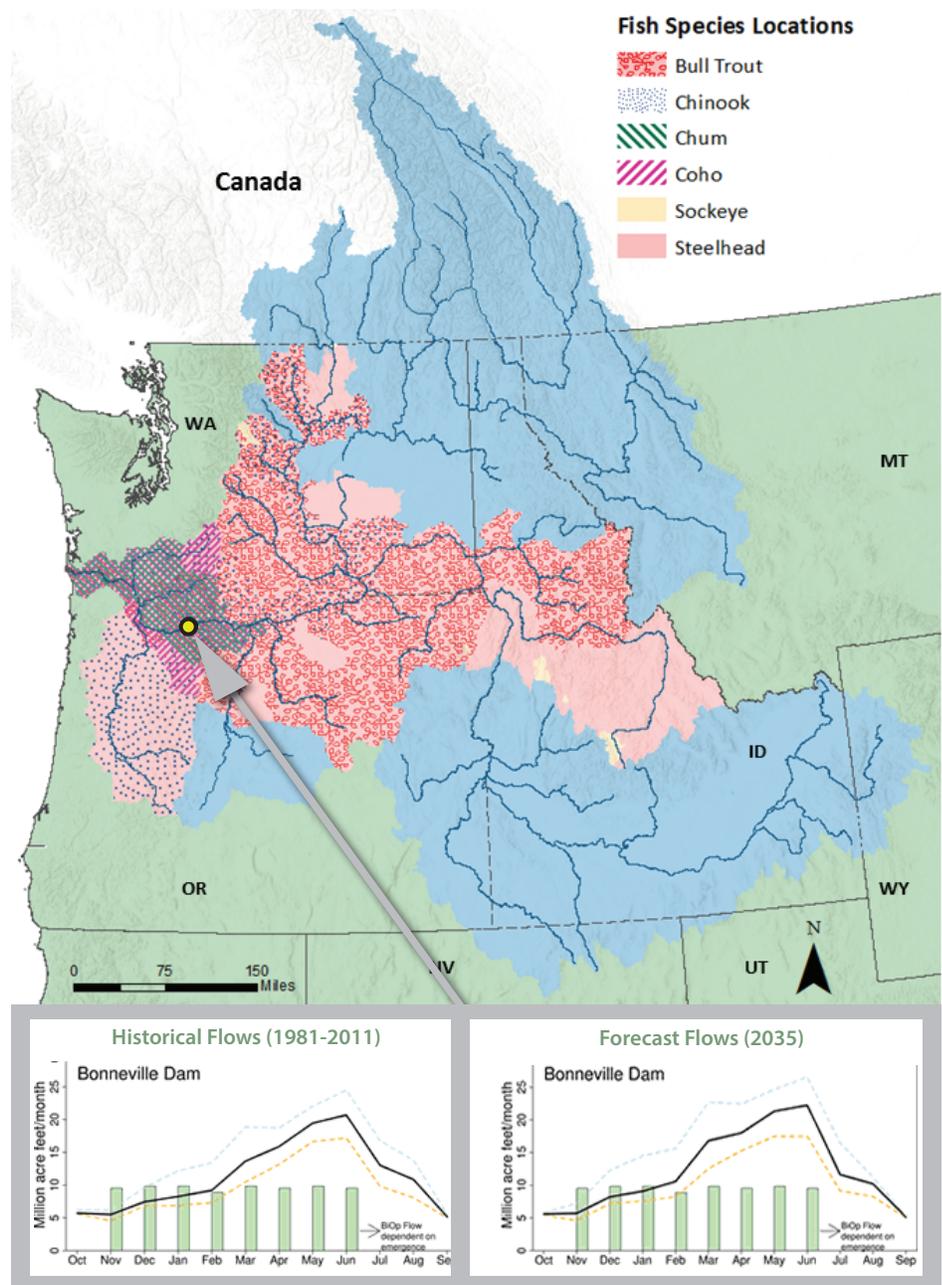


Figure 10. Distribution of fish listed under the Endangered Species Act in the Columbia River Basin. Inset panels show historical (1981-2011; left panel) and forecast (2035; right panel) surface water supplies at Bonneville Dam for low (20th percentile), median, and high (80th percentile) flow conditions averaged across 10 climate scenarios. Also shown are the federal Biological Opinion (BiOp) flow targets (bars in both inset panels).

15 gpcd stands for gallons per capita daily.

16 Lane, R.C., and Welch, W.B., 2015, Estimated freshwater withdrawals in Washington, 2010: U.S. Geological Survey Scientific Investigations Report 2015-5037, 48 p. Available online at <http://dx.doi.org/10.3133/sir20155037>.

coarse estimate of the potential impact of double cropping on future irrigation demand, to encourage discussion and feedback that can be used to guide future Forecasts.

Three values need to be estimated to determine how much additional water would be needed to support double cropping in 2035: (1) acres eligible for double cropping; (2) proportion of eligible acres that will actually be cropped twice each year by 2035; and (3) the average water needed for the additional (second) crop in 2035. The estimate provided here is

## BOX 9

### How model projections of supply and agricultural water demand are synthesized in the 2016 Forecast

To compare water supplies in 2035 to historical water supplies it is useful to have one number of acre-feet representing “historical”, and one number for 2035. However, it is important to recognize that we do not have the same amount of water every year. Instead, the amount varies, from year to year (and this is the interannual variability). Similarly, it is important to understand how much uncertainty there is related to the 2035 number, as models cannot make 100% accurate predictions of supply 20 years in the future (this is called climate uncertainty).

The 2016 Forecast results therefore provide:

1. A single number for historical values,
2. A single number for future values,
3. Alternative values (both for historical and future conditions) for low and high flow years, to quantify the interannual variability, and
4. A confidence interval accompanying each future value, to quantify the climate uncertainty.

This Box explains how these values are calculated, and the key terms used in the text to identify each, using the water supply for the entire Columbia River Basin above Bonneville Dam as an example. Note that analogous values and terms are used for agricultural water demand.

**Historical supply** = 126.5 million ac-ft. This is the median value of supply for the period 1981-2011. The integrated model takes weather information for each of those 31 years, and provides an annual supply value for each year. The 31 annual supply values are ordered from smallest to largest, and the value in the 16th position is selected. This is also called the 50th percentile value.

**Interannual variability in historical supply** = from 113 million ac-ft (20th percentile) to 159.6 million ac-ft (80th percentile). Once the supply values for the 31 years are ranked, we can select the value in the 5th position (driest 20% of years) and the value in the 27th position (wettest 20% of years, or “driest” 80%). These values provide the range in interannual variability.

**Future supply** = 145 million ac-ft. This is the average of the 10 median values of supply (from each of the 10 climate scenarios) for the period 2020 to 2050. As with historical supply, weather data from a climate scenario goes into the integrated model, and the annual supply for each of 31 years (2020-2050) is calculated. These are ordered from smallest to largest, and the value in the 16th position is selected (this is the median value for that climate change scenario).

**Interannual variability in future supply** = from 121 million ac-ft (20th percentile) to 173.2 million ac-ft (80th percentile). These were calculated in the same way as for historical supply: once the supply values for the 31 years from one climate scenario are ranked, we selected the 5th (20th percentile) and the 27th (80th percentile) values to provide the range in interannual variability.

**Climate uncertainty** = from 136.84 to 153.16 million ac-ft. There are 10 climate scenarios, and therefore 10 median values. To obtain the single future supply value to compare to the historical supply value, those 10 median values are averaged. In addition, a confidence interval is calculated based on how different those 10 median values are:  $\pm 8.16$  million ac-ft, to represent the climate uncertainty. In this case, results suggest we can be 90% certain that the average median future supply is between 136.84 and 153.16 million ac-ft.

coarse because it is based on broad assumptions related to these three values:

- *Acres eligible for double cropping:* There are about 1.8 million acres of irrigated cropland in Washington State, according to both the USDA and WSDA. To be somewhat conservative, only irrigated land in the Columbia Basin Project (671,000 acres) and in WRIA 32 (160,737 acres, including the Horse Heaven Hills and Patterson) was considered, adding up to a total of 831,737 acres. Due to water rights limitations, double cropping is not feasible on much of this land. Two sets of assumptions were used to set upper and lower bounds for the acreage eligible for double cropping:
  - *Upper bound:* Three crop groups each make up about a quarter of the 831,737 irrigated acres: vegetables, hay/silage, and cereal grains. Many of the vegetable crops can be double cropped, as can the primary cereal grains (wheat and corn). An important exception is potatoes (about 13% of the total irrigated acreage). Hay crops can be double cropped in their last year. Assuming that a typical alfalfa and Timothy hay planting lasts three years, only one third of the hay crop acreage could be double-cropped any particular year. These adjustments leave just under half of the irrigated acreage eligible for double cropping, or about 400,000 acres.
  - *Lower bound:* A lower bound value would only include the crops that are known to be frequently double cropped: sweet corn/peas and field corn/winter wheat. Wheat is not broken out into winter and spring in the WSDA layer, so the assumption was made that half the acreage would be winter wheat. Of the 831,737 irrigated acres being considered, these four crops account for approximately 200,000 acres.
- *Proportion of eligible acres that will actually be cropped twice each year by 2035:* There is no expectation that the full 200,000-400,000 would be double cropped. However, among the many assumptions, the most difficult to make is the assumption of what proportion of eligible acres will actually be cropped twice each year by 2035. As a starting point for discussion, an assumption that 10% of eligible irrigated land will be double cropped by 2035 was made: 20,000 to 40,000 acres.
- *Average water needed for the additional (second) crop in 2035:* An assumption was made that, on average, consumptive use by the second crop would be 3 acre-feet/acre.

Based on the assumptions described above, this initial estimate suggests that agricultural demand for water in 2035 could increase an additional 60,000 to 120,000 acre-feet (Table 5).

### *Impacts of Modeled Changes in Supply and Demand on Meeting Instream Flows across Eastern Washington*

Forecast changes in surface water supply timing and the shift in peak season for demands within and outside of Washington by 2035 are likely to increase the challenge of meeting instream demands. Lower flows, particularly in the summer and early fall, could negatively impact threatened and endangered fish, as well as other fish important to the culture and economy of eastern Washington. An in-depth analysis of how to meet the needs of fish as the climate changes is outside the scope of this Forecast (but see the tool being updated by WDFW, in the *Washington Watersheds' Instream Water Demands for Fish* section, below).

The possibility for re-negotiation of the international Columbia River Treaty and unquantified tribal water rights could also change the amounts and timing of water available to meet instream needs in the Columbia River mainstem within Washington State (and beyond). These factors have the potential to impact future water supplies in ways that are difficult to predict, and thus were not feasible to capture in this analysis.

### *Hydropower Demand in Washington*

The approach taken to estimate increases in water needed to provide the additional electricity that planning agencies project will be needed (see the *Columbia River Basin Hydropower Water Demand* section, above) has limitations, and is a very coarse first effort at estimating this value. Neither the data nor the range of factors that control the relationship between flows and energy produced are well captured in this first estimate. Trying to allocate some portion of the estimated additional 35,000-75,000 ac-ft needed to meet increases in hydropower demand by 2035 (Table 5) to Washington State or finer scales would simply provide a false sense of accuracy. Researchers therefore provided this estimate solely for the whole Columbia River Basin.

## Comparison of the 2011 and 2016 Forecasts' Estimates of Water Demands in Washington State

The estimated changes in demand for different sectors obtained in this 2016 Forecast are somewhat different to those estimated in the 2011 Forecast (Table 6). The most notable change is in the decreased agricultural water demand. There are multiple reasons why demand may change from one effort to the next (Box 10), including:

- *Changes in climate change projections.* The data used to characterize the climate in 2035 (CMIP5 climate change projections) are newer and more appropriate for this region, compared to the climate data for 2030 used in the 2011 Forecast (CMIP3 climate change projections). The CMIP5 projections estimate the region will be wetter than previously estimated using CMIP3 projections, which contributes to the explanation for why crops are expected to need less irrigation.

### BOX 10

#### Water Demand – What it is and why it might change

**What is demand for water?** Demand for water in this 2016 Forecast represents water needed for use by humans, crops, fish, and for hydropower generation.

**How is demand characterized?** Demand consists of uses that are met by current reliable water supplies, uses that are at risk to changing reliability of supplies (e.g. due to declining groundwater or to climate change), and uses that are unmet (e.g. no supply currently available, or supplies that will not be available in the future either temporarily during drought, or as a result of depletion).

**What Affects Demand Numbers?** Demand for different uses is affected by many factors. Agricultural water demand, for example, is affected by how warm it is and how much it rains, what crops are grown, whether it is an average or a drought year, the available acreage that can be developed, and the price of irrigation water (which is highly variable throughout Washington). The effects of many of these factors were explored in the 2016 Forecast through calculating agricultural water demand for several different scenarios. For example, historical agricultural water demand represents water needs of existing irrigated cropland, under the existing crop mix, and under the climate of the beginning of the 21st century. Projected agricultural water demand represents water needs of existing cropland under a projected crop mix and under projected climate for 2035.

**What does it mean when forecasted agricultural (met) demand changes as the Forecast is updated?** Crop water demand may increase or decrease on existing irrigated acreage due to changes in cropping patterns or climate change. Projected crop water use may also change as modeling efforts more accurately predict demand relative to previous forecasts.

**What are unmet crop water demands?** Unmet crop water demand (also called unmet irrigation requirements) occur when there is not enough water supply to meet all crops' irrigation needs on existing or potentially irrigated acres. The difference between the agricultural water needed for crops planted in a typical year to achieve optimal yield, and the water supply available for agricultural irrigation is the unmet requirement. Unmet demand also includes demand for water on cropland that could support irrigated production but is currently not under irrigation.

**What does it mean when forecasted unmet crop water demands go down?** Crop water demands may go down if additional water supplies allow for additional irrigated acres, or if they increase the reliability of water for existing uses (e.g. reduce the risk of curtailment to junior water rights).

**What does it mean when projected unmet crop water demands go up?** Again, this may be due to more accurate modeling, or if projected uses outpace water supply development, or if previously reliable supplies are now projected to be at risk.

- *Improved crop data, especially for irrigated pasture.* In 2011, the WSDA data used to determine crop mix and extent did not provide accurate information on irrigated pasture extent, a crop that has a high demand for water. By 2016, the WSDA’s characterization of irrigated pasture in their dataset is much improved, allowing a more accurate—and much lower—estimate of water needed by irrigated pasture, also contributing to the reduction in irrigation demand.

Another notable change was the increase in the estimate of unmet tributary instream flows, from 500,000 in the 2011 Forecast to almost 660,000 in this 2016 Forecast (Table 6). The main reason for the increase in unmet tributary instream flows between the 2011 and 2016 estimates is the addition of a new watershed. The Spokane River adopted instream flows in January 2015, explaining the increase in unmet flows from 2011 to 2016.

**Table 6:** Comparison of forecast changes in demand in eastern Washington from the 2011 and 2016 Forecasts. Values from the 2011 Forecast are projected for 2030, while those from the 2016 Forecast are projected for 2035. For details on each value, see the 2011 Forecast (Ecology Publication 11-12-011) and the *Water Supply and Demand Forecast for the Columbia River Basin* section of this report. Please see the caption and footnotes in Table 7 (2011 Forecast; Ecology Publication 11-12-011) and Table 5 (2016 Forecast) for details on how each value was estimated.

Water Use or Need	2011 Forecast Estimated Volume (acre-feet)	2016 Forecast Estimated Volume (acre-feet)
Projected changes in Irrigation Demand <sup>a</sup>	170,000	-332,837 to -250,027
Projected changes in Municipal and Domestic Demand (including municipally-supplied commercial)	117,500	80,000
Projected changes in Hydropower Demand <sup>b</sup>	0	35,000 to 75,000
<b>Water Use or Need to be Met with Surface Supplies</b>		
Unmet Columbia River Instream Flows	13,400,000	13,400,000
Unmet Tributary Instream Flows <sup>c</sup>	500,000	30,000 to 660,000
Unmet Columbia River Interruptibles	40,000 to 310,000	40,000 to 310,000
Yakima Basin Water Supply (pro-ratables, municipal/domestic and fish)	450,000	450,000
Alternate Supply for Odessa	164,000	155,000
Declining Groundwater Supplies (other than in the Odessa Subarea) <sup>d</sup>	N/A	750,000

<sup>a</sup> As described in this report, the overall decrease in agricultural water demand by 2035 is due to a combination of two factors: climate change and forecasted changes in crop mix. The climatically driven portion of this decrease is due to projected wetter spring conditions, warmer temperatures that reduce the length of and shift the irrigation season earlier in the year, as well as most of the crops being able to more efficiently use their water when atmospheric carbon dioxide concentrations are higher. The additional decrease attributable to changes in crop mix are due to the projected increase in acreage under crops with lower water demands.

<sup>b</sup> Estimates of hydropower demand are based on a very coarse conversion of energy projections to ac-ft of water needed to produce it. In addition, this value is for the entire Columbia River Basin. Due to the coarse nature of the estimate, allocating some portion of this volume to Washington State could not be achieved at this time.

<sup>c</sup> The main reason for the increase in unmet tributary instream flows between the 2011 and 2016 estimates is the addition of a new watershed. The Spokane River adopted instream flows between these two dates, explaining the increase in unmet flows.

<sup>d</sup> The evaluation of areas experiencing groundwater decline was not part of the 2011 Forecast.

## FORECAST FOR WASHINGTON'S WATERSHEDS

Within Washington State numerous management decisions are made at the scale of individual watersheds (Figure 11). As much of eastern Washington's water demands come from areas that cannot be hydrated by the Columbia River, the analysis of water supplies at the watershed level focused on those supplies generated within the watershed, excluding supplies from the mainstem Columbia and Snake Rivers (for insights on the contributions of the mainstem Columbia River see *Water Supply and Demand Forecast for Washington's Columbia River Mainstem*). In addition, for Washington's watersheds, detailed forecasting was carried out for municipal demand and the ability to meet instream flow (ISF) requirements (for those watersheds that have adopted ISFs).

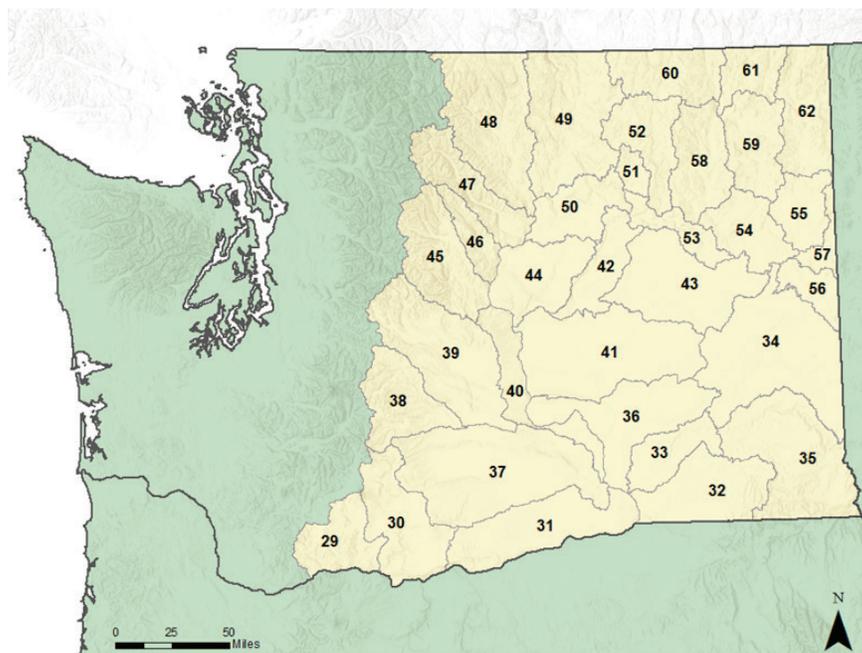


Figure 11: Washington's Watersheds geographic scope: Water Resource Inventory Areas (WRIAs) in eastern Washington.

### Washington Watersheds' Surface Water Supplies

Major tributary areas make sizeable water supply contributions to the Columbia River as it makes its way from the Canadian border to Bonneville Dam. Annual surface water supplies generated within these tributary watersheds are expected to increase by approximately 14.39% ( $\pm 3.82\%$ ) by 2035, on average<sup>17</sup>. This includes increases in water supplies expected in the Walla Walla (9.3% $\pm 1.58\%$ ), Palouse (49.81% $\pm 9.30\%$ ), Colville (36.74% $\pm 12.65\%$ ), Yakima (13.15% $\pm 5.95\%$ ), Wenatchee (12.75% $\pm 3.39\%$ ), Chelan (10.73% $\pm 2.42\%$ ), Methow (51.4% $\pm 4.00\%$ ), Spokane (3.61% $\pm 4.44\%$ ), and Okanogan (21.58% $\pm 10.71\%$ ) watersheds (Figure 12). While most of these rivers show primarily increases in supply regardless of the climate scenario used, three rivers showed mixed results, ranging from increasing to decreasing supplies as the climate scenarios varied: the Colville, Chelan, and Okanogan watersheds.

At the watershed scale, shifts in timing of water supply towards the winter and spring months by 2035 are similar to those observed for the entire Columbia River Basin. The details vary by watershed, however. The rivers experiencing the greatest shift in timing of supply are those for which streamflow was predominantly derived from snowmelt during the historical period, such as the Methow River (see *Washington Watersheds' Supply and Demand – Detailed Results*, below).

### Washington Watersheds' Water Demands

#### Washington Watersheds' Out-of-Stream Water Demands

Forecasted water demand for combined agricultural irrigation and municipal uses in 2035, including both surface water and groundwater demands, was concentrated within the southern and central Columbia Basin, including Lower Crab (WRIA 41), Lower Yakima (37), Esquatzel Coulee (36), and Rock-Glade (31), as well as Walla Walla (32), Lower Snake (33), and Upper Yakima (39) (Figure 13).

The change in agricultural water demand between historical (1981-2011) and forecast (2035) periods varied geographically and in magnitude. Individual WRIAs are projected to see changes that range from a 79,727 ac-ft decrease, on average, in the Lower Yakima (37) to a 37,095 ac-ft increase, on average, in the Upper Crab-Wilson (43) watershed (Table 7).

<sup>17</sup> In low flow years, the increase is 18.81% ( $\pm 3.96\%$ ), and in high flow years, the increase reaches 14.54% ( $\pm 2.36\%$ ).

With the exception of the Upper Crab-Wilson (43) watershed, all WRIsAs are projected to have increased municipal water demands by 2035, both in the estimated water diverted for municipal use, and in the amount of that water that is consumptively used. Maximum increases at the WRIA level were projected for Esquatzel Coulee (36), reaching 20,325 ac-ft and 8,127 ac-ft more by 2035, for diversions and consumptive use, respectively (Table 8).

### Washington Watersheds' Instream Water Demands for Fish

The CRIA Project led by WDFW scored each reach in 12 WRIsAs (Figure 1) based on fish stock status, fish habitat utilization, and instream flow. Combined scores and ranks varied across stream reaches (Ecology Publication No. 16-12-006). Interpretation of these variations led WDFW to conclude that flow augmentation is generally helpful in salmonid restoration efforts, especially in smaller systems that have limited flow, in over-appropriated basins, or in combination with other recovery measures. 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 or better habitat in higher elevations or less populous areas are likely to benefit from flow augmentation (orange in Table 9). Most anadromous stocks migrate through the low elevation mainstem reaches that benefit from the cumulative effects of upstream flow augmentation. However, these mainstem reaches are generally not targets for augmentation because large flow inputs would be needed for a measurable effect in these relatively high flow reaches.

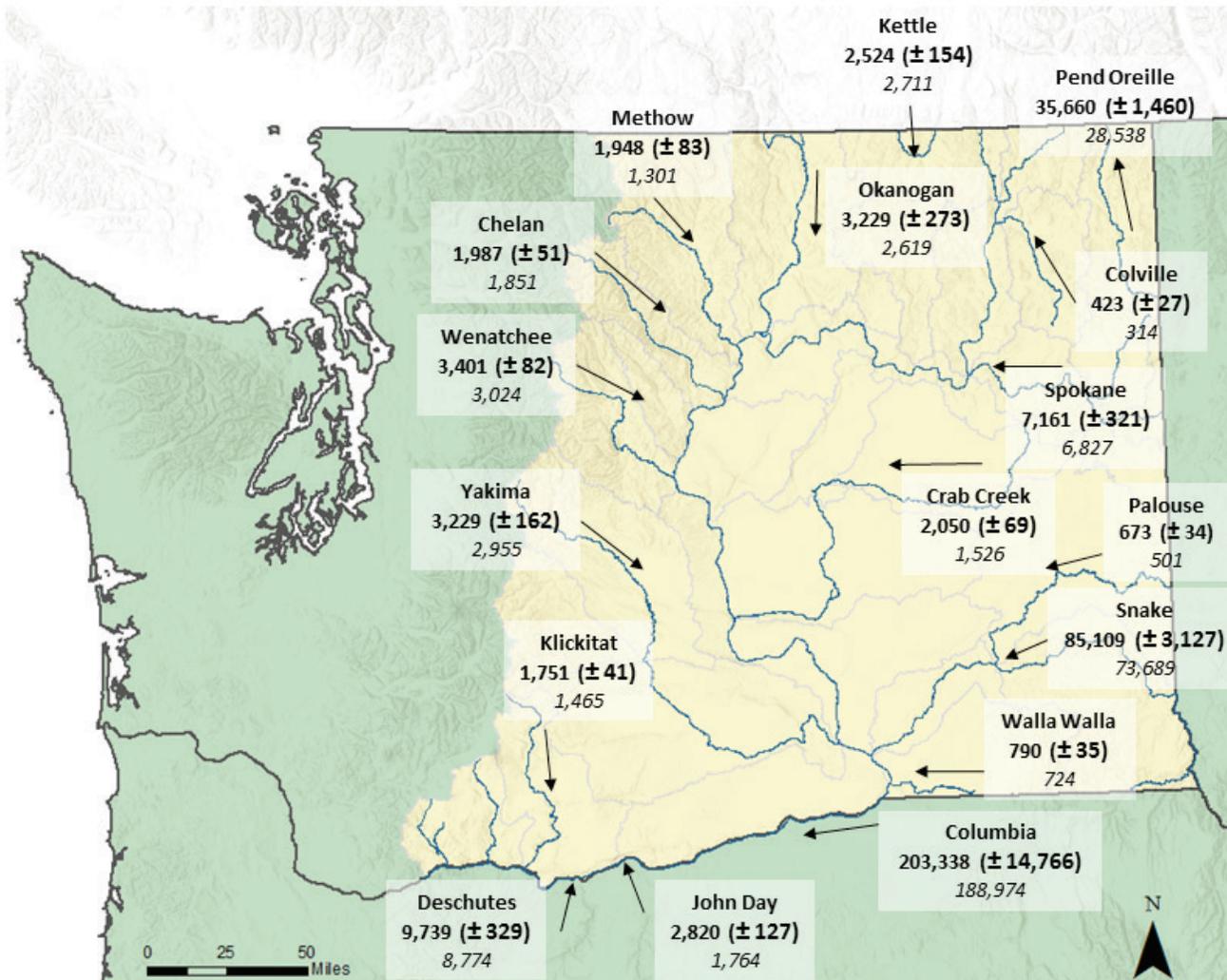


Figure 12: Water supplies (prior to accounting for demands) from tributaries to Washington's Columbia River Mainstem (above Bonneville Dam). The top number (in **bold**) refers to forecast (2035) surface water supplies for a median (50th percentile) flow year, averaged across 10 climate scenarios (confidence interval around that average in parentheses). The bottom number (in *italics*) refers to the historical (1981-2011) water supplies for a median (50th percentile) flow year. All values are in cubic feet per second.

**Table 7:** Modeled agricultural water demands excluding conveyance losses (known as “top of crop”) for each Washington Water Resource Inventory Area (WRIA) in eastern Washington. Estimates for each WRIA include the demand during median demand years in the historical (1981-2011) and forecast (2035) periods, as well as the proportion of said demand occurring 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	
		Historical	2035	Historical	2035	Historical	2035
29	Wind-White Salmon	5,677	4,210	0	0	0%	0%
30	Klickitat	14,341	9,465	0	0	0%	0%
31	Rock-Glade	240,161	227,827	50,159	47,557	21%	21%
32	Walla Walla	109,900	119,346	5,647	5,303	5%	4%
33	Lower Snake	95,270	87,202	0	0	0%	0%
34	Palouse	12,888	18,348	0	0	0%	0%
35	Middle Snake	1,051	1,039	0	0	0%	0%
36	Esquatzel Coulee	611,744	619,864	113,296	106,134	19%	17%
37	Lower Yakima	825,822	746,095	2,340	2,193	0%	0%
38	Naches	43,107	38,026	0	0	0%	0%
39	Upper Yakima	193,317	189,039	0	0	0%	0%
40	Alkali-Squilchuck	15,405	13,908	14,740	13,389	96%	96%
41	Lower Crab	960,381	993,822	44,816	43,677	5%	4%
42	Grand Coulee	46,512	47,902	0	0	0%	0%
43	Upper Crab-Wilson	13,529	50,624	0	0	0%	0%
44	Moses Coulee	19,004	16,801	14,570	12,495	77%	74%
45	Wenatchee	15,065	12,790	1,161	920	8%	7%
46	Entiat	1,252	1,247	486	557	39%	45%
47	Chelan	13,370	11,308	5,643	5,161	42%	46%
48	Methow	6,763	6,124	2,068	1,741	31%	28%
49	Okanogan	58,290	49,694	8,220	7,070	14%	14%
50	Foster	15,903	13,307	15,658	13,074	98%	98%
51	Nespelem	0	0	0	0	0%	0%
52	Sanpoil	131	119	0	0	0%	0%
53	Lower Lake Roosevelt	1,692	1,522	1,120	949	66%	62%
54	Lower Spokane	6,029	5,679	0	0	0%	0%
55	Little Spokane	2,112	2,136	0	0	0%	0%
56	Hangman	273	264	0	0	0%	0%
57	Middle Spokane	1,094	1,229	0	0	0%	0%
58	Middle Lake Roosevelt	1,332	1,320	745	681	56%	52%
59	Colville	7,430	8,485	0	0	0%	0%
60	Kettle	1,813	1,675	0	0	0%	0%
61	Upper Lake Roosevelt	261	233	151	151	58%	65%
62	Pend Oreille	116	145	0	0	0%	0%
<b>TOTAL</b>		<b>3,341,034</b>	<b>3,300,798</b>	<b>280,819</b>	<b>263,089</b>	<b>8%</b>	<b>8%</b>

## 2016 Columbia River Basin Long-Term Water Supply and Demand Forecast

**Table 8:** Estimated change in municipal water demands for each Washington Water Resource Inventory Area (WRIA) in eastern Washington. Estimates for each WRIA include the change in demand from the historical (2015) to the forecast (2035) period, for both water diversions and consumptive use of water.

WRIA	WRIA Name	2015 Population Estimate	2035 Population Estimate	Population Increase 2015-2035	Change in Diversion 2015-2035	Change in Consumptive Use 2015-2035
				%	(ac-ft/year)	(ac-ft/year)
29	Wind-White Salmon	15,294	17,384	14	480	278
30	Klickitat	11,456	11,668	2	55	31
31	Rock-Glade	83,196	94,540	14	2,723	911
32	Walla Walla	62,113	67,968	9	1,580	387
33	Lower Snake	3,463	3,761	9	88	23
34	Palouse	53,860	66,567	24	2,529	924
35	Middle Snake	25,232	26,668	6	365	119
36	Esquatzel Coulee	107,913	165,229	53	20,325	8,127
37	Lower Yakima	299,350	350,944	17	10,390	4,668
38	Naches	15,627	16,976	9	252	127
39	Upper Yakima	61,687	68,077	10	1,672	820
40	Alkali-Squilchuck	26,930	27,917	4	227	70
41	Lower Crab	80,563	108,726	35	11,810	7,132
42	Grand Coulee	10,403	11,908	14	606	356
43	Upper Crab-Wilson	7,199	7,151	-1	-17	-9
44	Moses Coulee	35,181	38,997	11	600	188
45	Wenatchee	57,125	63,197	11	1,116	193
46	Entiat	2,327	2,476	6	27	5
47	Chelan	11,281	13,511	20	417	83
48	Methow	6,968	8,267	19	365	243
49	Okanogan	30,461	32,101	5	476	331
50	Foster	4,731	5,708	21	161	57
51	Nespelem	1,301	1,341	3	11	8
52	Sanpoil	3,150	3,642	16	121	103
53	Lower Lake Roosevelt	5,118	5,711	12	199	127
54	Lower Spokane	101,217	115,141	14	4,501	1,696
55	Little Spokane	115,235	135,681	18	6,554	2,247
56	Hangman	60,859	76,658	26	5,061	1,639
57	Middle Spokane	223,066	241,763	8	6,029	1,952
58	Middle Lake Roosevelt	3,735	4,046	8	89	72
59	Colville	24,573	26,133	6	505	382
60	Kettle	4,426	4,803	9	95	81
61	Upper Lake Roosevelt	3,916	4,241	8	105	79
62	Pend Oreille	7,889	8,615	9	205	91
<b>TOTAL</b>		<b>1,566,845</b>	<b>1,837,515</b>	<b>17.3%</b>	<b>79,723</b>	<b>33,543</b>

The drought conditions during 2015 provided WDFW biologists with substantial insight on the effects of low flow conditions on fish stocks in the area under evaluation by the CRIA. Drought conditions result in critically low flow conditions in many streams, including small streams with water over-allocation, but also larger streams with moderate to low water diversions. A greater range of stream types would benefit from flow augmentation under such drought conditions (red in Table 9).

The OCR’s historical flow database provides site-specific information on historical flow levels, drought occurrences and how often instream flow rules are or are not met for tributaries to the Columbia River in Washington. Summaries of this information are provided in the Management Context page for each eastern Washington WRIA (see the *Forecast Results for Individual WRIs* section).

### *Curtailments for WRIs with Adopted Instream Flow Rules*

Though the patterns of change in the frequency and magnitude of curtailments projected under future climates vary from WRIA to WRIA, there appeared to be a trend towards increasing frequency and magnitude of curtailment in the spring, with a decrease in curtailments later in the irrigation season. These results are somewhat counter-intuitive, given that overall water supply in the spring is projected to increase by 2035. However, crop growth—and its associated irrigation requirements—is

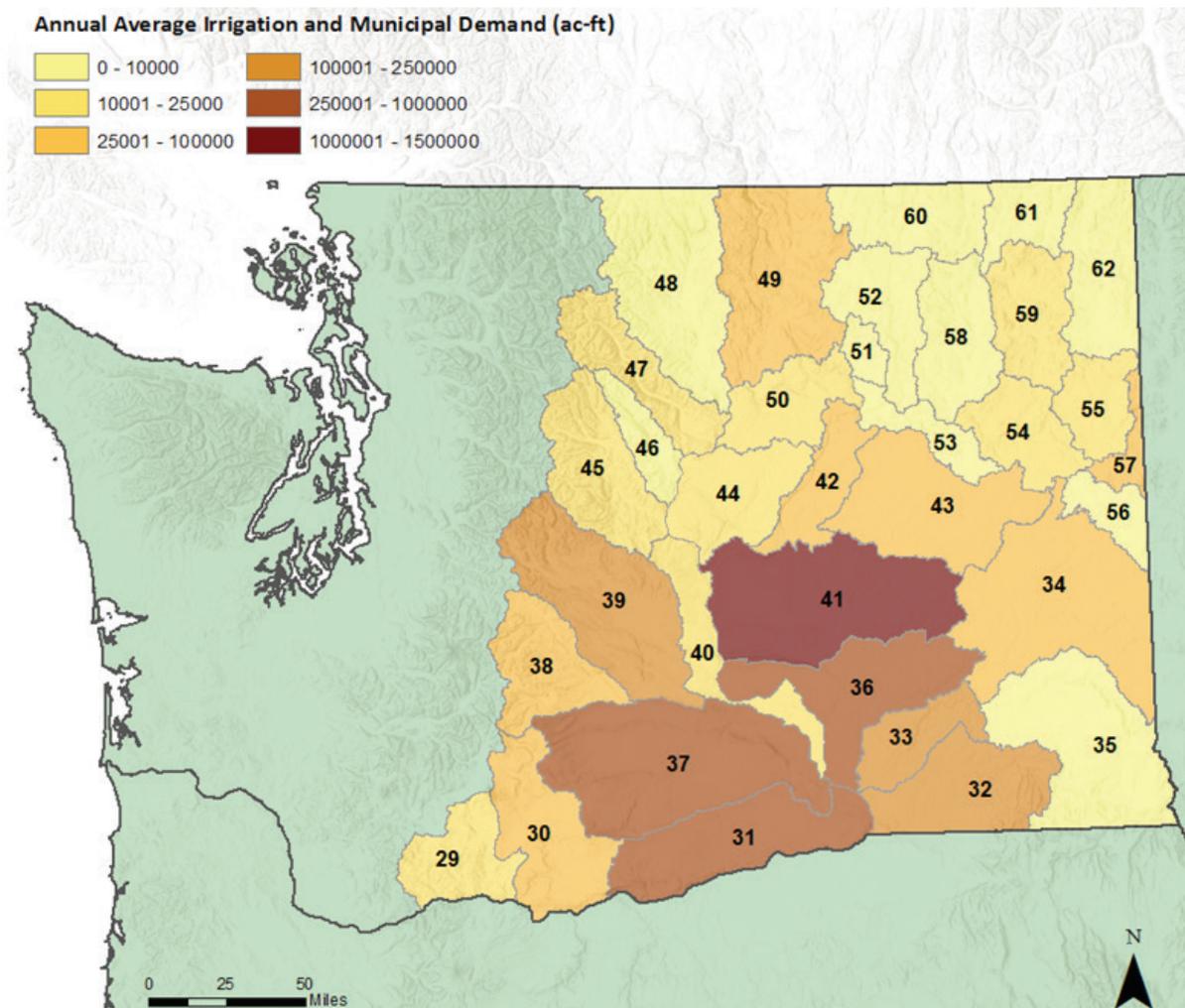


Figure 13: Total forecast (2035) median (50th percentile) annual water demands for agricultural and municipal uses by WRIA. Values include both surface and groundwater. The agricultural demand does not include conveyance losses; the municipal demand includes self-supplied domestic use. Forecast (2035) values reflect the average across 10 climate scenarios. All values are in ac-ft per year.

also projected to shift earlier due to increasing temperatures, and that shift in demand is expected to occur faster than the shift in supply. However, it is important to keep in mind that possible producer response to climate change, such as double cropping, would extend the irrigation season later in the season and increase the probability of late season curtailment.

Both the Wenatchee (45) and Methow (48) watersheds showed increased frequency and higher magnitude of curtailments earlier in the season by 2035, while appearing less vulnerable to curtailment later in the season. Similar changes in curtailment frequency were projected for the Walla Walla (32) watershed for 2035, though without a clear trend in changes in magnitude. Projected changes in the Okanogan (49), Little Spokane (55), and Colville (59) watersheds were not conclusive. In the latter two watersheds, this was in part because of mixed results from the two emission scenarios.

Due to the differences in how curtailments occur and were modeled in the Yakima River Basin, results do not show seasonality of curtailment. The annual average prorationing rate in the Yakima Basin is not projected to change much, though the frequency of prorationing is expected to increase by 2035.

Details of both historical (1981-2011) and forecasted (2020-2050) curtailments are provided in the Curtailment page for each of these eastern Washington WRIs (see the *Forecast Results for Individual WRIs* section).

## Washington Watersheds’ Supply and Demand – Detailed Results

Water supply and demand—and changes in supply and demand forecasted for 2035—vary in magnitude and in some cases direction of change, from WRIA to WRIA. Similarly, the water right claims, certificates, permits and applications vary by WRIA (Figure 14). Detailed results for individual WRIs, including modeled historical and forecast water supply, and modeled historical and forecast water demand by sector, are provided in the *Forecast Results for Individual WRIs* section. For WRIs with adopted instream flow rules, this section also includes detailed results on the magnitude and frequency of curtailment. For all WRIs in eastern Washington, additional information on the management context—the watershed’s water management, water allocation, and (for fish-critical WRIs) fish populations—is also provided. This section also includes guidance on how to read and interpret these WRIA-specific results (see the *How to Read the WRIA’s Results* guide).

## Exploring the Economic Benefits of More Water for Agriculture

### Using Water Values to Estimate the Impacts of Drought

Once the water values are calculated for different crops in a watershed, this information can be used to calculate the impacts of particular reductions in water available for irrigation. It is important to recognize that it is necessary to make significant assumptions about which crops are affected by curtailment. In order to demonstrate these concepts, an example is provided below for a hypothetical watershed. In this example there are 83,560 acres of irrigated cropland and a crop mix that is similar to what is found in the Walla Walla watershed (WRIA 32). The key point of this example is to demonstrate how to arrive at a lower- and upper-bound estimates of the impacts of drought, recognizing that the actual impact is likely somewhere in the middle.

**Table 9:** Conditions under which flow augmentation could provide benefits to stream reaches where anadromous fish populations exist and physical habitat conditions are good or better. Certain stream types would benefit from flow augmentation in most years, including normal and drought conditions (orange). Others would benefit primarily under drought conditions (red).

Flow Conditions and Stream Types	Flow Appropriation/Instream Restrictions		
	Low	Medium	High
Low/Larger Streams			
Medium/ Medium			
High/ Small Stream			

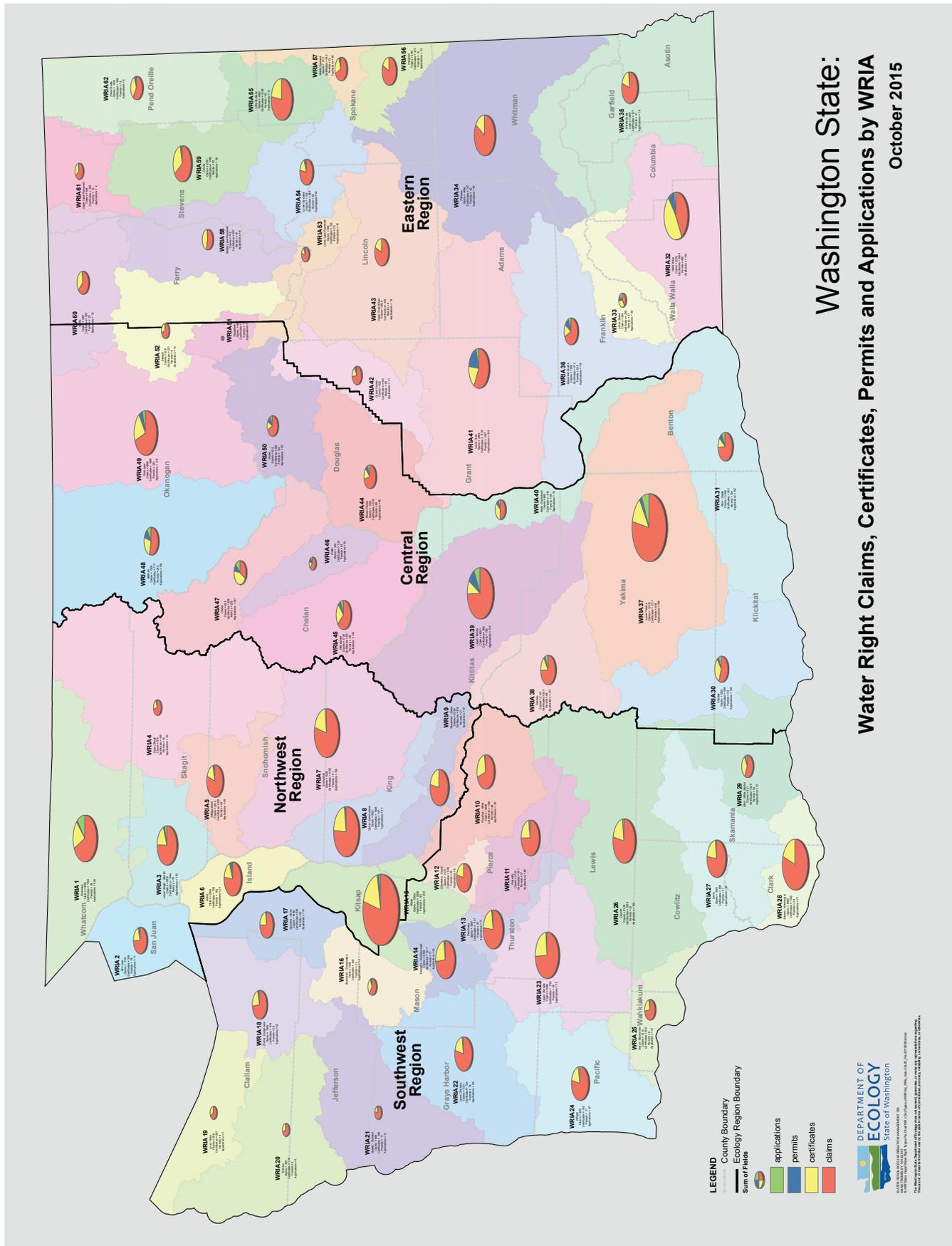


Figure 14. Water right claims, certificates, permits and applications in Washington Department of Ecology’s Water Rights Tracking System (WRTS), by WRIA. The WRTS data do not include tribal or federal quantified or unquantified water rights. The size of the pie chart in each WRIA reflects the total number of water right documents in that WRIA.

*Steps to calculate a lower-bound estimate of drought impacts:*

The guiding assumption for the lower-bound estimate is that lower-value crops' water is curtailed first, leaving available water to irrigate the highest-value crops.

1. Collect data on total irrigated acres growing each crop in the watershed (Figure 15a), total water use by each crop in the watershed (Figure 15b), and profit per acre for each crop in the watershed (Figure 15c).
2. Combine information on total water use for each crop and water value into a bar chart. The height of the bars in Figure 15b is an estimate of the total water use for each crop. The crops are ordered from left to right based on their estimated water value (from highest water value to lowest water value).
3. Based on their water value, calculate water "saved" by not planting the lowest value crop. This is simply the height of the bars starting at the far right of Figure 15b. Does this achieve the curtailment amount? If not, continue to add the height of the bars to the left.
4. If achieving the curtailment amount requires only a portion of that crop's water, then approximate the share required. For example, say this watershed is curtailed by 100,000 acre-feet. This would require fallowing all of cereal grains (~75,000 acre-feet), oilseeds (very few acre-feet), and the 'Other' category (~24,000 acre-feet).
5. To estimate the economic costs of curtailment, use the total profit from each crop, shown in Figure 15c. Curtailment costs then are simply the crops that were fallowed in the previous step, which included cereal grains, oilseeds, and other. Adding up the height of those crops' bars in Figure 15c totals about \$2 million.

*Steps to calculate the upper-bound estimate of drought impacts:*

The guiding assumption for the upper-bound estimate is that all crops receive less water, in proportion to their water use across the watershed.

1. Figure 15c shows that cereal grains and vegetables use the most water followed by seed crops and hay, in the hypothetical watershed described above. This means that the cost of drought will largely be driven by the value of water for those crops relative to the crops with smaller amounts of acreage.
2. The first step is to estimate an average water value for the entire watershed. This is a weighted average where the weight is amount of water the particular crop uses. The estimate for the hypothetical watershed is that the average value for water is \$178/acre-foot.
3. Multiply the lost water due to drought by the average water value for the watershed. Keeping with the 100,000 acre-foot curtailment example, this is \$178 million.

The difference in the lower- and upper-bound estimates is substantial. This is mainly due to the fact that in this watershed cereal grains receive a large amount of irrigation water but generate very little of the total profit associated with irrigated agriculture. Typically, however, the difference between the two estimates will converge as curtailment rate increases.

*Using Water Values to Estimate the Benefits of Additional Water for New Irrigated Acreage*

The value of water can be used to estimate the benefits of developing additional water for new irrigated acreage. The water value calculated above is the benefit obtained from adding 1 ac-ft of water to 1 acre of that crop for a single year. To calculate the total value from using the water in perpetuity on that acre, the present value must be calculated:

$$\text{Total Value} = (\text{single year value})/(\text{discount rate})$$

A common assumption for the discount rate is 4%, so:

$$\text{Total Value} = \$75/\text{ac-ft} \div 0.04 = \$1,875/\text{acre-foot}$$

A value that changes with quantity requires estimating values "at the margin". In this example, the value of water could change as more water is available, because the benefit obtained from adding 1 ac-ft of water when you already have 4 ac-ft will likely be less than the value of that same additional ac-ft if you only have 1 ac-ft (this is known as diminishing returns). Therefore, the value of water should decrease as more is made available for agricultural use. One real world motivation for assuming diminishing returns is that the remaining unirrigated land is of lower quality than currently irrigated land. However, as long as (1) high quality land remains, (2) increased supply of crops does not depress prices, and (3) crop mix

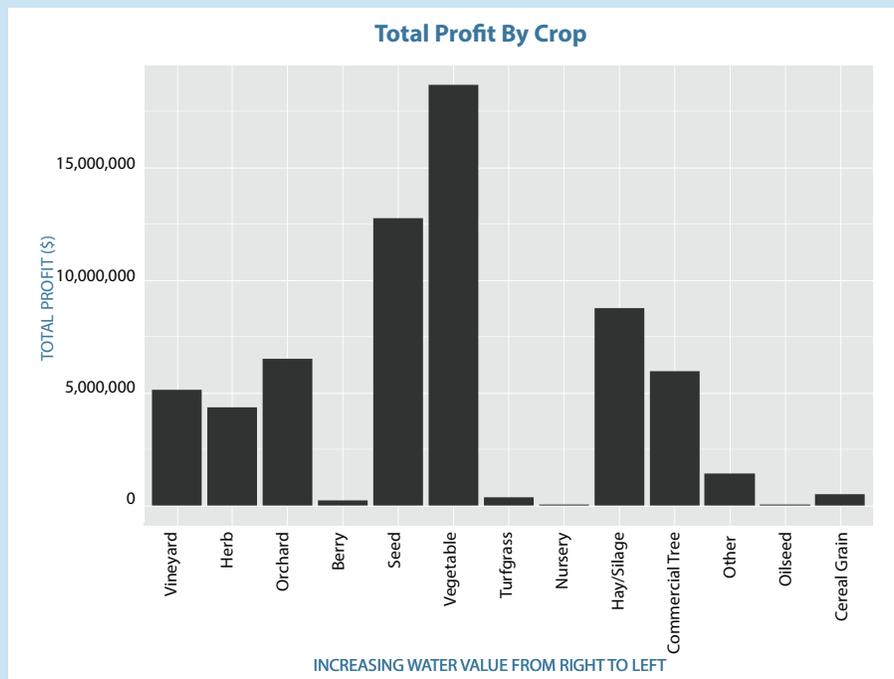
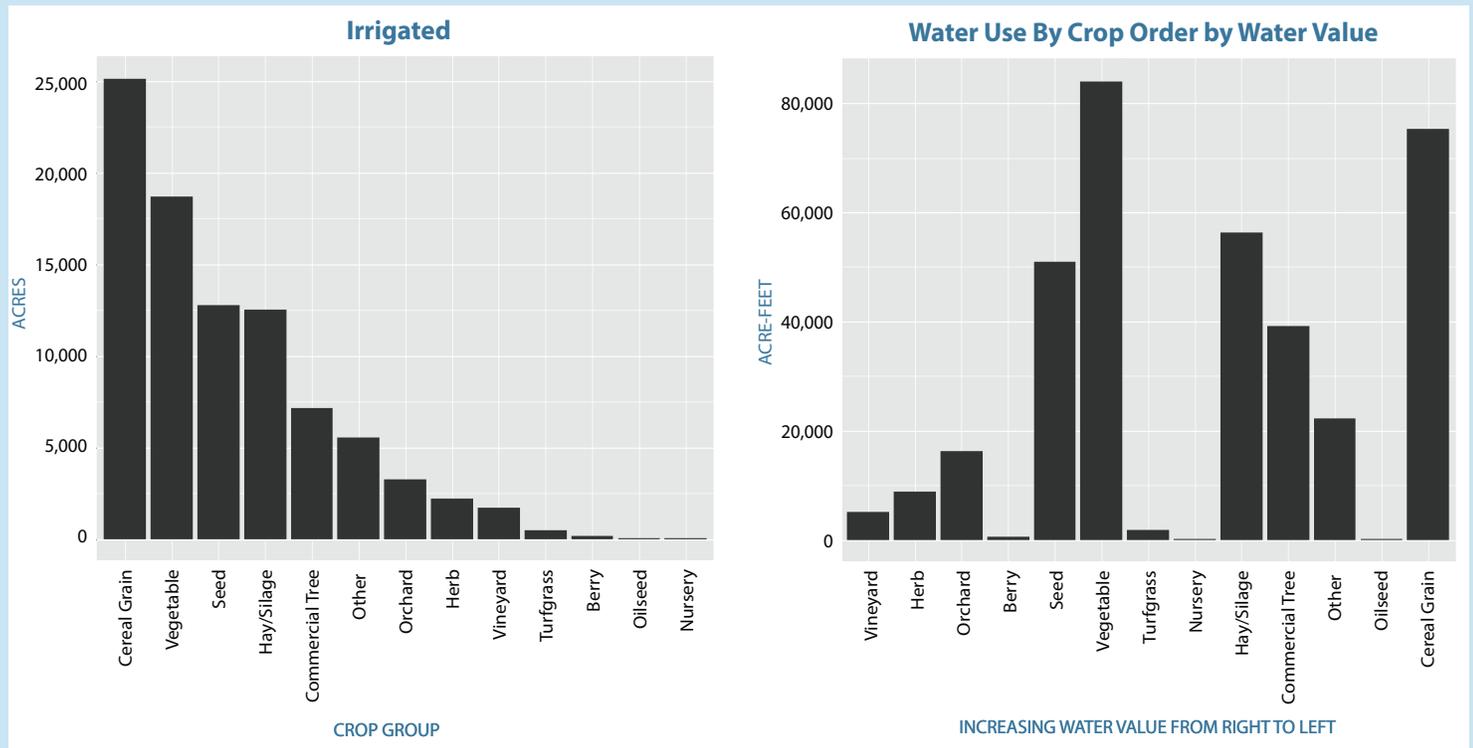


Figure 15. Example method to calculate the impacts of drought using water values. Data used in this example is from the Walla Walla watershed (WRIA 32). (a) Total acreage in the WRIA growing different groups of crops. (b) Total acre-feet of water used by each group of crops across WRIA 32. Crops are ordered from lowest to highest water value (see Box 6 for details). (c) Total profit expected from each group of crops across WRIA 32. Crops are again ordered from lowest to highest water value.

on new irrigated acres is similar to the mix on the existing irrigated acres in the region, one can assume that the marginal value of water is equal to the average value for the WRIA. Taking WRIA 32 as an example, a reason to not assume diminishing returns is that wine grapes are a major crop. Wine grapes tend to flourish on land that is often classified as less productive for agriculture.

Another way to estimate the benefit of water for agriculture is to look at how much farms, municipalities, and other entities are willing to pay (actual transactions are likely to be more accurate, but data is harder to come by) (see the *Effects of User-Pay Requirements on Water Permitting* module). There is evidence that agricultural users are paying more than \$3,000/ac-ft, particularly when the crop is wine grapes.

How does this compare to the cost of making new water supplies available? The OCR has information on recent water development projects that can inform this (Figure 1). Over the past ten years OCR has developed 375,000 acre feet at an average cost of \$506/ac-ft. If we reverse the calculations described above, we can calculate how much profit would need to be obtained from a crop with a water duty of 4 ac-ft/acre to support that average cost of water development (\$506/ac-ft):

1. Convert the total value to an annualized price or value of water:  

$$\text{\$506/ac-ft} = (\text{single year value}) / (0.04)$$

$$\text{Annual value of water} = \text{\$20.24/ac-ft}$$
2. Calculate the profit per acre for the crop being irrigated:  

$$\text{\$20.24 ac-ft} = \text{profit per acre} \div 4 \text{ ac-ft/ac}$$

$$\text{Profit per acre} = \text{\$80.96/acre}$$

This means that with profits greater than \$81/acre, the benefits of OCR's water supply projects would, on average, be greater than the cost of those projects. This is a fairly reasonable assumption on profitability for most irrigated crops.

If land values are thought of as the benefits of growing that crop in perpetuity on that acre, then the land value of an acre producing \$81 in profit per year when adding 1 ac-ft of additional water (using the same 4% discount rate) is:

$$\text{\$81/ac} \div 0.04 = \text{\$2,025/acre}$$

Most irrigated land sells for more than \$2,000/acre.

# WATER SUPPLY & DEMAND

## FORECAST FOR WASHINGTON'S COLUMBIA RIVER MAINSTEM

Flows on the Columbia River mainstem within Washington State (Figure 16) are a reflection of water supplies and demands 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 and other fish species, hydroelectricity as part of the federal Columbia River Power System, and water for out-of-stream uses—dominated by agriculture—in proximity to the river.

### Proportion of WRIA-Level Agricultural Demand along the Columbia River Mainstem

The Columbia River provides an important source of water supply to meet agricultural water demand for many WRIA water users within close proximity to the river. To give a sense of what portion of WRIA-level surface water irrigation demand was close enough to the Columbia River mainstem to possibly be supplied by the mainstem, a one-mile corridor on each side of the Columbia River was defined, based on OCR's guidance. The Forecast found that:

- Both historically and in the future (2035), more than half of the surface water agricultural demand (excluding conveyance losses) was within one mile of the Columbia River mainstem for five WRIs: Alkali-Squilchuck (WRIA 40), Moses Coulee (44), Foster (50), Lower Lake Roosevelt (53), and Upper Lake Roosevelt (61) (Table 7).
- Three additional WRIs—Rock Glade (31), Esquatzel Coulee (36), and Lower Crab (41)—each have more than 40,000 ac-ft per year of surface water agricultural demand within one mile of the Columbia River mainstem, although this does not represent a large proportion of their irrigation demand, as there are large numbers of irrigated acres in all of these WRIs.
- The percent of a WRIA's agricultural water demand provided by the mainstem in no case changed by more than seven percentage points (increase or decrease) from historical to future timeframes.

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, and 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, or whether it is feasible to serve specific areas with water diverted from the Columbia River.

### Comparison of Modeled Surface Water Supplies and Regulatory and Management Schemes

Regulation of mainstem water users is not triggered unless the total water supply forecasted on March 1 at The Dalles is less than 60 million ac-ft. On a month-to-month basis, modeled historical and forecasted (regulated) surface water supplies prior to meeting demands under average flow conditions were considered sufficient to meet Washington State instream flow targets (WA ISF) in most months at most points along the mainstem (Figures 17 and 18). However:

- Under median flow conditions, both historically (1981-2011) and in the future (2035), modeled November to January water supplies at Priest Rapids Dam and July to August at Priest Rapids and McNary would not meet WA ISF targets.

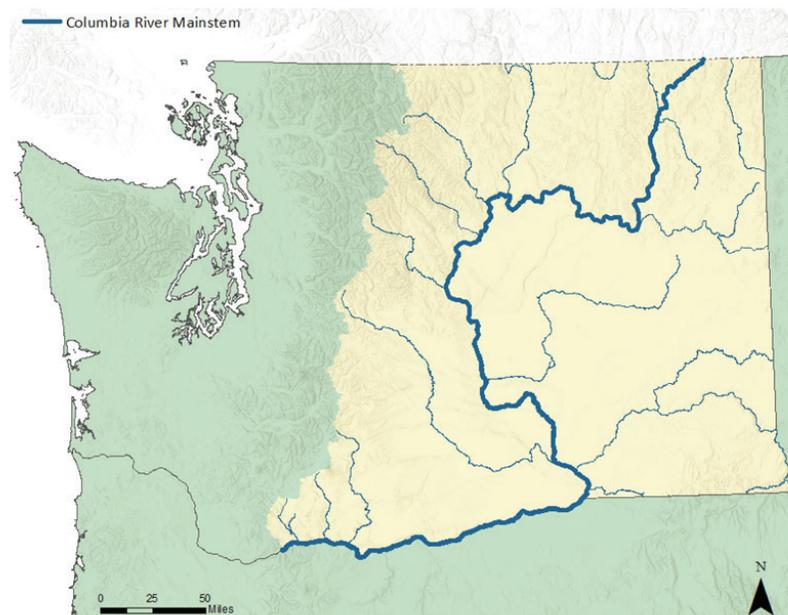


Figure 16. Washington's Columbia River Mainstem geographic scope.

- Under low flow conditions, similar patterns of failing to meet flow targets occur.

Compared to WA ISF targets, water supplies prior to meeting demands were considered insufficient to meet BiOp targets in fewer months, in both the historical (1981-2011) and forecast (2035) conditions (Figures 17 and 18):

- Under average flow conditions, modeled historical and forecasted water supplies were below BiOp flow targets from June to August at McNary Dam.
- Under average flow conditions, both modeled historical and forecasted water supplies were below BiOp flow targets at Bonneville in November through January. Imbalances were generally smaller in the future (2035) than the historical period for the summer months.
- Under low flow conditions, there are even more months when modeled surface water supplies failed to meet BiOp flow targets: water supplies were below BiOp flow targets at McNary Dam from April through August.
- Under low flow conditions, modeled surface water supplies failed to meet BiOp flow targets at Priest Rapids Dam in June for both historical (1981-2011) and forecast (2035) conditions, and also in April for the historical conditions.
- Under low flow conditions, modeled surface water supplies failed to meet BiOp flow targets at Priest Rapids Dam in July for both historical (1981-2011) and forecast (2035) conditions, and also in April for the historical conditions.

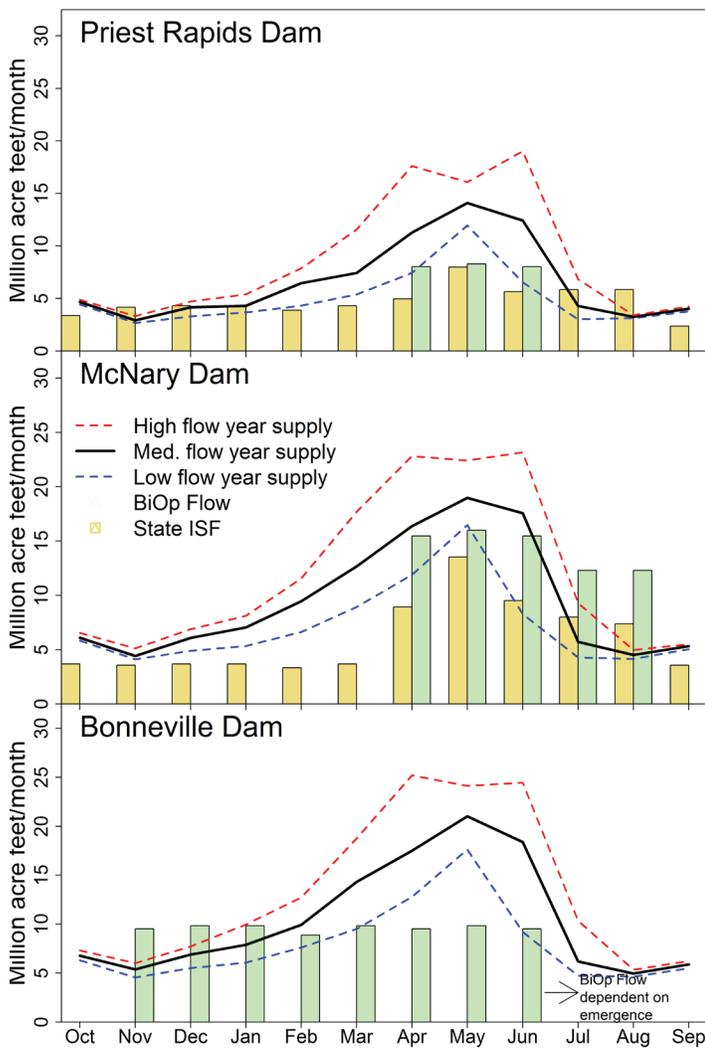


Figure 17. Historical (1981-2011) regulated surface water supply at Priest Rapids, McNary and Bonneville Dams for low (20th percentile), median (50th percentile), and high (80th percentile) flow years, averaged across 10 climate scenarios. Also shown are the Washington State instream flow (ISF) and federal Biological Opinion (BiOp) flow targets (bars).

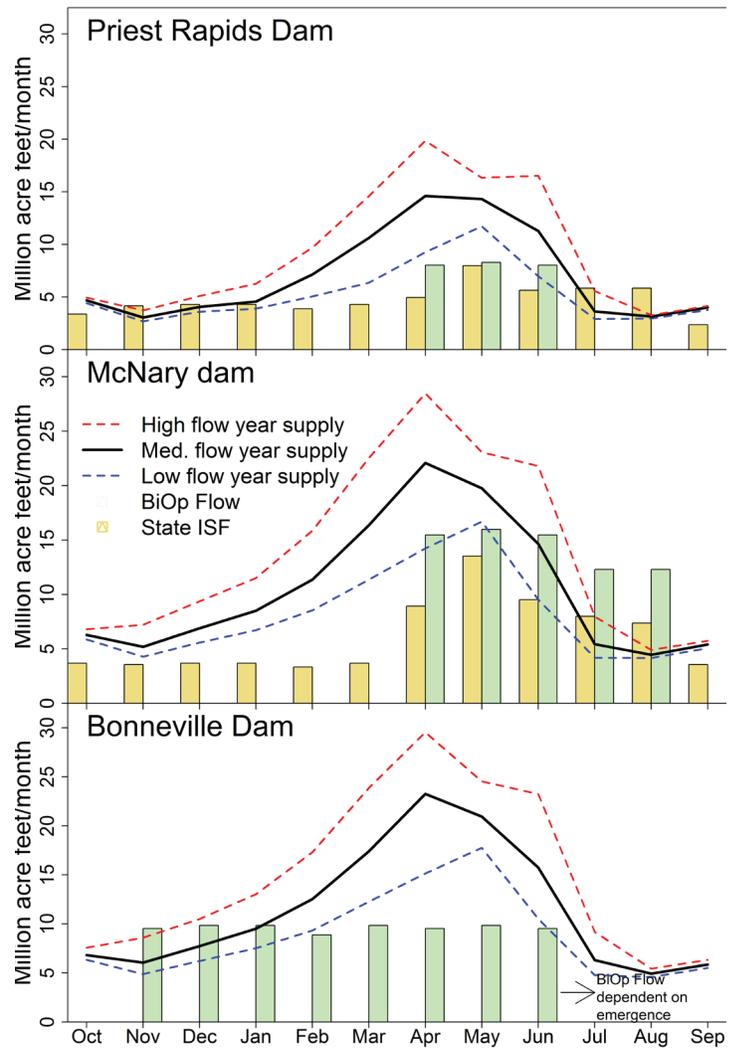


Figure 18. Forecast (2035) regulated surface water supply at Priest Rapids, McNary and Bonneville Dams for low (20th percentile), median (50th percentile), and high (80th percentile) flow years, averaged across 10 climate scenarios. Also shown are the Washington State instream flow (ISF) and federal Biological Opinion (BiOp) flow targets (bars).

These two regulatory schemes are important because of their role in regulating interruptible water rights holders and managing federal dams and the Quad Cities water permit.

## Curtailment along the Columbia River Mainstem

Similar to the curtailment results obtained for WRIsAs with adopted instream flow rules (see the *Curtailments for WRIsAs with Adopted Instream Flow Rules* section), modeled results project a shift in the frequency and magnitude of curtailments for different locations along the Columbia River Mainstem in Washington State. The details of those shifts vary from location to location (Figures 19 and 20).

In general, the magnitude of curtailment is projected to either start earlier in the spring, particularly under the medium range greenhouse gas emissions scenario (Figure 19, for example: McNary and Priest Rapids), or increase sometime through July (Figure 19, for example: Rock Island and Rocky Reach). Curtailment magnitude is projected to decrease late in the irrigation season at some locations, such as Rock Island and Wanapum.

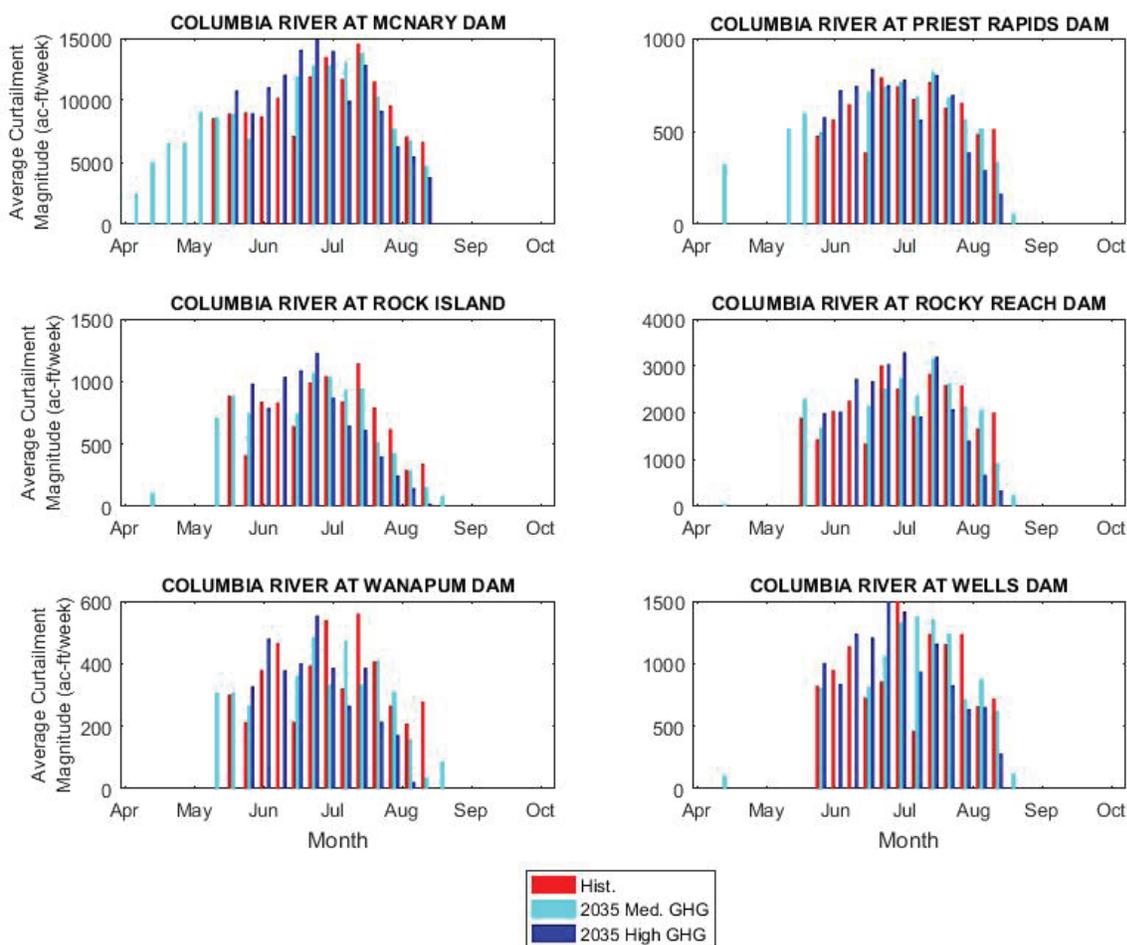


Figure 19. Modeled historical (1981-2009; two years dropped due to model simulation constraints) and forecast (2035) median curtailment magnitude (ac-ft per week) at six dams along Washington’s Columbia River Mainstem (Wells, Rocky Reach, Rock Island, Wanapum, Priest Rapids, McNary). Only results for dam locations with curtailment magnitude of at least 100 ac-ft per week are included. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment.

The shift in frequency of curtailment projected for 2035 appears to be more consistent than the magnitude shifts, across locations along the Columbia River Mainstem<sup>18</sup> (Figure 20). Results suggest that the frequency of curtailment will increase in July and August, particularly under the medium greenhouse gas emissions scenario, for all locations (Figure 20). In addition, some locations are also projected to see increased curtailment frequencies early in the season (for example, McNary; Figure 20). It is important to note, however, that these curtailment frequencies remain relatively small (3 to 6% of years), and that projections of curtailment frequency under a high greenhouse gas emissions scenario are similar to historical frequencies.

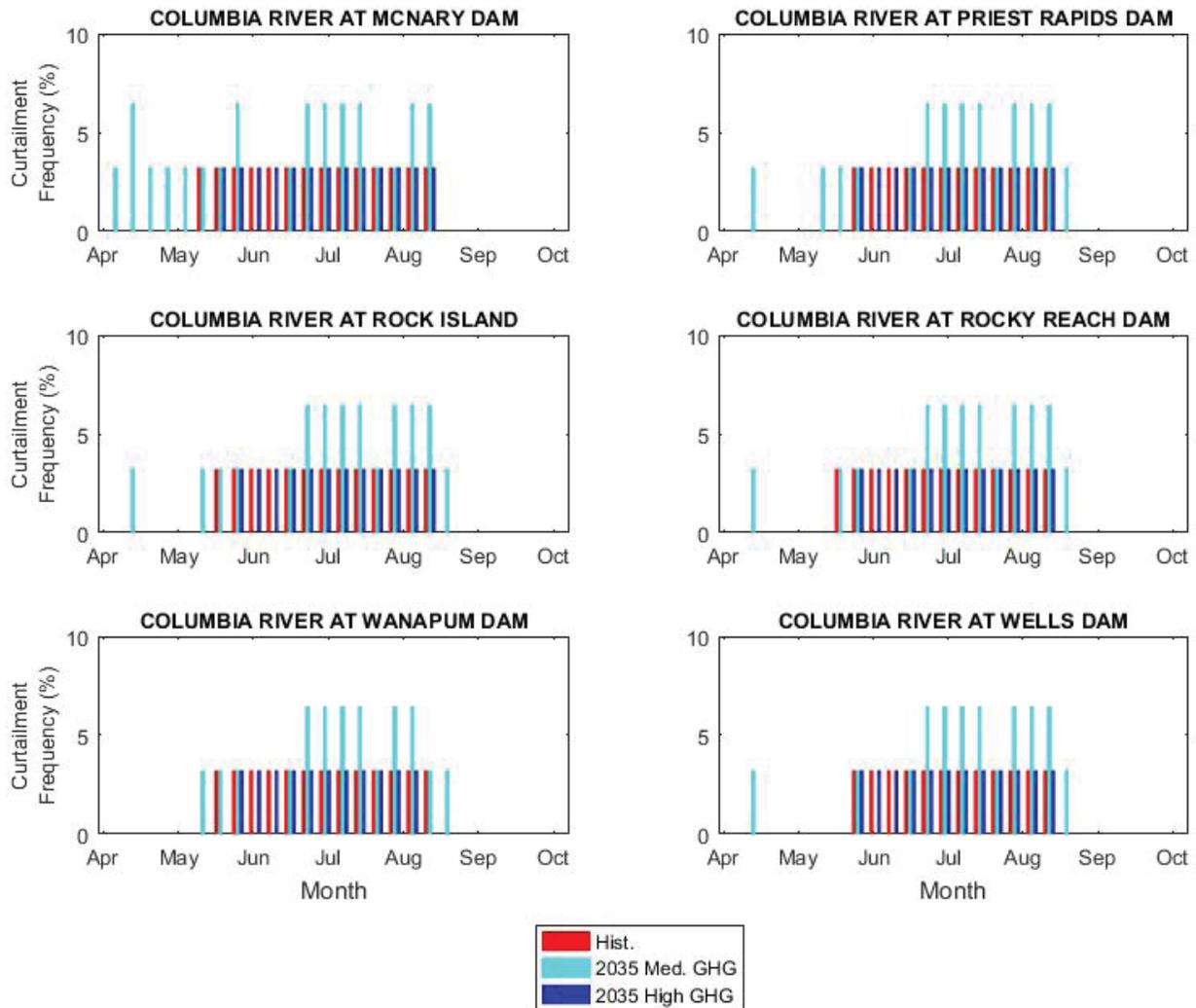


Figure 20. Modeled historical (1981-2009; two years dropped due to model simulation constraints) and forecast (2035) median curtailment frequency (%) at six dams along Washington’s Columbia River Mainstem (Wells, Rocky Reach, Rock Island, Wanapum, Priest Rapids, McNary). Only results for dam locations with curtailment magnitude of at least 100 ac-ft per week are included. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

18 Note that curtailment frequency can vary from week to week. If the curtailment program is in effect for a particular year, a weekly decision to curtail or not that week is made, based on a comparison of weekly stream flows, instream flow requirements, and out-of-stream demands. These three aspects change on a weekly basis, and thus some weeks may have curtailments, while others may not. For example, in the historical case, where the curtailment program was in effect just one year out of 29, some weeks will see a frequency of 3% (1 year out of 29) and others will have zero.

# CONCLUSION

The results of the 2016 Forecast suggest that overall seasonal shifts in timing of water supply and demand will be a dominant issue, and will likely require area-specific management and adaptation strategies in the future. However, irrigation demand was forecast to decrease on average, due to wetter springs and a shifting of the growing season into the spring, when rain is projected to be more plentiful. Under warming temperatures, some crops will also reach maturity faster, thus decreasing irrigation demand later during the irrigation season. If realized, this decrease in demand could help to alleviate a reduction in summer water supply, at least in non-drought years.

Two important considerations that highlight the complexity of water management in the region are:

- Producers with existing water rights will likely respond to the decreased irrigation demand of crops, by using the water in other ways. Anecdotal evidence already suggests that increases in double-cropping and cover cropping are occurring. Actual irrigation demand in 2035 may therefore not decrease to the extent projected in this Forecast. The Washington Department of Agriculture data do not distinguish these double-cropping patterns, so accurately estimating this trend is not straightforward. However, an initial, coarse estimate suggests that double-cropping would need to occur over much greater than 10% of the eligible acreage by 2035 to lead to an increase in irrigation demand. (Table 5)
- Vulnerability of agricultural production to future changes in climate will be most apparent in drought years, which are generally expected to occur more frequently as the climate changes, with droughts also becoming more severe. Though the specific patterns of change in the frequency and magnitude of curtailments projected under future climates vary across eastern Washington, forecast results present a trend towards increasing frequency and magnitude of curtailment in the spring, with a decrease in curtailments later in the irrigation season. Given that overall water supply in the spring is projected to increase by 2035, these results suggest that the shift in demand will likely occur faster than the shift in supply. However, it is important to keep in mind that possible producer response to climate change, such as double cropping, would extend the irrigation season later in the season and increase the probability of late season curtailment.



*Banks Lake Reservoir below Grand Coulee Dam*

This Forecast improves our understanding of future surface water supplies and instream and out-of-stream demands. Unfortunately, it cannot answer all questions related to water supply and demand in the Columbia River Basin. However, it does provide projections 20 years into the future and highlights the main changes that can be expected in water supply and demand. It can therefore provide a benchmark around which stakeholders interested in the management of water can discuss how to prepare for changes in water availability as the climate changes, and the implications for different stakeholders of OCR's decisions. The results and methods of the 2016 Forecast can also serve as a capital investment planning tool to help OCR and others make decisions. The calculations on the economic benefits obtained from water development projects suggests that the profits needed to cover the average cost of those projects are possible and feasible in this region. In this way, the 2016 Forecast can inform OCR's efforts, so that they contribute to maintaining and enhancing the region's and eastern Washington's economic, environmental, and cultural prosperity in the future.

## Next Steps—Building Towards the 2021 Forecast

Many of the improvements in the 2016 Forecast stemmed from shortfalls identified in the 2011 Forecast by both the Forecast team and the public. These 2016 improvements include steps towards integrating groundwater limitations in our understanding of future water supply and demand. The Legislature's mandate to update the forecast again in 2021 provides an opportunity for OCR to implement several of the recommendations arising from the 2016 Forecast and the public's response, to continue to advance both the state-of-the-science and key policy initiatives that affect water supply and demand in central and eastern Washington.

The OCR has prioritized these recommendations, and defined the areas they will focus on initially, in cooperation with Ecology's Water Resources Program and local, state, federal, and tribal partners. In the next 5 years, OCR plans to:

### Forecast Methodology:

- *Double cropping:* Partner with the Washington State Department of Agriculture and other agricultural interests to better understand double-cropping patterns in Washington today (types of crops, frequency, amount of acres), and its likely expansion in response to longer growing seasons associated with climate change.
- *Curtailment records:* Develop improved water master and stream patrolmen records on water rights in each subbasin that are currently curtailed according to priority calls, to gain a better understanding of the frequency of those calls, and to identify the rights and/or subbasins that may be at risk to increased curtailment in the future.
- *Municipal demand:* Coordinate with the Washington State Department of Health, the Washington Water Utilities Council, the Washington State Municipal Research Center, and other municipal interests to refine and improve the municipal forecasting methodology, to better inform decisions on municipal water use as supplies and demands change.
- *Hydropower demand:* Coordinate with the Northwest Power Planning Council and public and private hydropower providers to provide greater input into the 2021 Forecast on hydropower, to improve understanding of water needs for hydropower production in the face of changing renewable energy initiatives and investments and the Columbia River Treaty.
- *Groundwater:* Incorporate deep groundwater dynamics into the 2021 water supply Forecast, to better capture groundwater dynamics that impact availability of surface water for different uses.
- *International Columbia River Treaty:* If necessary, incorporate the results of post-2024 flood risk analysis of the Columbia River mainstem, to better understand its effect on reservoir operations and on future water supply.

### Declining Groundwater:

- Expand the database of water level measurements in declining groundwater areas through a mix of voluntary and agency-coordination, to improve the understanding of groundwater availability and need for additional surface water to meet demands currently filled by groundwater.
- Utilize water master and water rights data to rank curtailment risk of water rights relying on declining groundwater, to better inform water supply investment decisions.

- Coordinate with Counties and the Washington State Department of Health to improve awareness and extend the useful life of existing aquifers by implementing programs to reduce curtailment risk in declining groundwater areas.

**METRIC:**

- Expand the pilot scale evaluation to other key areas of eastern Washington to confirm its applicability.
- Explore the use of METRIC as a remote sensing option to fill in data gaps due to limited ability to carry out on-the-ground verification of cropping patterns and acreages.
- Evaluate the potential to integrate METRIC into pre-adjudication irrigation evaluations, to streamline the claim evidentiary review process when documenting historic beneficial use.

**Water Banking:**

- Develop a water banking policy on public interest criteria to guide the formation of new water banks, in coordination with the Columbia River Policy Advisory Group and the Water Resource Advisory Committee. Such criteria would allow Ecology to prioritize new water banks where they can solve key water supply problems and meet Ecology's legislatively-prioritized objectives.

**Cost Effects:**

- Revise the new water right application form to require applicants to include information more closely aligned to that necessary to make a permit decision, with the goal of increasing transparency and creating clearer expectations amongst applicants regarding the level of effort and cost of processing of new water rights.
- Coordinate with the Columbia River Policy Advisory Group on new investments and local constituencies in areas where new water supplies are proposed, to improve the likelihood that a market exists for a project post-implementation.

**State Water Forecast:**

- In conjunction with the Ecology's Water Resources Program, conduct outreach to key western Washington stakeholder groups (e.g. Water Resources Advisory Committee, Washington Water Utilities Council, Puget Sound Partnership, etc.) on the merits and methods to provide statewide water planning.

Successfully completing the work embodied by this set of priorities will help Ecology's Office of the Columbia River fulfill its legislative-designated mandate, and support the science endeavors that provide the foundation for good decisions in the face of a changing climate, year-to-year variability, and the uncertainty inherent in making investments to sustain the region's economic growth and environmental and cultural enhancement 20 years into the future and beyond.

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# How to Read the WRIA's Results

**WRIA Highlights** note key, WRIA-specific results. Particular focus is given to aspects where this WRIA might differ from other Washington WRIsAs.

**Management Context** describes the regulatory and planning context of the specific WRIA.

**Use By Fish Species on the Endangered Species List** provides information on the months of the year when flows are most critical to threatened and endangered fish species in the WRIA. Only available for some WRIsAs.

**Historical Flows Data** provide information on how flows have varied historically at the stream gauge located furthest downstream in this WRIA.

**Modeled Historical and Forecast Surface Water Supply** shows how much water is available in the WRIA each month, prior to accounting for demands. The three panels show the expected supply in years with low, median, and high flow conditions, respectively. The three lines in each panel show: (1) Historical supply, modeled and calibrated with 1981-2011 climate data (black line); (2) Projected water supply in 2035 under a moderate climate change scenario (light blue polygon); and (3) Projected water supply in 2035 under a more severe climate change scenario (dark blue polygon). The range shown by the polygons reflects how results for 2035 depend on the climate model used.

WRIA 37, 38, 39

MANAGEMENT CONTEXT

- The regulated tributary surface water supply forecast for the Yakima is characterized by increases from November through March, followed by decreases primarily in May and June.
- Irrigation is the primary source of demand in these WRIsAs. 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 in WRIA 37 are significantly larger than most other WRIsAs of eastern Washington.
- Assuming no change in irrigated acreage, irrigation demand is forecasted to increase during March through May and decrease during June through September. These changes are somewhat equally due to both climate and crop mix changes.
- Municipal demand is projected to grow by 17%, 9%, and 10% for WRIsAs 37, 38, and 39, respectively, by 2035.
- These WRIsAs are included in the Columbia River Instream Atlas [Ecology Publication in preparation], which contains information on instream water demands for 12 WRIsAs that provide habitat for ESA-listed anadromous salmonids.
- Forecast shows no major changes in the magnitude of proration rates between historical and future simulations.
- Forecast shows an increased frequency of proration rates 90% or lower in the future simulations.

MANAGEMENT CONTEXT	
Adjudicated Areas	Ahtanum Creek, Coviche Creek, Wenas Creek, Tenaway River, Cooke Creek, Big Creek, Basin-wide adjudication in process
Watershed Planning	Phase 4 (implementation)
Adopted Instream Flow Rules	NO (Target flows, enacted by Congress, and instream flow tribal treaty rights, affirmed by the Yakima Superior Court, are in place, both managed by the U.S. Bureau of Reclamation)
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Middle Columbia Steelhead, [WRIA 37 is also Columbia mainstem migratory corridor]
Groundwater Management Area	YES (Upper Kittitas Groundwater Rule and Lower Yakima Valley Groundwater Management Area). For additional information on groundwater decline areas within WRIA 37, see Module 1c.

<sup>1</sup>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.

A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 185. Summaries are also available online at <http://apps.wdfw.wa.gov/salmonscape/>.

Ahtanum Creek Dry, Average and Wet Year Flows

(Ahtanum Creek at Union Gap, WA 1961-2015)

Historical flows plots: Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis/>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (dry year), the year with the highest annual flow on record (wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent "average" years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

Lower Yakima, Naches & Upper Yakima

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WRIA 37, 38, 39

SUPPLY

Lower Yakima, Naches & Upper Yakima

WRIA 37, 38, 39

SUPPLY

Lower Yakima, Naches & Upper Yakima

Modeled historical (1981-2011) and forecast (2035) surface water supply generated via the Hydrologic Modeling Analysis and Planning System (HMAPS) for the low (left), median (middle), and high (right) supply conditions. Water supply was forecasted using the "Med. GHG" and the "2035 Range-High GHG" values represent supply forecast under the "Med. GHG" and "High GHG" scenarios, respectively. The spread of each 2035 supply is due to the range of climate change scenarios used. Demand is shown as green bars. Demand is shown as green bars with error bars. These results do not consider water curtailment to accounting for demands, and thus should not be compared to observed flows.

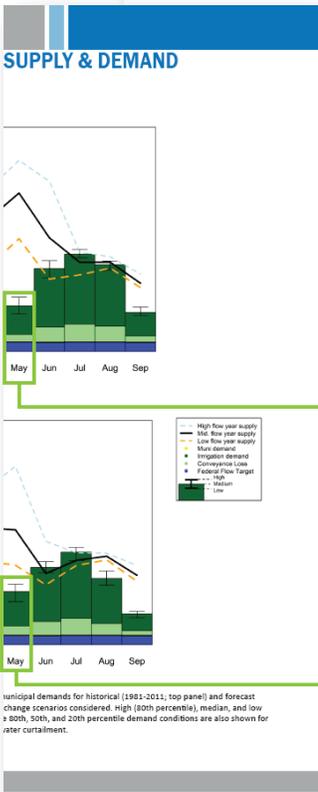
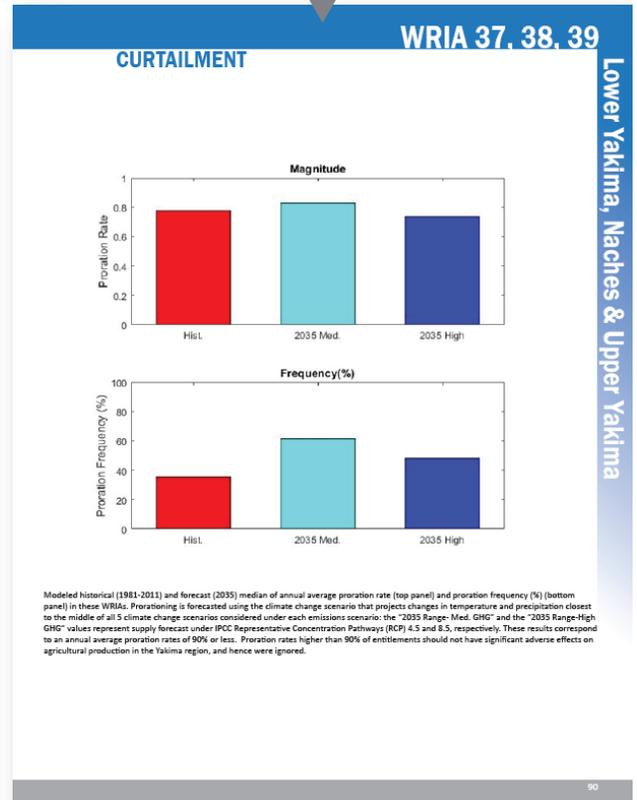
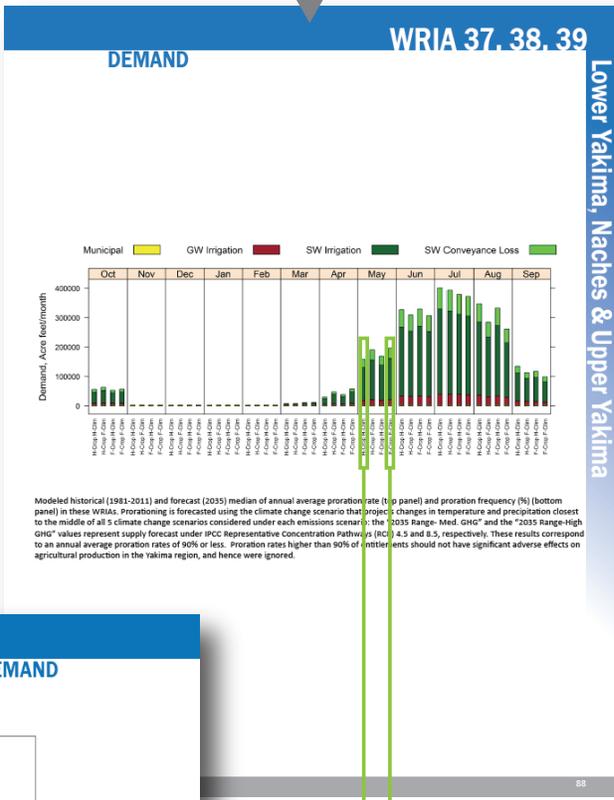
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**Comparison of Water Supply and Demand** overlays water supply and water demand on the same graph, for the historical (1981-2011) period (top panel), and for the forecast (2035), including moderate changes in climate and changes in crop mix period (bottom panel).

**Modeled Historical and Forecast Water Demand** shows how much water is needed in the WRIA each month for different uses (shown in different colors) under average demand conditions. The four bars for each month show:

- (1) Historical demand, modeled and calibrated with 1981-2011 climate data and 2013 crop mix data;
- (2) Projected demand in 2035 under a moderate climate change scenario, and the crop mix expected in 2035 based on existing trends. The other two bars help distinguish the effects on water demand of only a changing climate (3) versus only a change in the crop mix (4).

**Modeled Historical and Forecast Curtailment Magnitude and Frequency** shows how much and how frequently producers see (or can expect to see) their irrigation water use curtailed due to supplies not being sufficient to meet all demands, including those from adopted instream flow rules. These results are only provided for WRIAs with adopted instream flow rules. For most of these WRIAs, curtailment is defined on a weekly basis, and that is reflected in the magnitude and frequency figures. In the Yakima Basin, however, water is managed differently. The modeled results for these WRIAs, therefore, show the average annual proration rate and proration frequency for each time period.

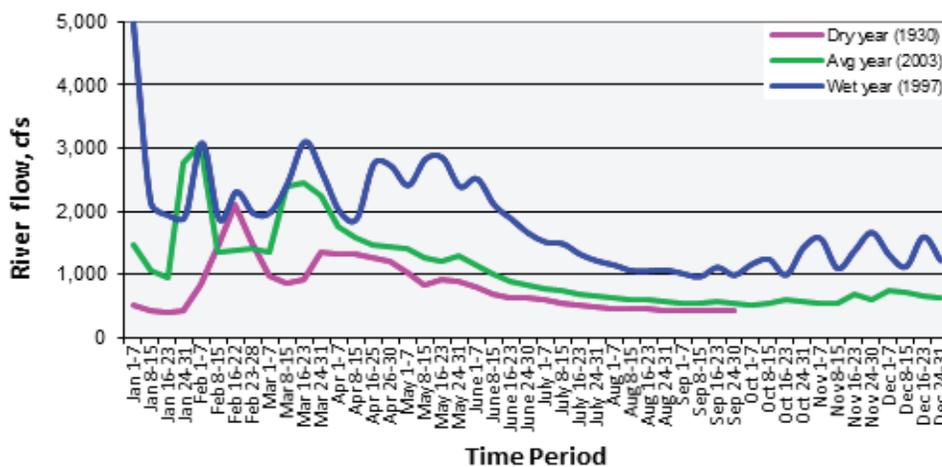


- The tributary surface water supply forecast for Wind-White Salmon is characterized mostly by increases from late fall through early spring, with smaller decreases in the late spring and summer.
- Irrigation is the dominant source of demand, although it is smaller than irrigation demands in many other WRIs of eastern Washington. Municipal demands are very small in comparison.
- Assuming no change in irrigated acreage, irrigation demands are projected to increase in May, June, and August, and decrease in July, September, and October.
- Municipal demands are expected to grow 14% by 2035, though the total municipal demand will still be quite small in comparison to other watersheds.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIs that provide habitat for ESA-listed anadromous salmonids.

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 <sup>1</sup>	Bull Trout, Lower Columbia River Chinook, Lower Columbia River Steelhead, Middle Columbia Steelhead, Lower Columbia River Coho, Columbia River Chum Salmon [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

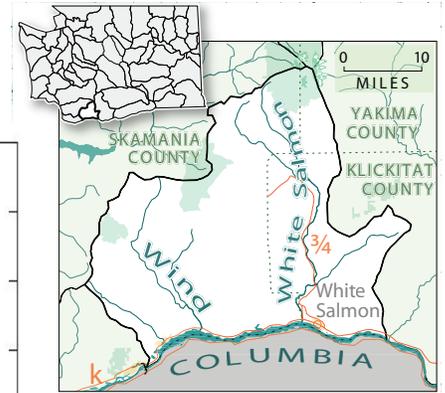
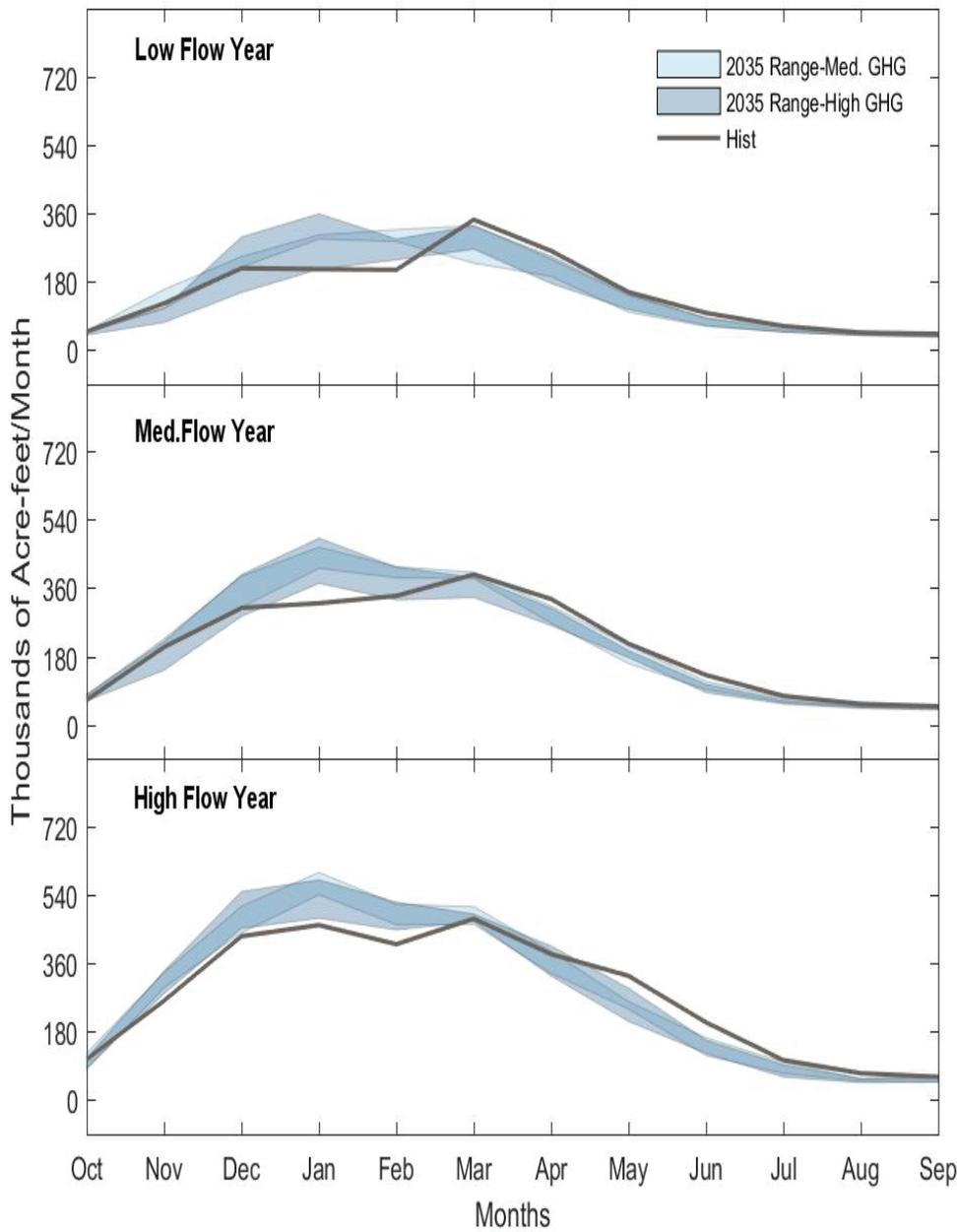
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

**White Salmon River Dry, Average and Wet Years Flow**  
(White Salmon River near Underwood, WA) 1915-2015

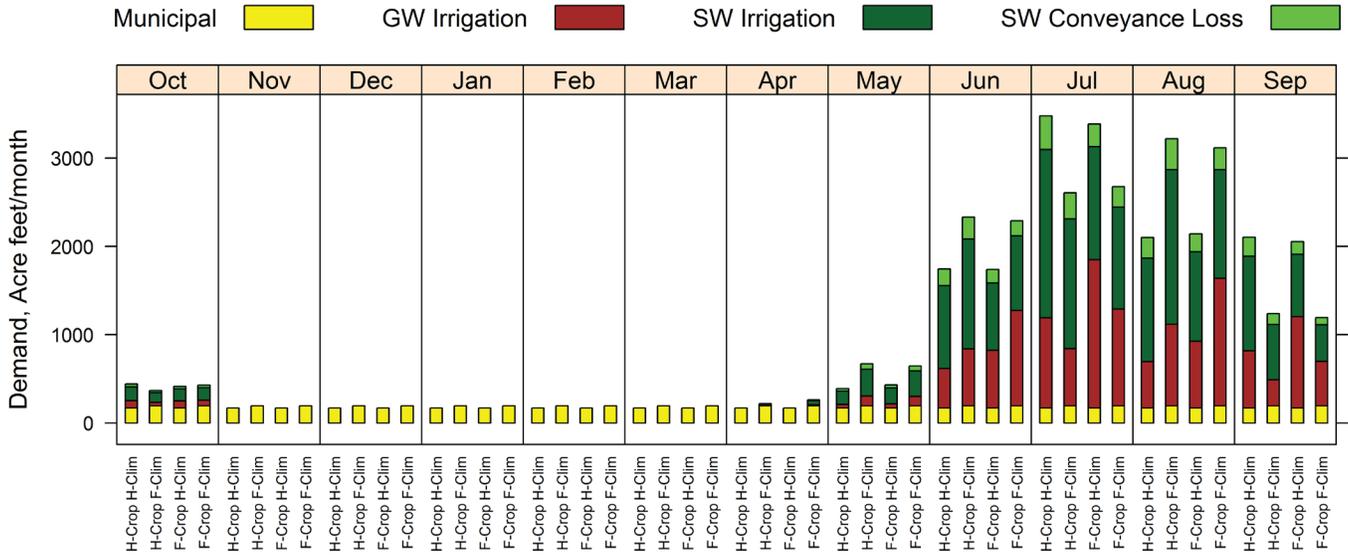


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

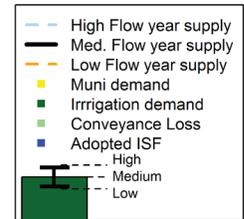
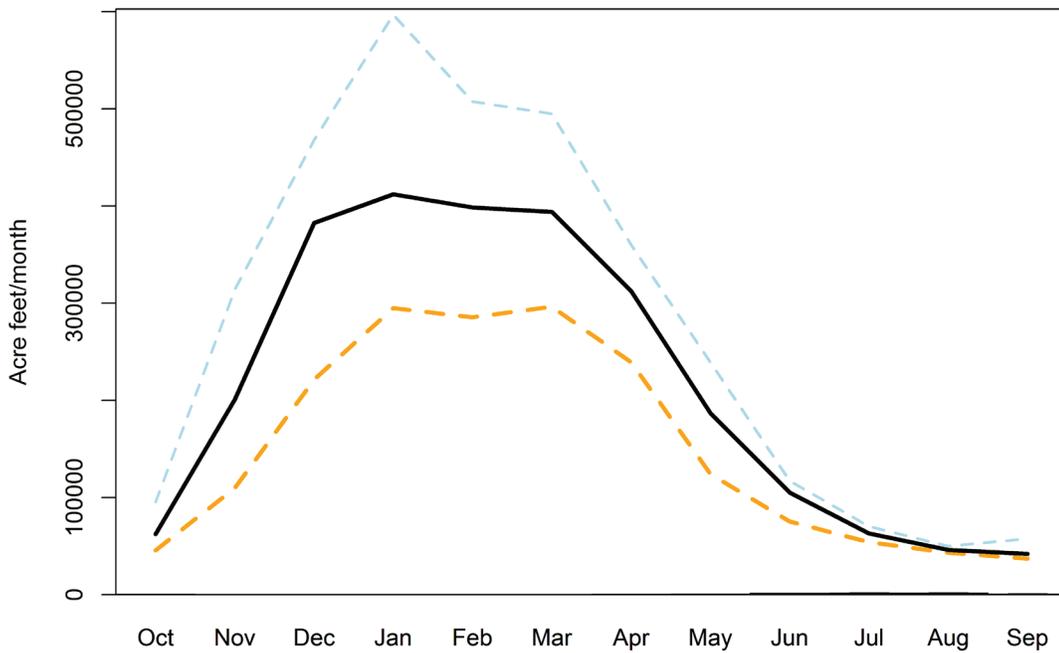
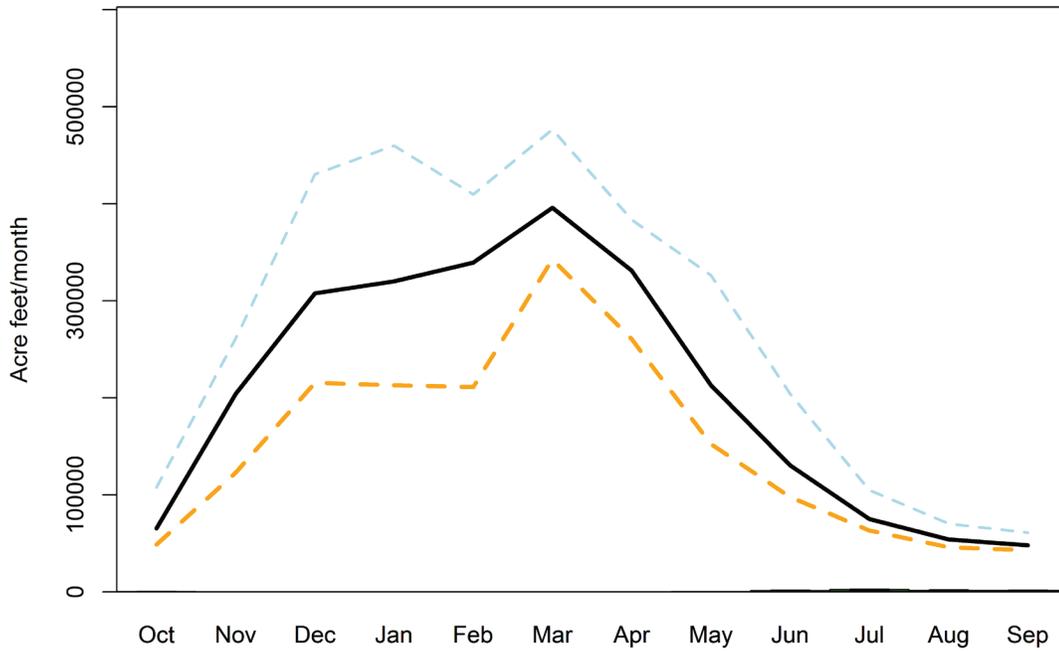


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

## SUPPLY & DEMAND

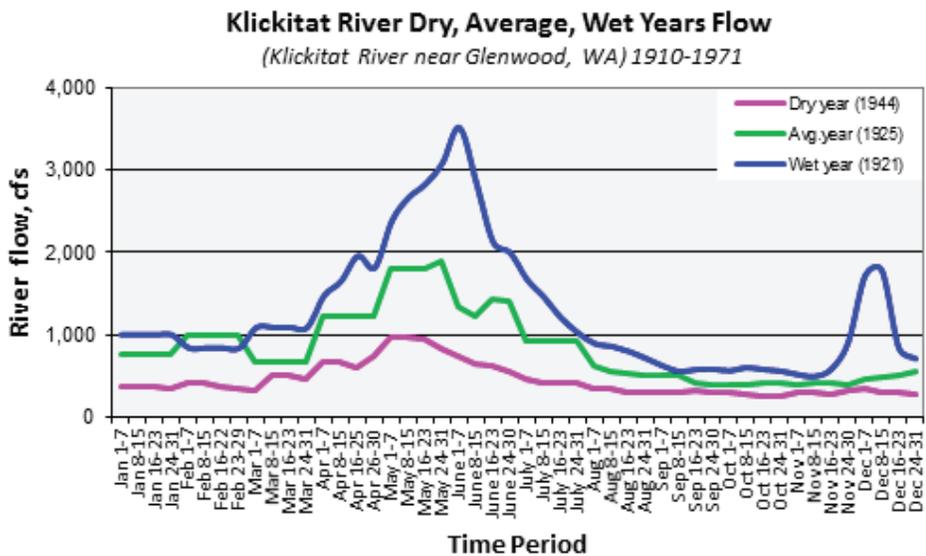


Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- The tributary surface water supply forecast for Wenatchee shows increases during the months of October through March for most of the years and decreases for June and July.
- Irrigation is the dominant source of demand, with municipal demands that are much smaller.
- Assuming no change in irrigated acreage, irrigation demand is forecasted to decrease in response to climate change and crop mix changes for most months of the irrigation season in the future. Irrigation demand increases in June and August.
- Municipal demands are expected to grow 2% by 2035.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIsAs that provide habitat for ESA-listed anadromous salmonids.

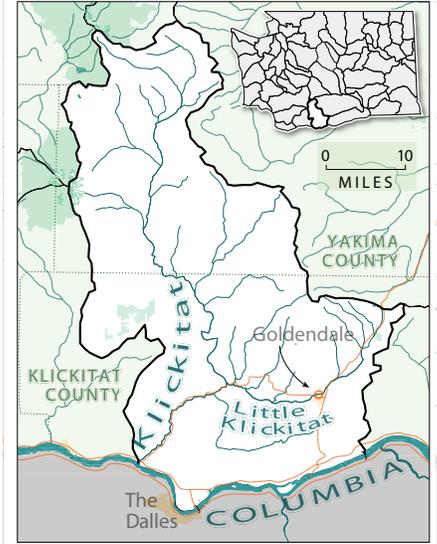
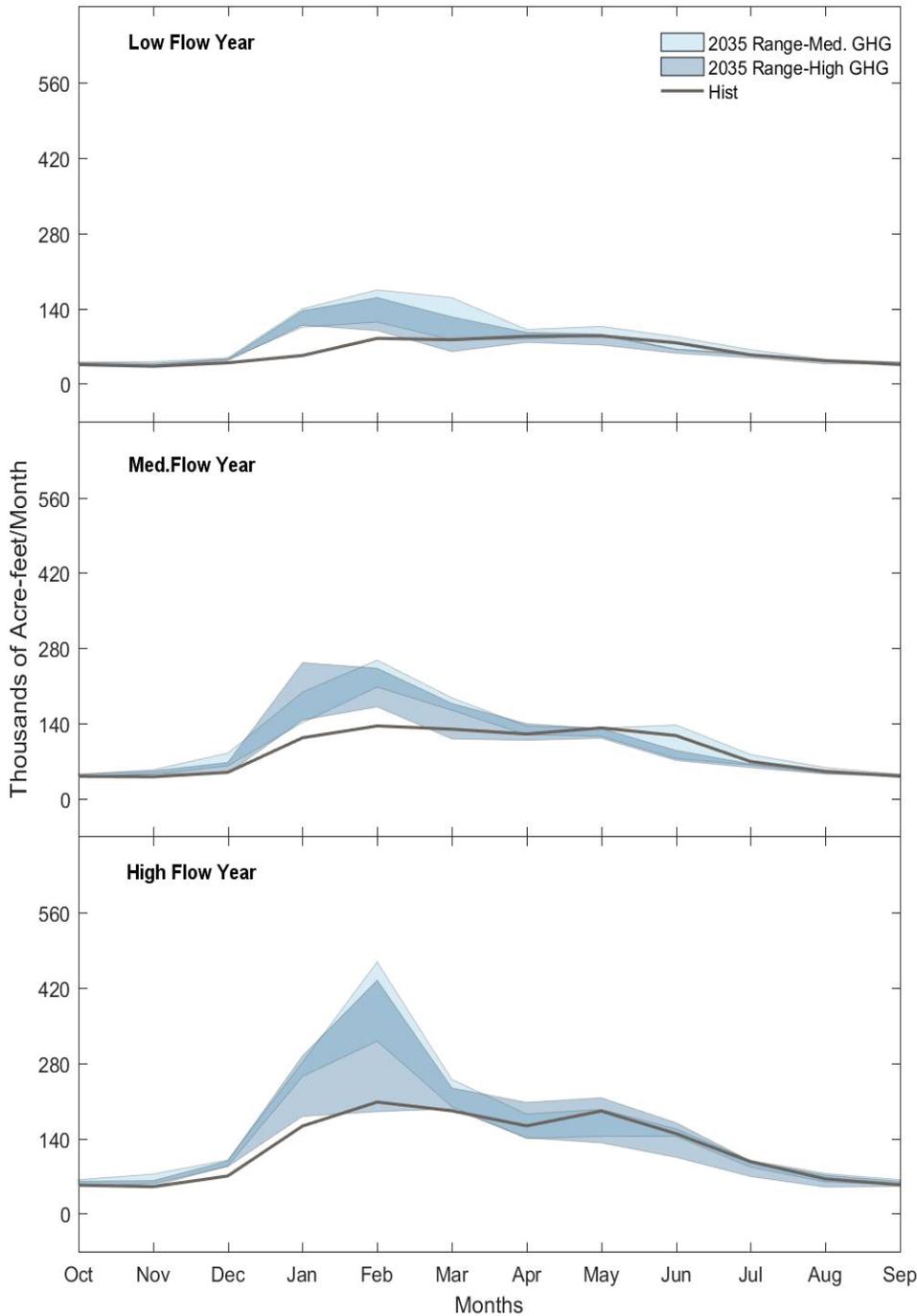
MANAGEMENT CONTEXT	
Adjudicated Areas	Bird-Frazier Creeks, Bacon Creek, Little Klickitat River, Mill Creek, Blockhouse Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Middle Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

<sup>1</sup>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.



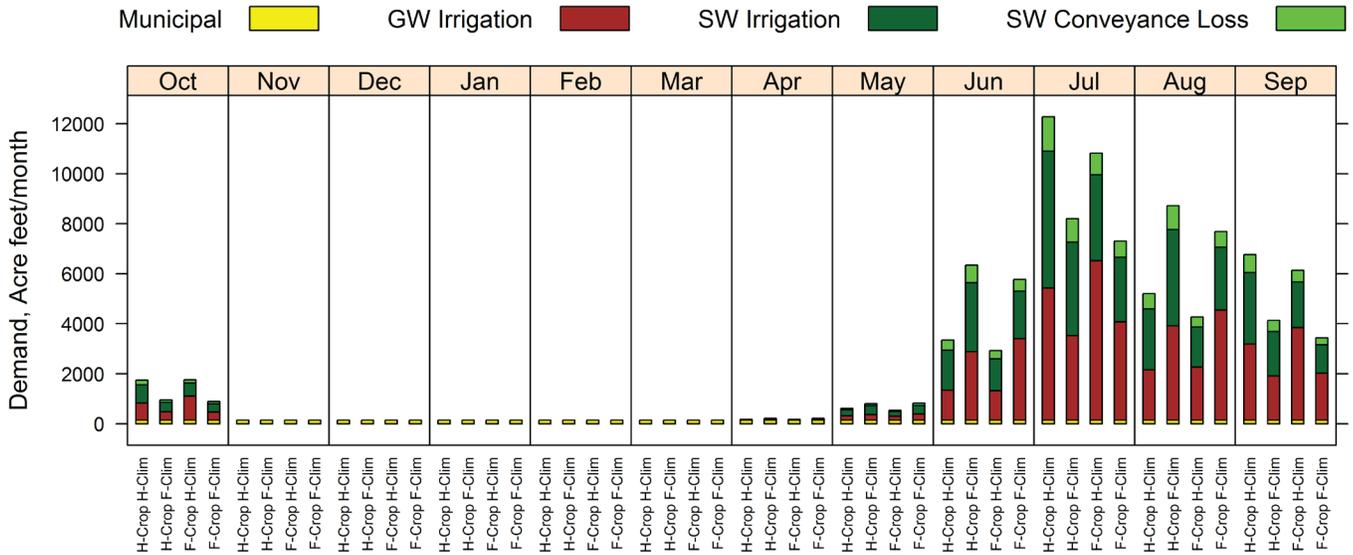
Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

SUPPLY



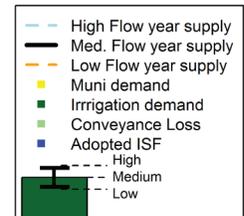
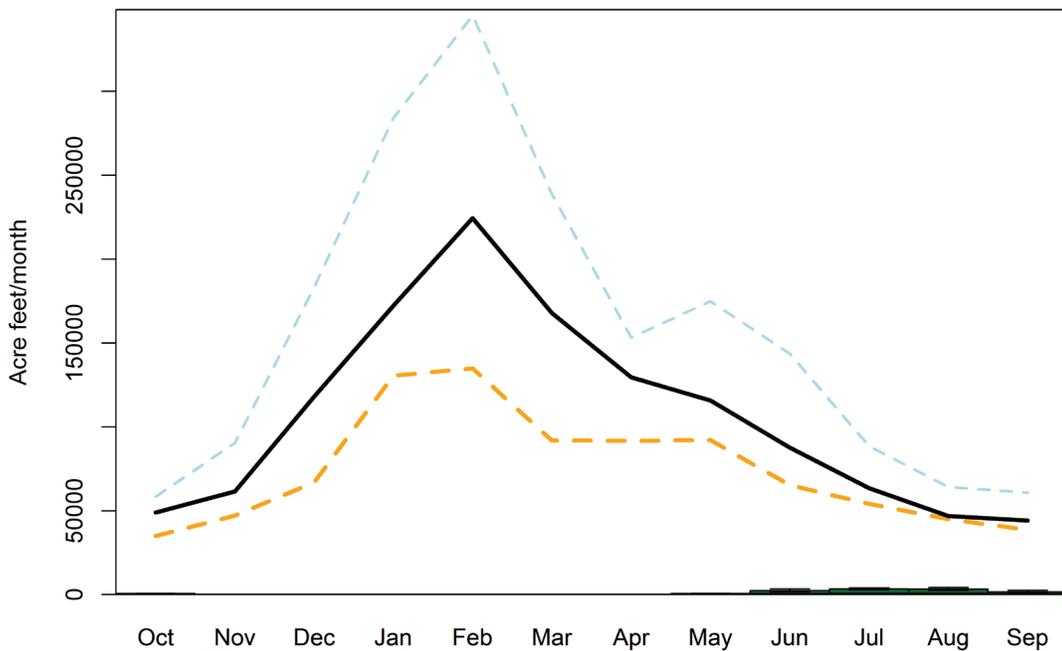
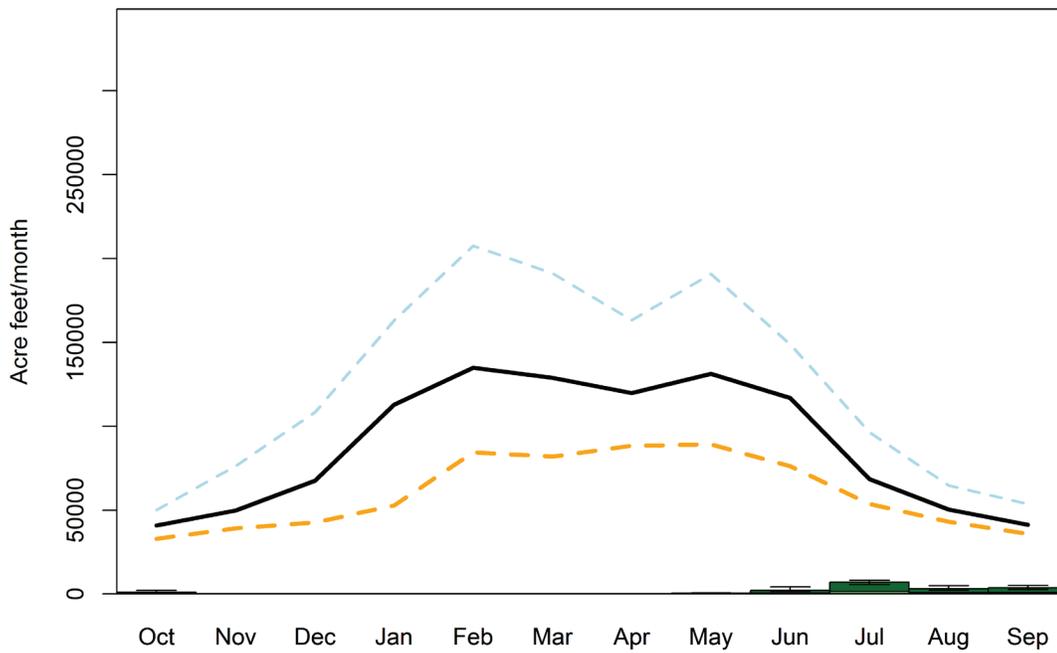
Klickitat

Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND

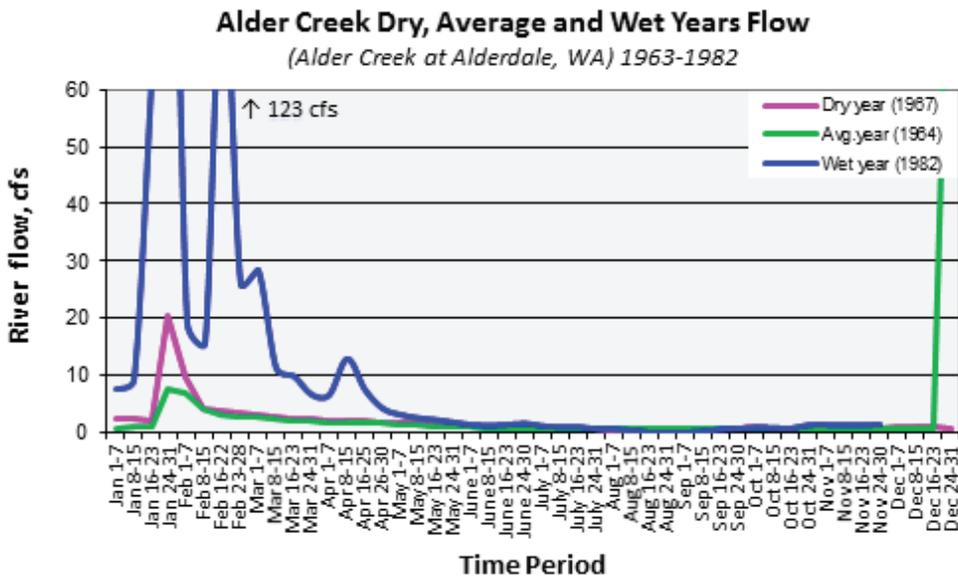


Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- 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, with much smaller municipal demands.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase slightly during April, May and October, and decrease slightly during July through September. These changes are primarily in response to climate change rather than crop mix changes.
- Municipal demands are expected to grow 14% by 2035.

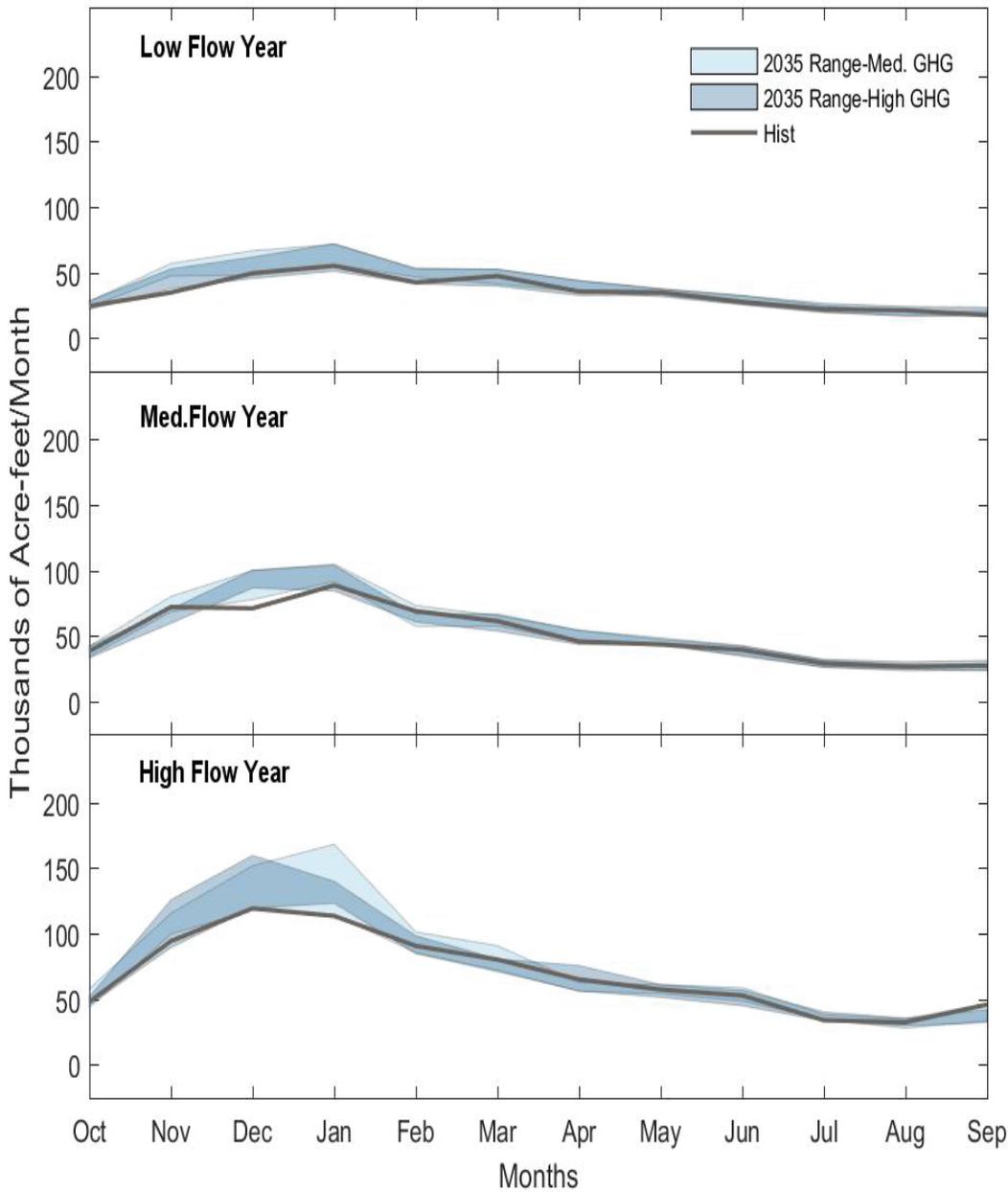
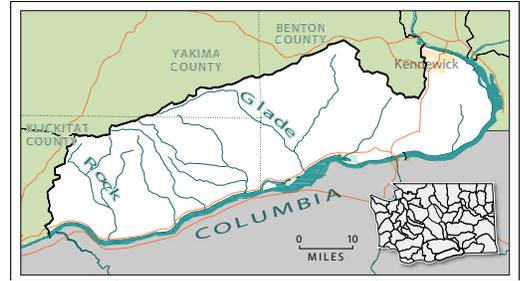
MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Middle Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

<sup>1</sup>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.

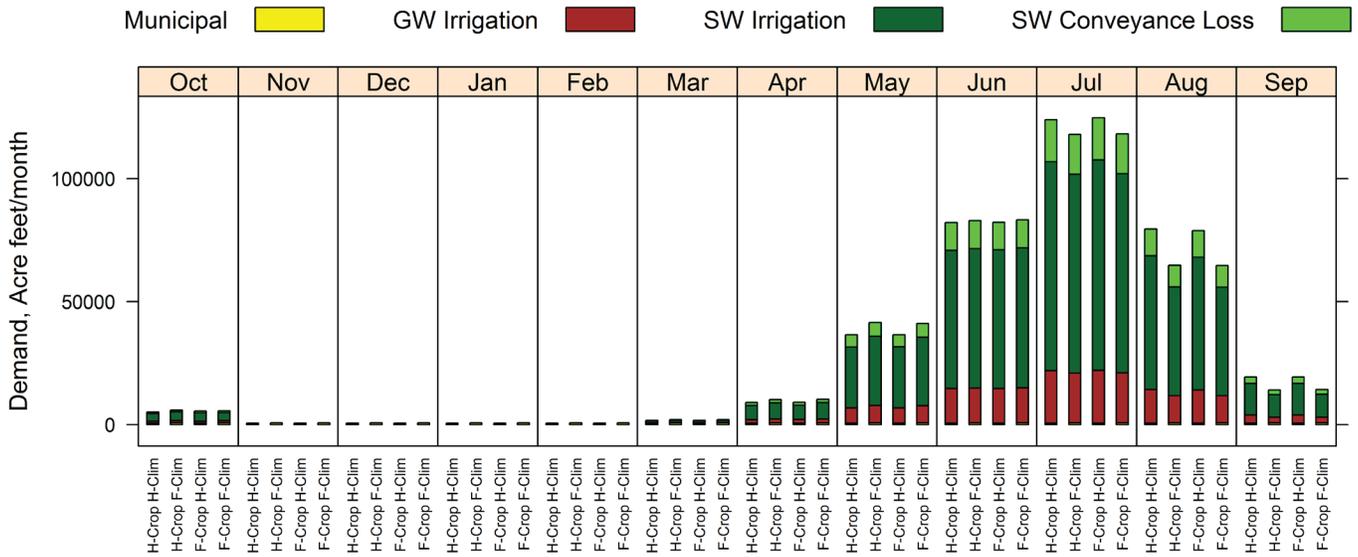


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

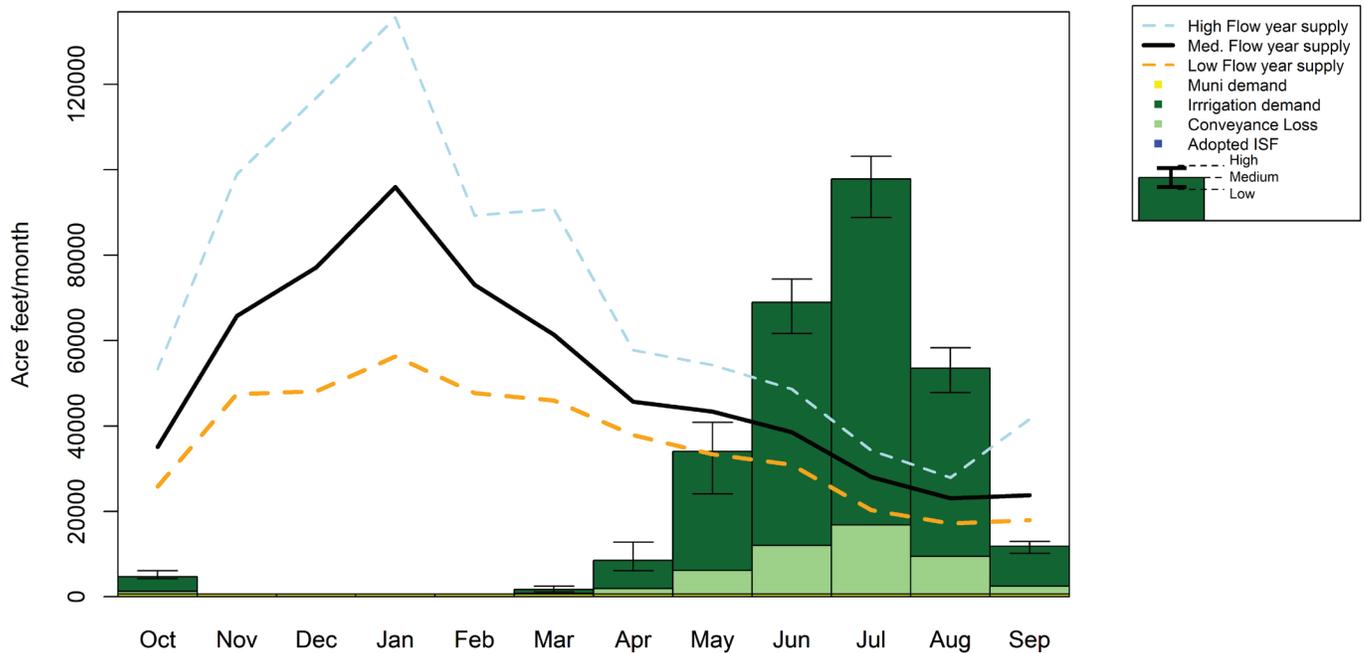
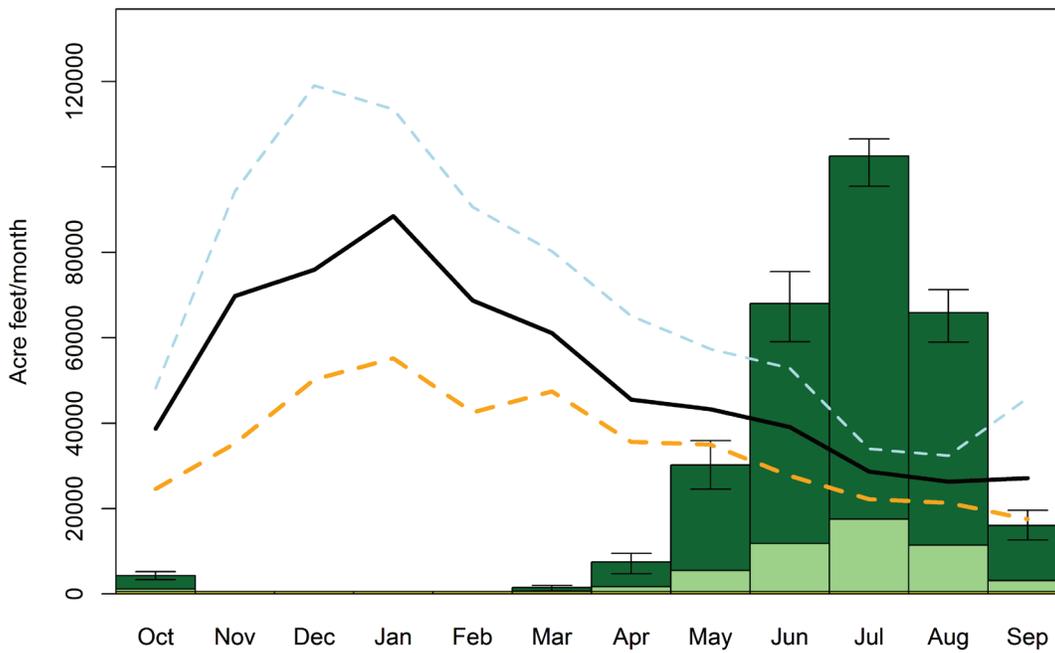


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) “H-Crop H-Clim”, b) “H-Crop F-Clim”, c) “F-Crop H-Clim”, and d) “F-Crop F-Clim” where “H-Crop” represents historic crop mix; “F-Crop” as future crop mix under medium economic scenario, “H-Clim” as historic climate and “F-Clim” values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

## SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

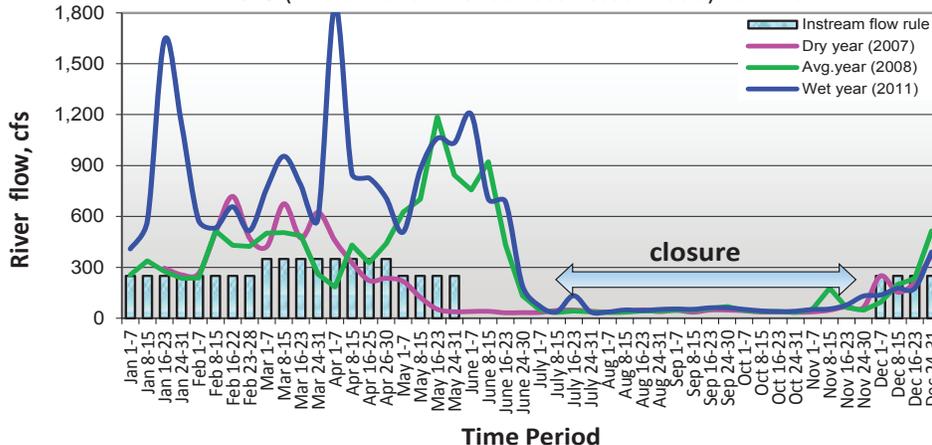
- The tributary surface water supply forecast for Walla Walla is uncertain with climate scenarios showing a combination of increases and decreases from January through June.
- Primary demands are irrigation and instream flow requirements, with much smaller municipal demands.
- Assuming no change in irrigated acreage, irrigation demands are forecasted to increase during the irrigation season between April and October. This increase is primarily due to crop mix changes (particularly during the months of May through September) with climate changes resulting (in isolation) in decreases in demand for Jun through September.
- Municipal demands are projected to grow 9% by 2035.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIs that provide habitat for ESA-listed anadromous salmonids.
- Curtailment magnitude peaks during May and July; however July through September are the months with the most number of curtailment events for both historical and future conditions.
- Forecast shows more frequent curtailment events earlier in the season.

MANAGEMENT CONTEXT	
Adjudicated Areas	Upper Stone Creek, Doan Creek, Bigelow Gulch Creek, Touchet River, Dry Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-532 WAC). 65 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 averaged 4 to 5 years from December to June (85% reliable), and 8 years from July to October (75% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Middle Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

<sup>1</sup>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.

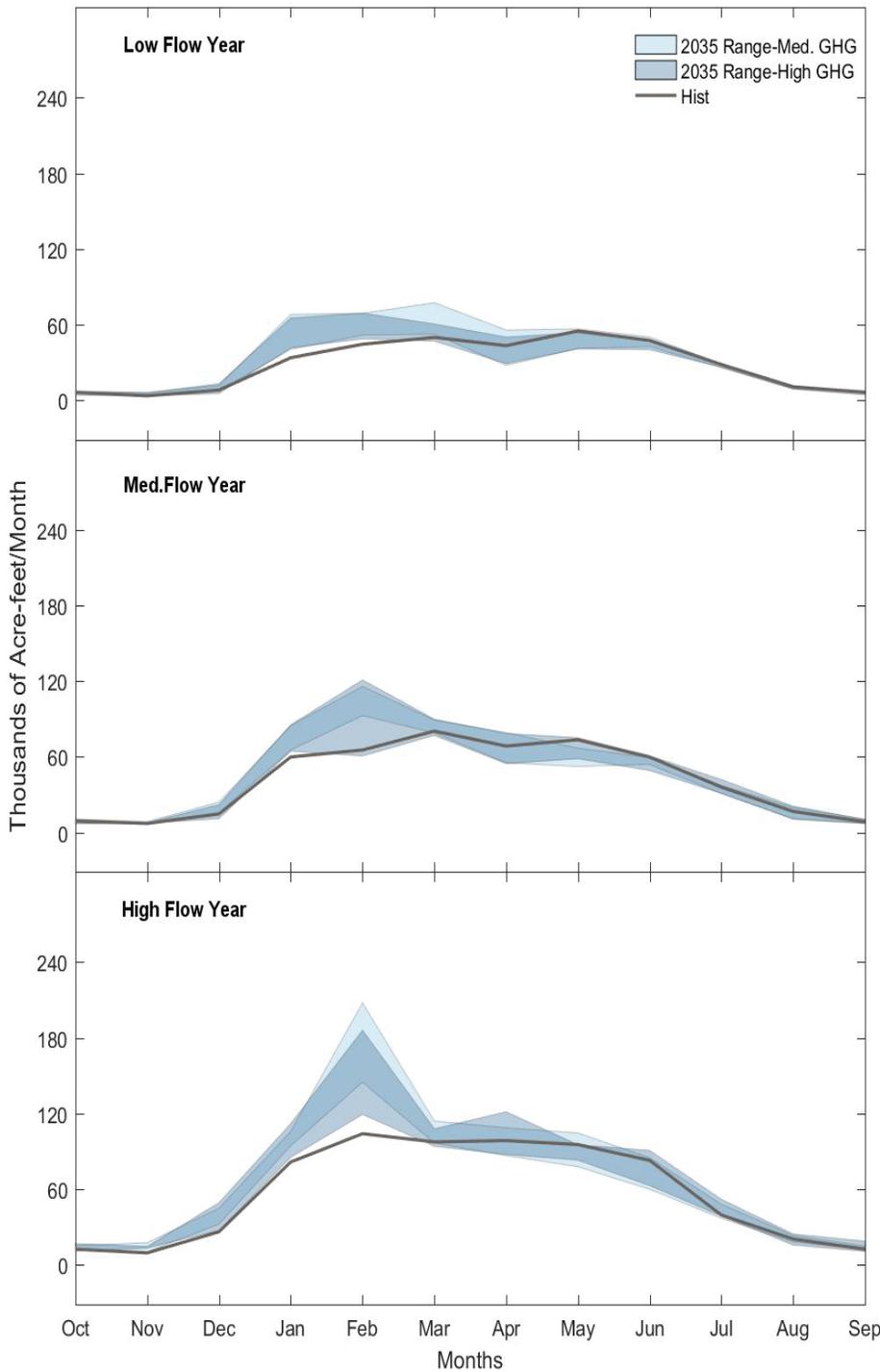
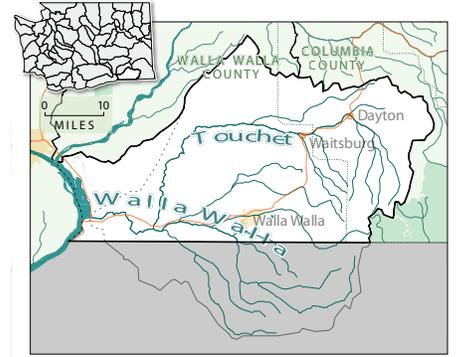
A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 186. Summaries are also available online at <http://apps.wdfw.wa.gov/salmonscape/>.

**Comparison of Dry, Average and Wet Year Flows to Instream Flow Rule**  
 Rule (Walla Walla River at East Detour Road) 2007-2011

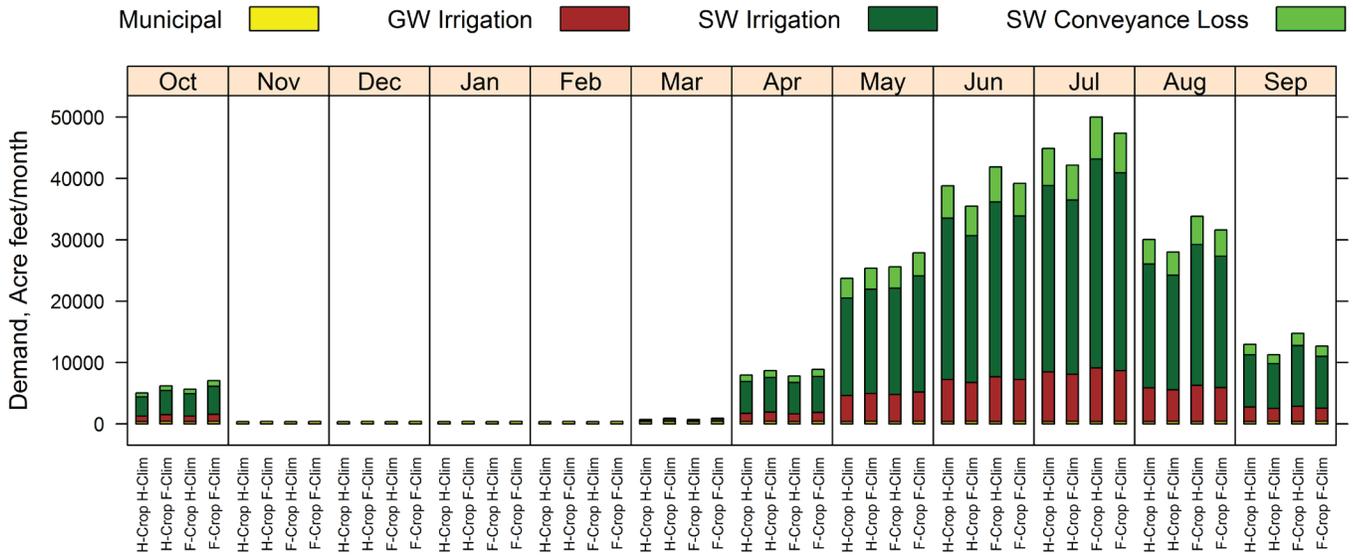


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

SUPPLY

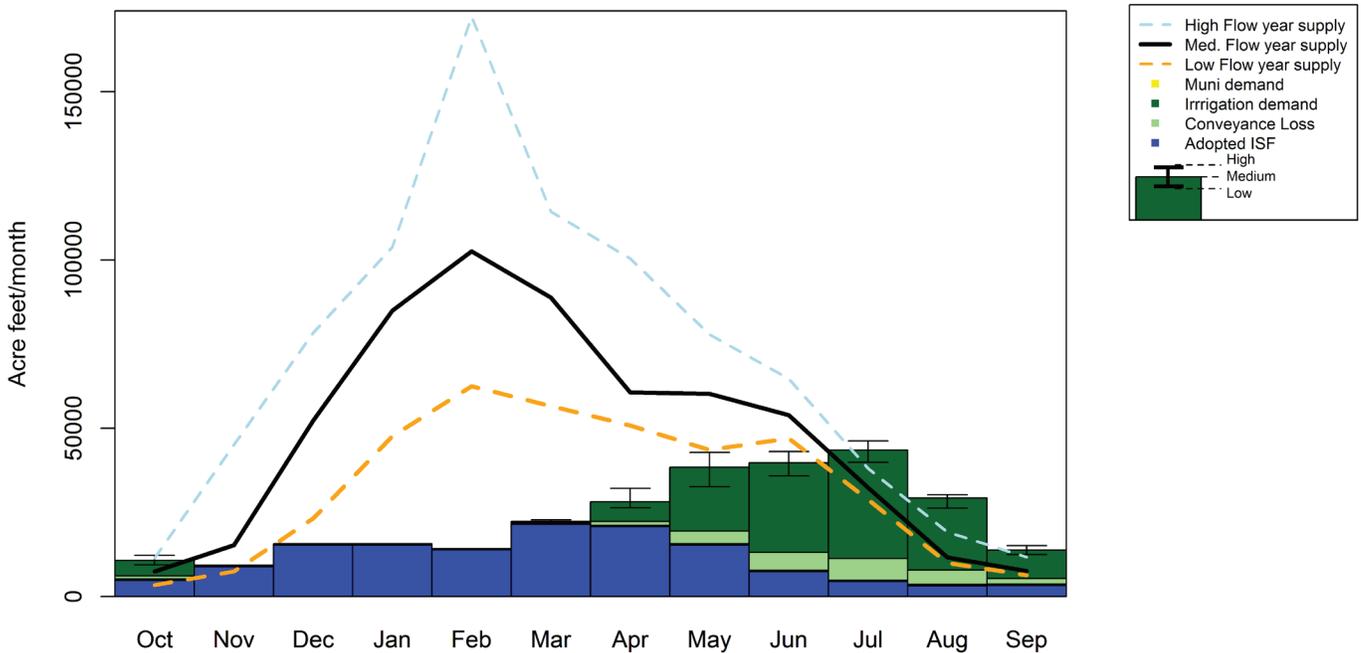
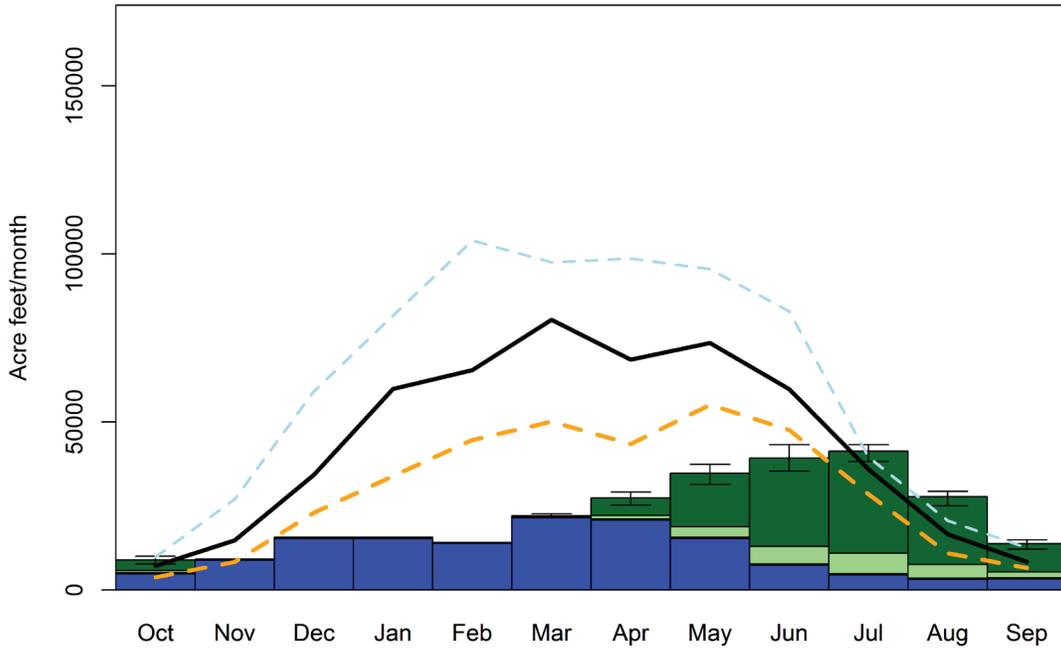


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

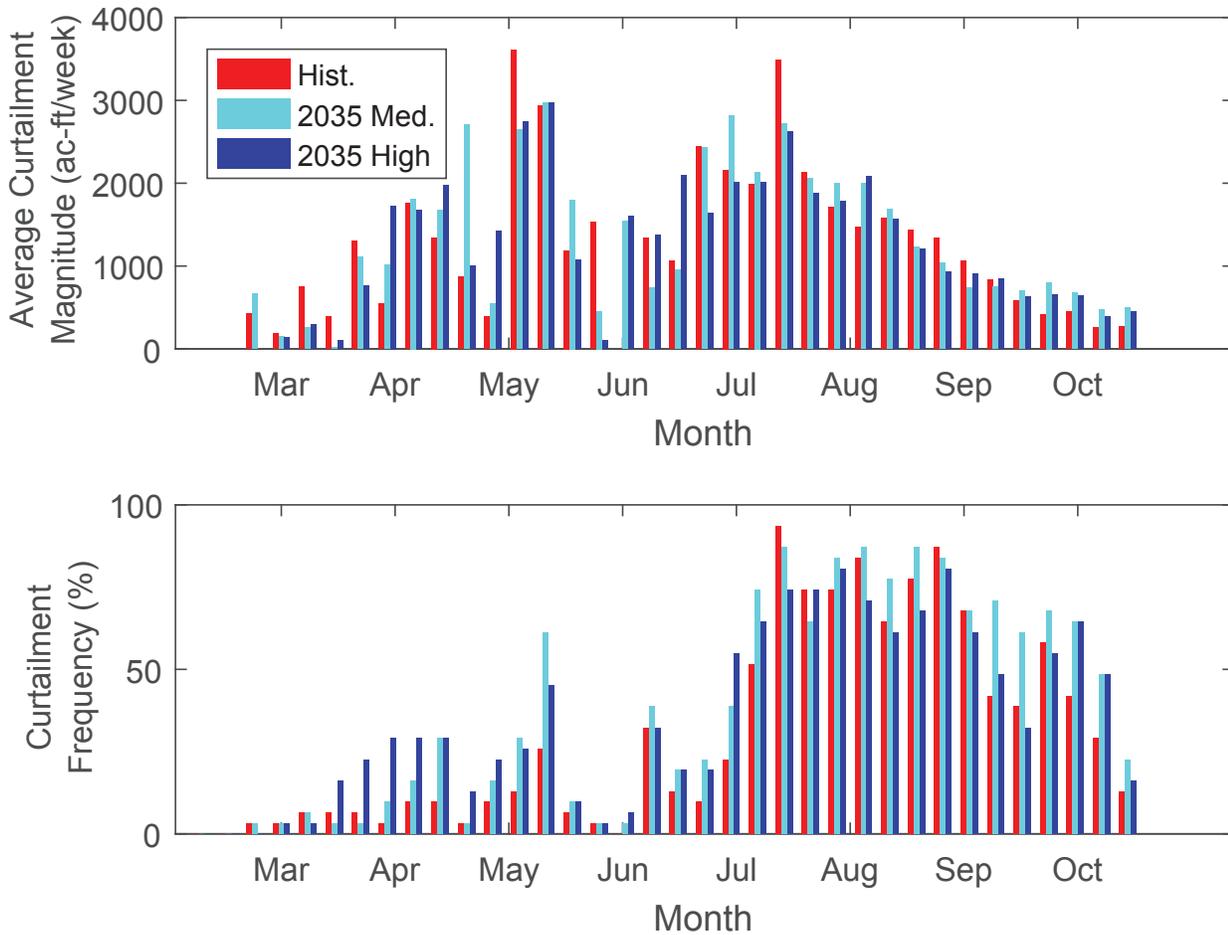


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.



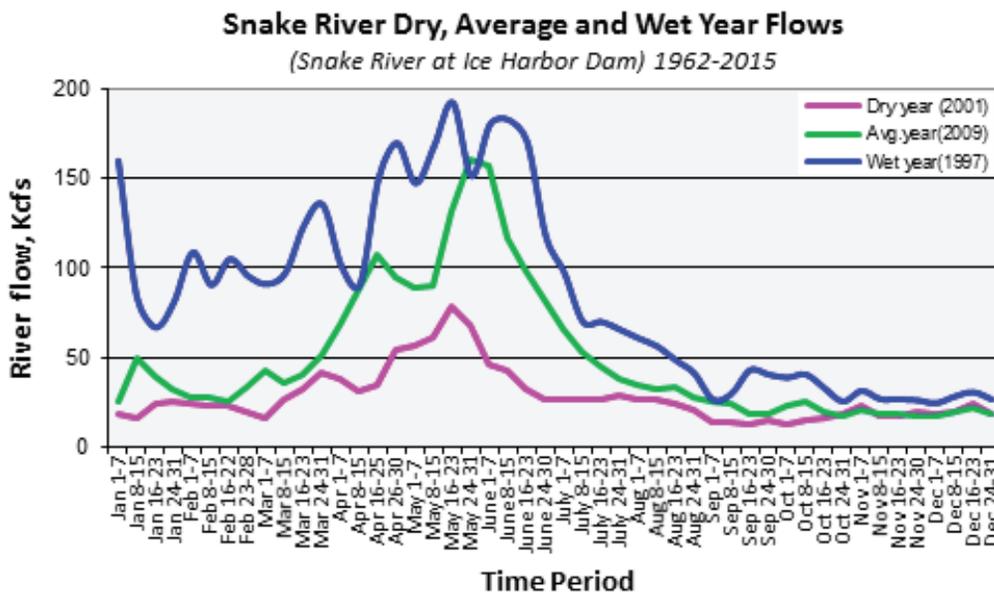
Modeled historical (1981-2011) and forecast (2035) median curtailment magnitude (ac-ft per week) (top panel) and curtailment frequency (%) (bottom panel) in this WRIA. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

## MANAGEMENT CONTEXT

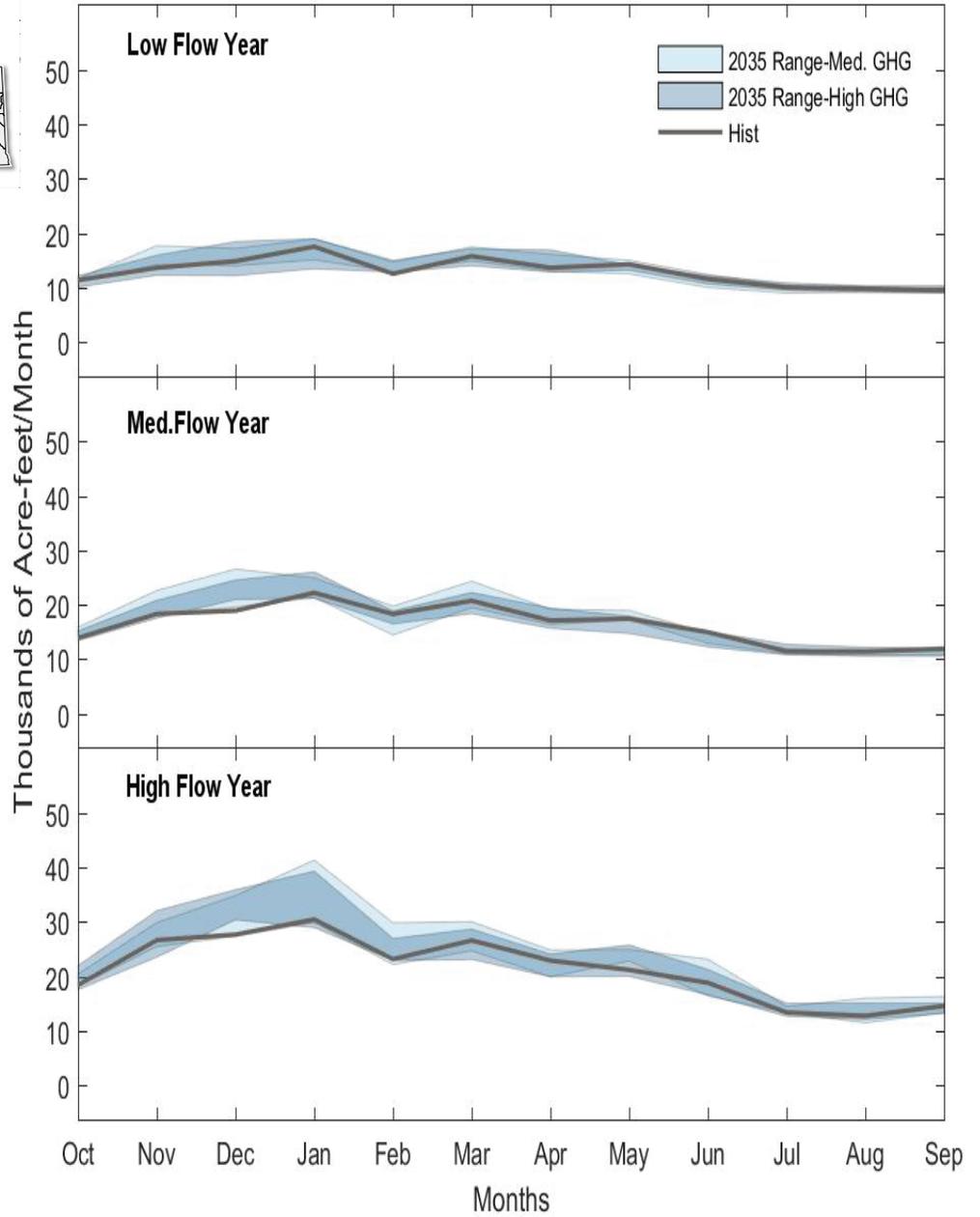
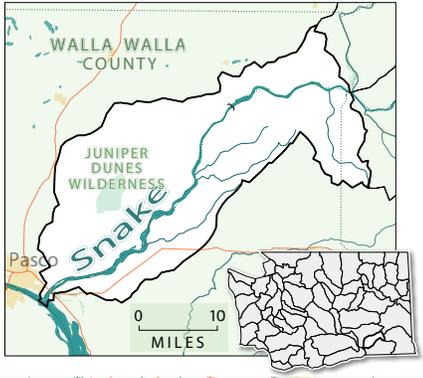
- The tributary surface water supply forecast for Lower Snake is characterized mostly by small increases in some years from October through February, and lower but uncertain changes from March through September.
- As in many other WRIsAs in eastern Washington, irrigation demands dominate, and municipal demands are much smaller.
- Assuming no change in irrigated acreage, irrigation demands are projected to decrease somewhat for June through September and increase somewhat for October, April, and May. The changes are primarily in response to a crop mix change.
- Municipal demands are expected to grow 9% by 2035.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	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)

<sup>1</sup>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.

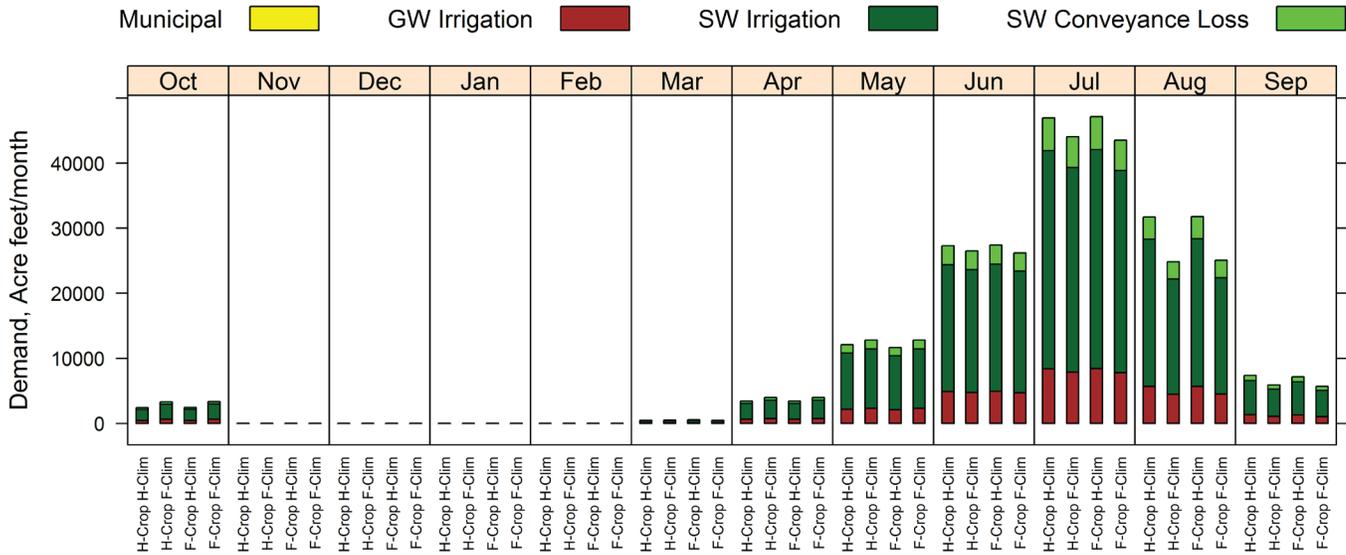


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

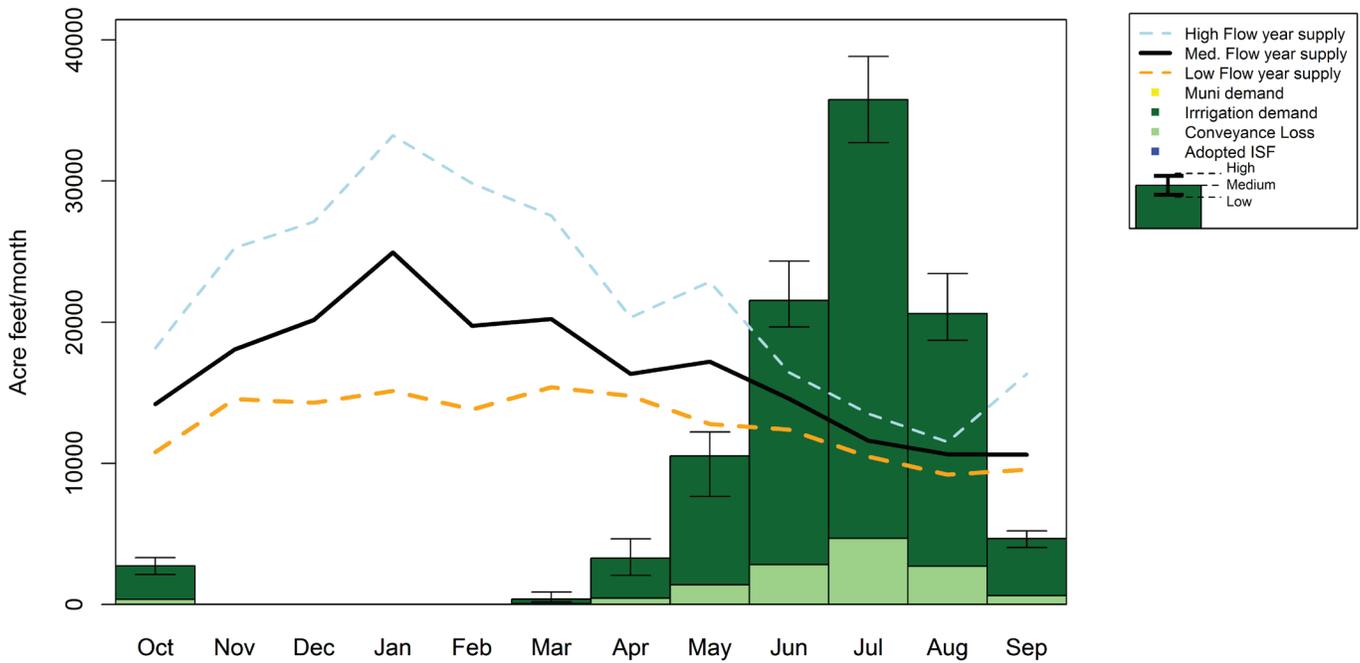
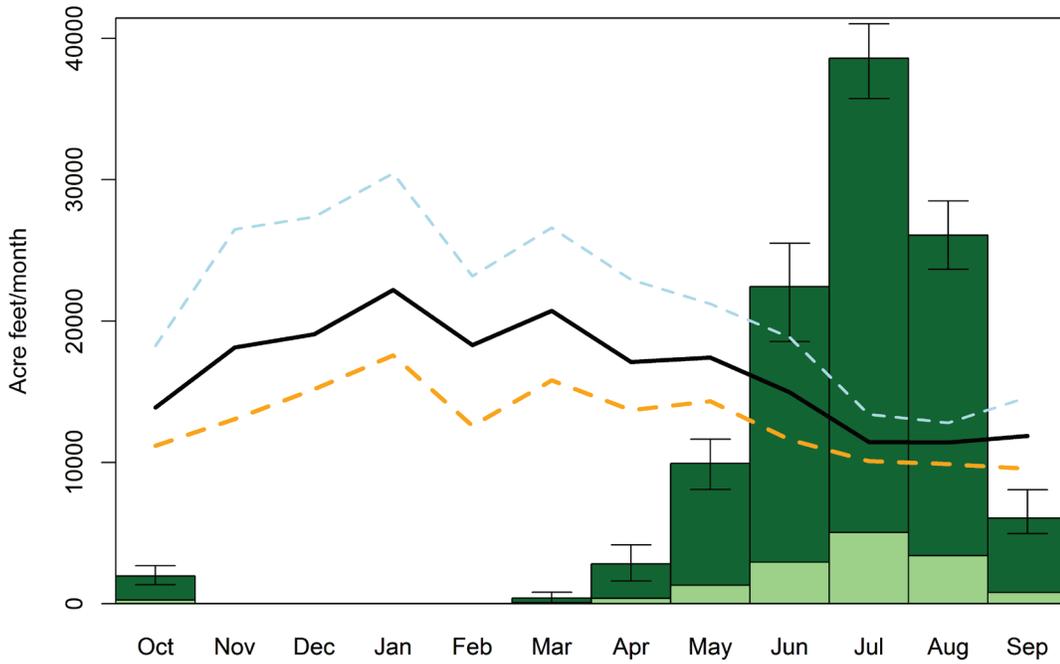


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



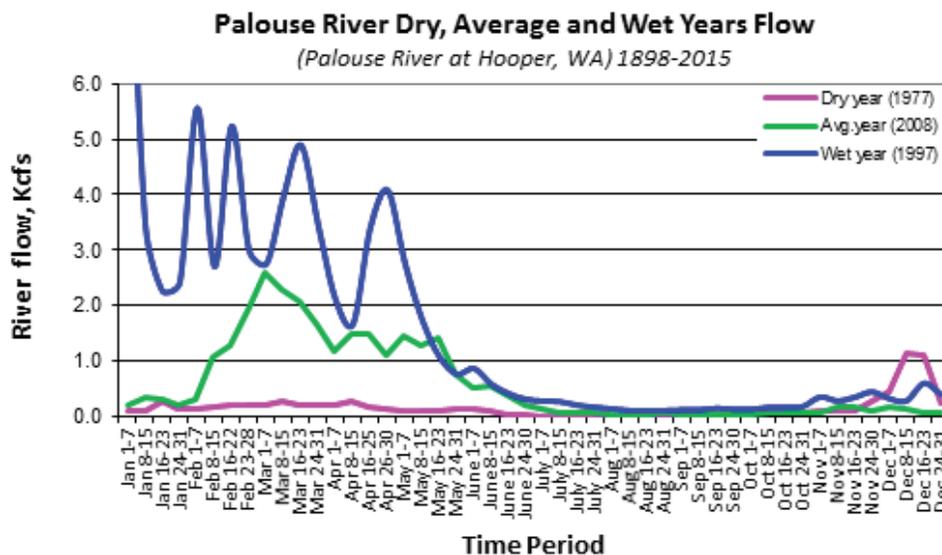
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

## MANAGEMENT CONTEXT

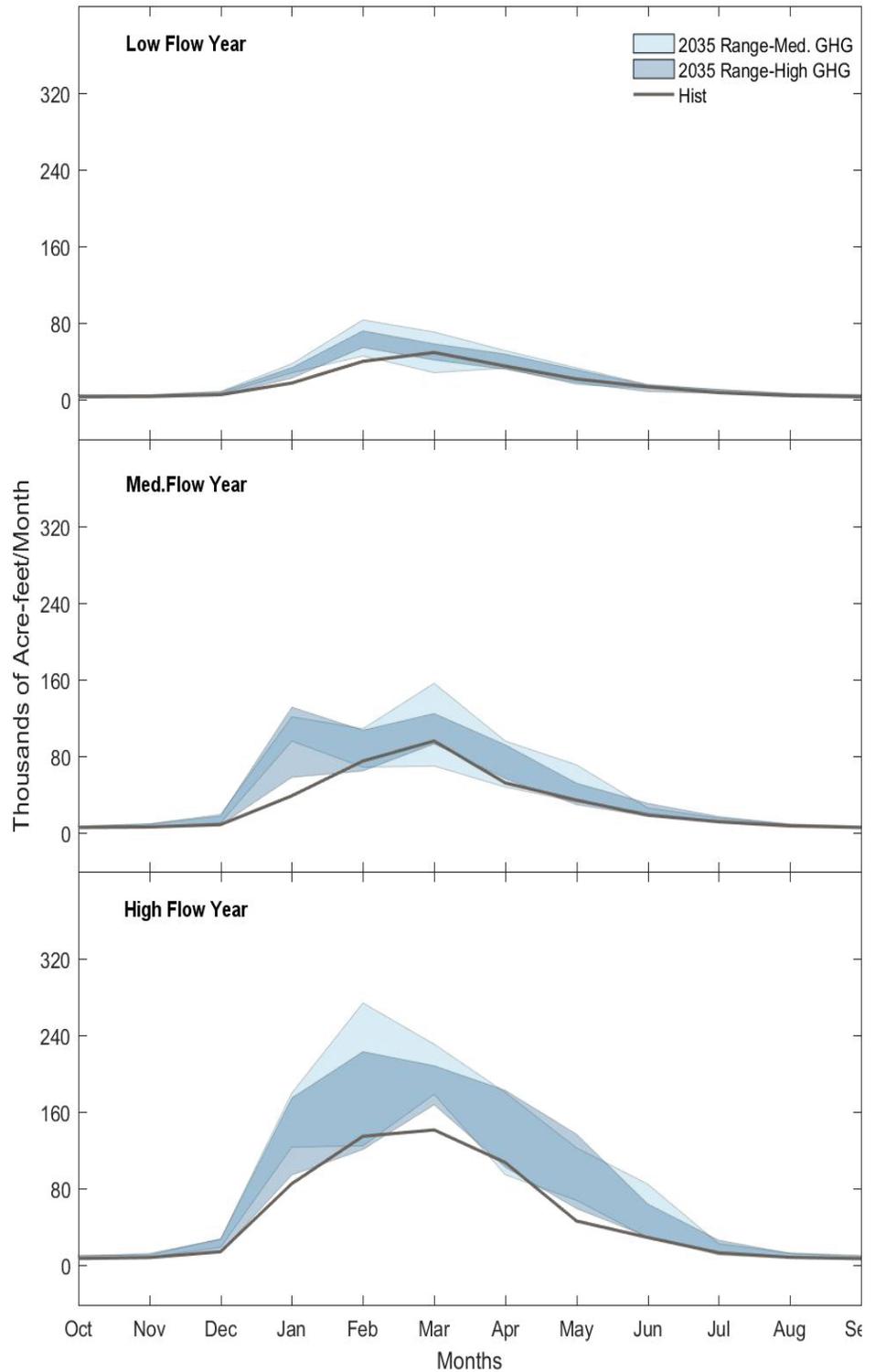
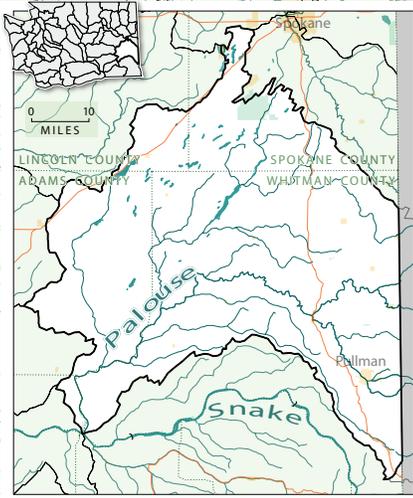
- The tributary surface water supply forecast for Palouse is less certain with climate scenarios showing a range of increases and decreases from January through May, although the 80th supply year shows primarily increases in February and March.
- Irrigation is the primary demand, though municipal demands are also sizeable.
- Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in most months of the irrigation season. Increase in demand is primarily attributed from climate change. Decrease in demand in June, August, and October are due to both crop mix changes and climate changes. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2035 from groundwater to surface water. Municipal demands are projected to increase 24% by 2035, a smaller increase than in most other watersheds in eastern Washington.

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 <sup>1</sup>	[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)

<sup>1</sup>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.

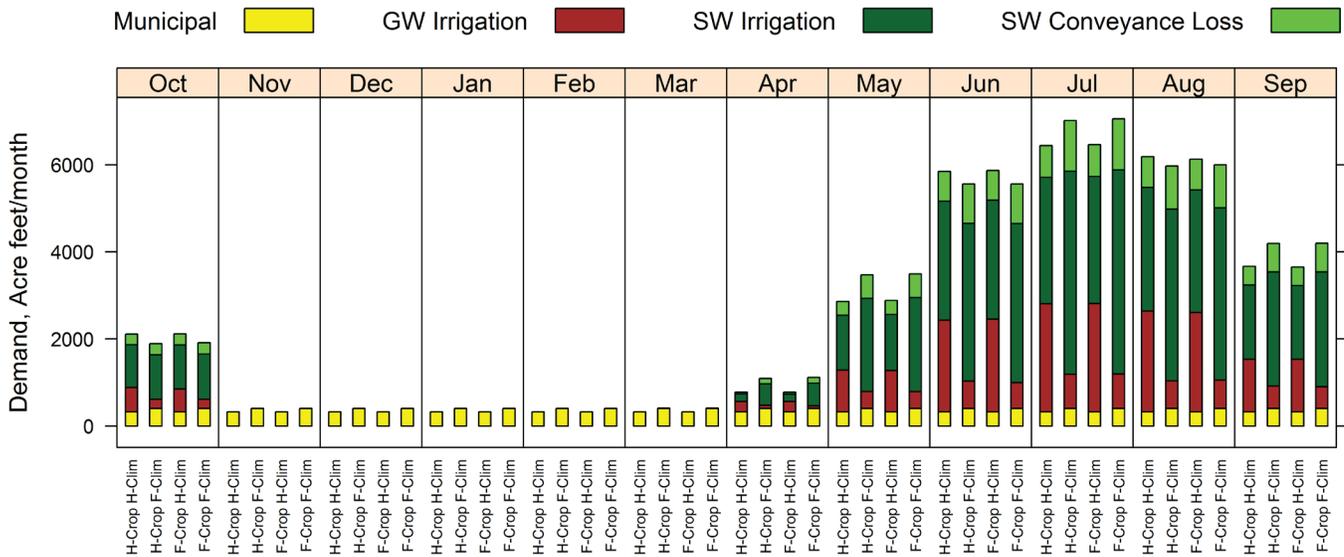


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

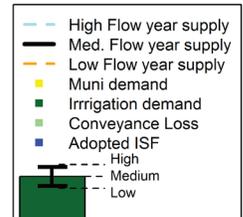
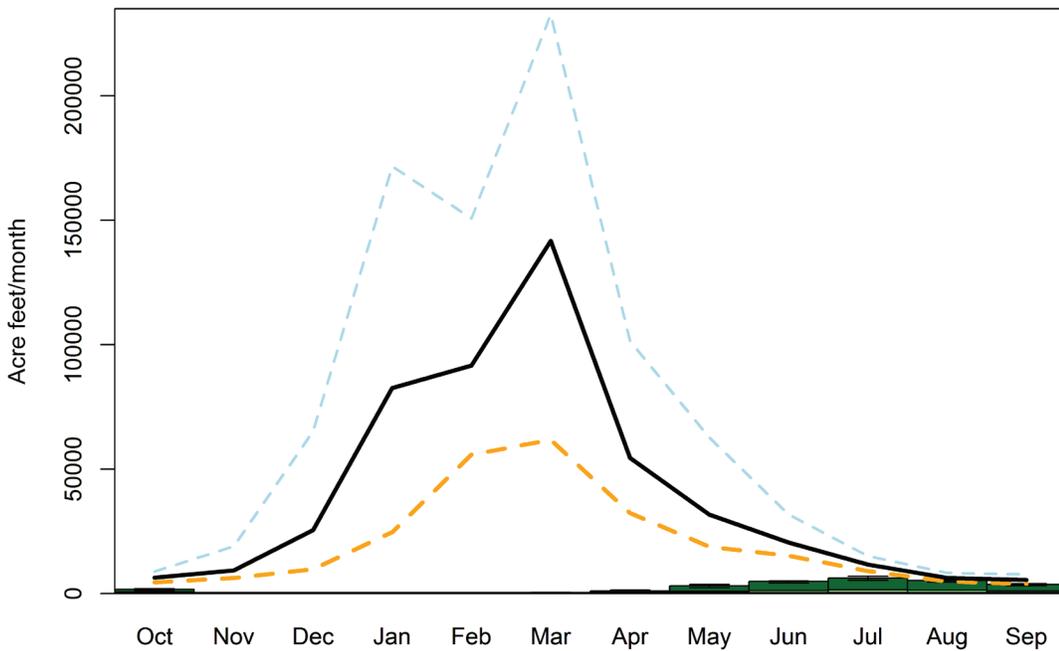
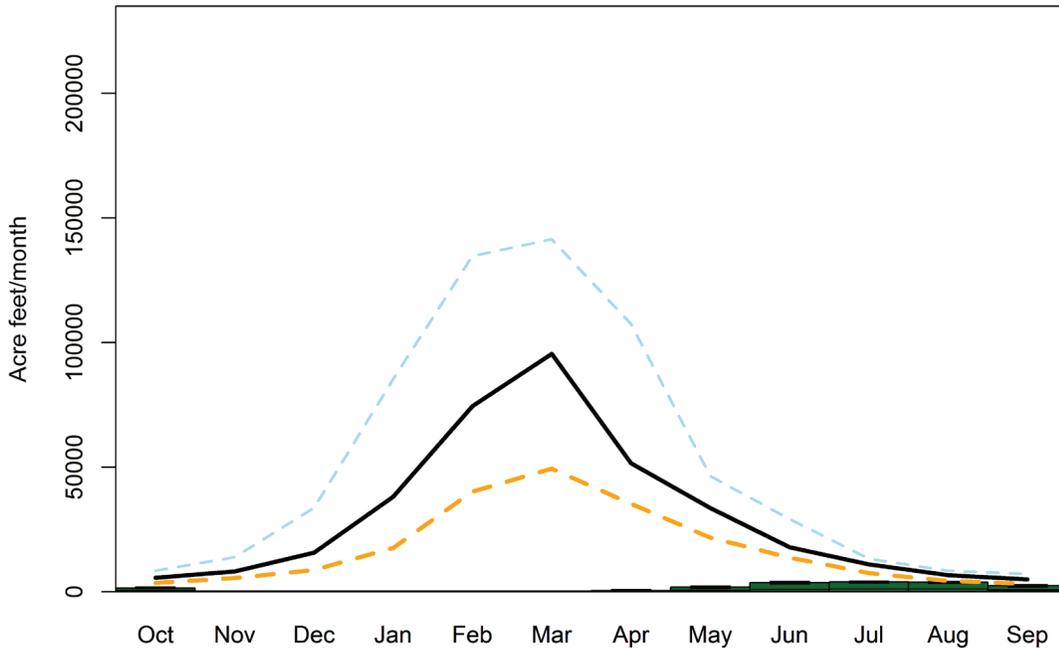


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

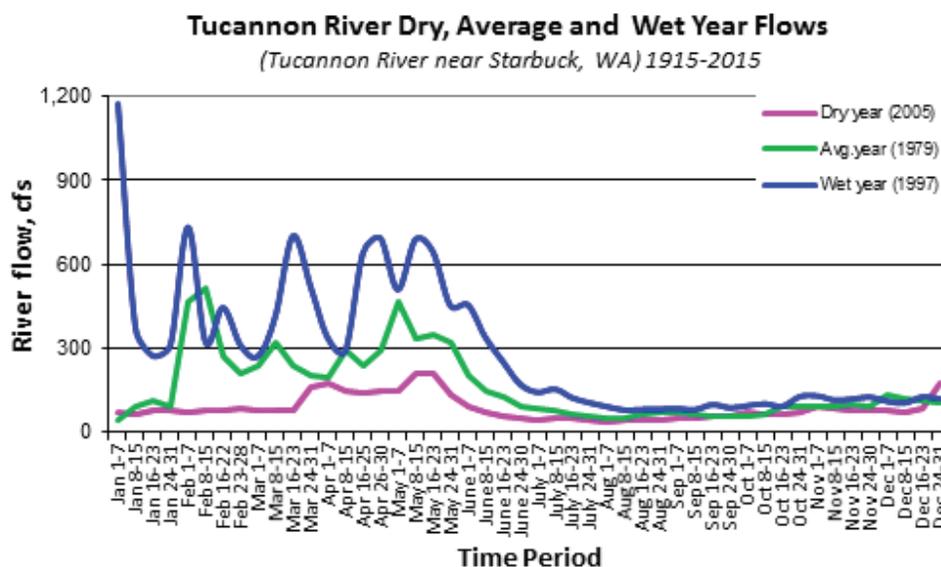
## MANAGEMENT CONTEXT

- The tributary surface water supply forecast for Middle Snake is characterized mostly by increases from late fall through early spring, followed by decreases for March and April. While the 20th and 50th percentile supply years show decreases in June, the 80th percentile supply year shows primarily increases.
- Overall demands are relatively modest compared to other watersheds in eastern Washington, with municipal demands that are generally on par with irrigation demands, depending on the month.
- Assuming no change in irrigated acreage, irrigation demand is expected to increase in July only with decreases during the remainder of the irrigation season. Climate and crop mix changes are both contributing to decrease in June, August, and October while increase in only July, showing opposite results in rest of the irrigation months.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIs that provide habitat for ESA-listed anadromous salmonids.

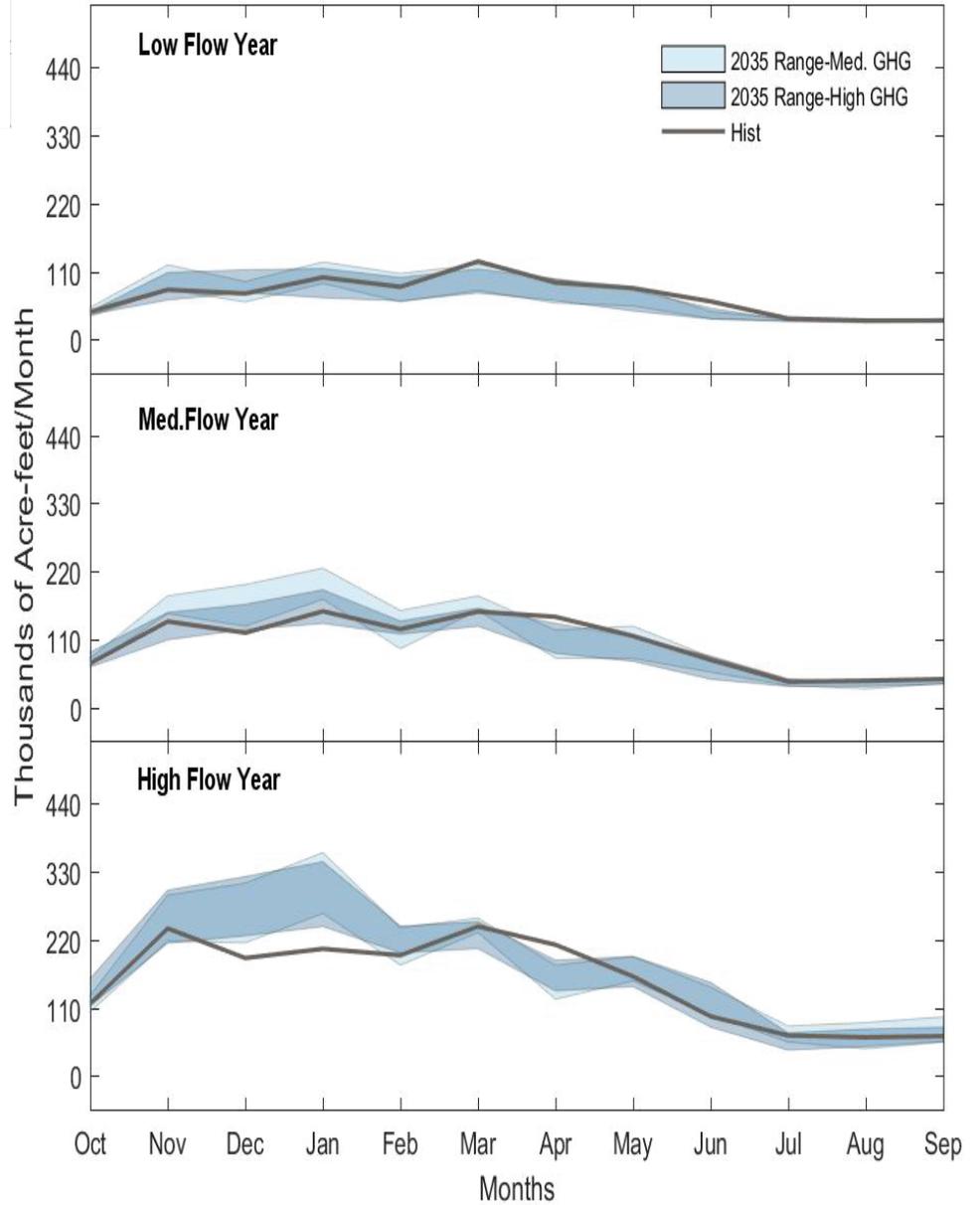
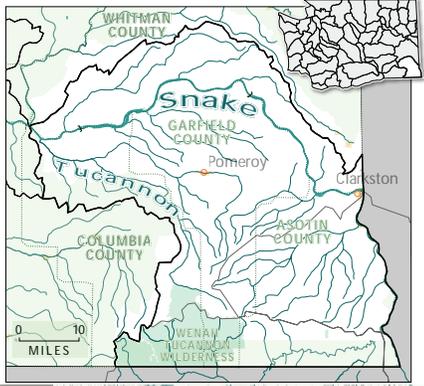
MANAGEMENT CONTEXT	
Adjudicated Areas	Deadman Creek , Wawawai Creek, Meadow Gulch Creek, Alpowa Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Snake River Basin Steelhead, Snake River Bull Trout, Snake River Fall Run Chinook, Snake River Spring and Summer Run Chinook [Snake mainstem migratory corridor for Snake River sockeye]
Groundwater Management Area	NO

<sup>1</sup>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.

A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 186. Summaries are also available online at <http://apps.wdfw.wa.gov/salmonscope/>.

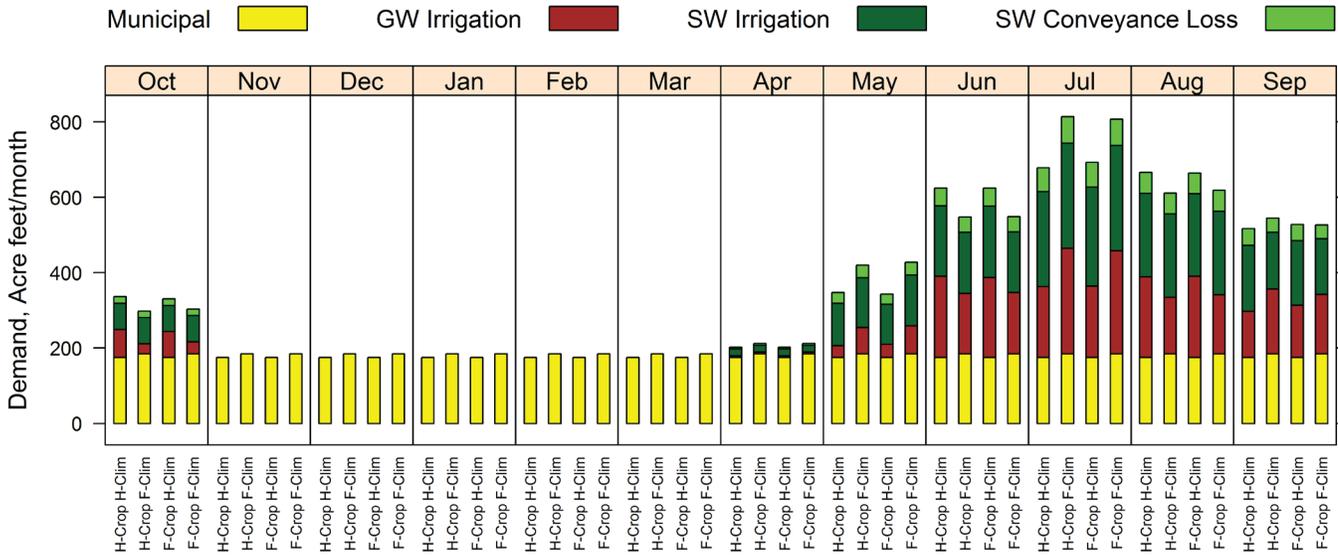


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

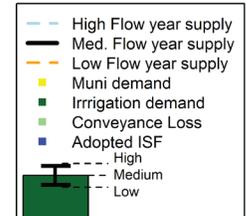
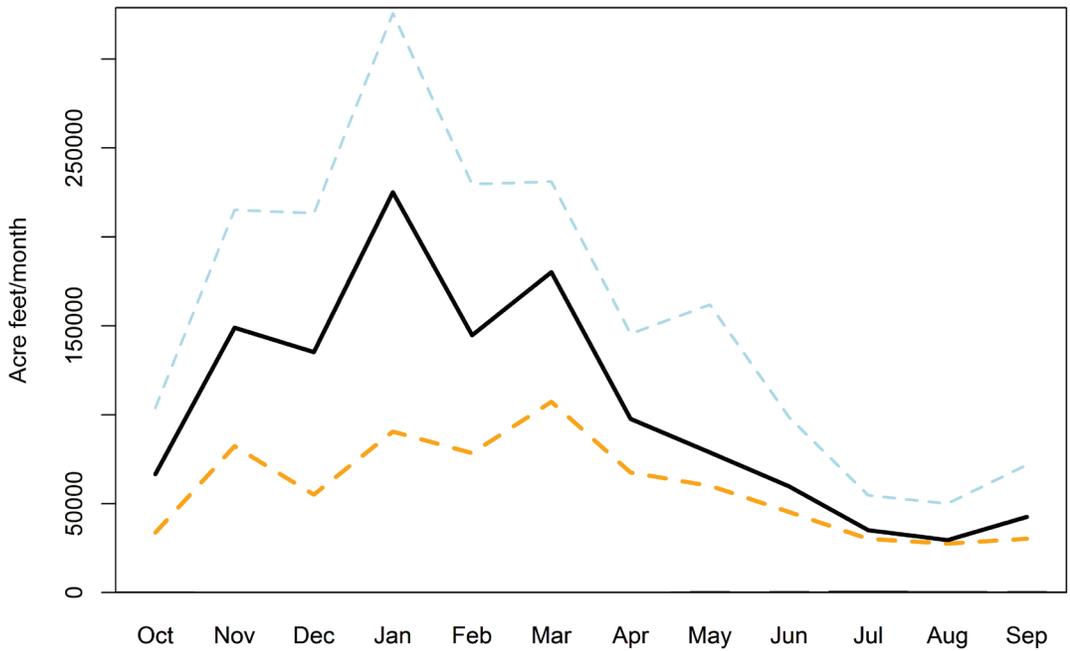
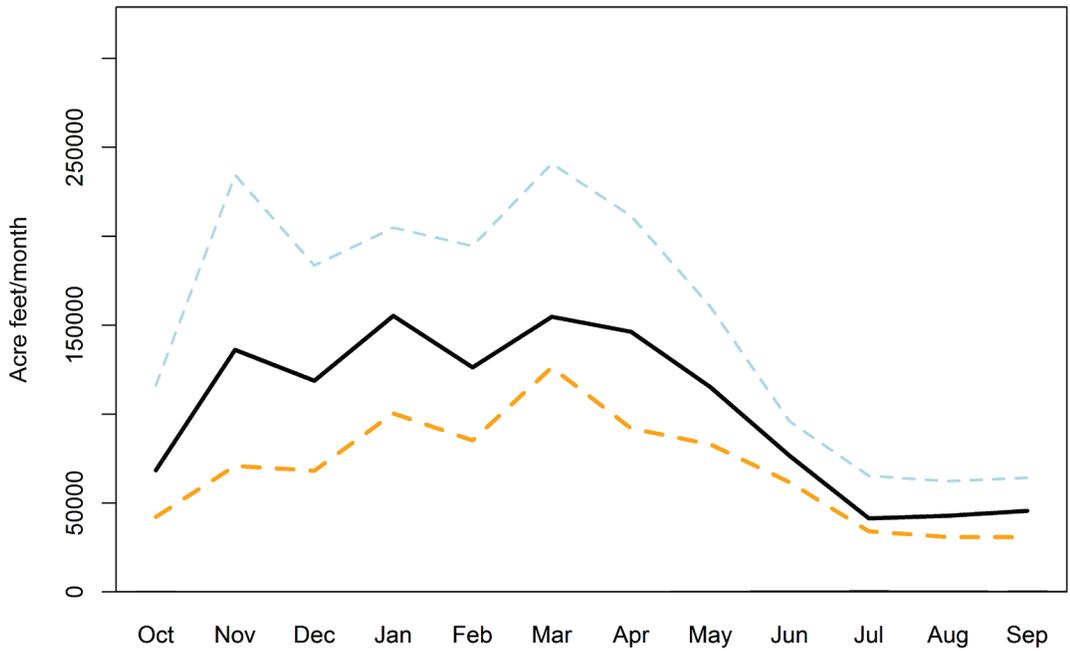


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



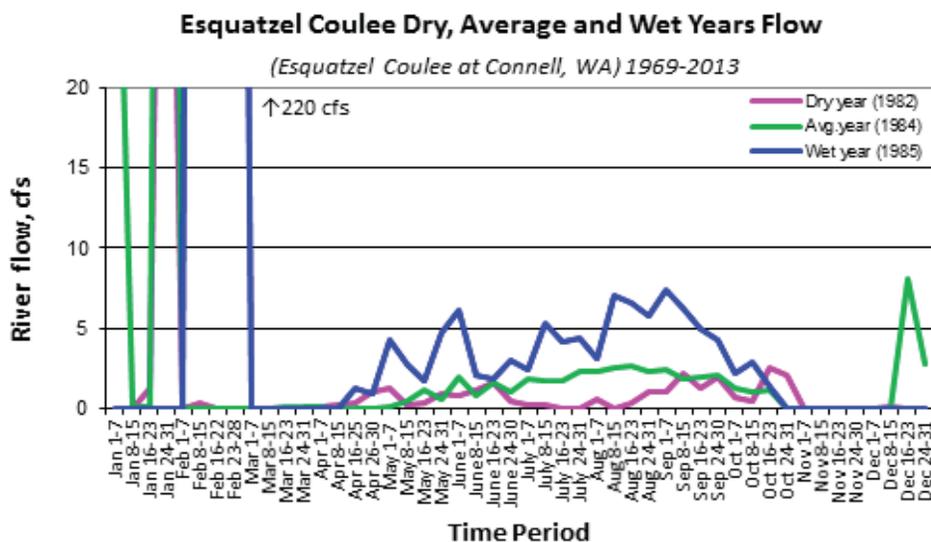
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

## MANAGEMENT CONTEXT

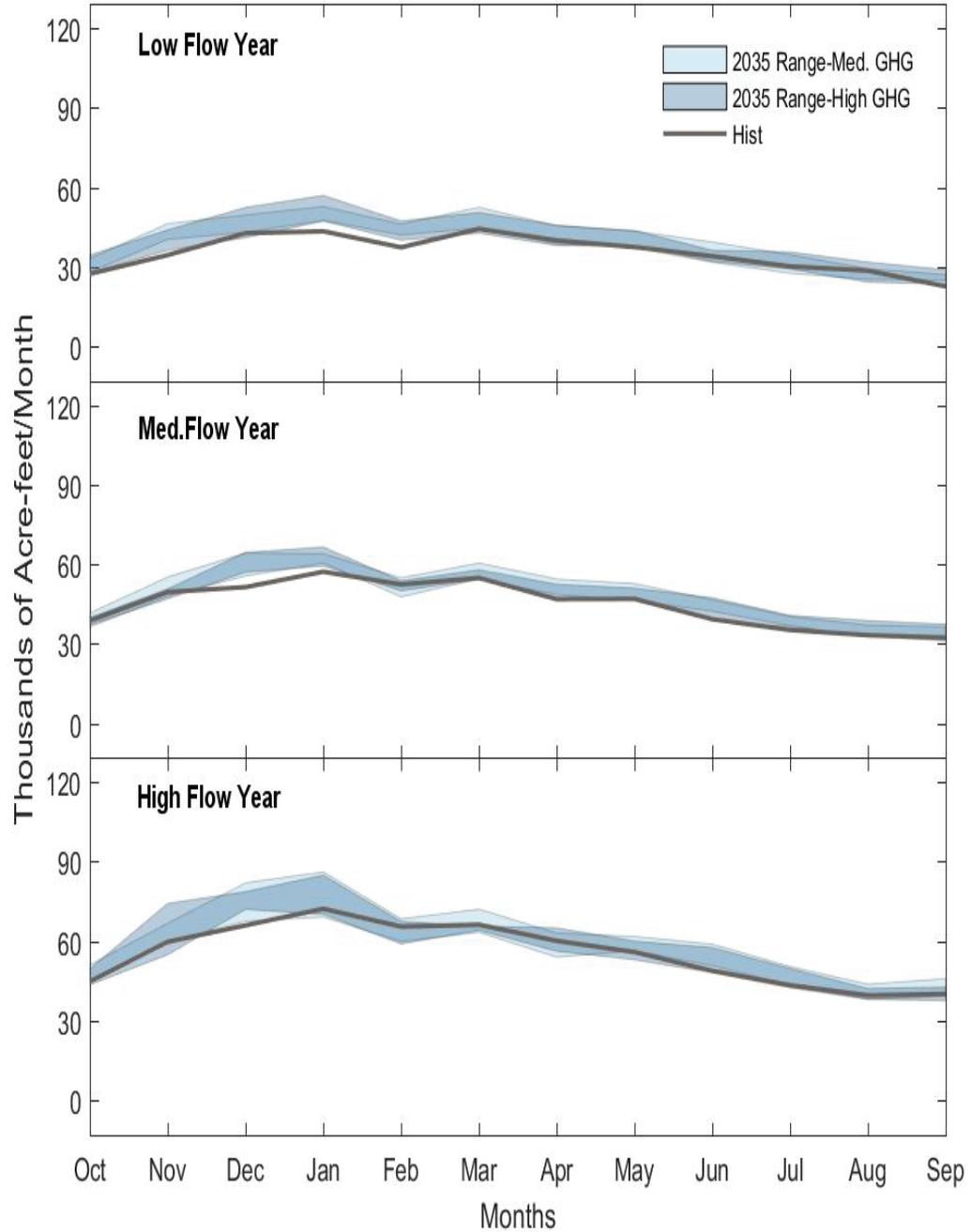
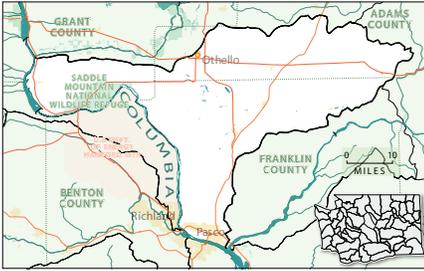
- The tributary surface water supply forecast for Esquatzel Coulee shows little change, with possible slight increases throughout the year but primarily from September through January.
- Irrigation is the most significant source of demand. Municipal demands are quite small in comparison, though larger than those of many other eastern Washington WRIsAs.
- Assuming no change in irrigated acreage, irrigation demand is expected to increase in April and May, but decrease in other future months. Decrease in demand in July is primarily contributed from climate change while in August and September from both climate change and crop mix change. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2035 from groundwater to surface water.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	[Columbia mainstem migratory corridor]
Groundwater Management Area	YES (Columbia Basin GWMA and Odessa Subarea)

<sup>1</sup>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.

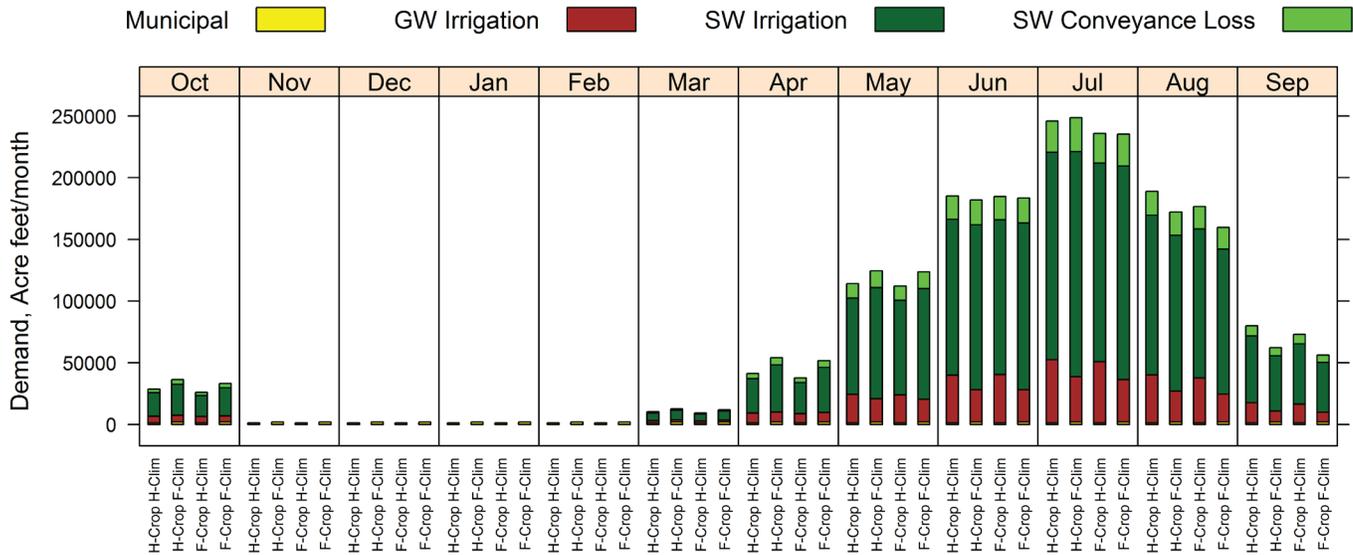


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

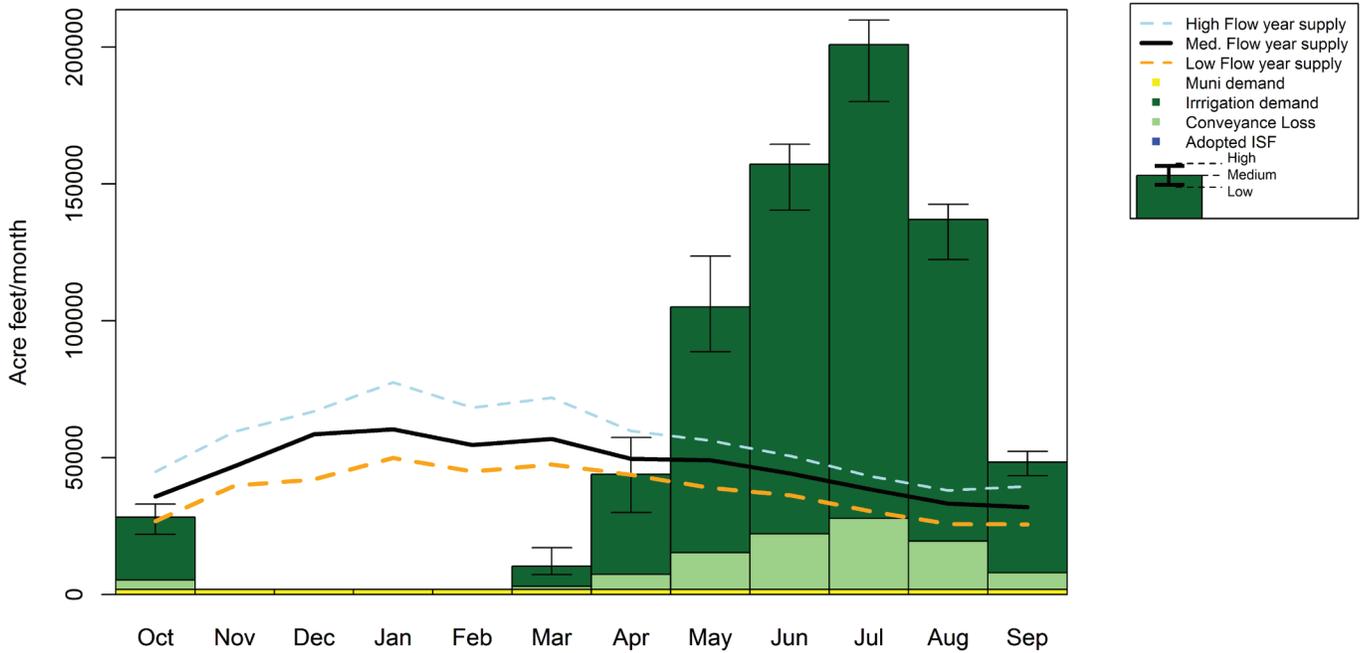
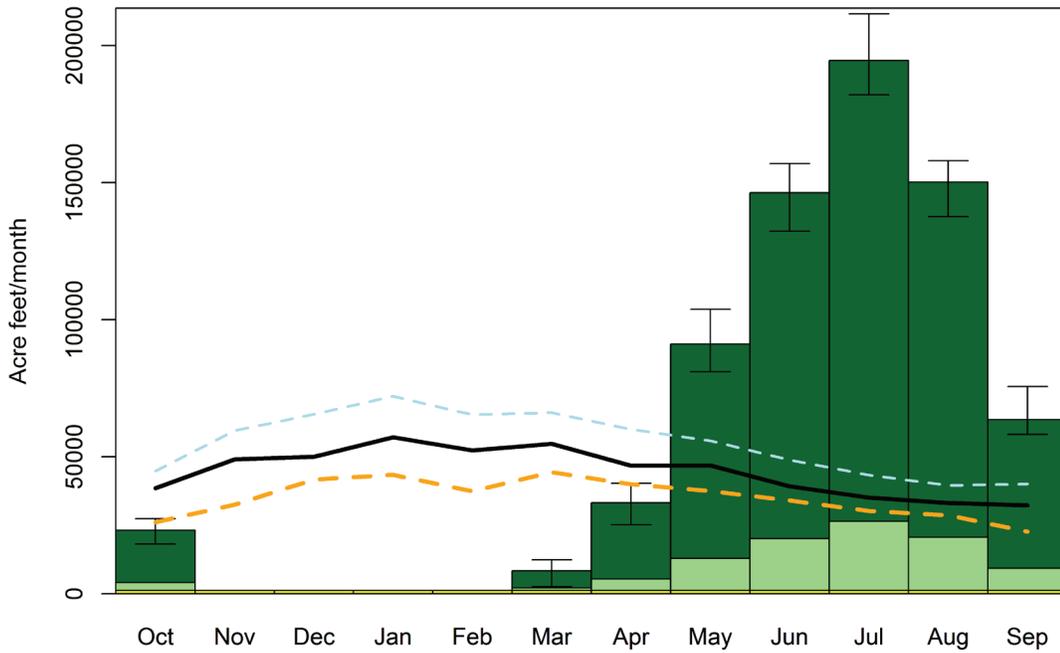


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) “H-Crop H-Clim”, b) “H-Crop F-Clim”, c) “F-Crop H-Clim”, and d) “F-Crop F-Clim” where “H-Crop” represents historic crop mix; “F-Crop” as future crop mix under medium economic scenario, “H-Clim” as historic climate and “F-Clim” values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

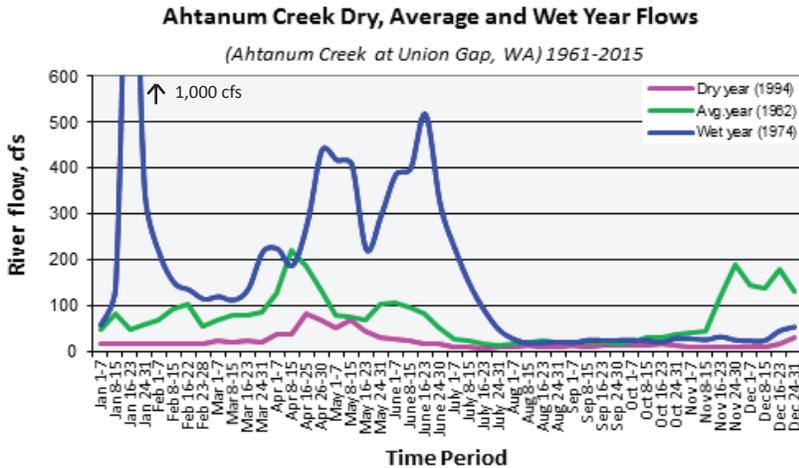
MANAGEMENT CONTEXT

- The regulated tributary surface water supply forecast for the Yakima is characterized by increases from November through March, followed by decreases primarily in May and June.
- Irrigation is the primary source of demand in these WRIs. 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 in WRIA 37 are significantly larger than most other WRIs of eastern Washington.
- Assuming no change in irrigated acreage, irrigation demand is forecasted to increase during March through May and decrease during June through September. These changes are somewhat equally due to both climate and crop mix changes.
- Municipal demand is projected to grow by 17%, 9%, and 10% for WRIs 37, 38, and 39, respectively, by 2035.
- These WRIs are included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIs that provide habitat for ESA-listed anadromous salmonids.
- Forecast shows no major changes in the magnitude of proration rates between historical and future simulations.
- Forecast shows an increased frequency of proration rates 90% or lower in the future simulations.

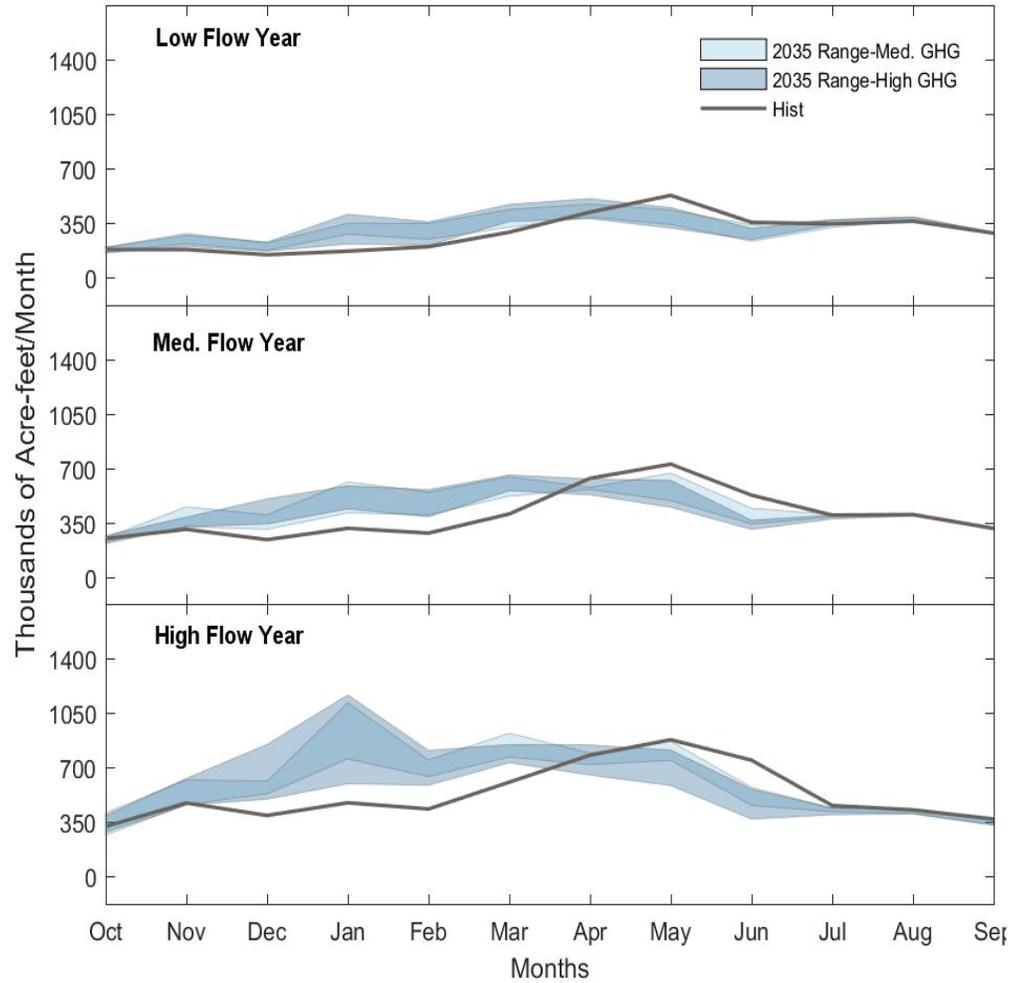
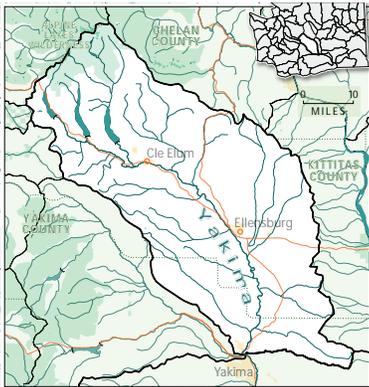
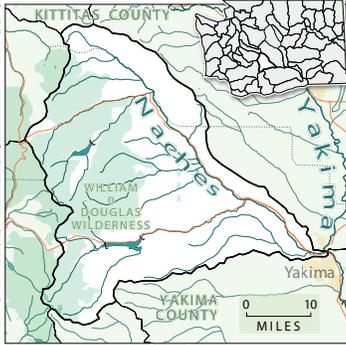
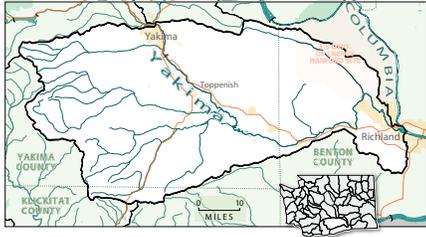
MANAGEMENT CONTEXT	
Adjudicated Areas	Ahtanum Creek, Cowiche Creek, Wenas Creek, Tenaway River, Cooke Creek, Big Creek, Basin-wide adjudication in process
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO (Target flows, enacted by Congress, and instream flow tribal treaty rights, affirmed by the Yakima Superior Court, are in place, both managed by the U.S. Bureau of Reclamation)
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Middle Columbia Steelhead, [WRIA 37 is also Columbia mainstem migratory corridor]
Groundwater Management Area	YES (Upper Kittitas Groundwater Rule and Lower Yakima Valley Groundwater Management Area). For additional information on groundwater decline areas within WRIA 37, see Module xx.

<sup>1</sup>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.

A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 187. Summaries are also available online at <http://apps.wdfw.wa.gov/salmscape/>.

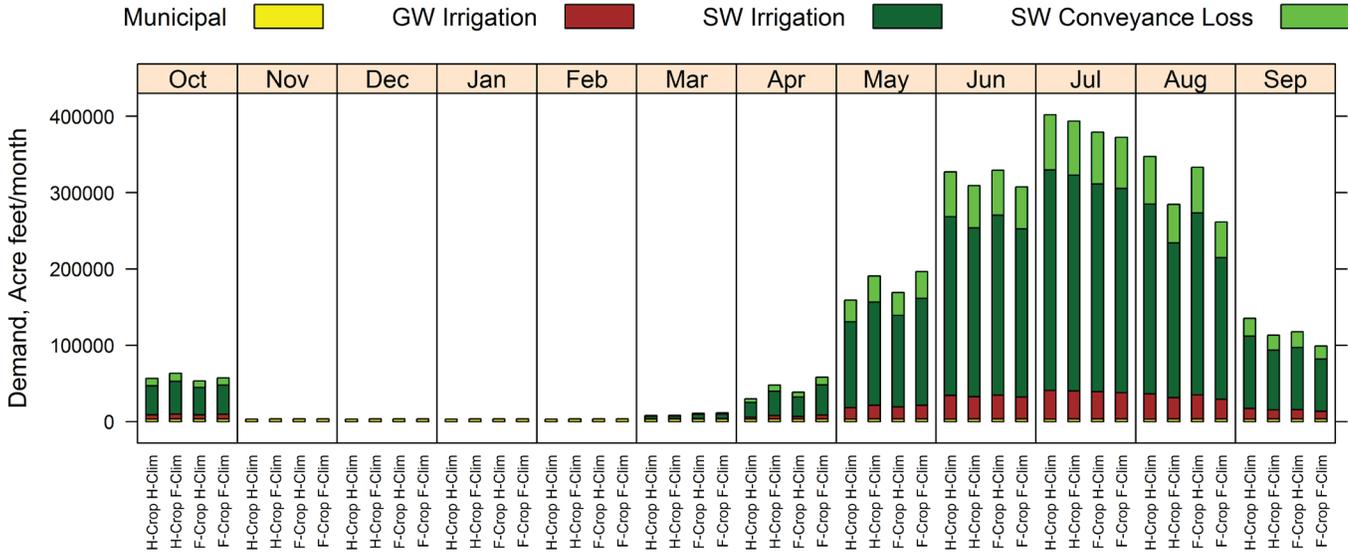


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

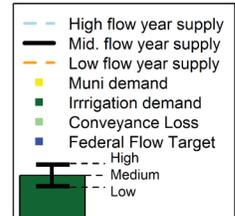
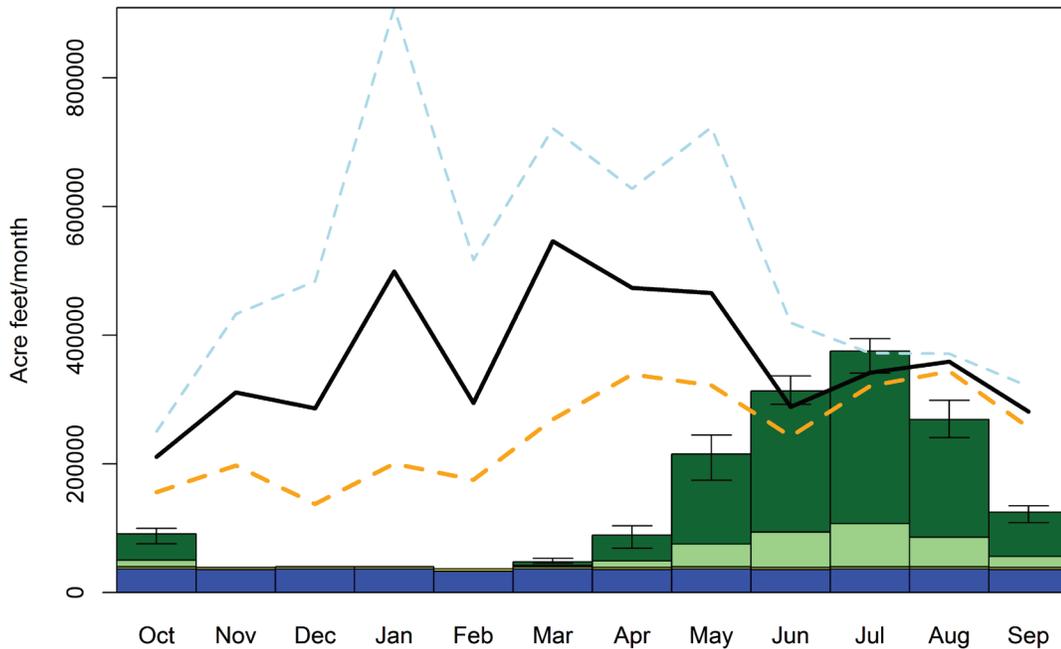
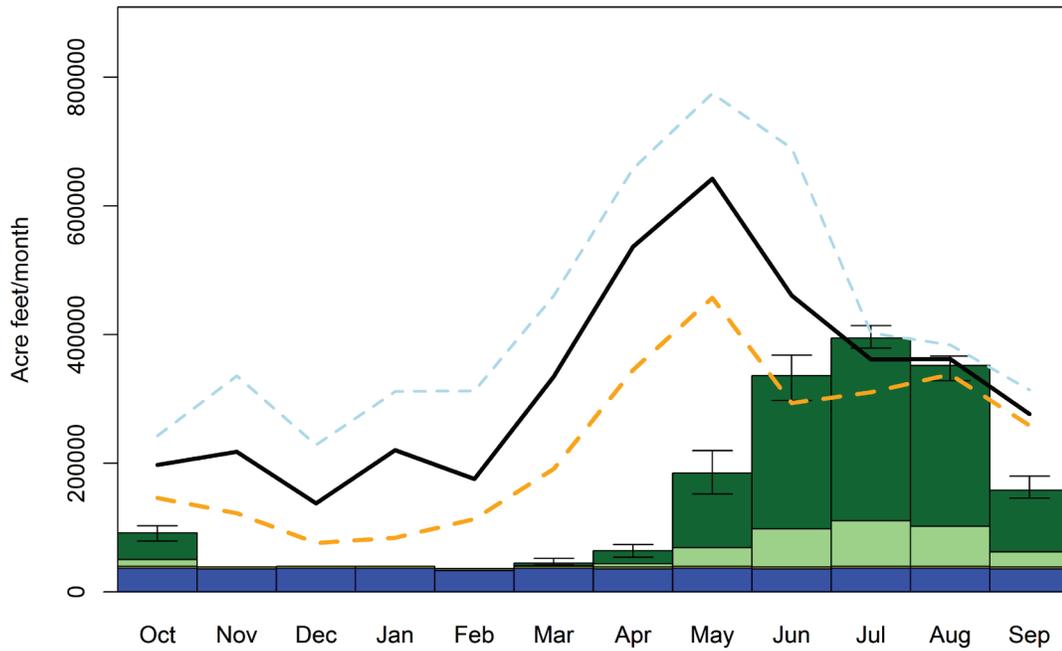


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND

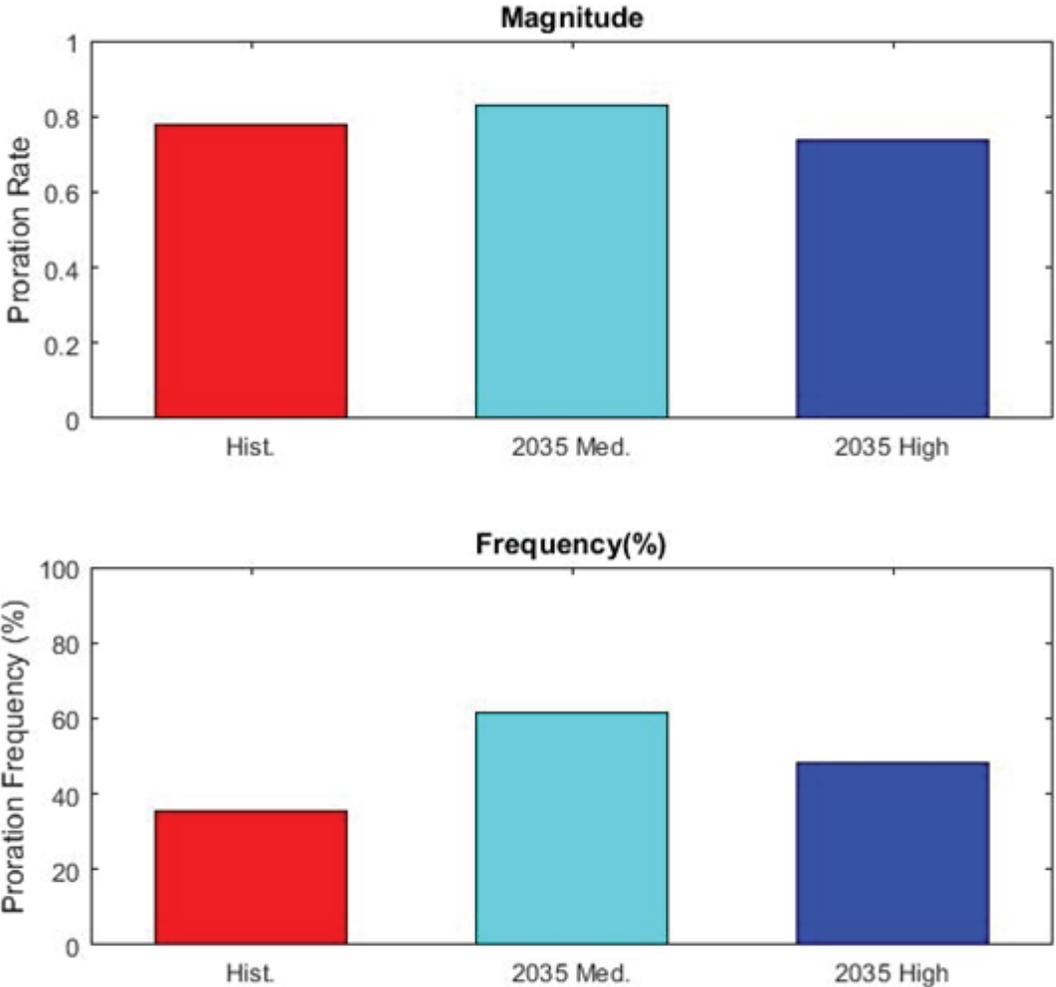


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) “H-Crop H-Clim”, b) “H-Crop F-Clim”, c) “F-Crop H-Clim”, and d) “F-Crop F-Clim” where “H-Crop” represents historic crop mix; “F-Crop” as future crop mix under medium economic scenario, “H-Clim” as historic climate and “F-Clim” values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

CURTAILMENT



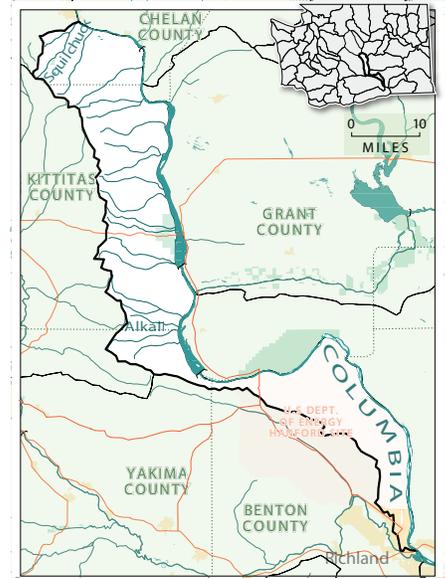
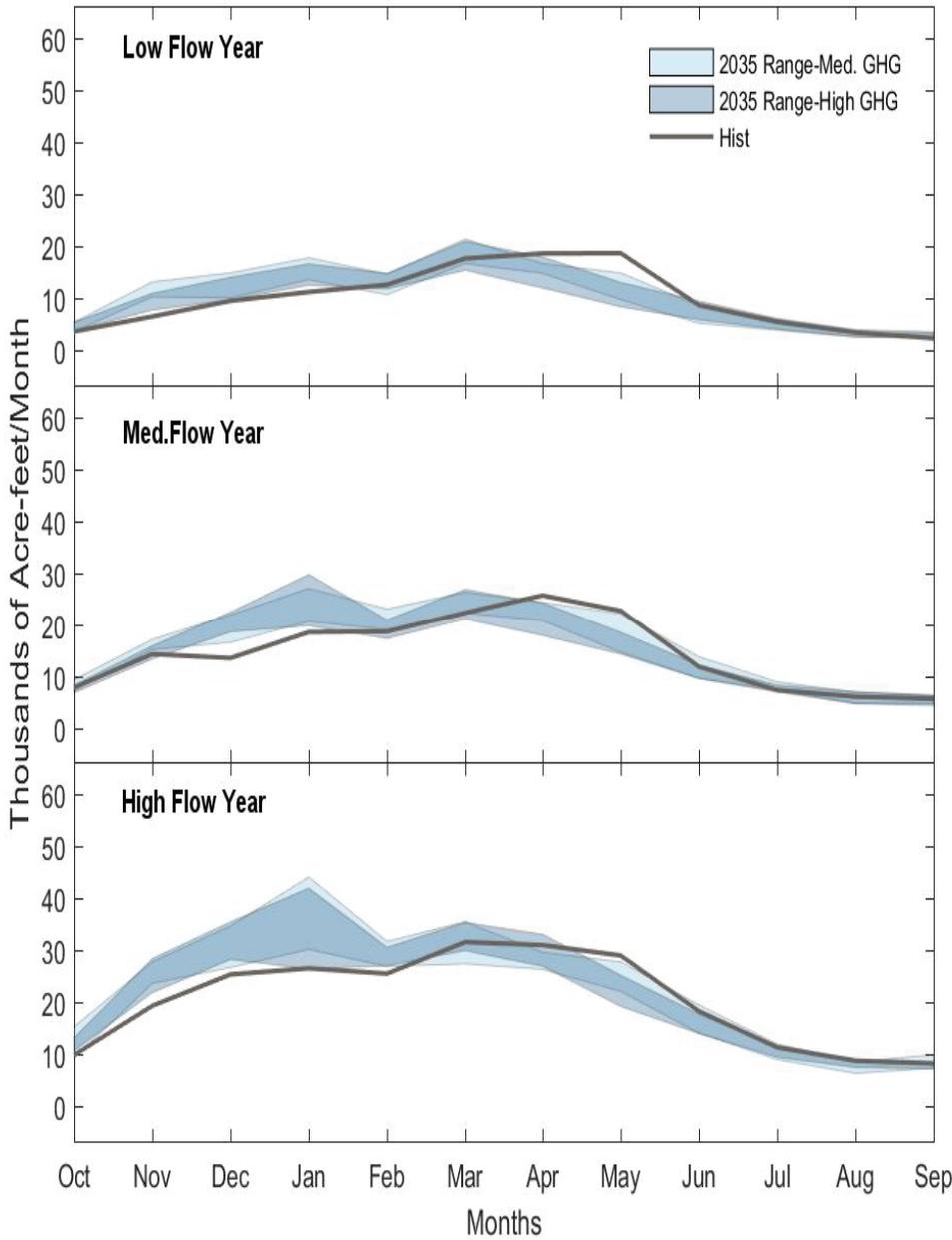
Modeled historical (1981-2011) and forecast (2035) median of annual average proration rate (top panel) and proration frequency (%) (bottom panel) in these WRIAs. Prorationing is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. These results correspond to an annual average proration rates of 90% or less. Proration rates higher than 90% of entitlements should not have significant adverse effects on agricultural production in the Yakima region, and hence were ignored.

- The tributary surface water supply forecast for Alkali-Squillchuck and Stemilt Squillchuck is characterized by small increases from late fall through winter, and decreases from Spring through mid-Summer.
- Primary demands in these WRIAs are irrigation and municipal.
- Assuming no change in irrigated acreage, irrigation demand is forecasted to increase in April and May and decrease from June through September. These changes are primarily in response to climate change rather than crop mix changes.
- Municipal demands are expected to increase roughly 4%, a smaller increase than in many other WRIAs of eastern Washington.

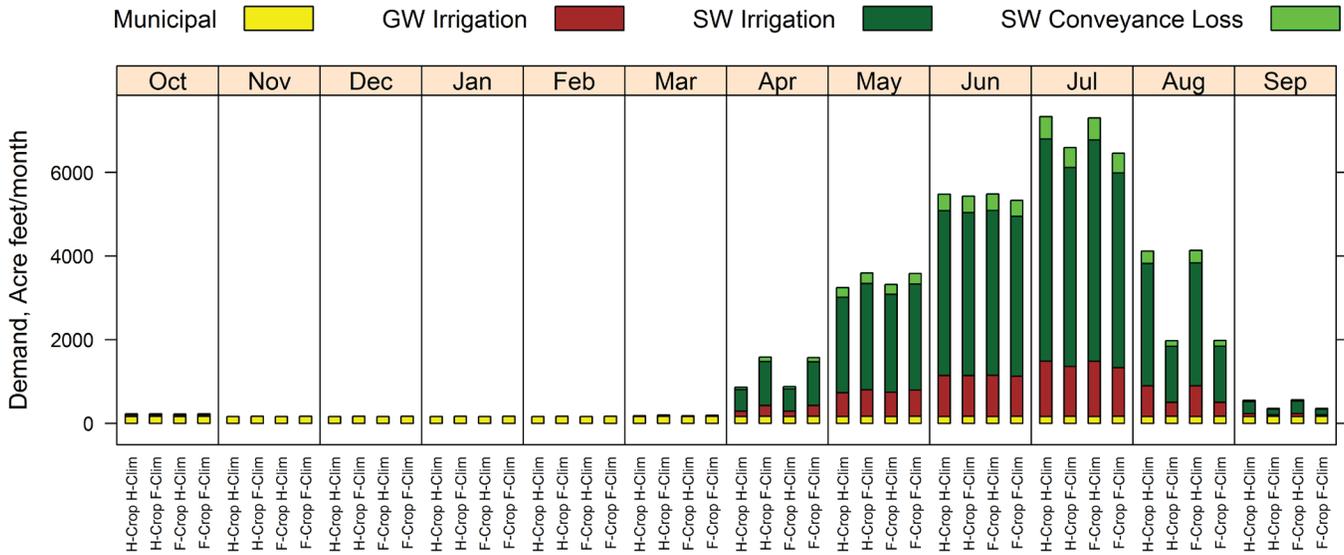
MANAGEMENT CONTEXT	
Adjudicated Areas	Stemilt Creek, Squillchuck Creek, Cummings Canyon Creek
Watershed Planning	WRIA 40a: Phase 4 (Implementation), WRIA 40: NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	[Columbia mainstem migratory corridor]
Groundwater Management Area	YES (references listed in WSU's technical report)

<sup>1</sup>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.

## SUPPLY

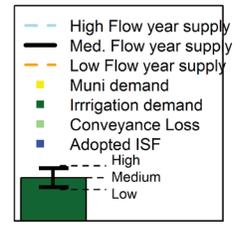
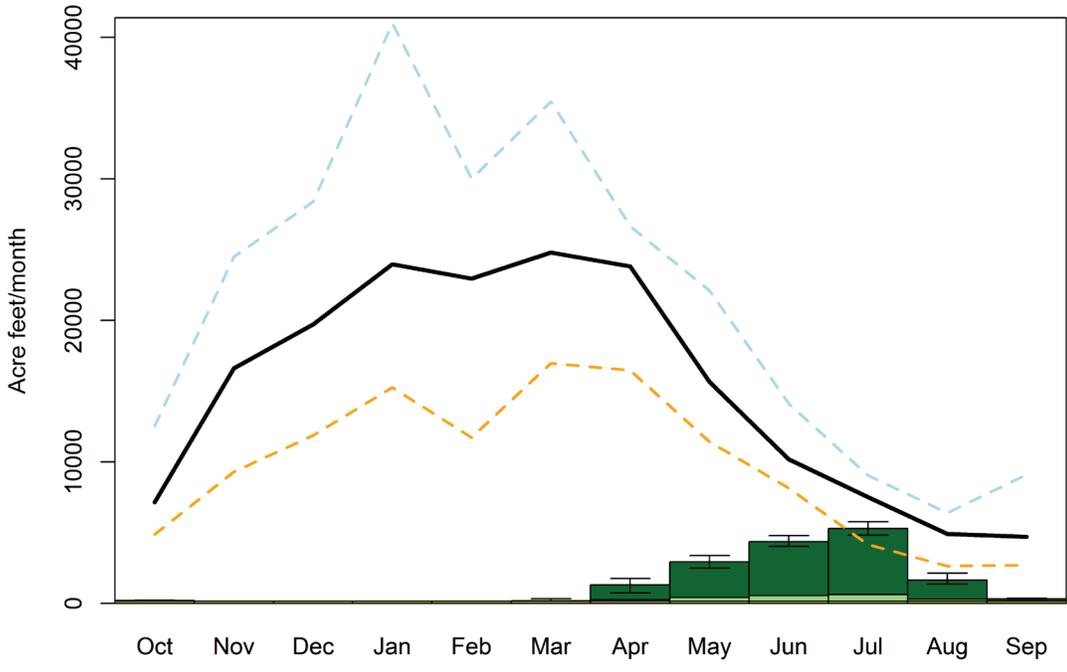
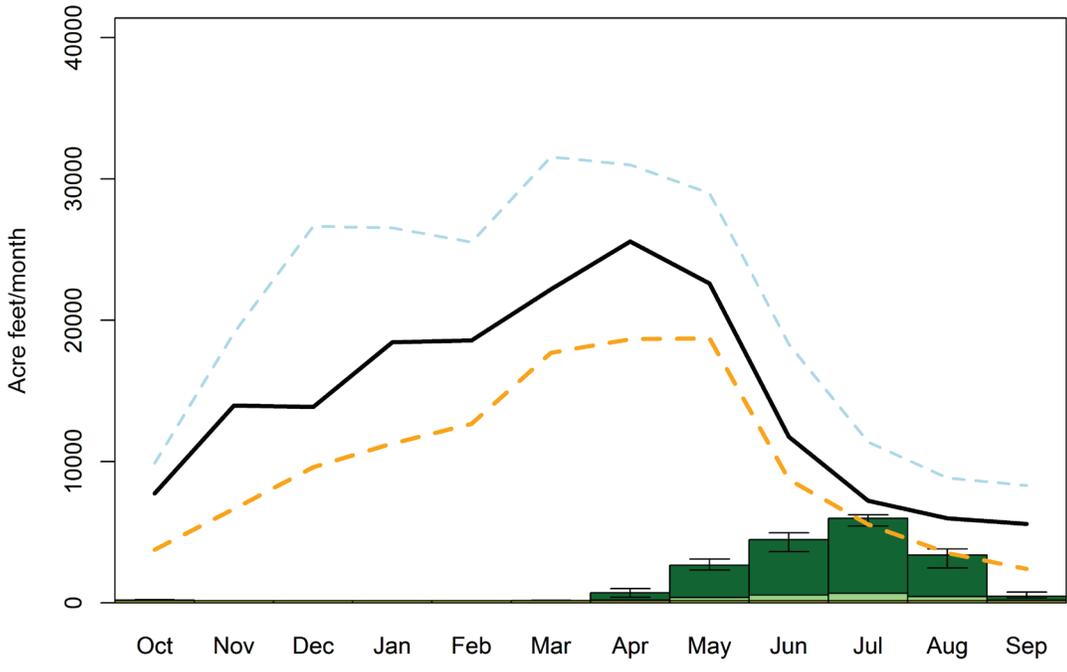


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

## SUPPLY & DEMAND

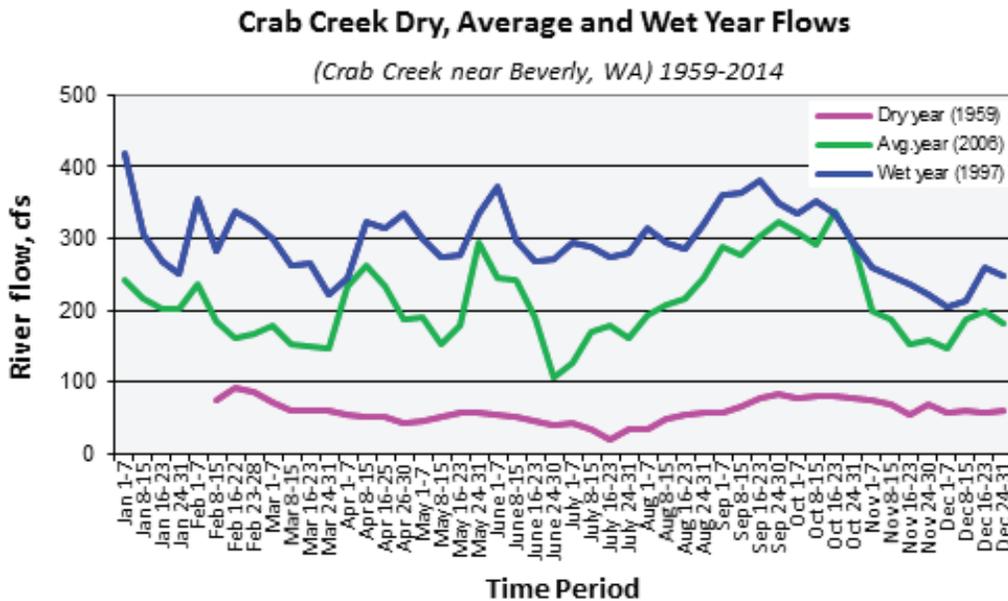


Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- The tributary surface water supply forecast for Lower Crab is characterized mostly by increases from November through January for all percentiles, and in February for the 20th and 50th percentiles. The remaining months are less certain with a combination of increases and decreases, depending on climate scenario.
- Irrigation is the primary source of demand, with much smaller municipal demands.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase in April, May and July with decrease in rest of the months. Increasing change is primarily contributed from the climate change. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2035 from groundwater to surface water. Municipal demands are projected to grow by 35% by 2035.

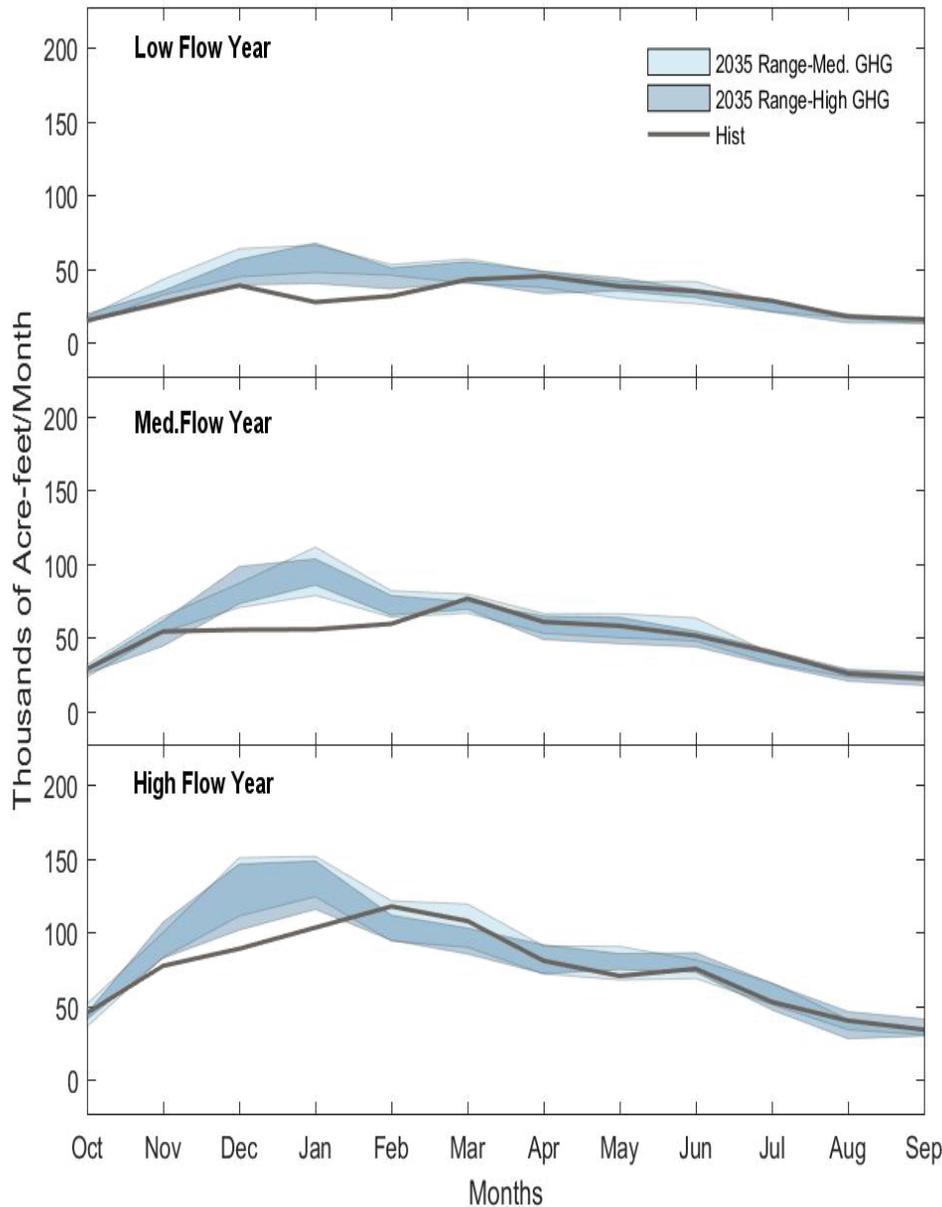
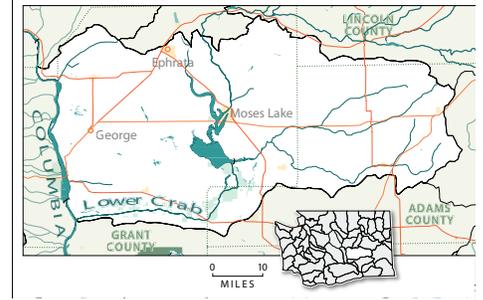
MANAGEMENT CONTEXT	
Adjudicated Areas	Crab Creek & Moses Lake
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	YES (Columbia Basin GWMA, Odessa Subarea, and Quincy Subarea. For additional information on groundwater decline areas within this WRIA, see Module xx.

<sup>1</sup>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.

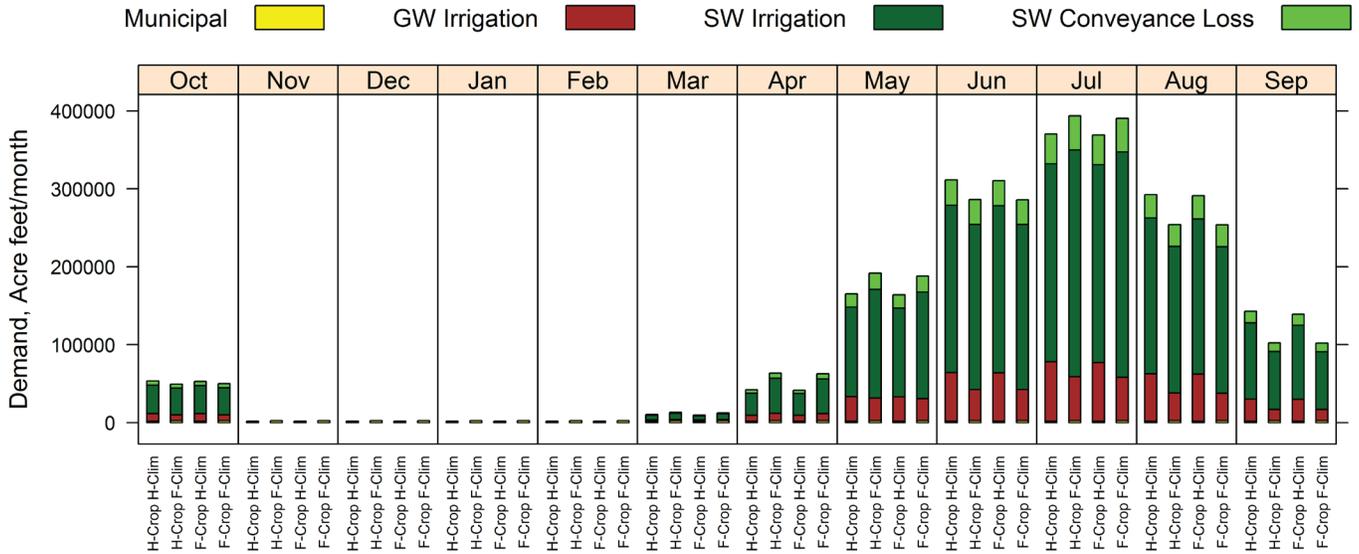


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

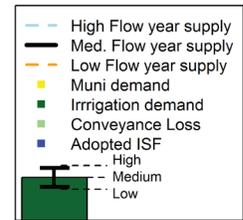
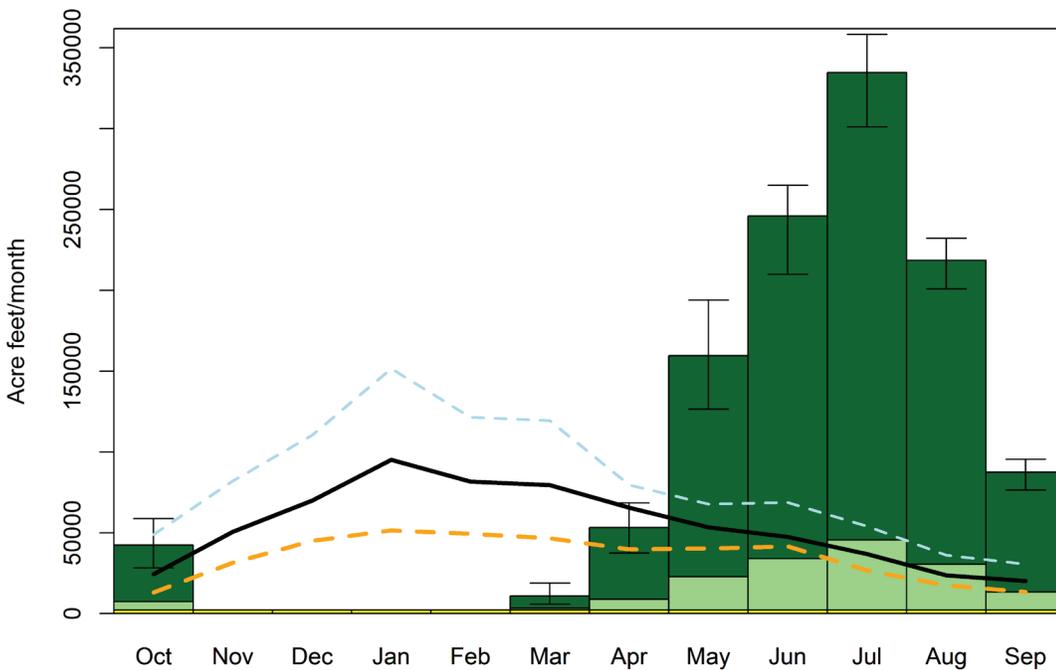
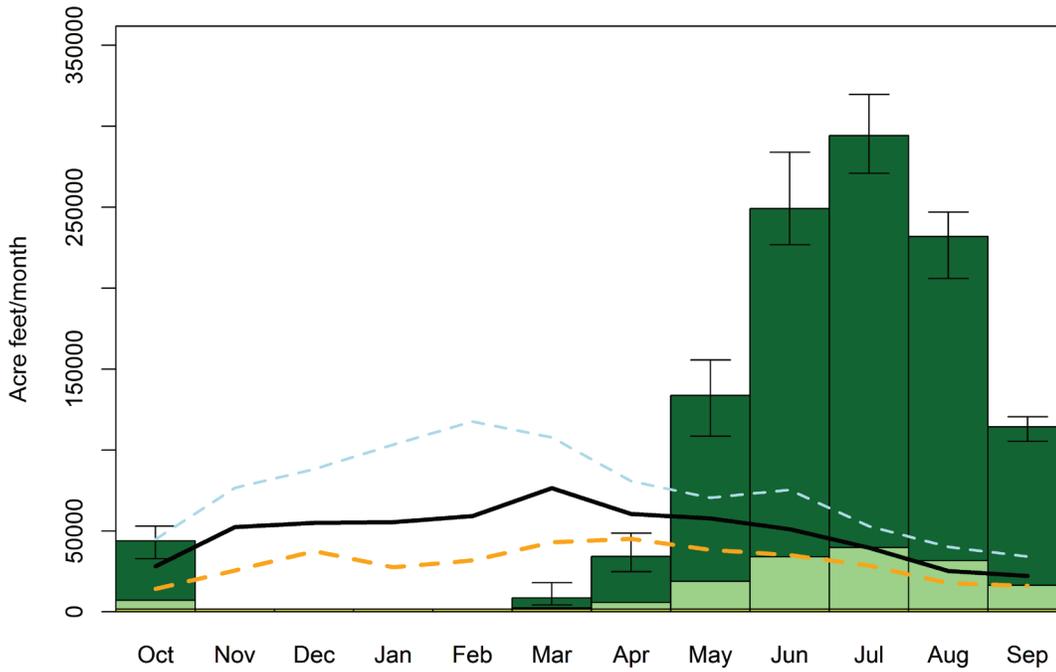


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b)"H-Crop F-Clim", c)"F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario,"H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- The tributary surface water supply forecast for Grand Coulee is characterized mostly by increases from November through January for all percentiles, and in February as well for the 20th and 50th percentiles. The other months are less certain with a combination of increases and decreases, depending on climate scenario.
- As in many other WRIs 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. Increase in demand in April, May and July is primarily in response to climate change while crop changes mostly contributed to decrease. Because of declining groundwater in the Odessa area, some irrigation demand is forecasted to shift by 2035 from groundwater to surface water. Municipal demands are projected to grow by 15%, a smaller increase than in many other watersheds of eastern Washington.

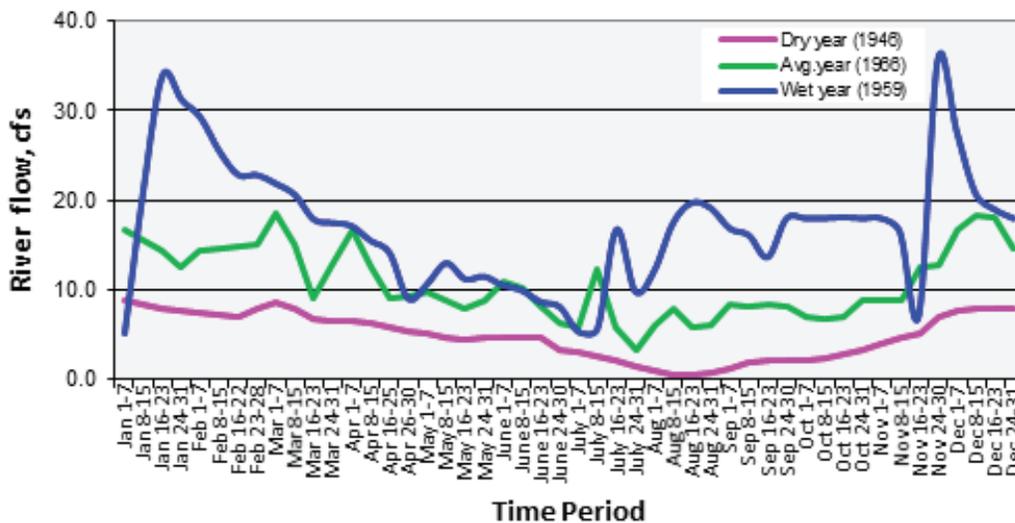
### MANAGEMENT CONTEXT

Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	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)

<sup>1</sup>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.

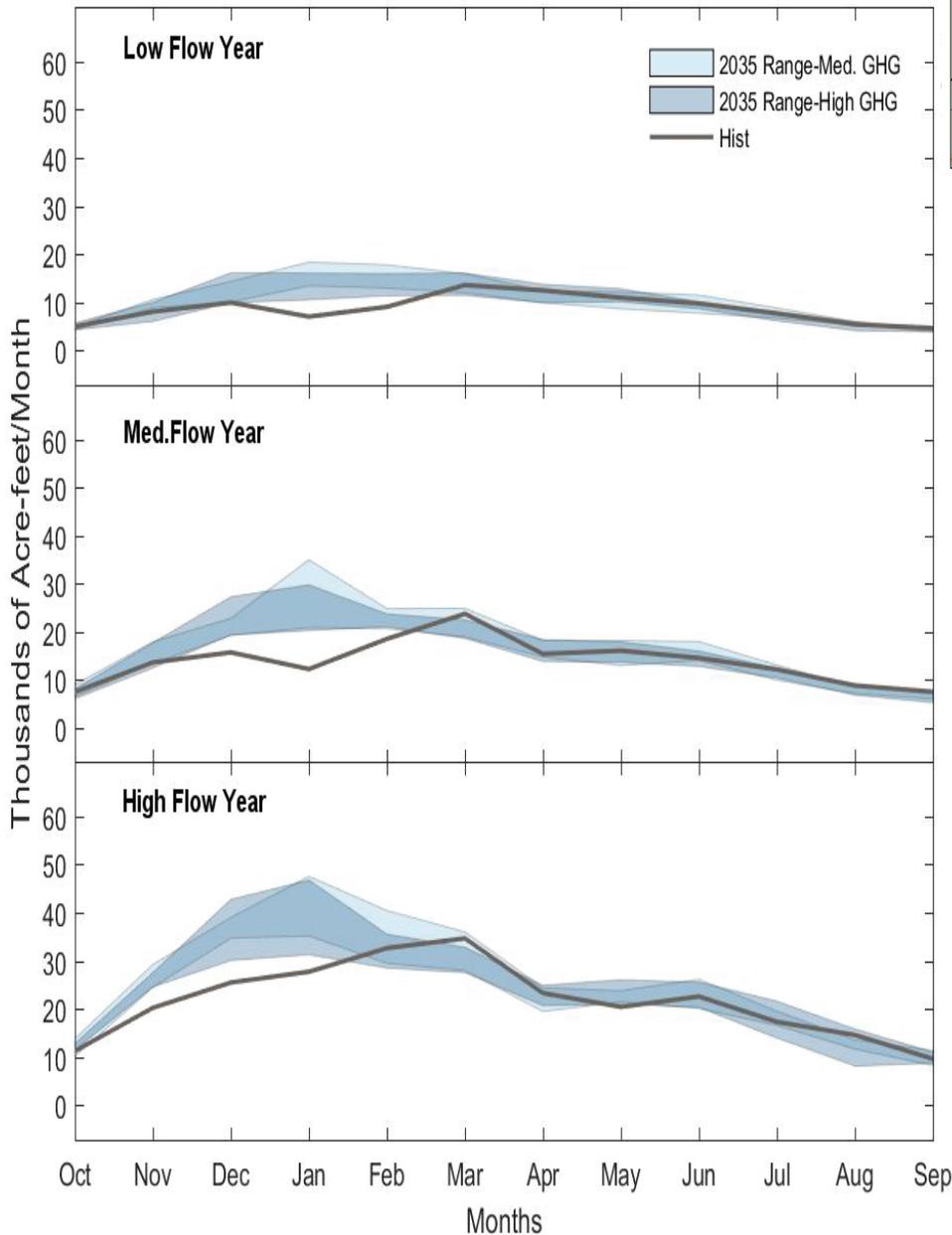
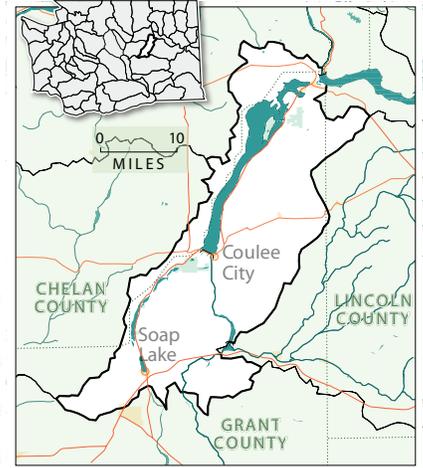
### Park Creek Dry, Average and Wet Year Flows

(Park Creek below Park Lake near Coulee City, WA) 1946-1968

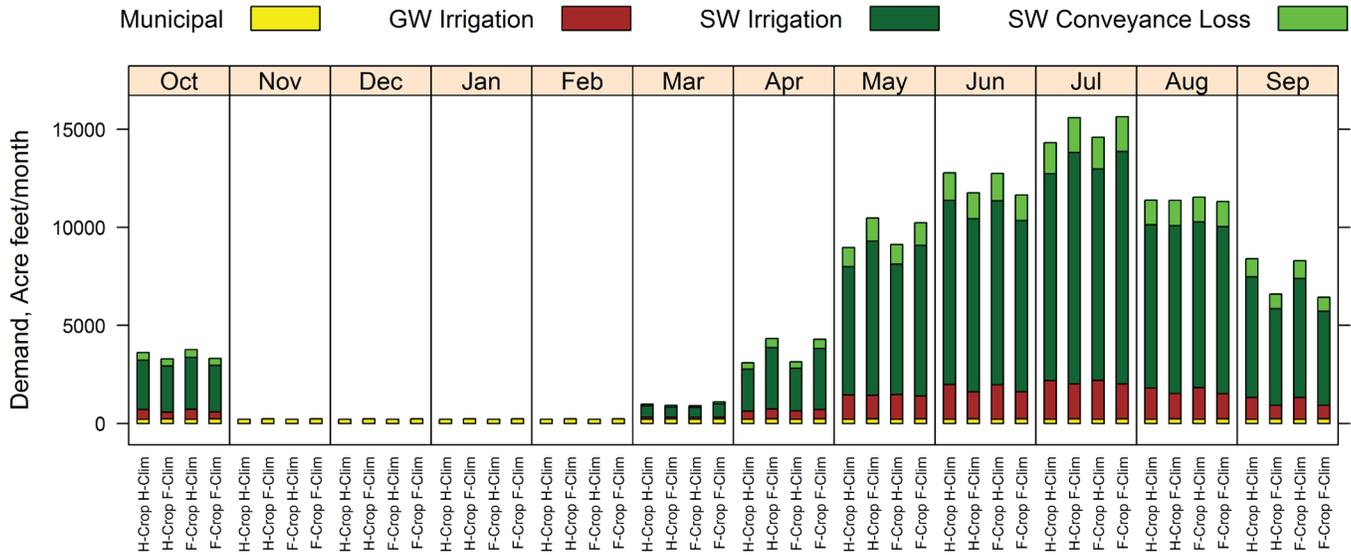


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

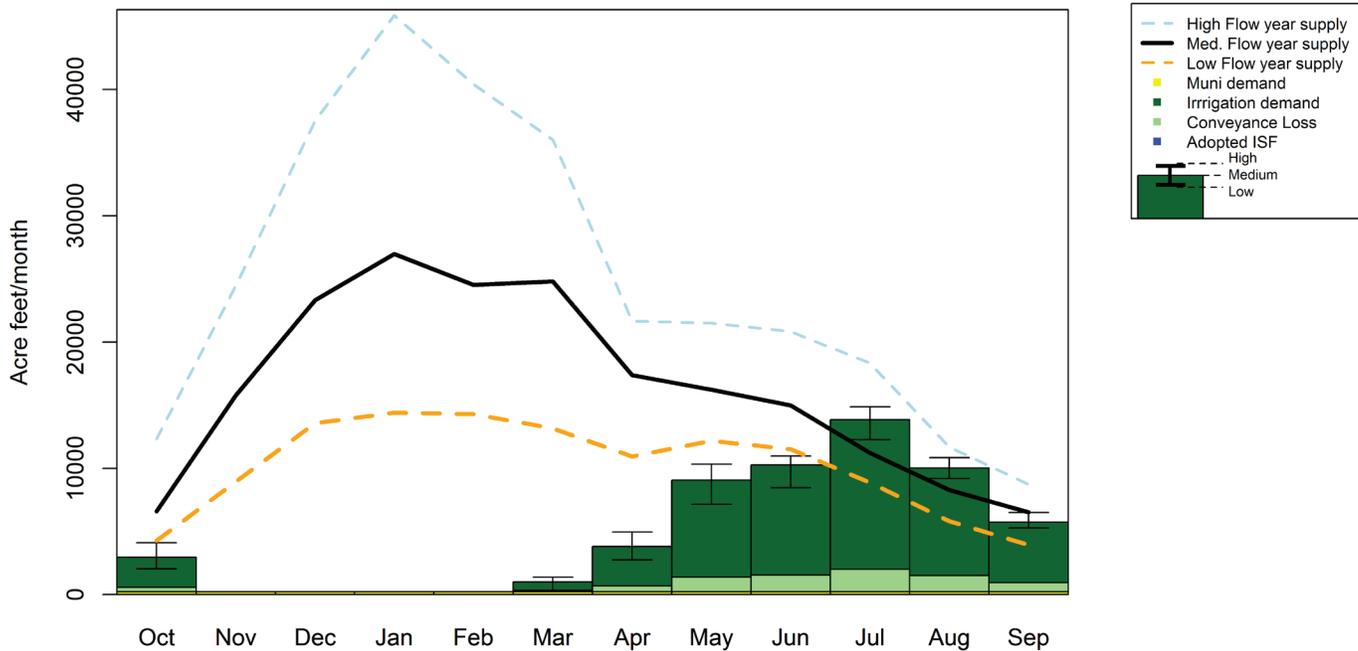
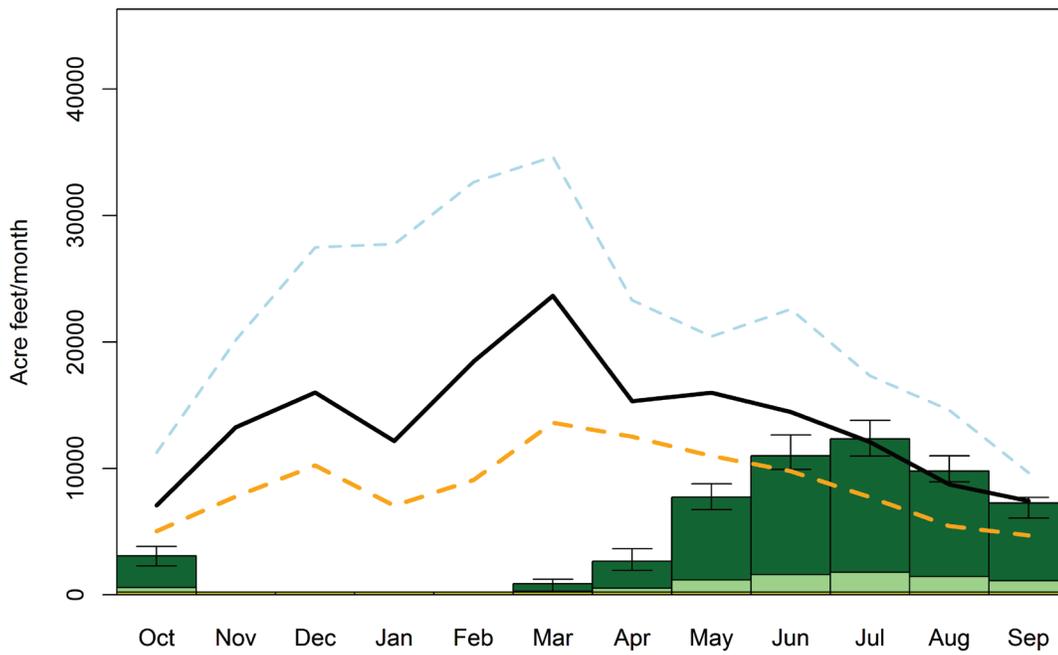


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) “H-Crop H-Clim”, b) “H-Crop F-Clim”, c) “F-Crop H-Clim”, and d) “F-Crop F-Clim” where “H-Crop” represents historic crop mix; “F-Crop” as future crop mix under medium economic scenario, “H-Clim” as historic climate and “F-Clim” values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND

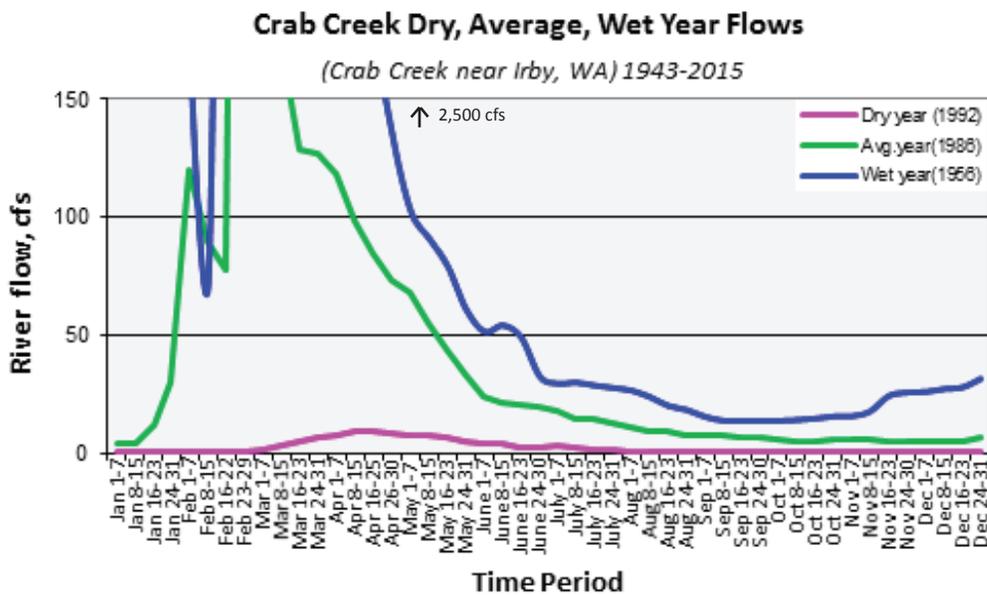


Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- The tributary surface water supply forecast for Upper Crab-Wilson is characterized mostly by increases from October through January for the 80th year percentile year, and in January and February for the 20th and 50th percentiles. The other months are less certain with a combination of increases and decreases, depending on climate scenario.
- As in many other WRIs 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 in the future. These changes are primarily due to climate changes. Because of declining groundwater in the Odessa area, irrigation demand is forecasted to shift by 2035 from predominantly groundwater to nearly all surface water.
- Municipal demands are projected to shrink by 1%, the only WRIA in eastern Washington for which we projected a decrease based upon population projections.

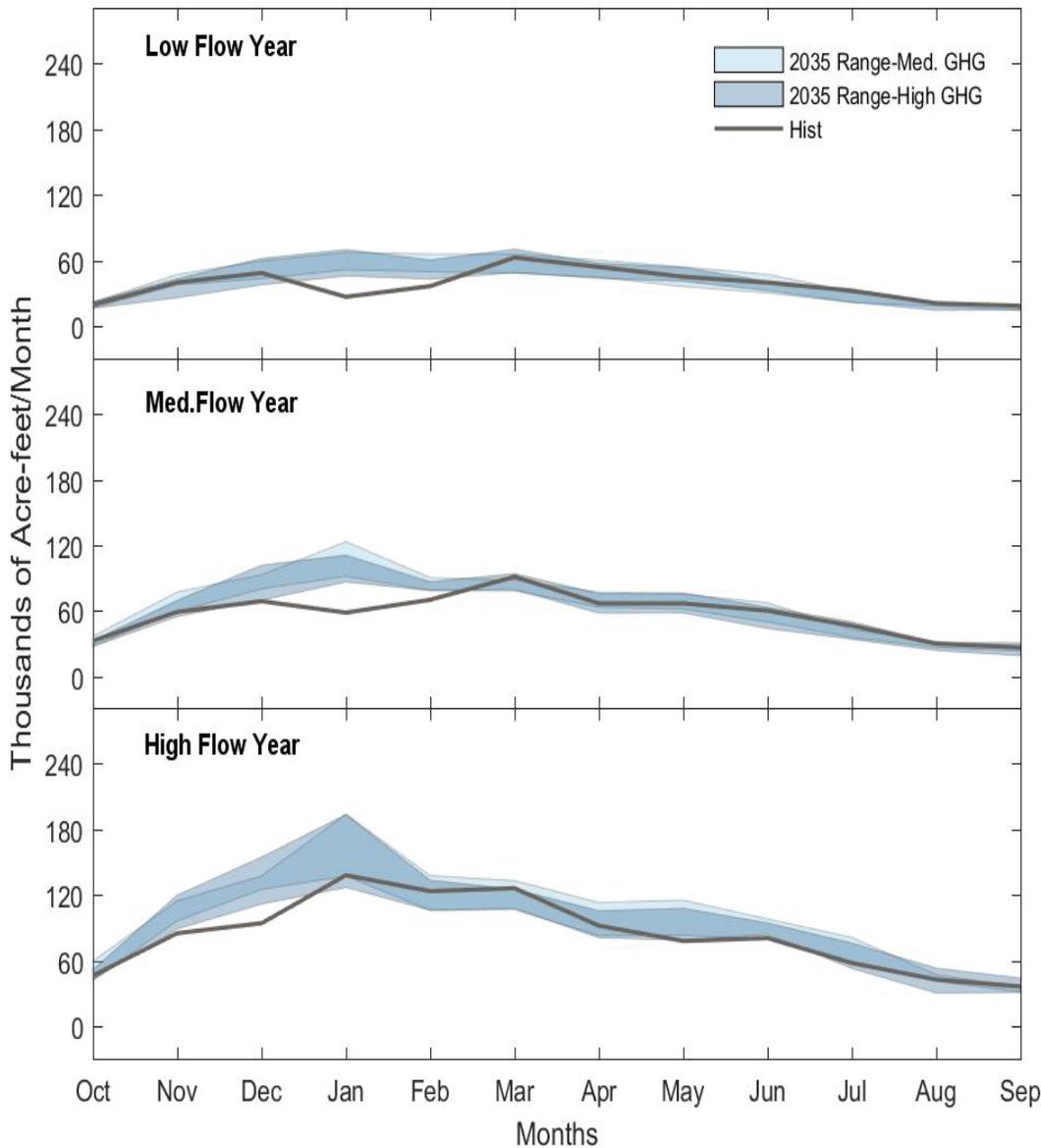
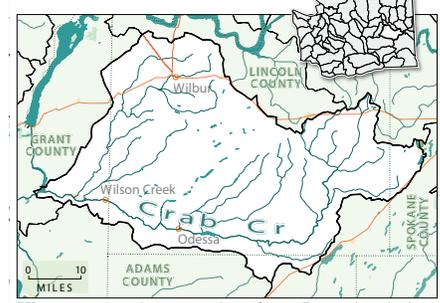
MANAGEMENT CONTEXT	
Adjudicated Areas	Crab Creek between Sylvan Lake & Odessa , Crab Creek, South Fork
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	YES (references listed in WSU's technical report) For additional information on groundwater decline areas within this WRIA, see Module xx.

<sup>1</sup>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.

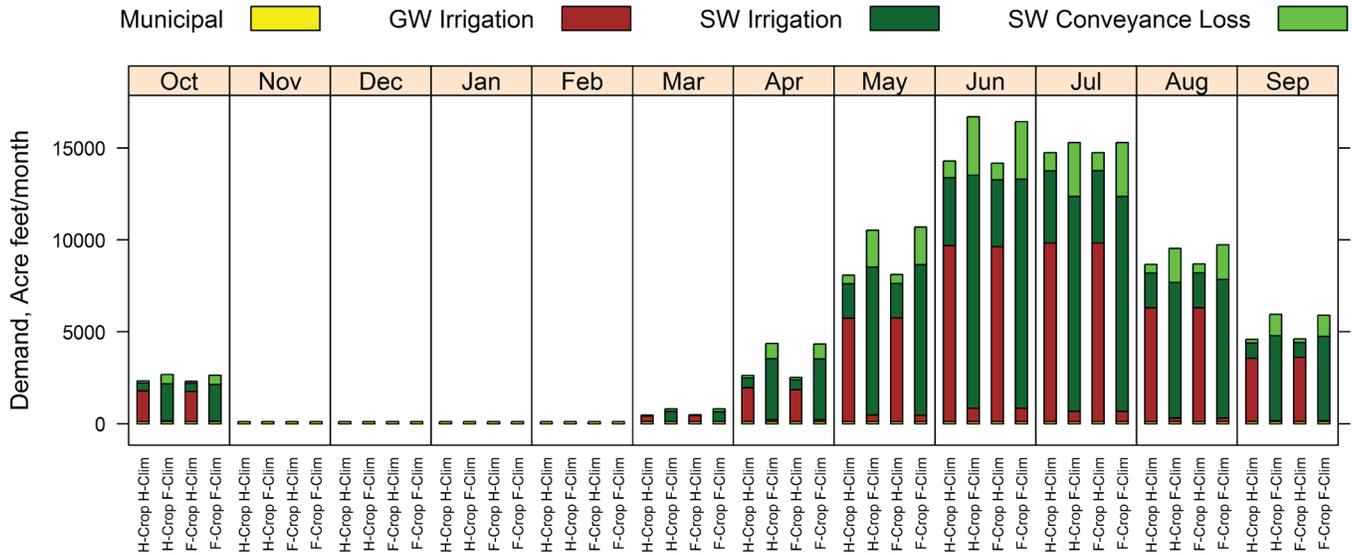


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

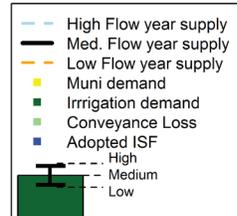
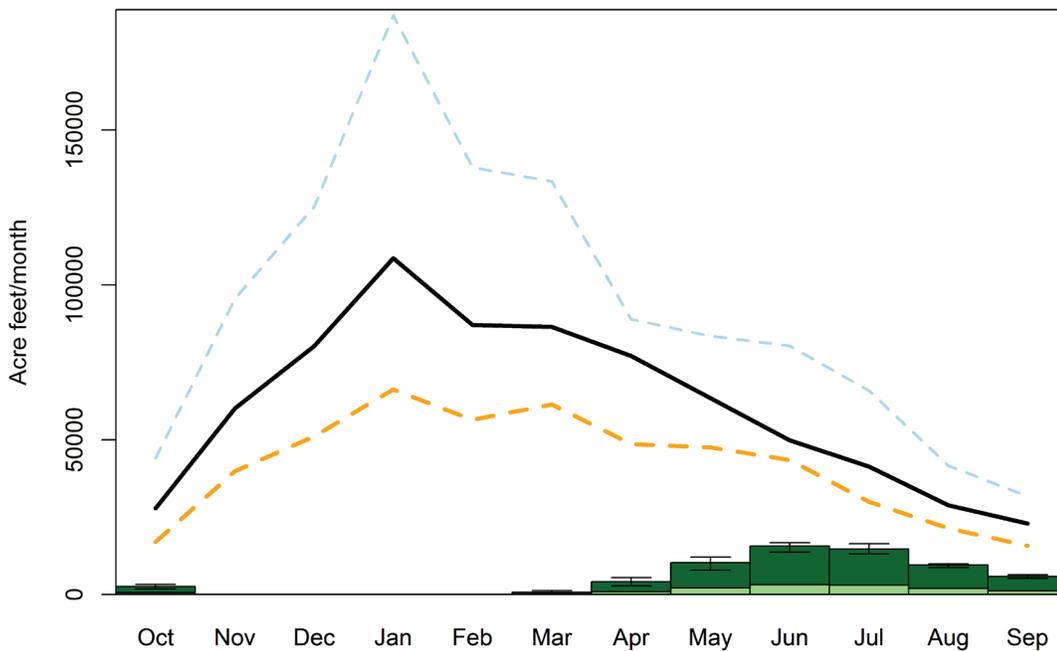
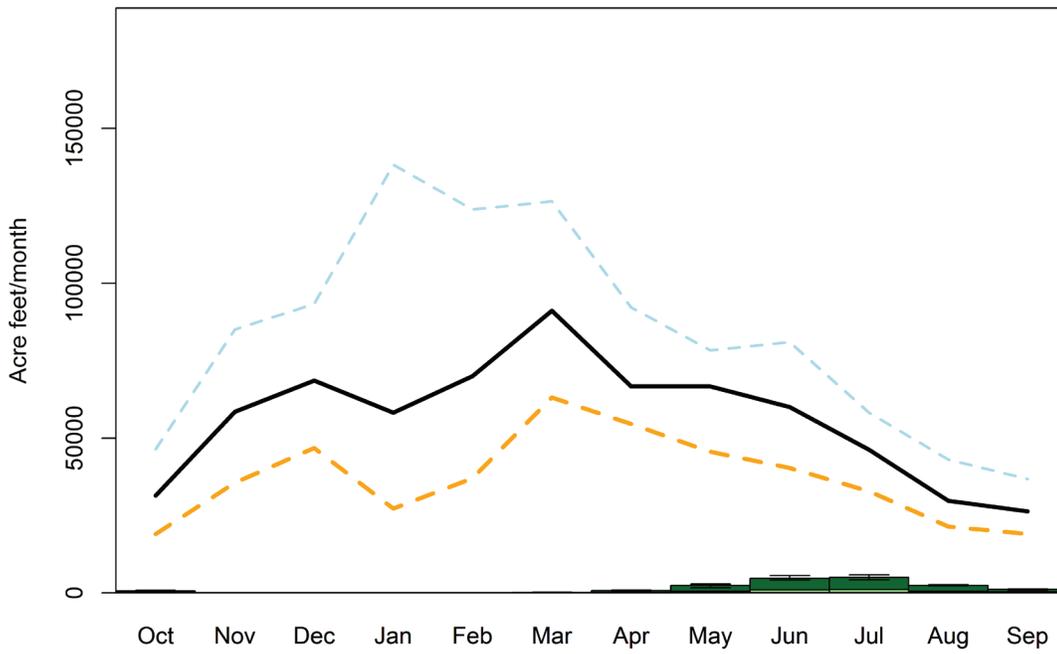


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

## SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

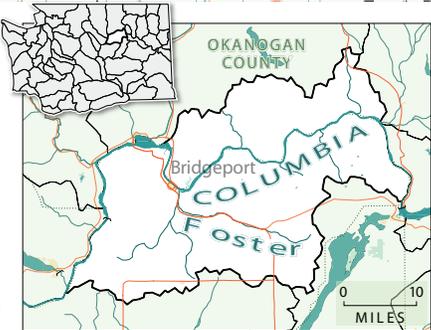
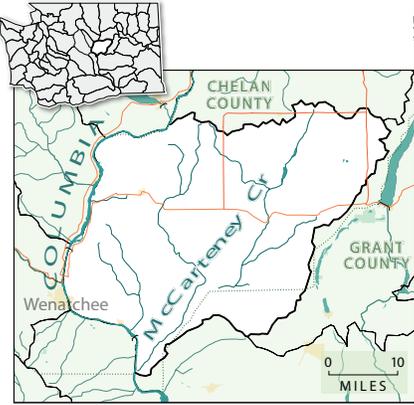
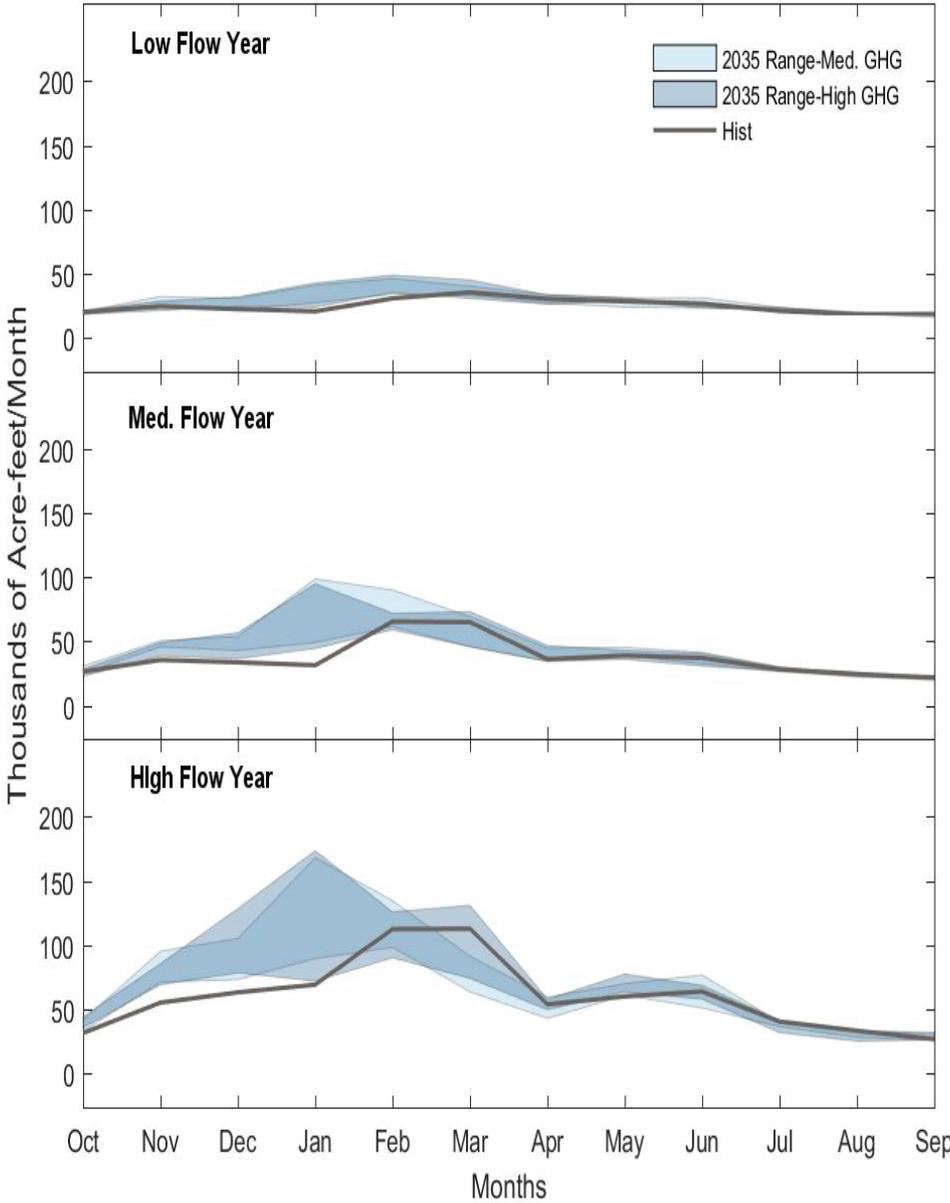
- The tributary surface water supply forecast for Moses Coulee and Foster is characterized mostly by increases from late fall through winter and decreases in March for the 80th percentile supply year.
- As in many other watersheds of eastern Washington, municipal demands in these WRIAs are much smaller than irrigation demands.
- Assuming no change in irrigated acreage, irrigation demands are forecasted to increase in April and May and decrease from June through October. These changes are primarily in response to climate changes.
- Municipal demands are forecasted to grow by 11% and 21% for WRIAs 44 and 50, respectively, by 2035.
- WRIA 50 is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIAs that provide habitat for ESA-listed anadromous salmonids.

### MANAGEMENT CONTEXT

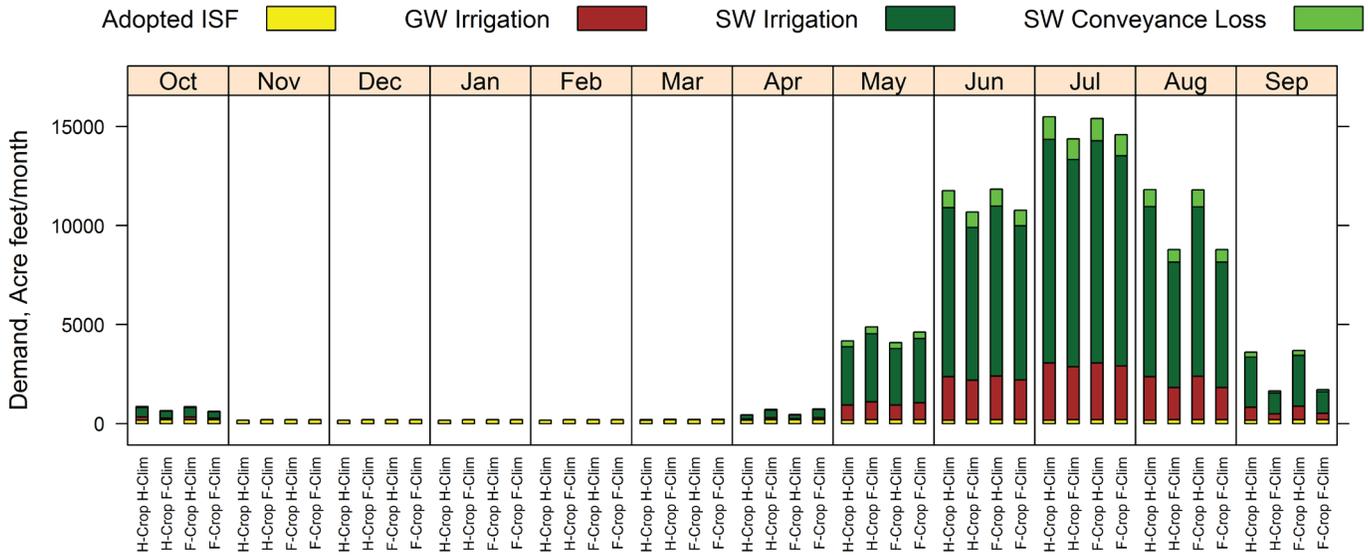
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	WRIA 44: No ESA-listed fish spawn or rear in WRIA waters, WRIA 50: Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead, [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

<sup>1</sup>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.

## SUPPLY

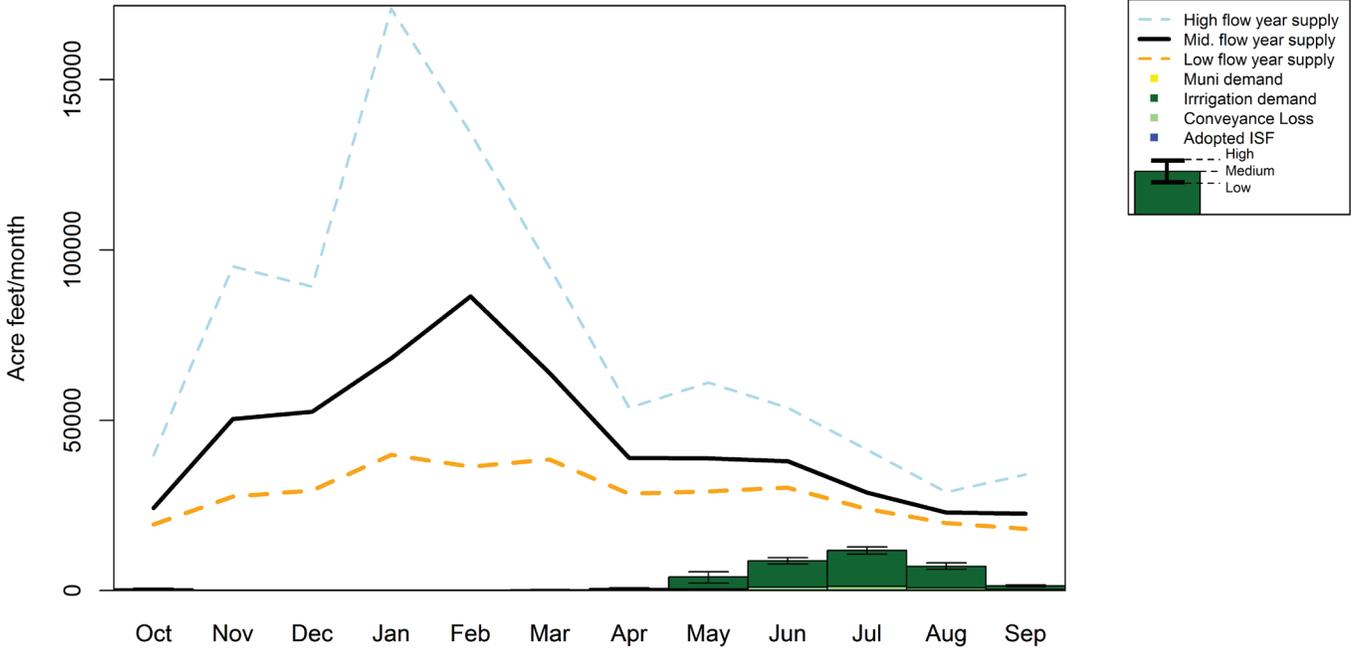
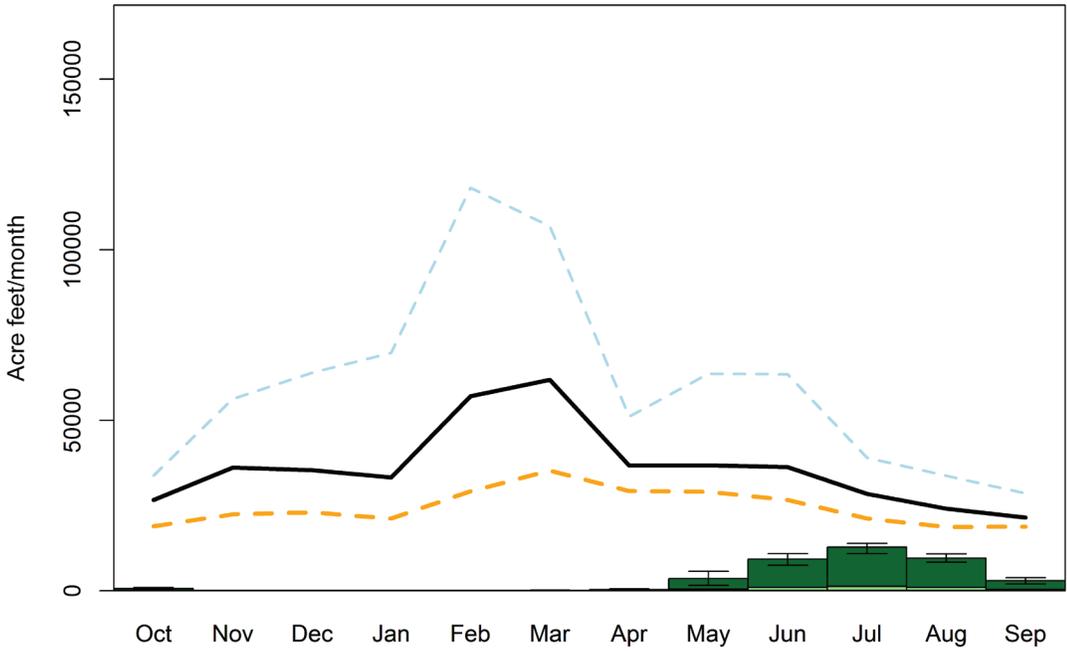


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

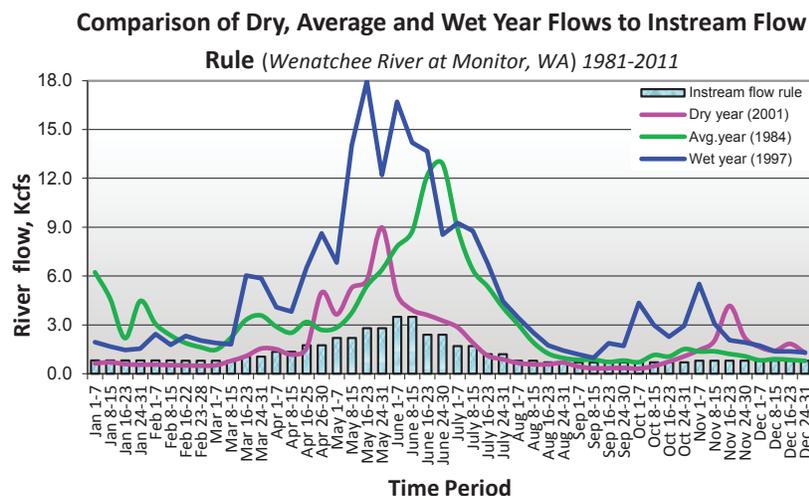
- The tributary surface water supply forecast for Wenatchee shows increases during the months of October through March for most of the years and decreases for June and July.
- Instream flow requirements are the largest water demand, which has smaller irrigation demands and even smaller municipal demands.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase in May, with small change in June and July, and large decreases in August through October. The large decreases are in response to crop mix changes.
- Municipal demands are forecasted to increase by 11% by 2035.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIsAs that provide habitat for ESA-listed anadromous salmonids.
- Both curtailment frequency and magnitude peak during July in the future conditions.
- Forecast shows more frequent and higher magnitude of curtailment events earlier in the season, and less after July.

### MANAGEMENT CONTEXT

Adjudicated Areas	Icicle Creek, Joe Creek, Chumstick Creek, Nahahum Canyon
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-545 WAC). 47 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 ranged from 0 to 5 years from November to June (80% to 100% reliable), and from 5 to 22 years from July to October (25% to 80% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

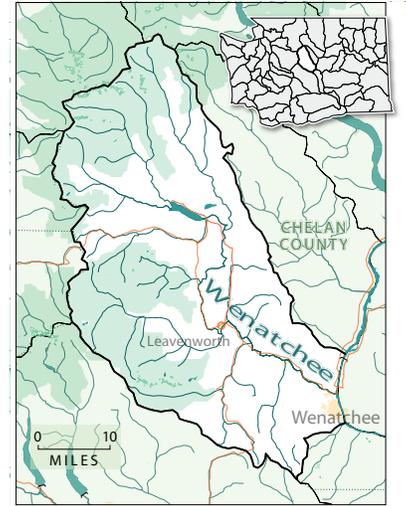
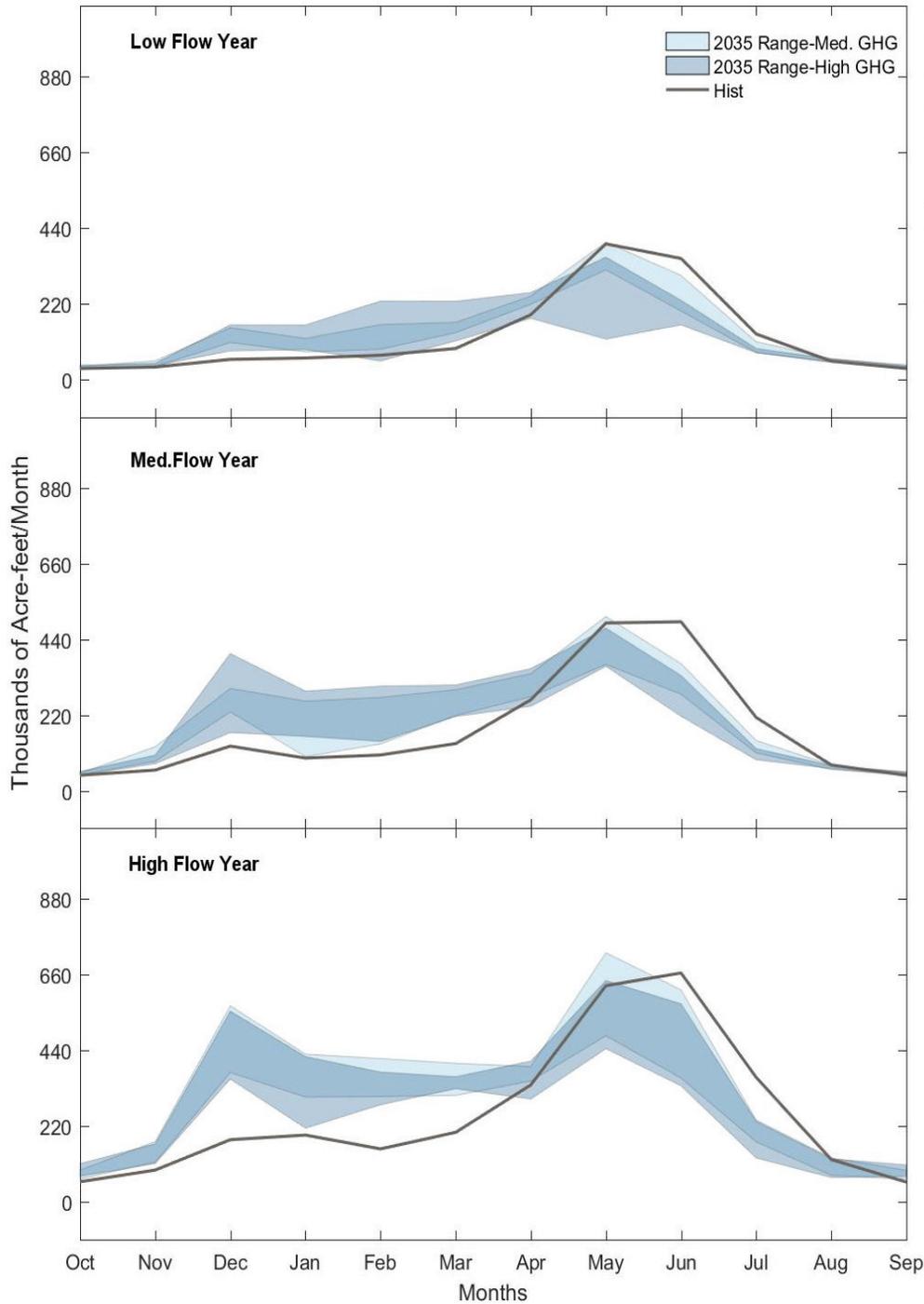
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 188. Summaries are also available online at <http://apps.wdfw.wa.gov/salmonscape/>.

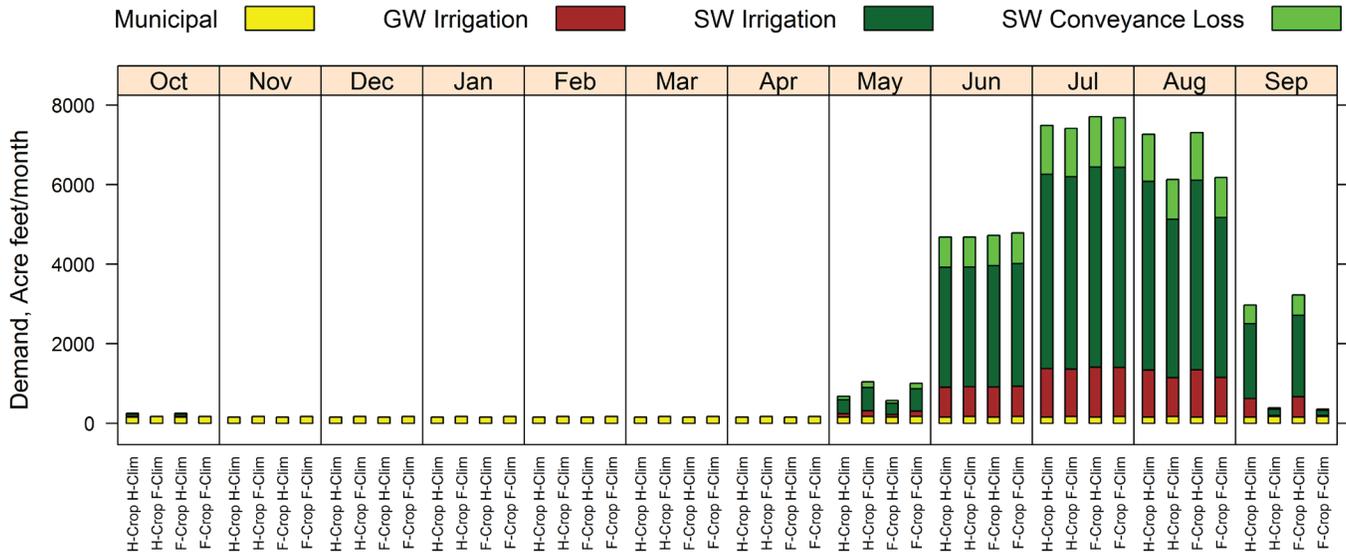


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

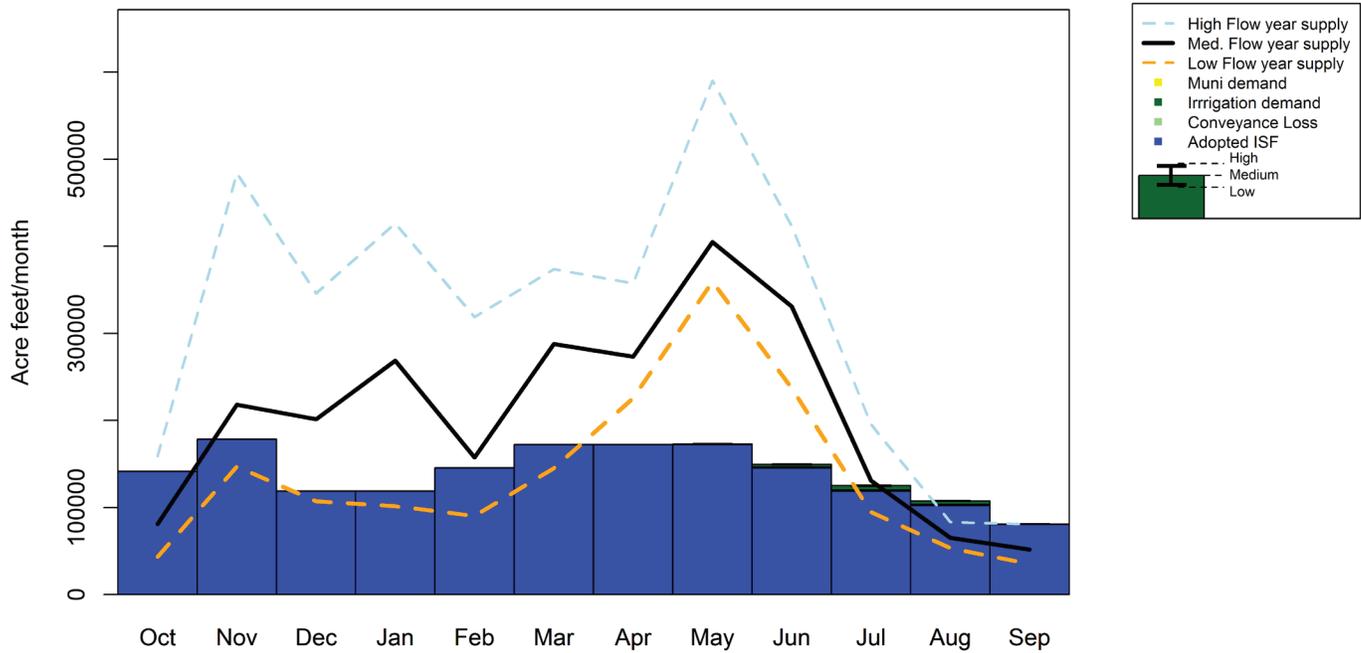
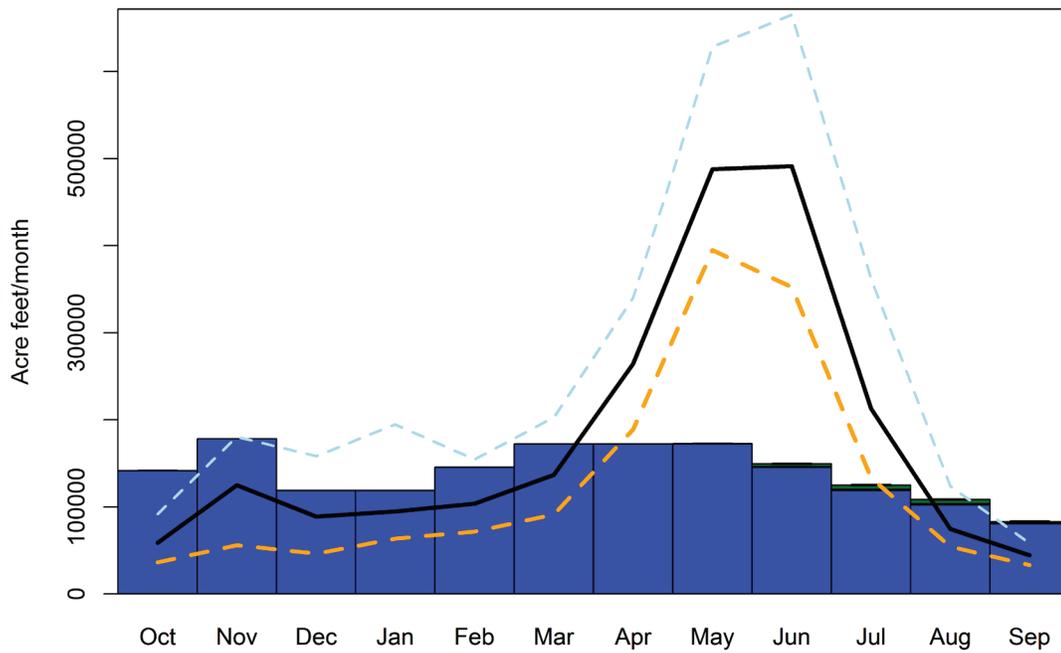


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

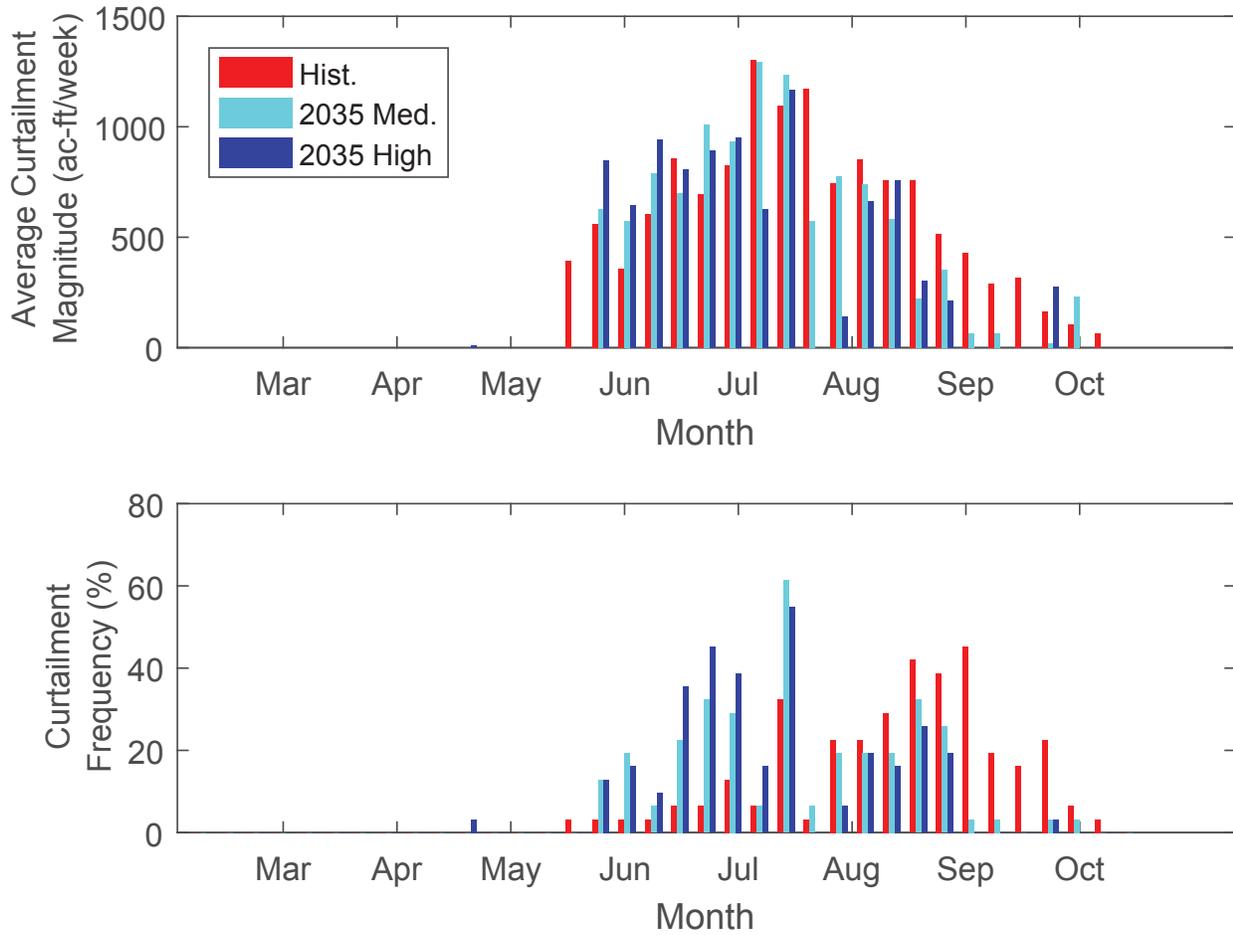


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.



Modeled historical (1981-2011) and forecast (2035) median curtailment magnitude (ac-ft per week) (top panel) and curtailment frequency (%) (bottom panel) in this WRIA. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

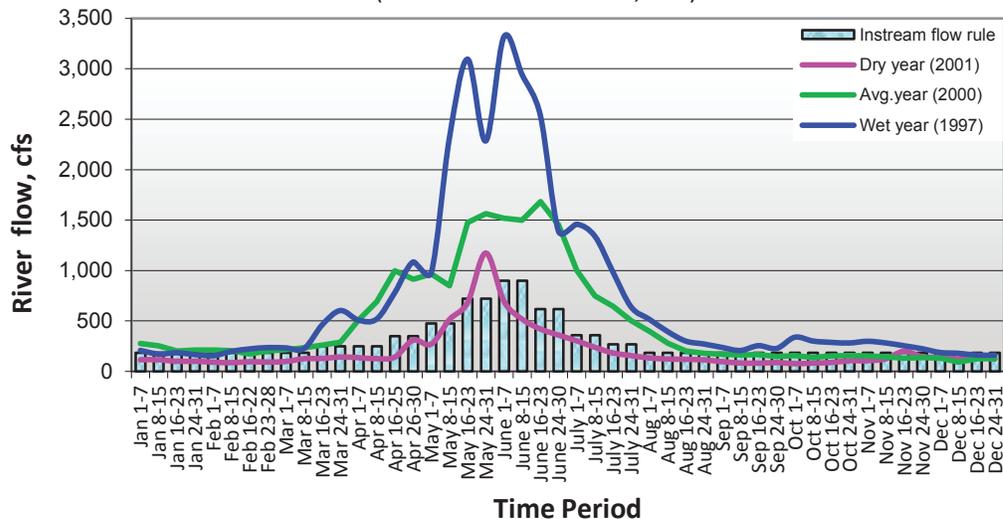
# MANAGEMENT CONTEXT

- The tributary surface water supply forecast for Entiat shows one of the most pronounced supply timing changes in response to warming among all of the WRIsAs. It is characterized by increases from November through March and decreases from May through July.
- Instream flow requirements are the largest demand, with much smaller irrigation and municipal demands.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase in May, remain unchanged in June, and decrease from July through September. The decreases are in response to climate change.
- Municipal demands are forecasted to increase by 6% by 2035.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIsAs that provide habitat for ESA-listed anadromous salmonids.

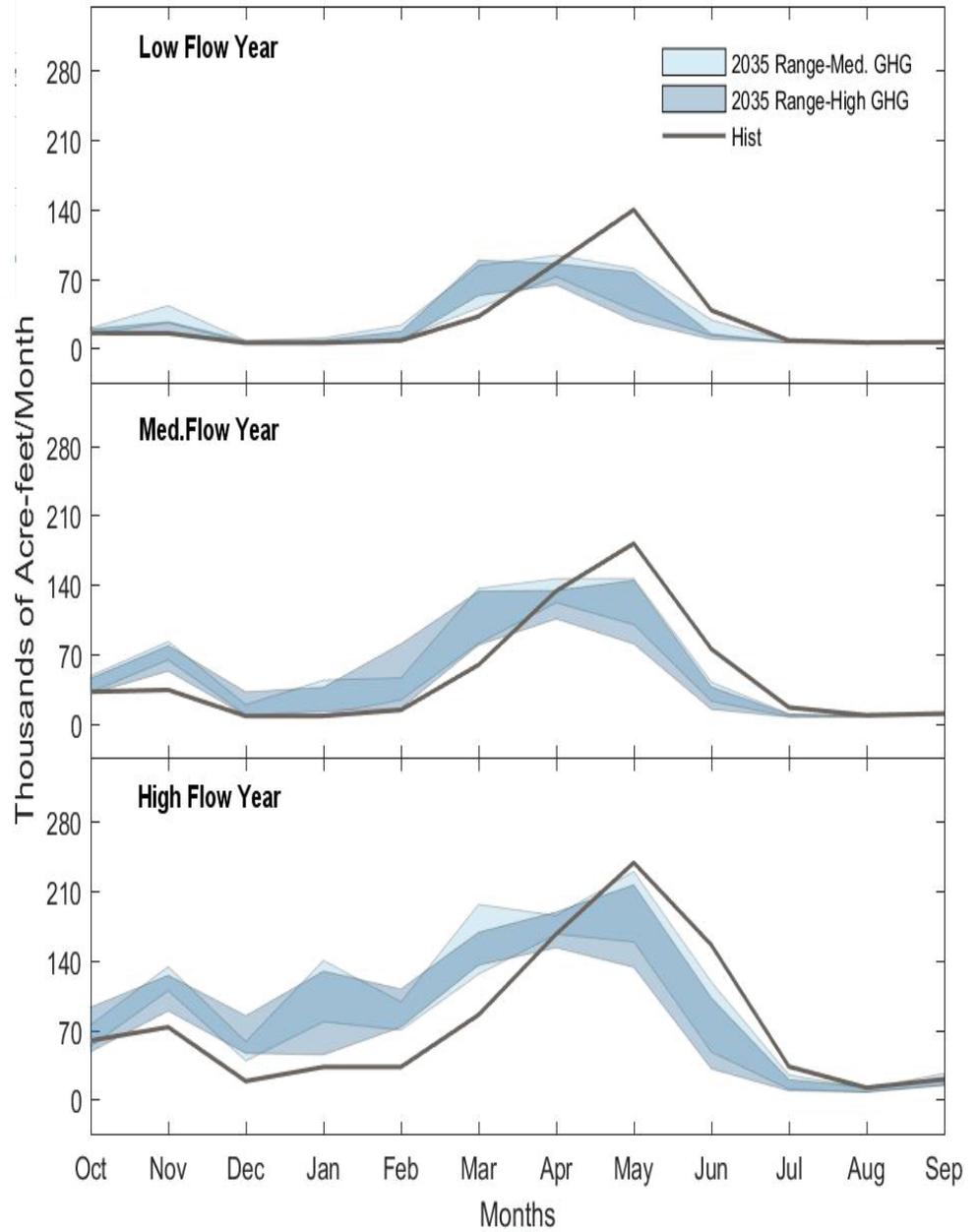
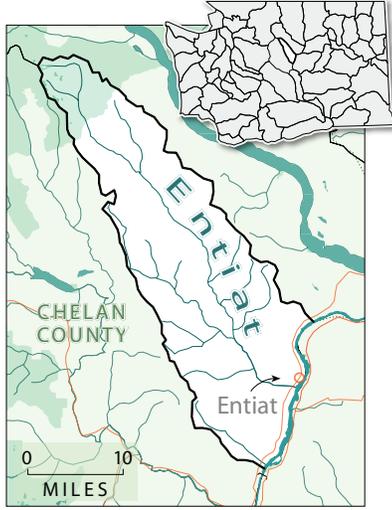
MANAGEMENT CONTEXT	
Adjudicated Areas	Roaring Creek, Johnson Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-546 WAC). 12 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 ranged from 3 to 9 years from August to March (70% to 90% reliable), and from 0 to 2 years from April to July (93% to 100% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead, [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

<sup>1</sup>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.

**Comparison of Dry, Average and Wet Year Flows to Instream Flow Rule (Entiat River near Entiat, WA) 1981-2011**

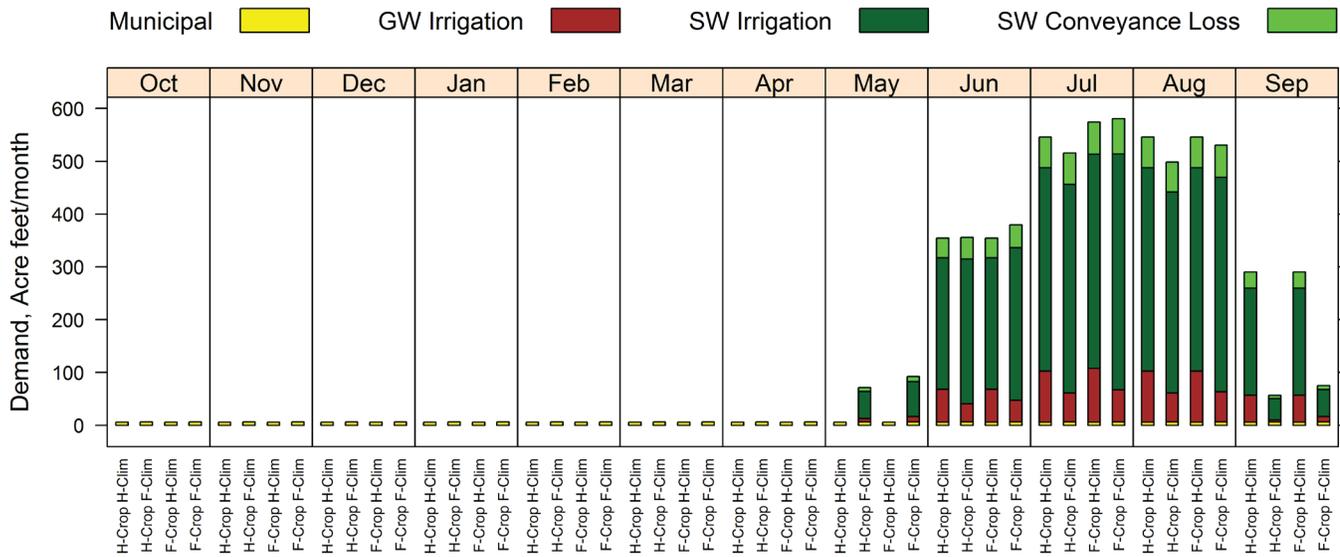


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

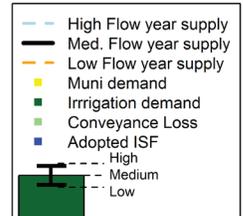
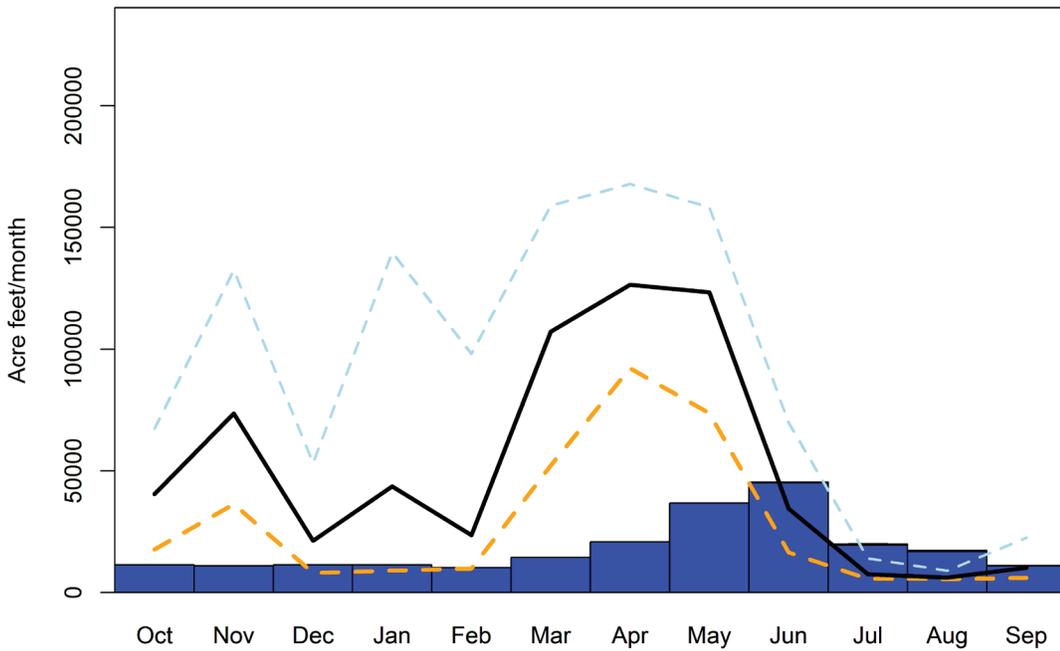
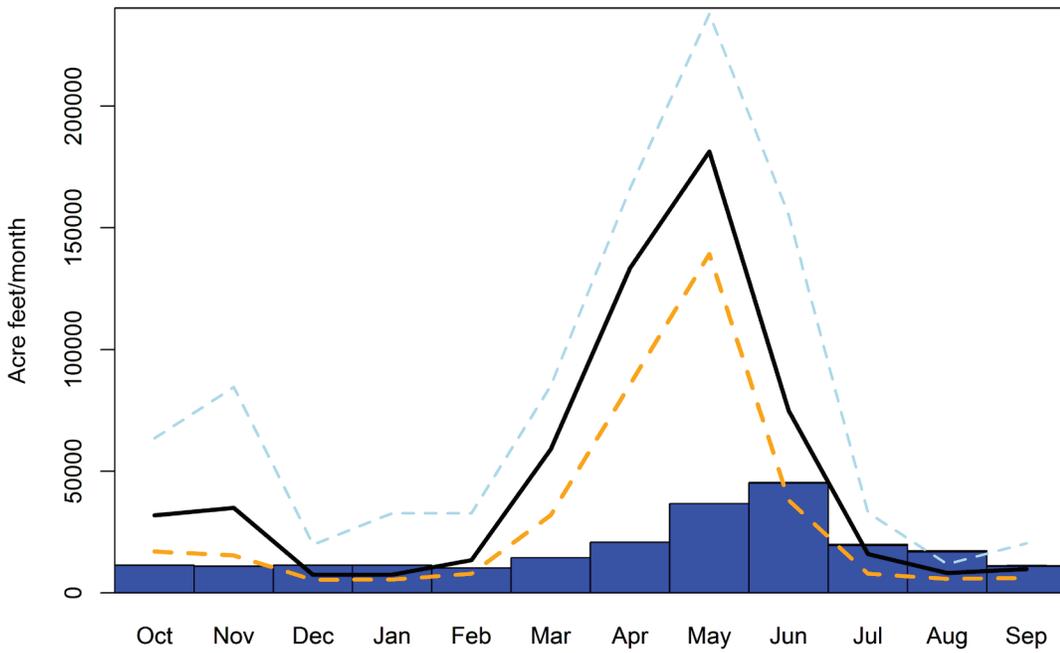


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



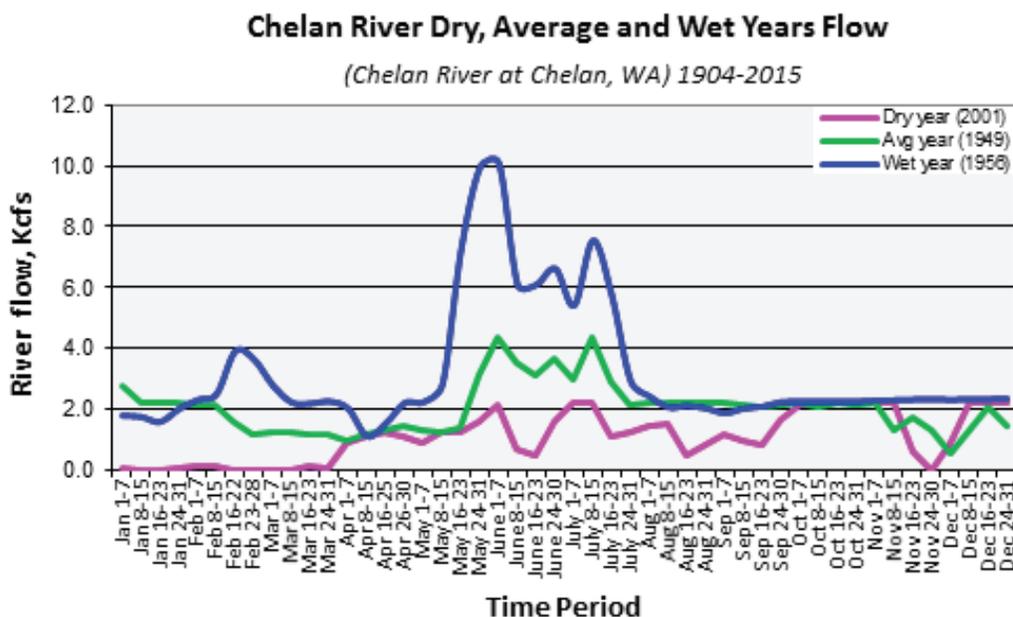
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

## MANAGEMENT CONTEXT

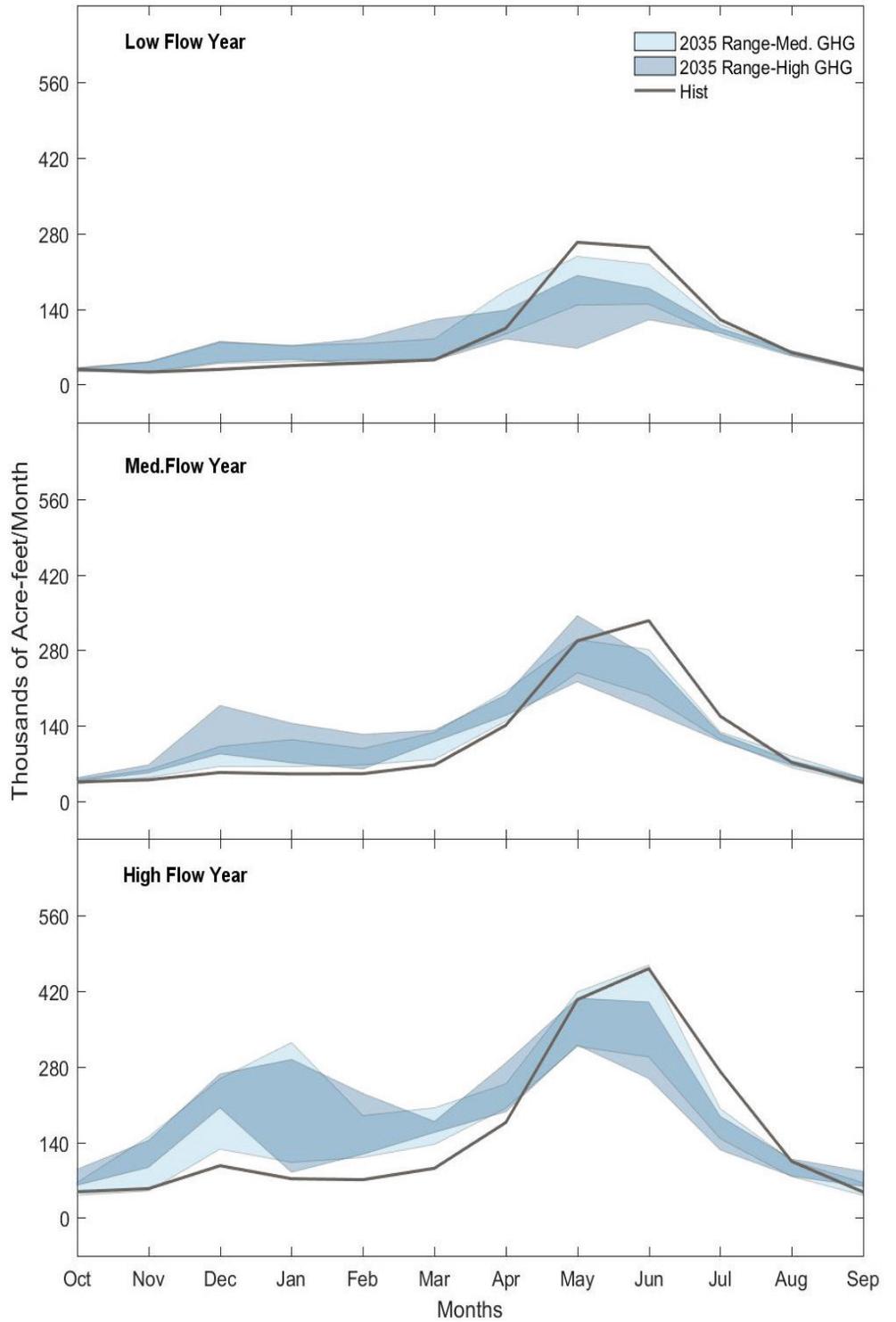
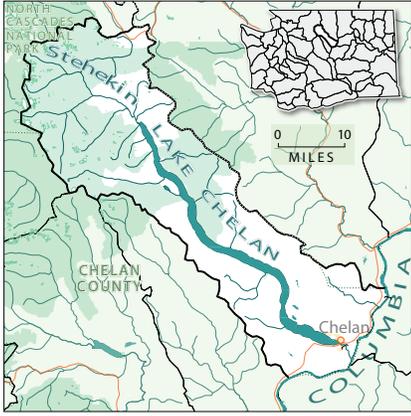
- The tributary surface water supply forecast for Wenatchee shows very prominent changes with increases during the months of October through March for most of the years and decreases for June and July.
- Irrigation is the primary demand, with much smaller municipal demands.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase in May and decrease from June through October. These changes are primarily in response to climate change.
- Municipal demand projected to grow by roughly 20% by 2035.

MANAGEMENT CONTEXT	
Adjudicated Areas	Antoine Creek , Safety Harbor Creek
Watershed Planning	Phase 2 (Assessment)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	[Columbia mainstem migratory corridor]
Groundwater Management Area	NO

<sup>1</sup>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.

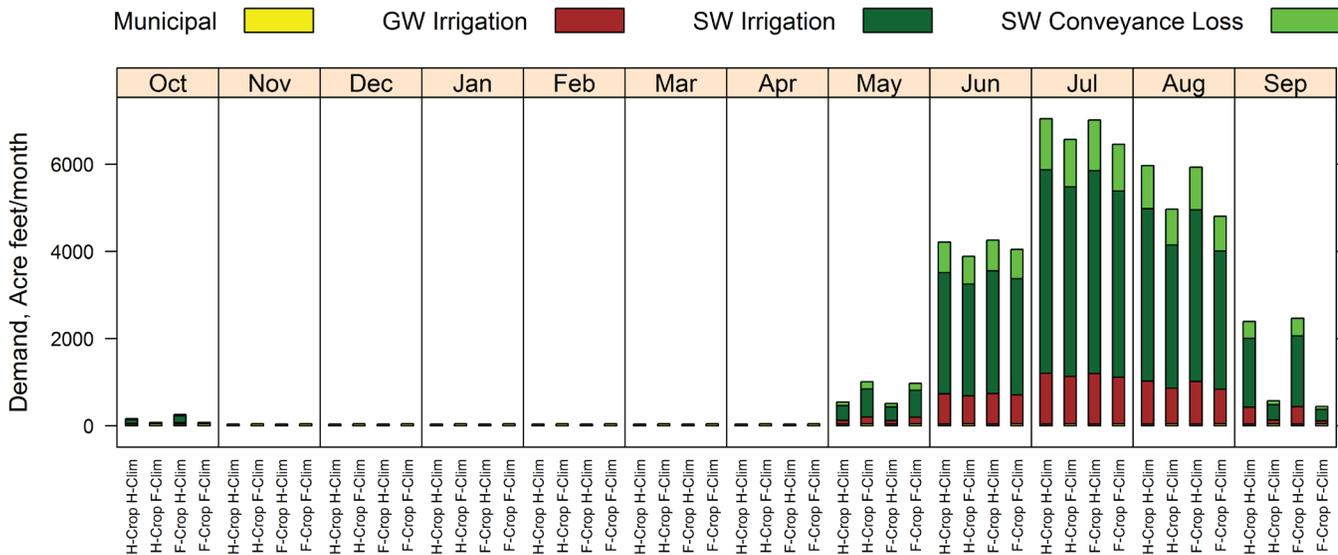


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

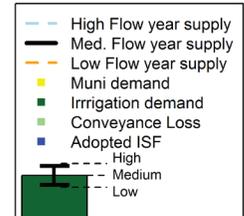
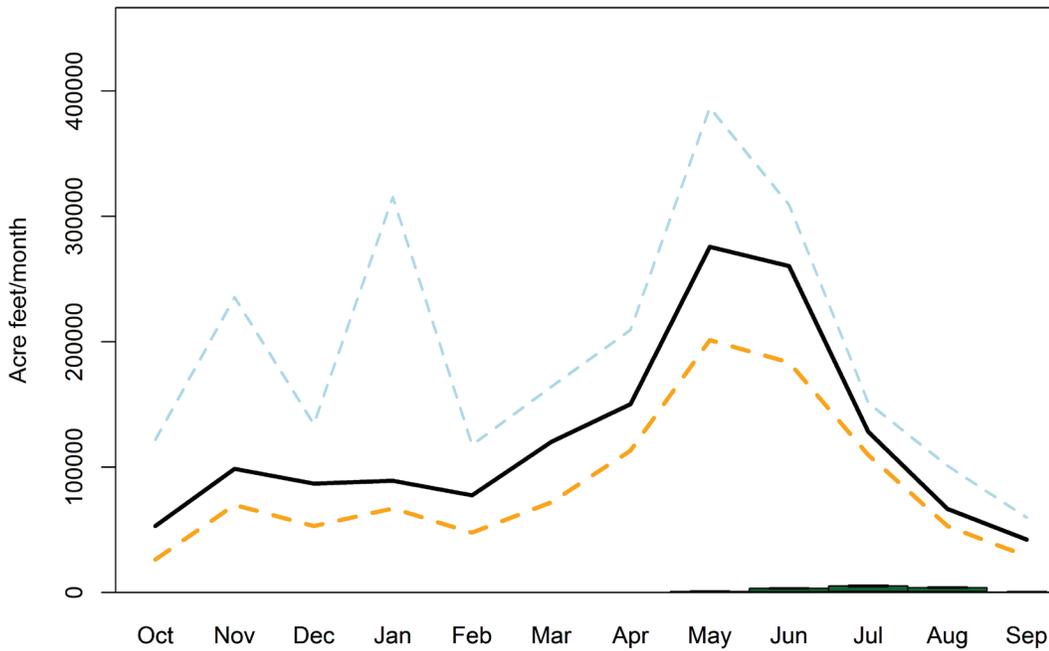
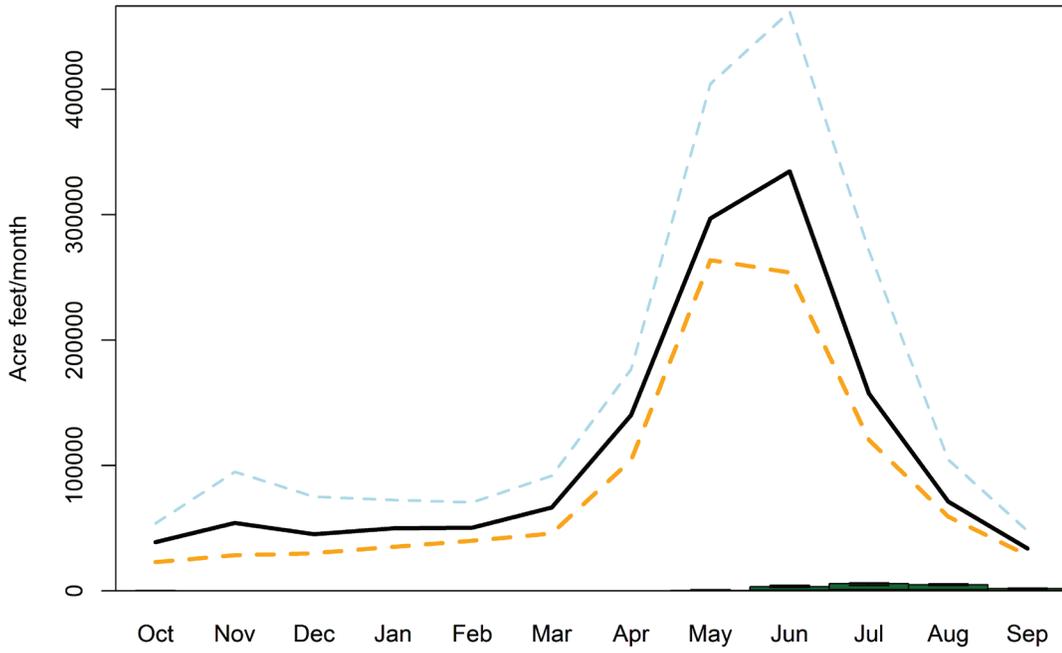


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

## DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

## MANAGEMENT CONTEXT

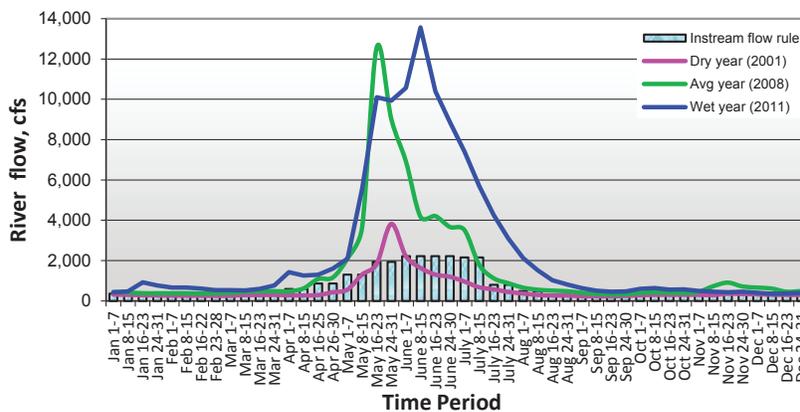
- The tributary surface water supply forecast for Methow is less certain for the summer months with a combination of increases and decreases, depending on climate scenario. Supply change is prominent for the fall and spring with increases from October through April.
- This WRIA has much larger instream flow requirements than irrigation demands, and even smaller municipal demands.
- Assuming no change in irrigated acreage, irrigation demand is projected to decrease for all months during the irrigation season. These changes are primarily in response to both climate change and crop mix changes for June through September and in response to crop mix changes in May and October.
- Municipal demands are forecasted to grow by 19% by 2035.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIAs that provide habitat for ESA-listed anadromous salmonids.
- Forecast curtailment magnitude peaks in July, with the highest frequency in June.
- Forecast shows higher magnitude of curtailment events during May, August, and September, with consistently higher frequency in June and July.
- High magnitude of curtailment events are forecasted for May while they were absent for the historical period.

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). 48 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 ranged from 0 to 4 years from April to May (90% to 100% reliable), and 15 years from June to March (50% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout, Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Management Area	NO

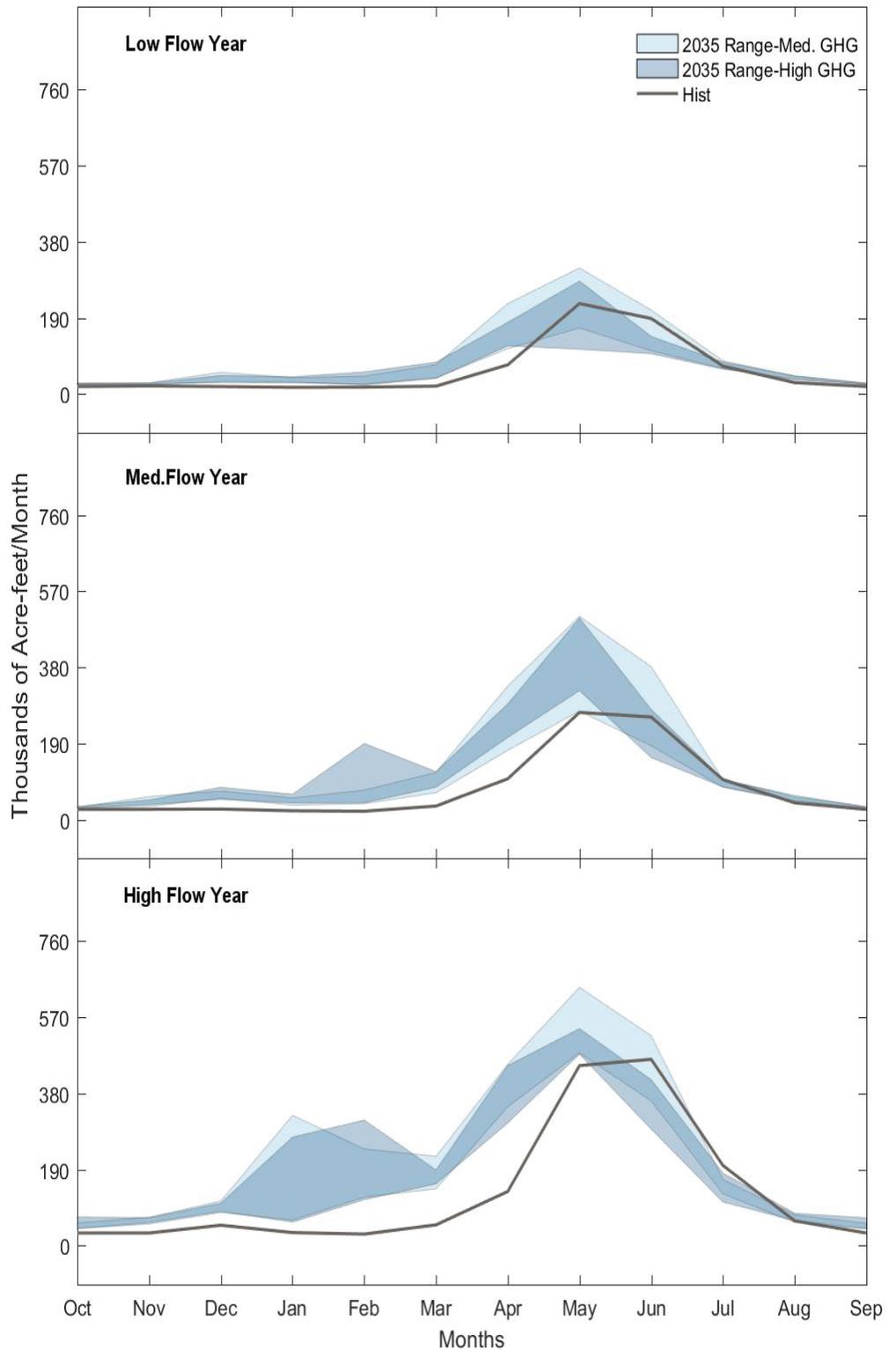
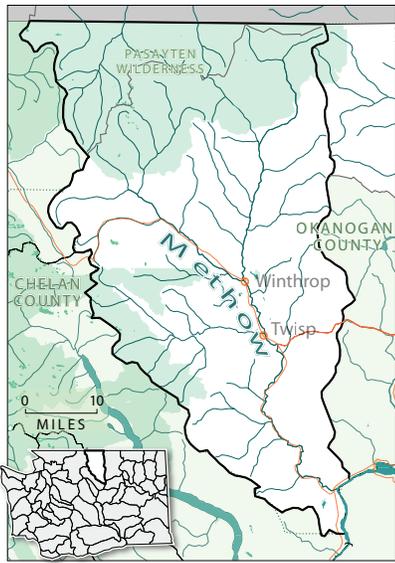
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 189. Summaries are also available online at <http://apps.wdfw.wa.gov/salmonscape/>.

**Comparison of Dry, Average and Wet Year Flows to Instream Flow Rule (Methow River near Pateros, WA) 1981-2011**

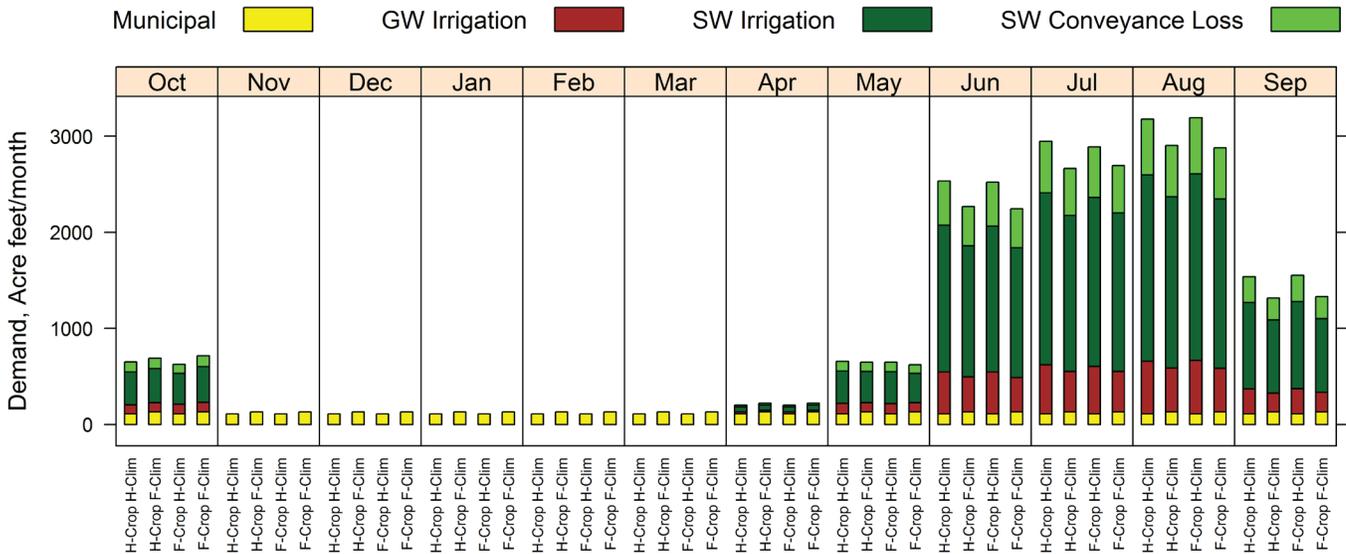


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

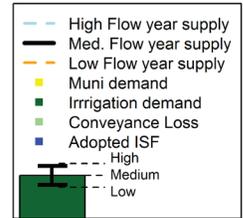
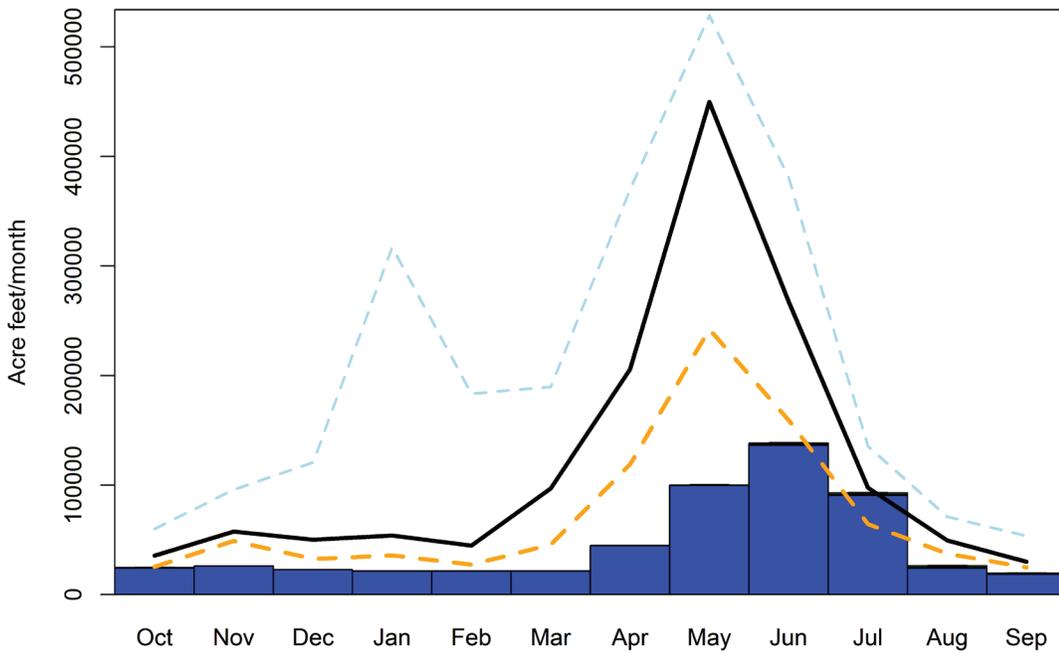
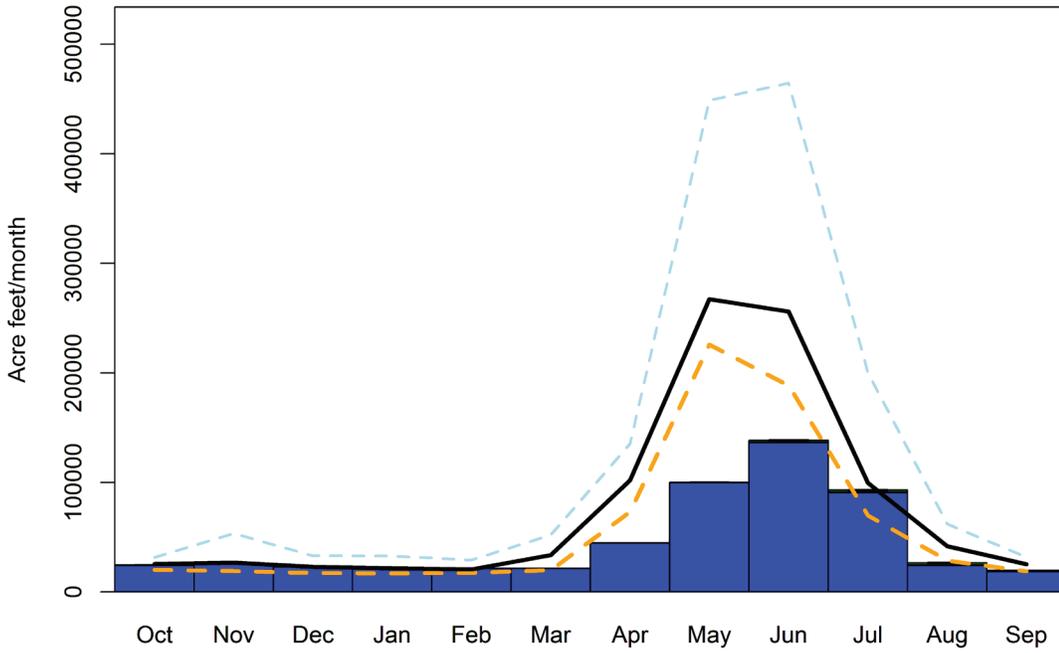


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND

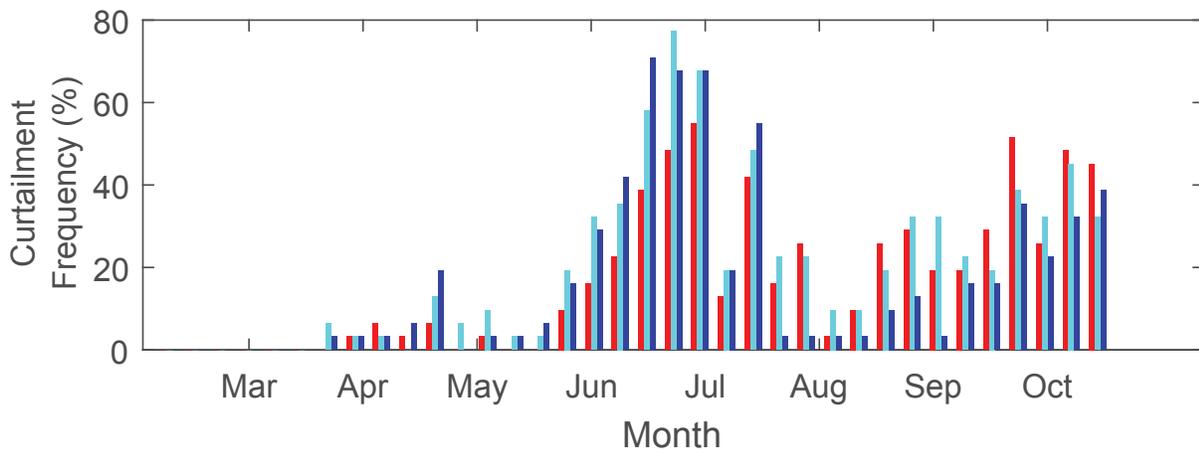
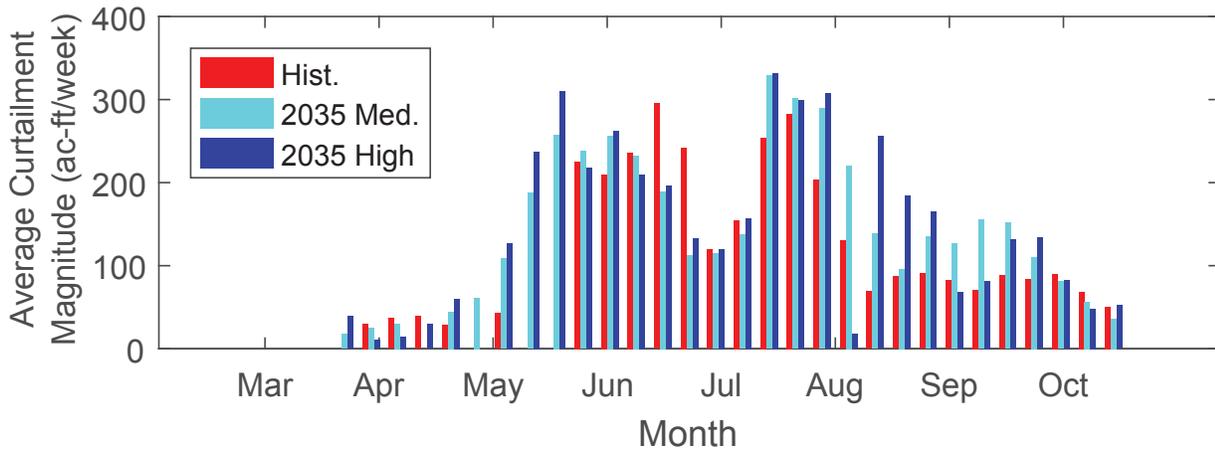


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

CURTAILMENT



Modeled historical (1981-2011) and forecast (2035) median curtailment magnitude (ac-ft per week) (top panel) and curtailment frequency (%) (bottom panel) in this WRIA. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

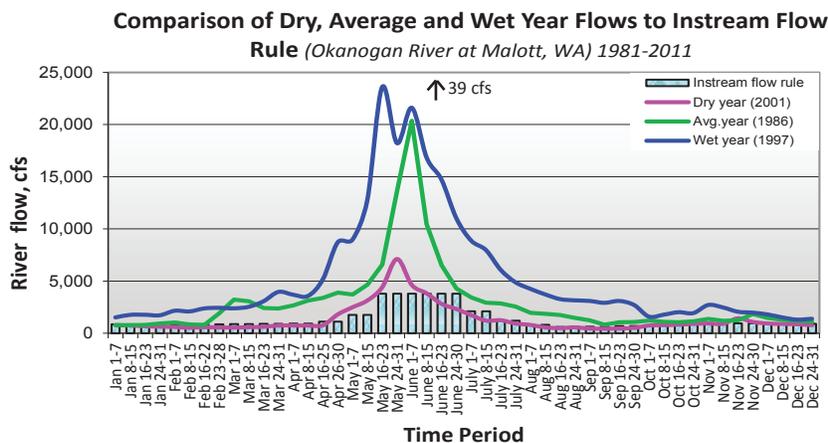
- The tributary surface water supply forecast for Okanogan is characterized mostly by increases from October through March (although the 20th percentile supply years show a combination of increases and decreases in March), followed by decreases in April for the 80th supply year and in June for the 20th and 50th supply years.
- The largest demands are from instream demands, though irrigation demands are also important. Municipal demands are much smaller.
- Assuming no change in irrigated acreage, irrigation demand is projected to decrease from June through October due to both climate and crop mix changes. April and May changes are less certain with climate change causing a increase in demands and crop mix changes causing an decrease in demands.
- Municipal demands are forecasted to grow by 5% by 2035.
- This WRIA is included in the Columbia River Instream Atlas (Ecology Publication in preparation), which contains information on instream water demands for 12 WRIAs that provide habitat for ESA-listed anadromous salmonids.
- Forecast curtailment magnitude peaks in July.
- Forecast shows slightly decreasing curtailment magnitude later in the season, with increasing frequency for the Medium Range Green House Gas scenario.
- Forecast frequency increases during the mid to late irrigation season.

MANAGEMENT CONTEXT

Adjudicated Areas	Simikameen River, Salmon Creek, North Fork, Johnson Creek, Lower Antoine Creek, Sinlahekin Creek, Myers Creek, Whitestone Lake, Chiliwist Creek, Bonaparte Creek & Lake, Duck Lake Ground Water Subarea
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-549 WAC). 96 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 ranged from 1 to 4 years from April to May (90% to 97% reliable), and averaged 10 years in June to March (67% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Upper Columbia Steelhead, [Columbia mainstem migratory corridor]
Groundwater Management Area	YES (Duck Lake subarea)

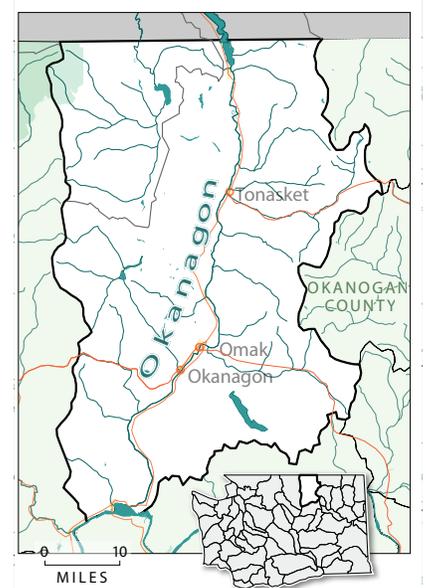
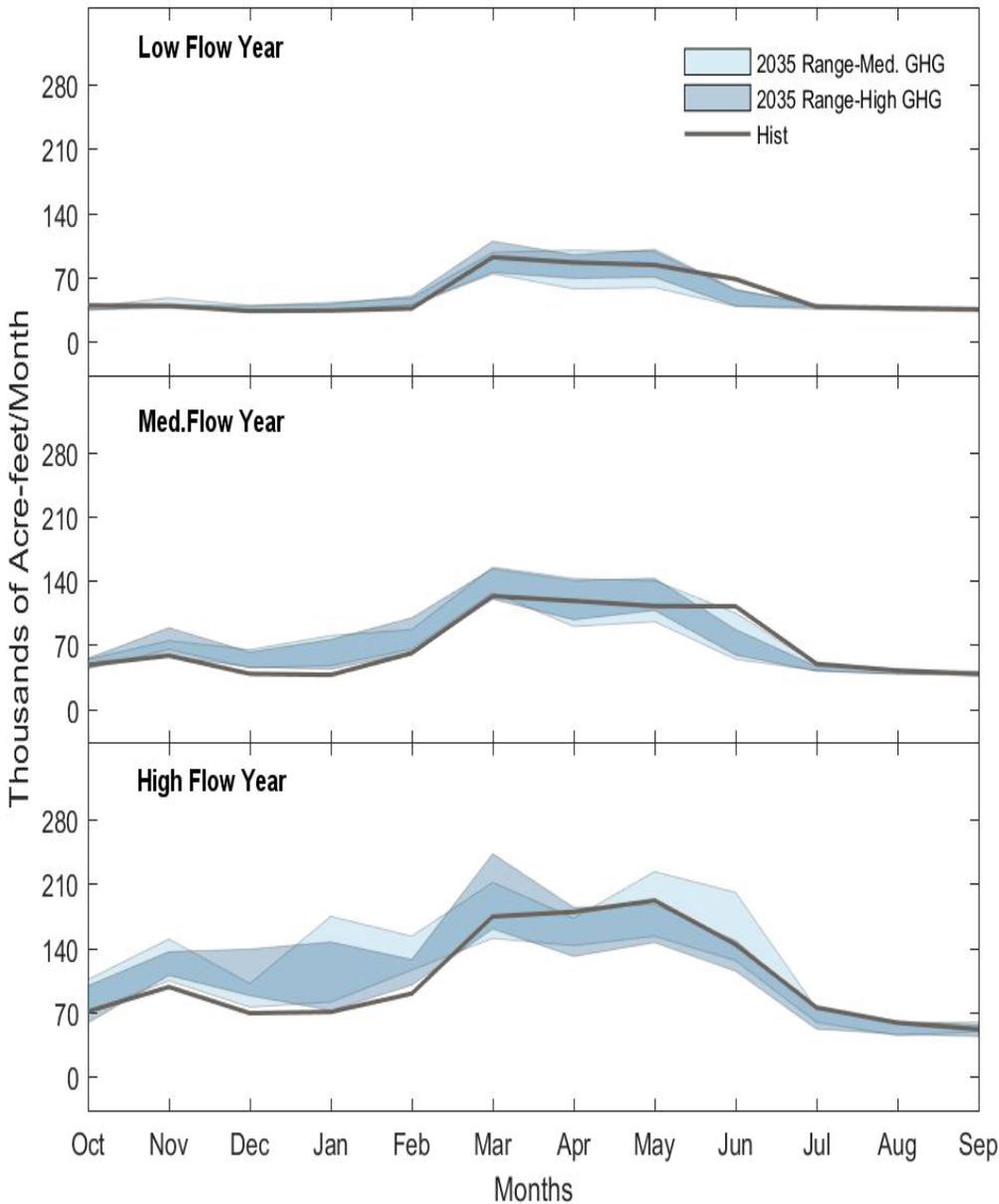
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

A table showing salmon, steelhead, and bull trout use of WRIA waters (provided by the Washington Department of Fish and Wildlife (WDFW)) is available on page 189. Summaries are also available online at <http://apps.wdfw.wa.gov/salmonscape/>.

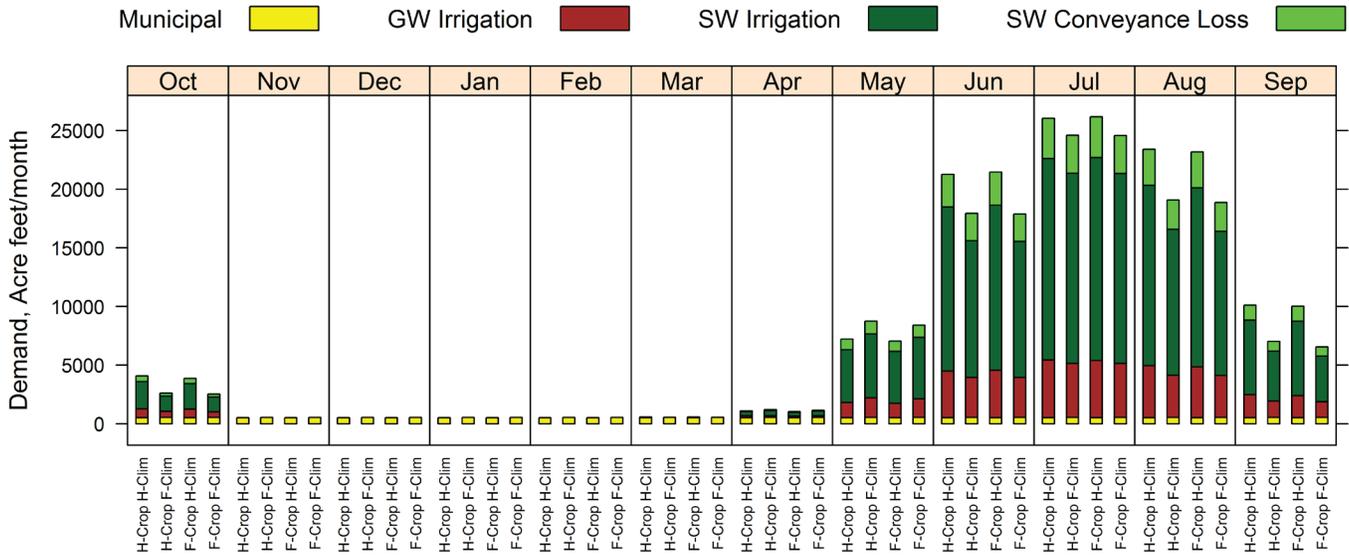


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## SUPPLY

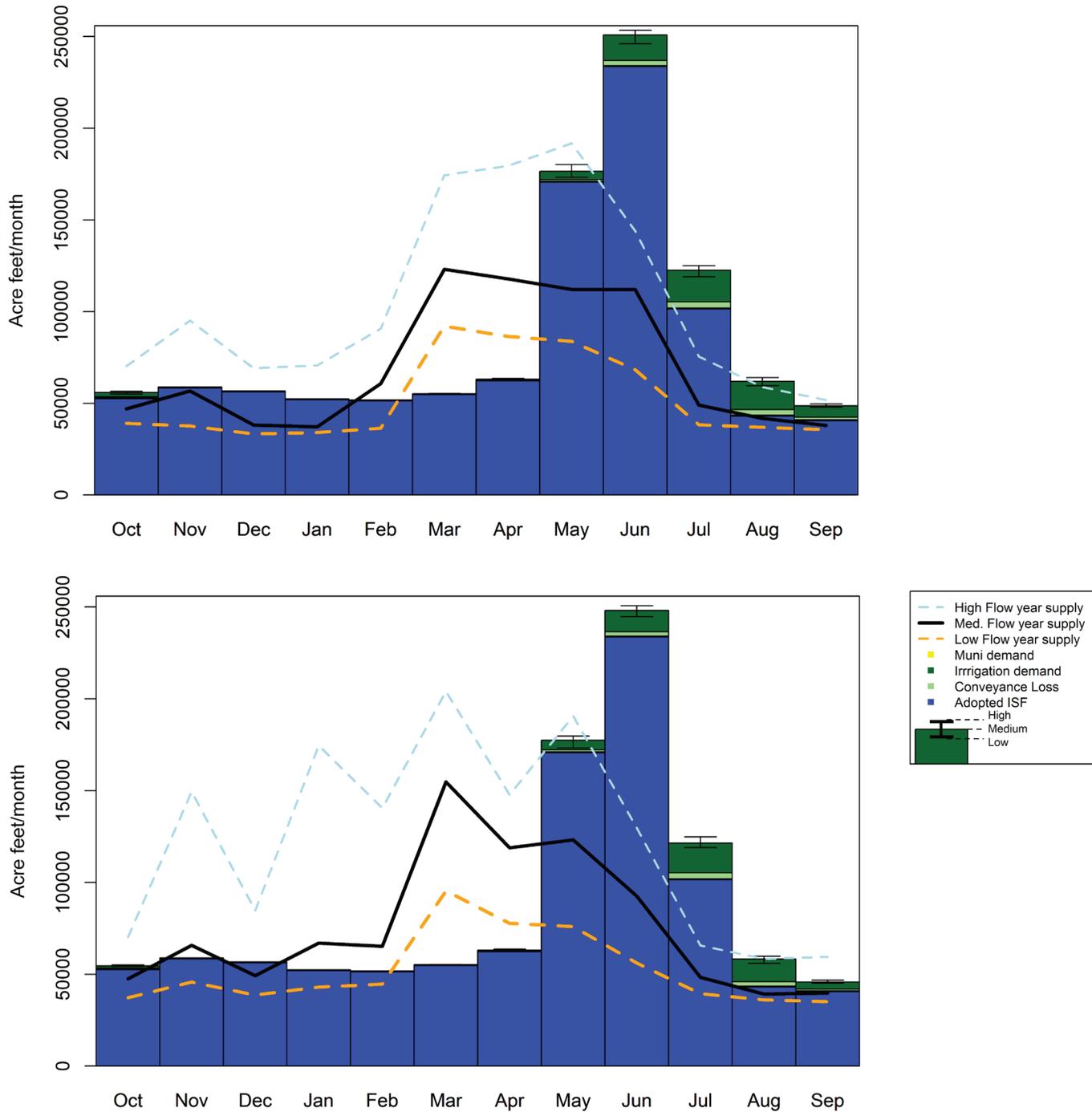


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

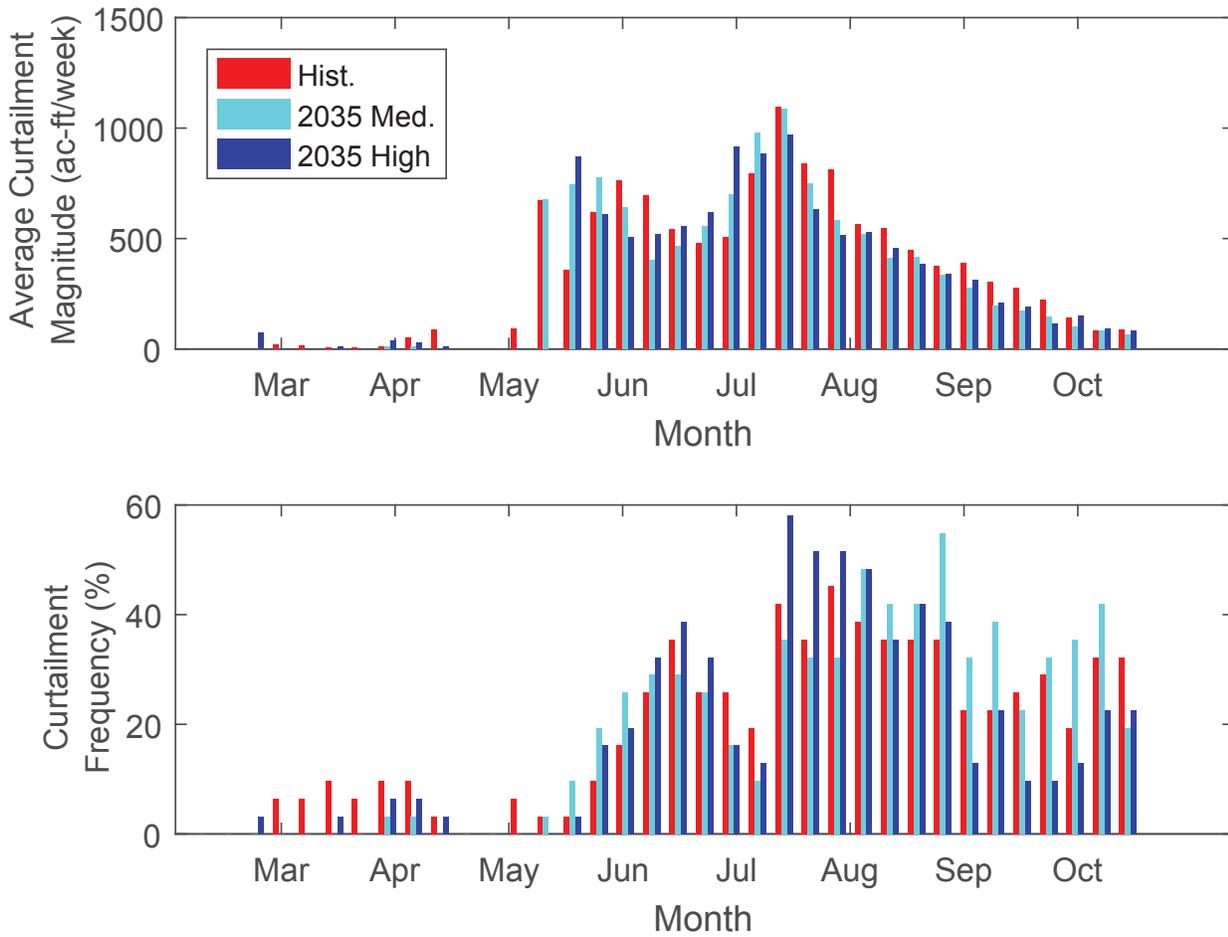


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.



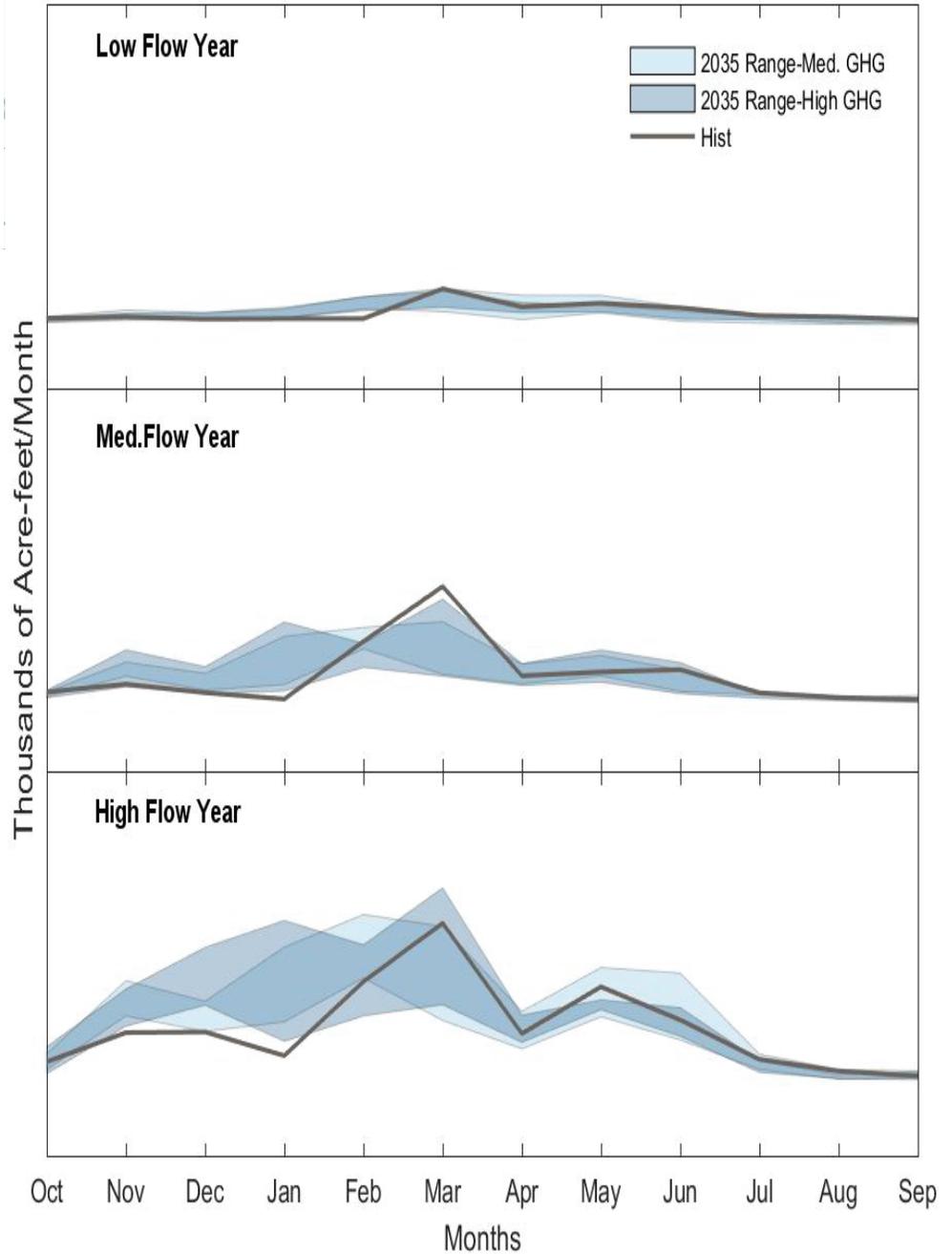
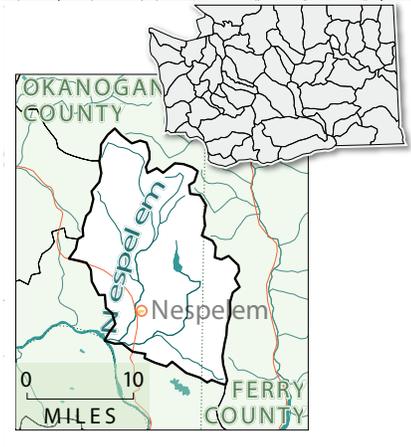
Modeled historical (1981-2011) and forecast (2035) median curtailment magnitude (ac-ft per week) (top panel) and curtailment frequency (%) (bottom panel) in this WRIA. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

# MANAGEMENT CONTEXT

- The supply forecast for Nespelem is characterized by increases in supply from November through January, with decreases in March for most scenarios, and a mix of increases and decreases the remaining months, depending on climate scenario.
- Municipal/domestic demands are quite small in this watershed compared to other watersheds in eastern Washington, and there were very small modeled irrigation demands in either the historical or the future period.
- Municipal demands are forecasted to grow 3% by 2035, a smaller increase than in many other watersheds of eastern Washington.
- Assuming no change in irrigated acreage, irrigation demands are projected to decrease in July, and September and increase in other months in response due to climate changes.

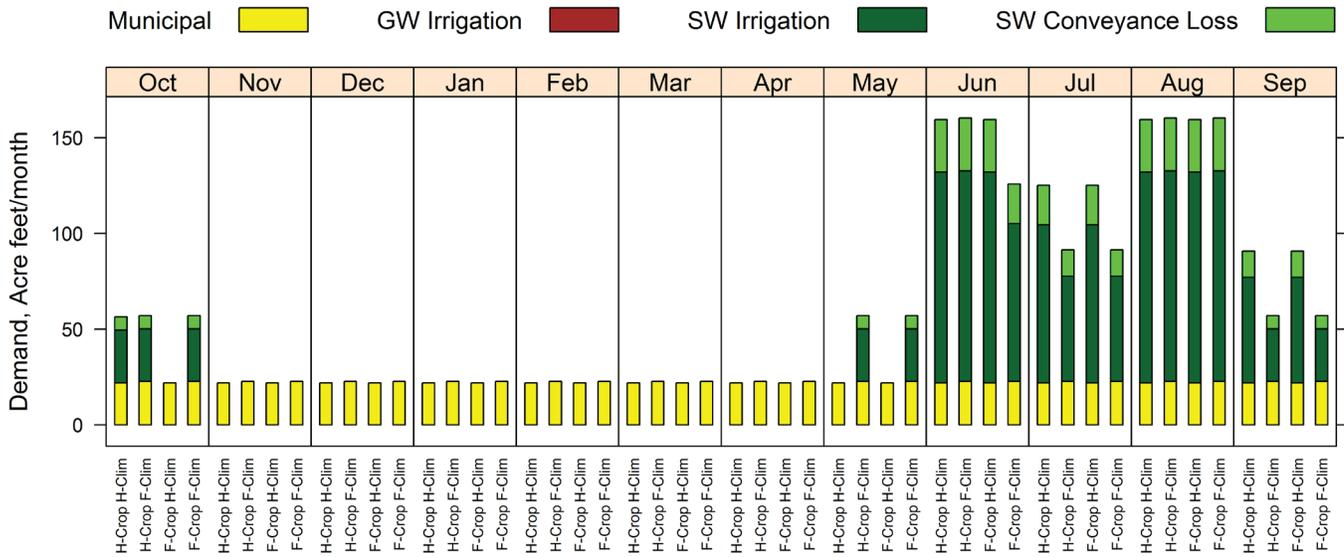
MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

<sup>1</sup>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.

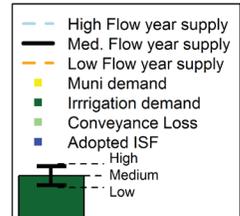
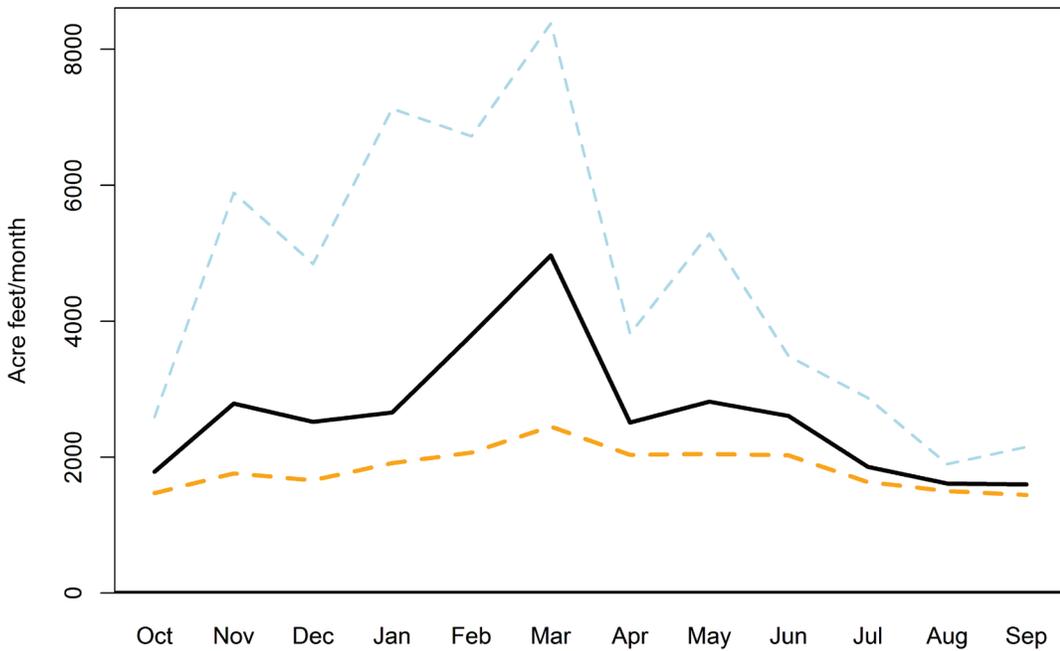
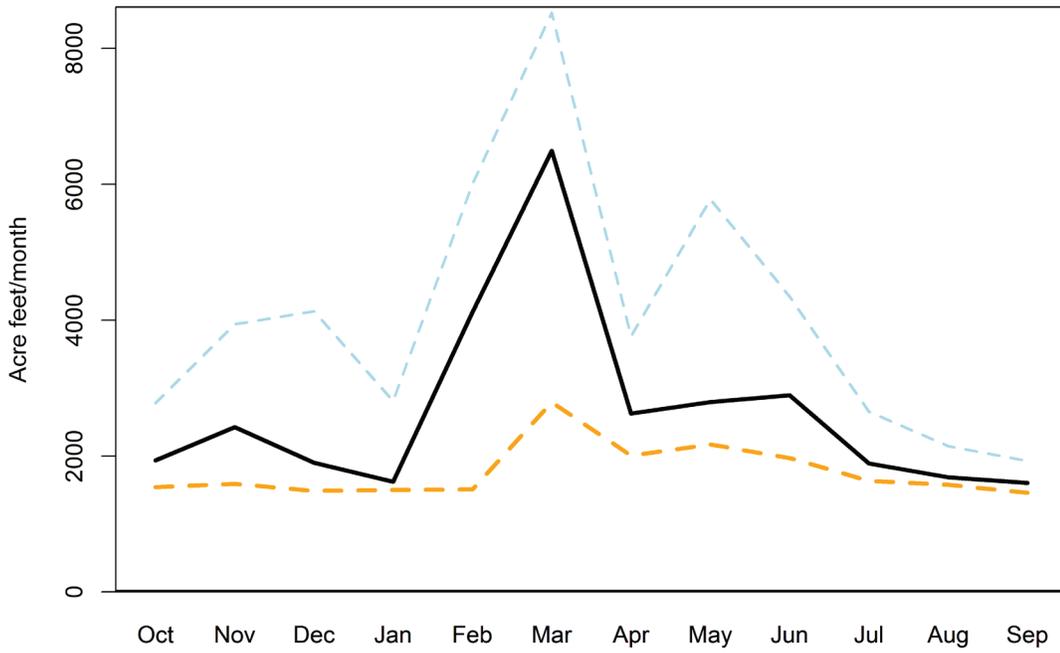


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



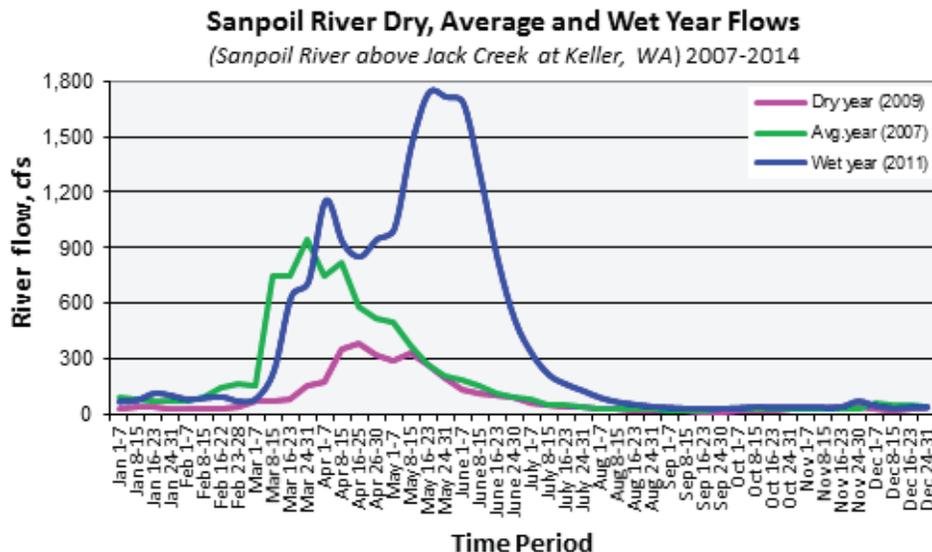
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

# MANAGEMENT CONTEXT

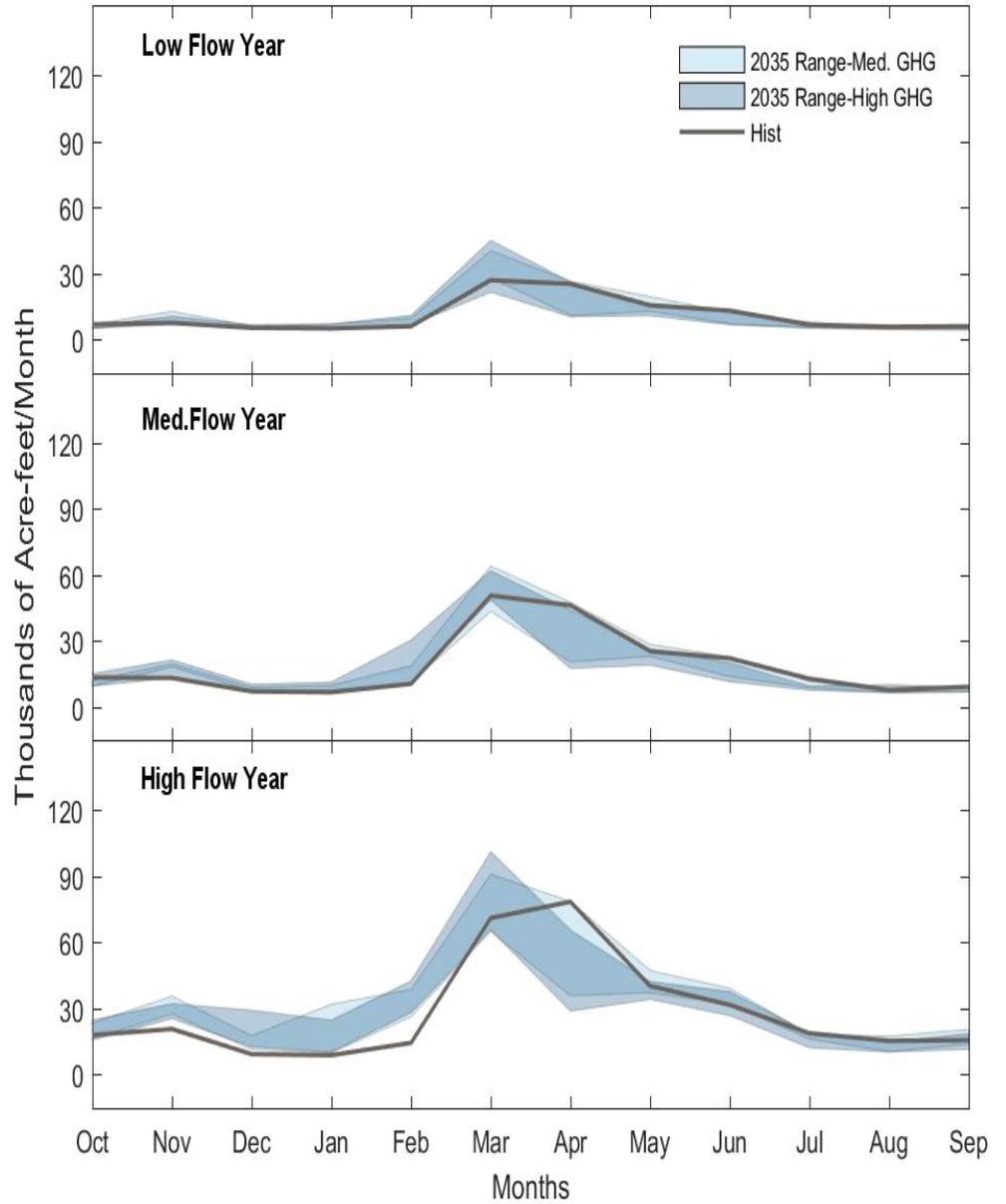
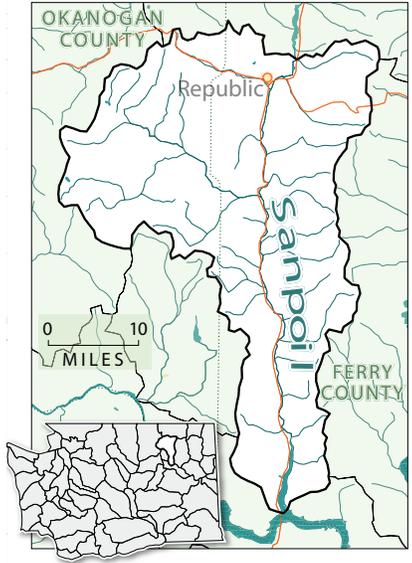
- The tributary surface water supply forecast for Sanpoil is characterized mostly by increases from October through March and decreases from April through July.
- Both irrigation and municipal/domestic demands are quite small in this watershed.
- Assuming no change in irrigated acreage, irrigation demands are projected to increase in August and decrease in September, and October in response to mainly climate changes.
- Municipal demands are forecasted to grow 16% by 2035.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

<sup>1</sup>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.

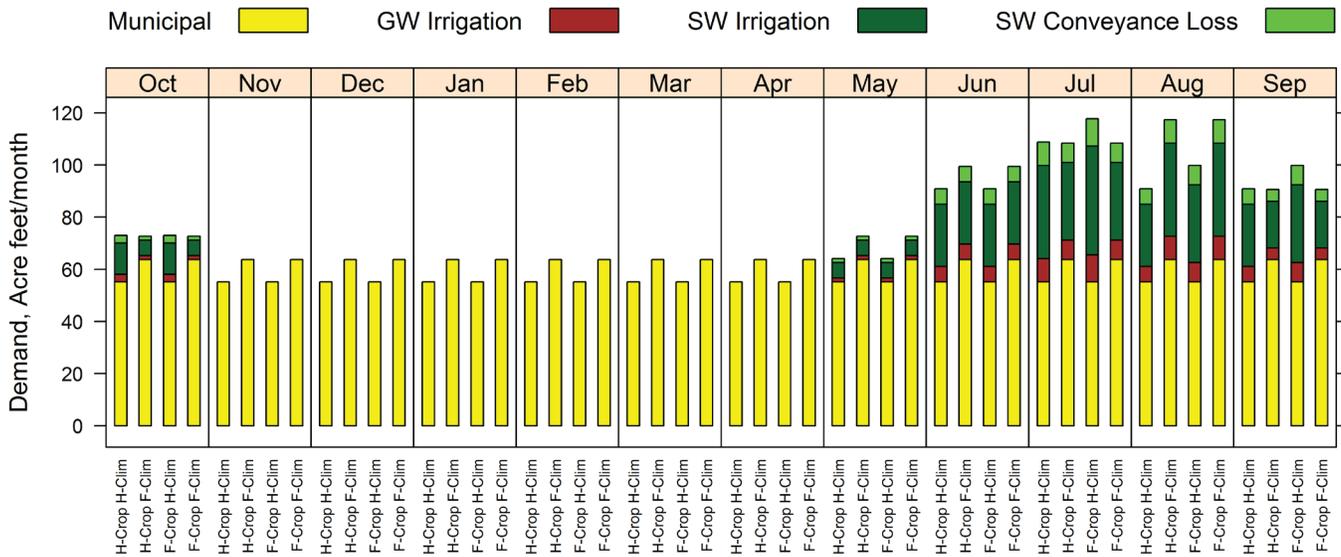


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

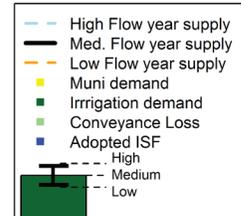
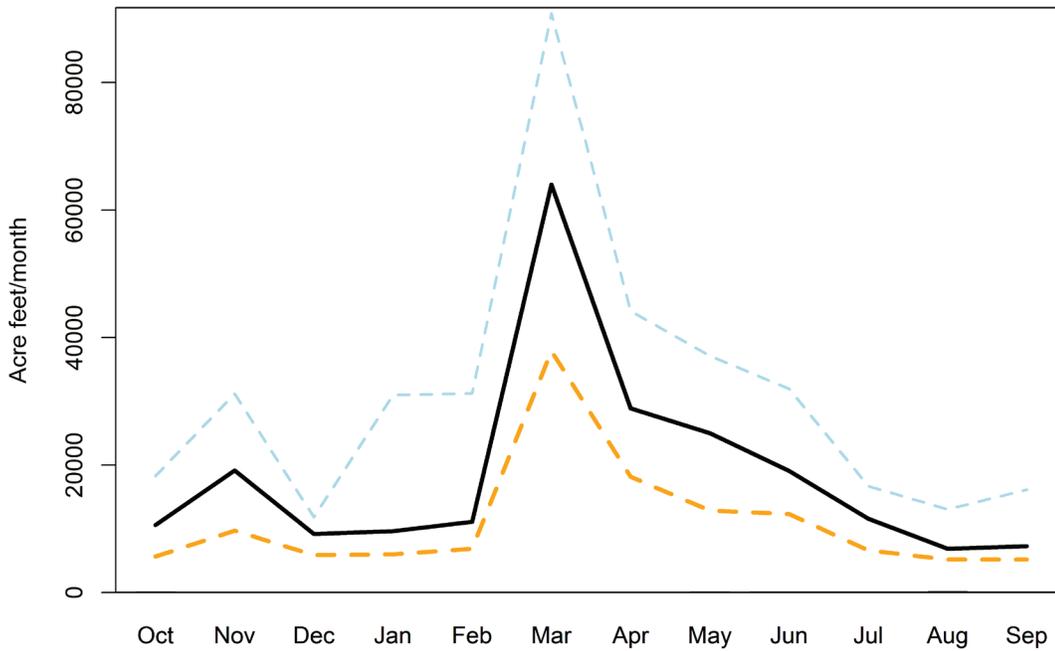
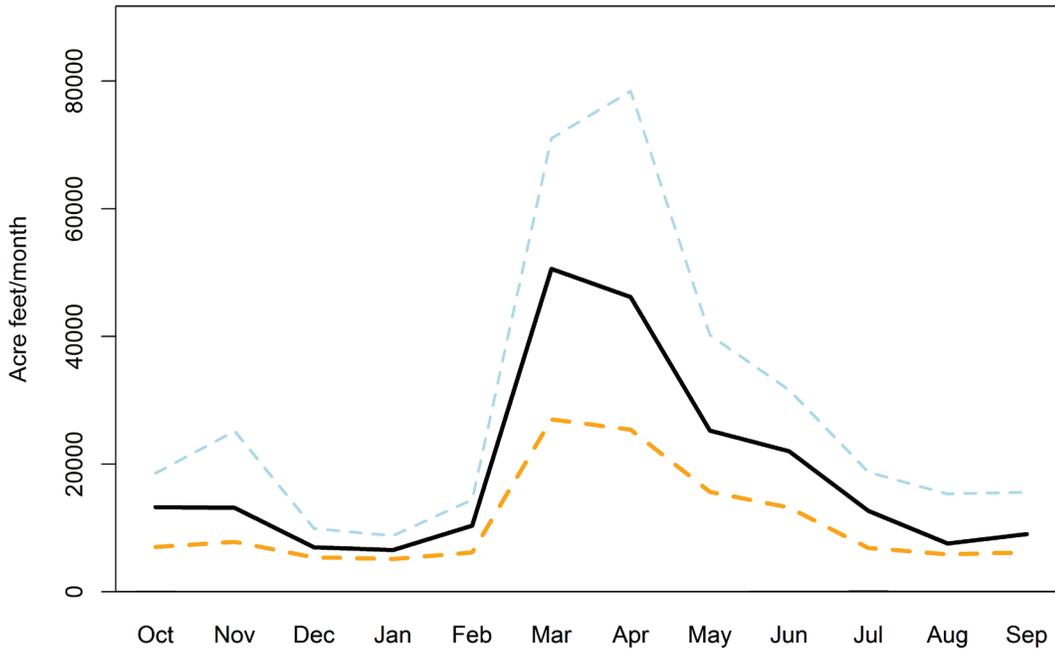


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b)"H-Crop F-Clim", c)"F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario,"H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



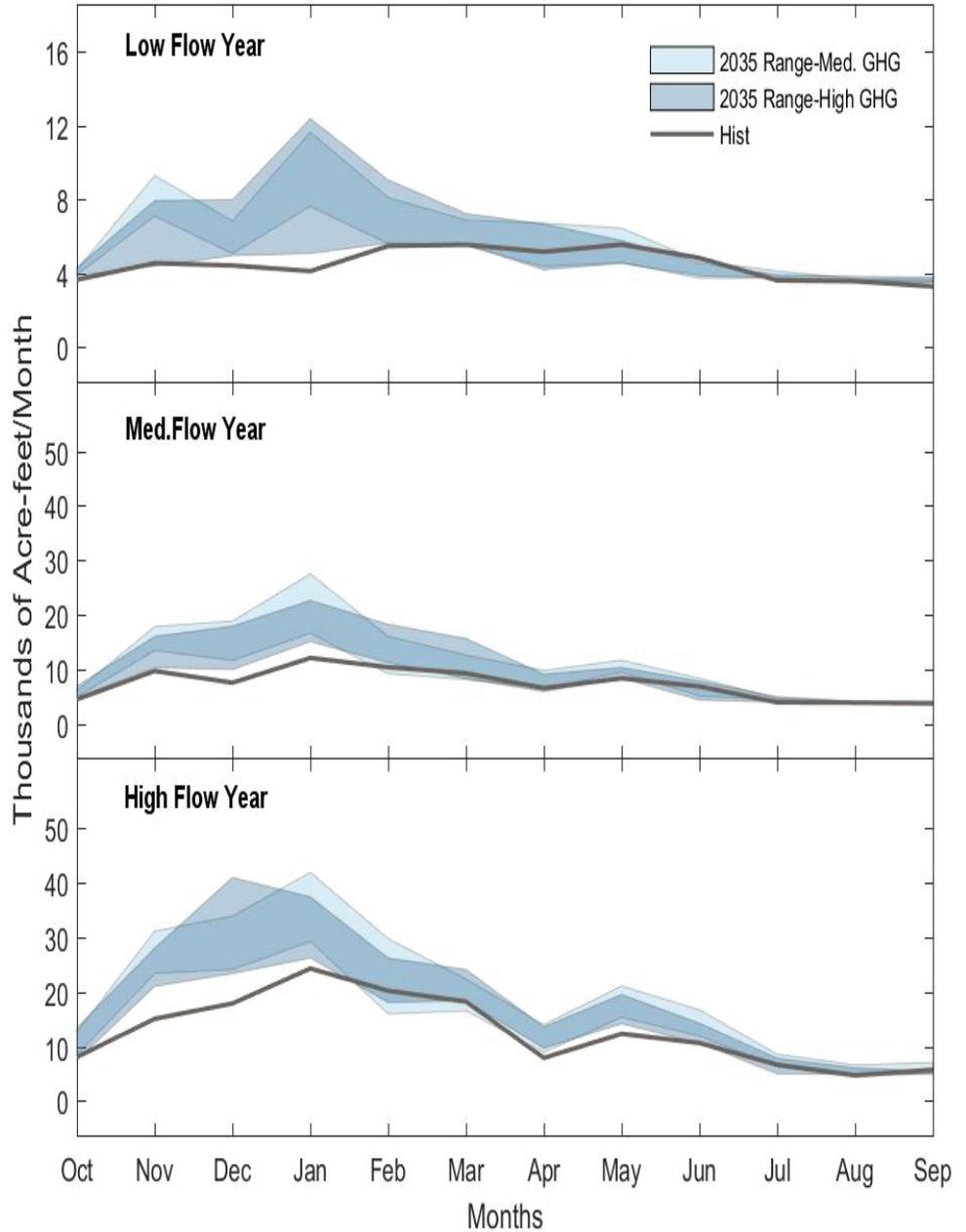
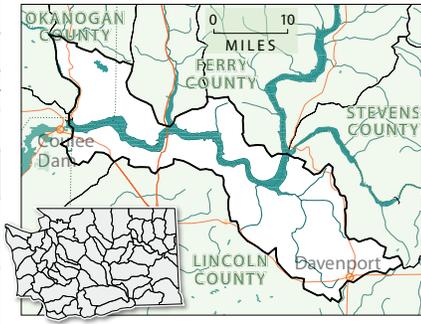
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

# MANAGEMENT CONTEXT

- The tributary surface water supply forecast for Lower Lake Roosevelt is characterized mostly by increases from October through May for all percentiles, and also in June for the 80th percentile supply year. The 20th supply year is projected to decrease in June.
- 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 projected to decrease from June through August and in April, in response to climate change. Changes during May and September are projected to increase.
- Municipal demands are forecasted to grow by 12% by 2035.

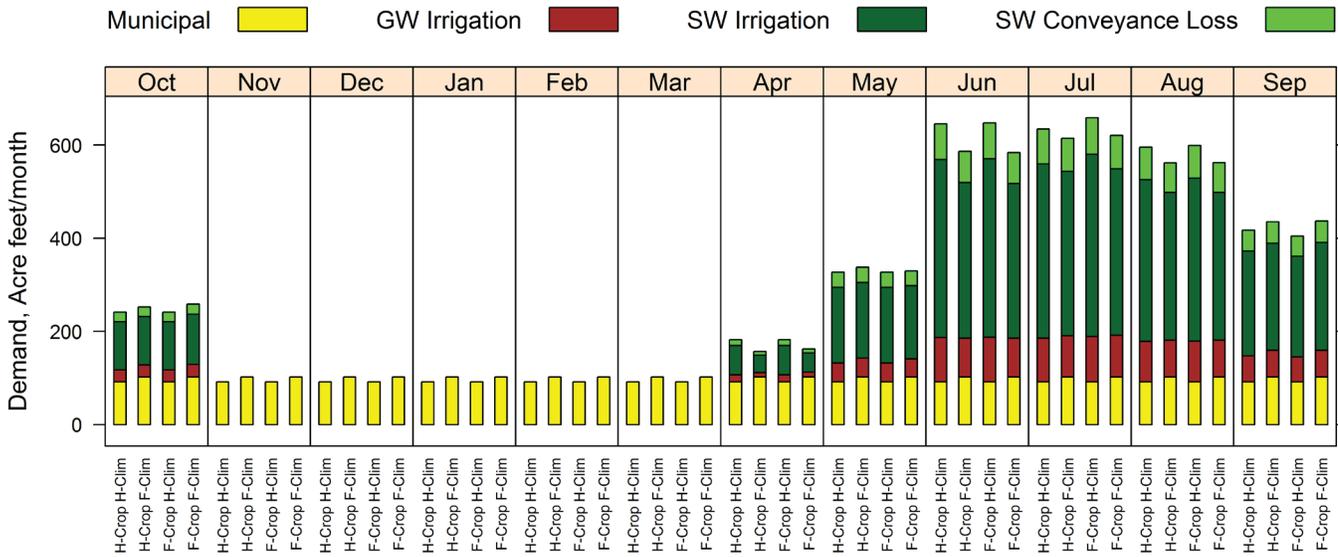
MANAGEMENT CONTEXT	
Adjudicated Areas	Hawkes Creek (incomplete)
Watershed Planning	Phase 2 (Assessment)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout
Groundwater Management Area	NO

<sup>1</sup>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.

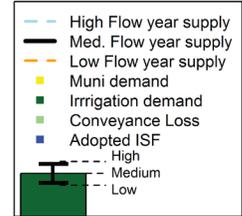
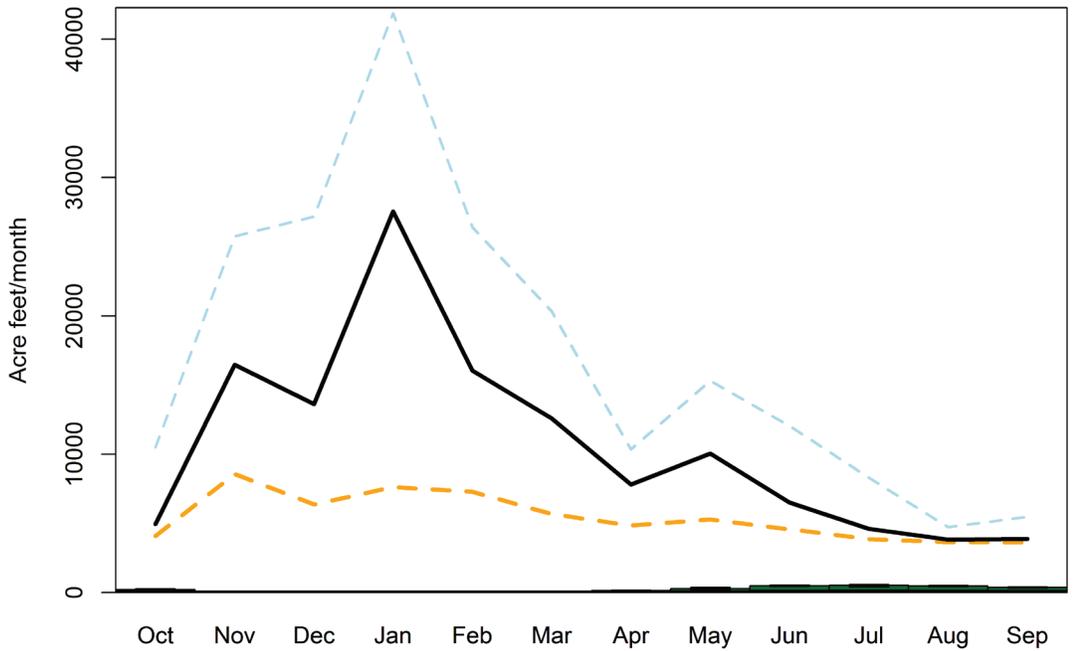
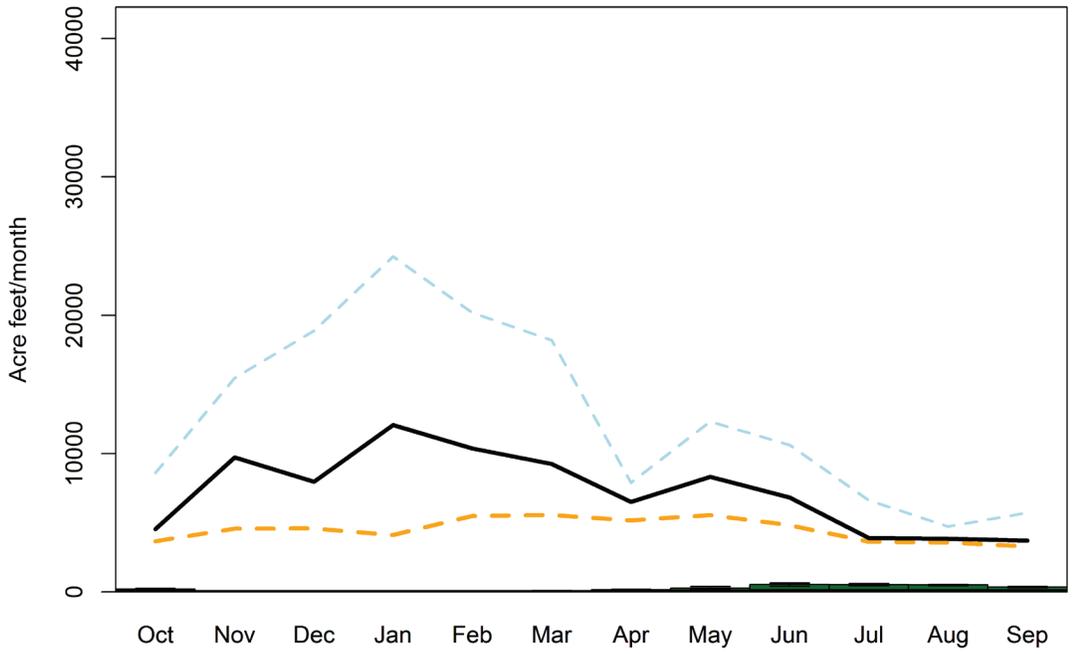


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

MANAGEMENT CONTEXT

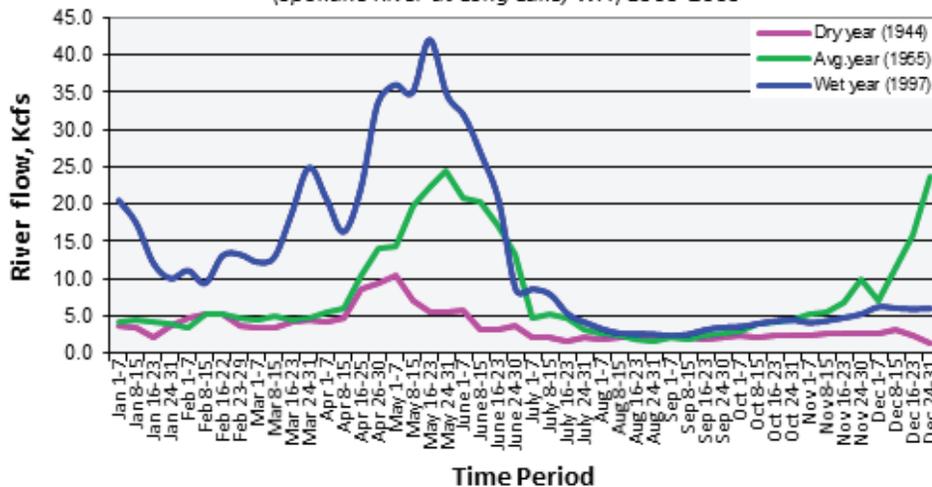
- The tributary surface water supply forecast for Lower Spokane is characterized mostly by increases from October through January for all percentile years, with increases in May and June for the 80th percentile supply year.
- Irrigation demands are somewhat balanced with municipal demands in this watershed, and are relatively modest overall.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase in May and decrease in June, July and August. Climate change have the most influence in both decreasing and increasing demands.
- Municipal demand is forecasted to increase by 14% by 2035.

MANAGEMENT CONTEXT	
Adjudicated Areas	Chamokane Creek (federally administered)
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-557 WAC)
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO (For additional information on groundwater decline areas within this WRIA, see Module xx.)

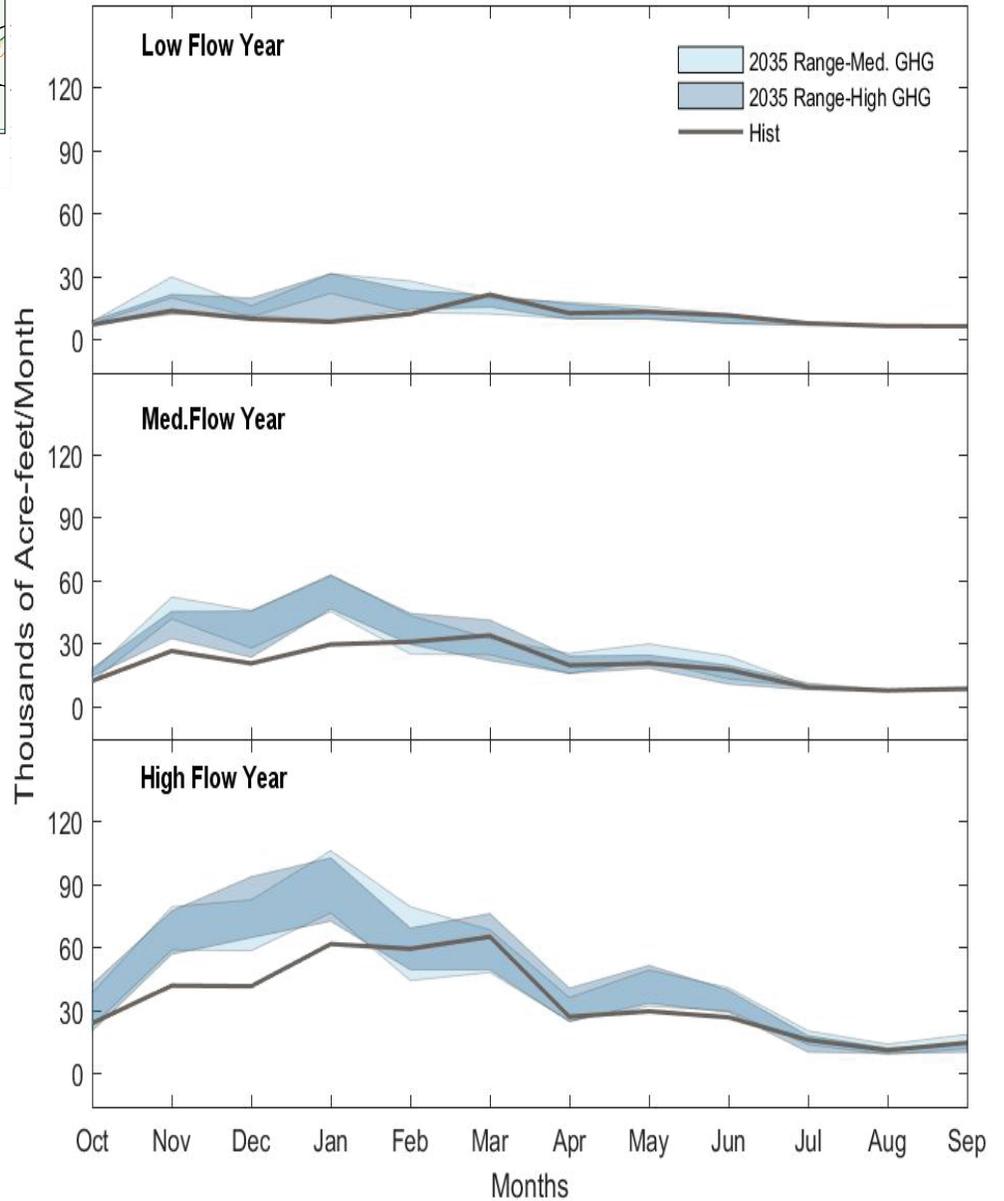
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

Spokane River Dry, Average and Wet Year Flows

(Spokane River at Long Lake, WA) 1939-2009

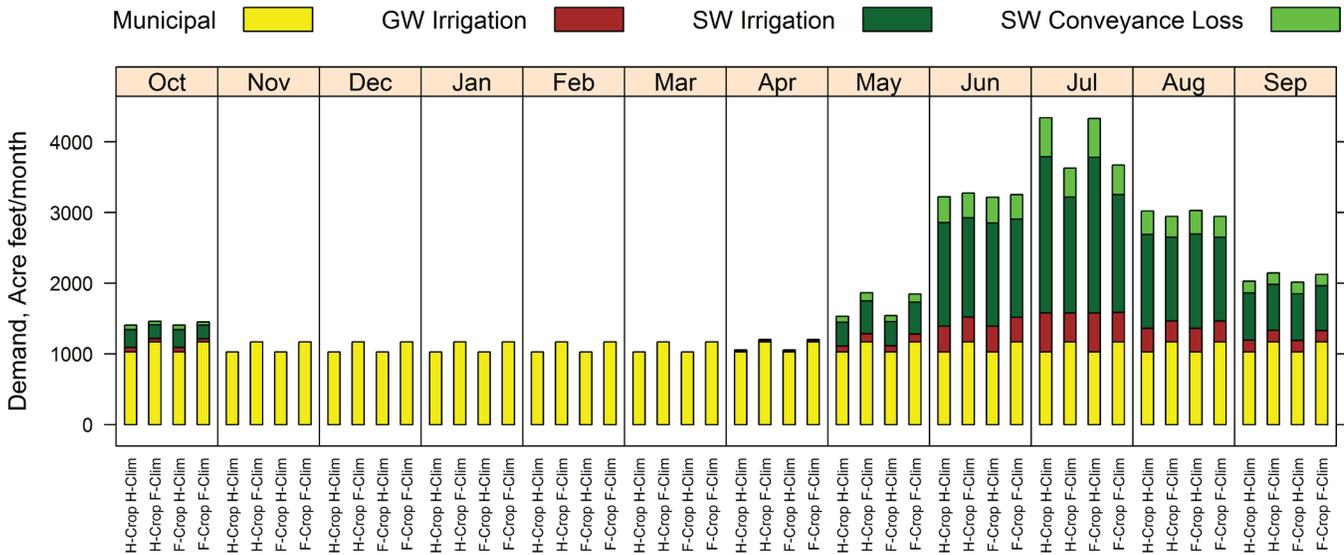


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

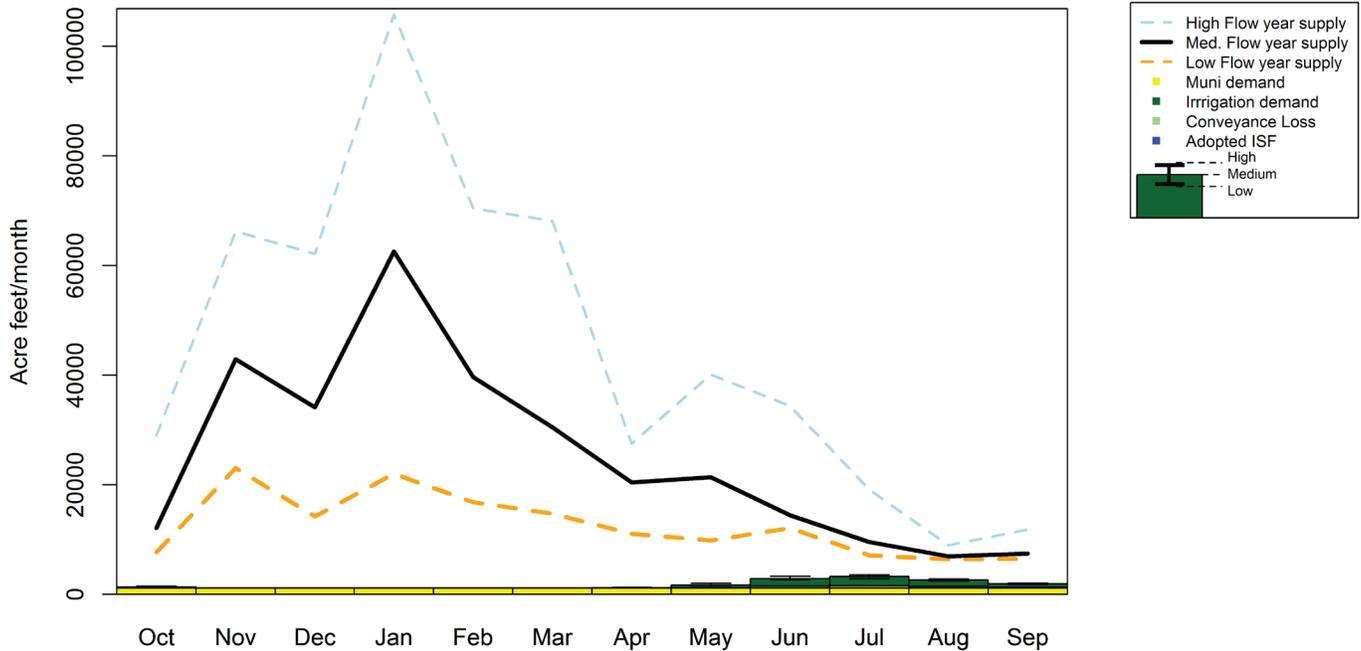
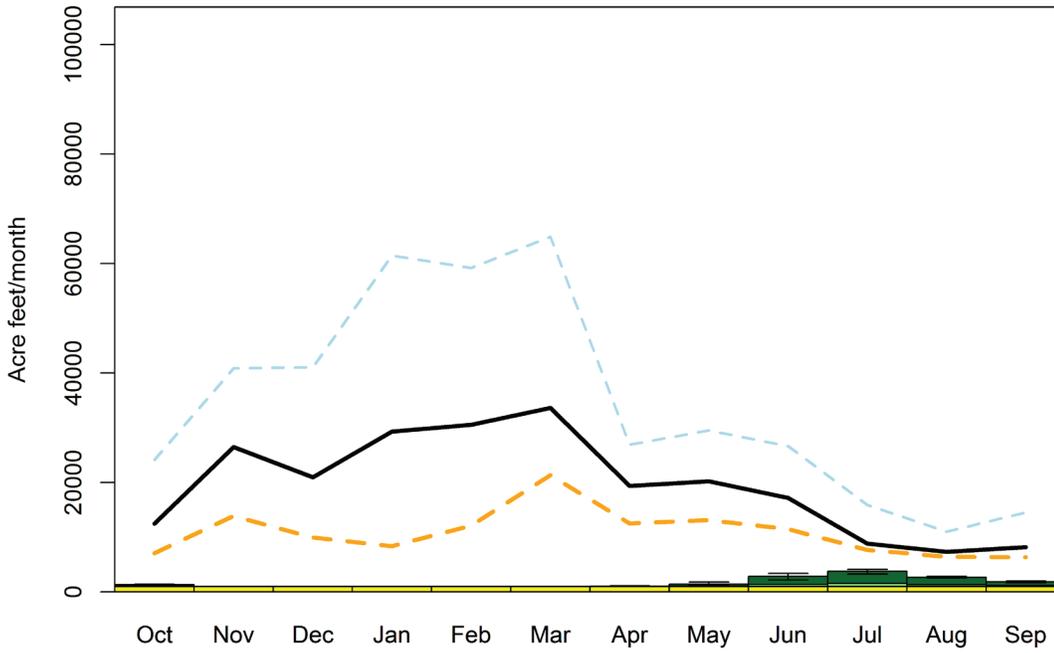


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b)"H-Crop F-Clim", c)"F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario,"H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

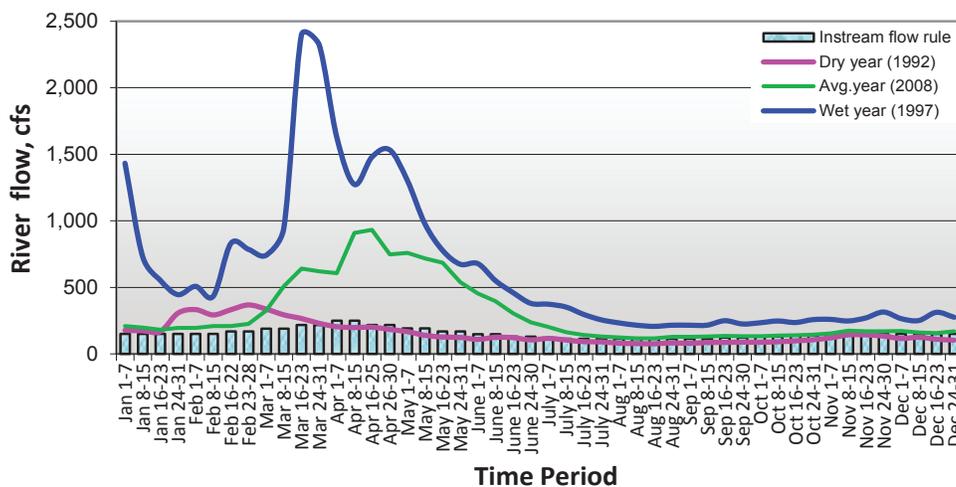
# MANAGEMENT CONTEXT

- The tributary surface water supply forecast for Little Spokane is unclear as a combination of increases and decreases in supply (depending on climate scenario) occur from January through July.
- 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.
- Assuming no change in irrigated acreage, irrigation demands are projected to increase for all months except July, which is projected to decrease. However, in June and August climate and crop mix changes result in opposite signs of demand change (increases for climate change and mostly decreases for crop mixes).
- Municipal demand is projected to increase by 18% by 2035.
- Forecast shows curtailment only for the Medium Range Green House Gas scenario.
- Forecast curtailment magnitude peaks during August.

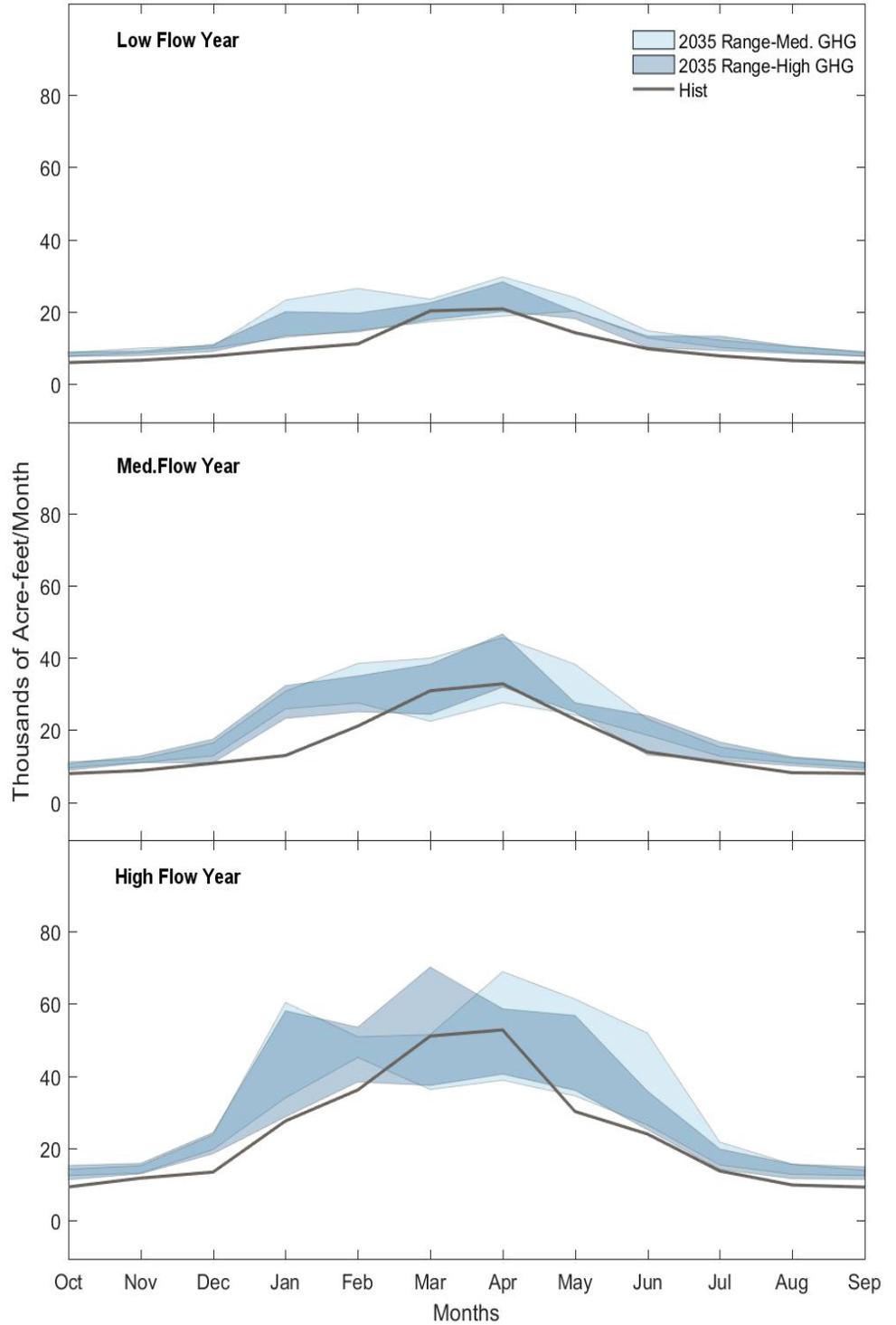
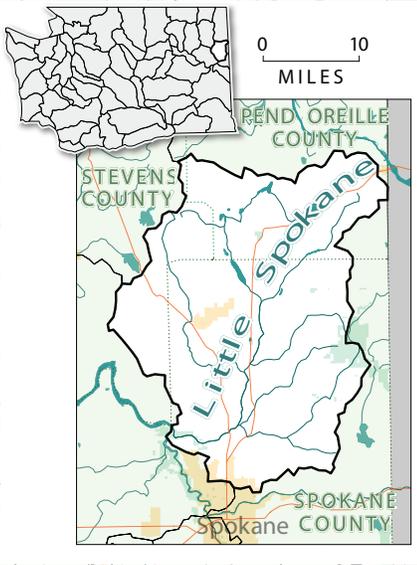
MANAGEMENT CONTEXT	
Adjudicated Areas	Deadman Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-555 WAC). 196 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 averaged 2 years from December to June (94% reliable), and ranged from 6 to 20 years from July to November (33% to 80% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

<sup>1</sup>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.

**Comparison of Dry, Average and Wet Year Flows to Instream Flow Rule**  
(Little Spokane River at Dartford, WA) 1981-2011

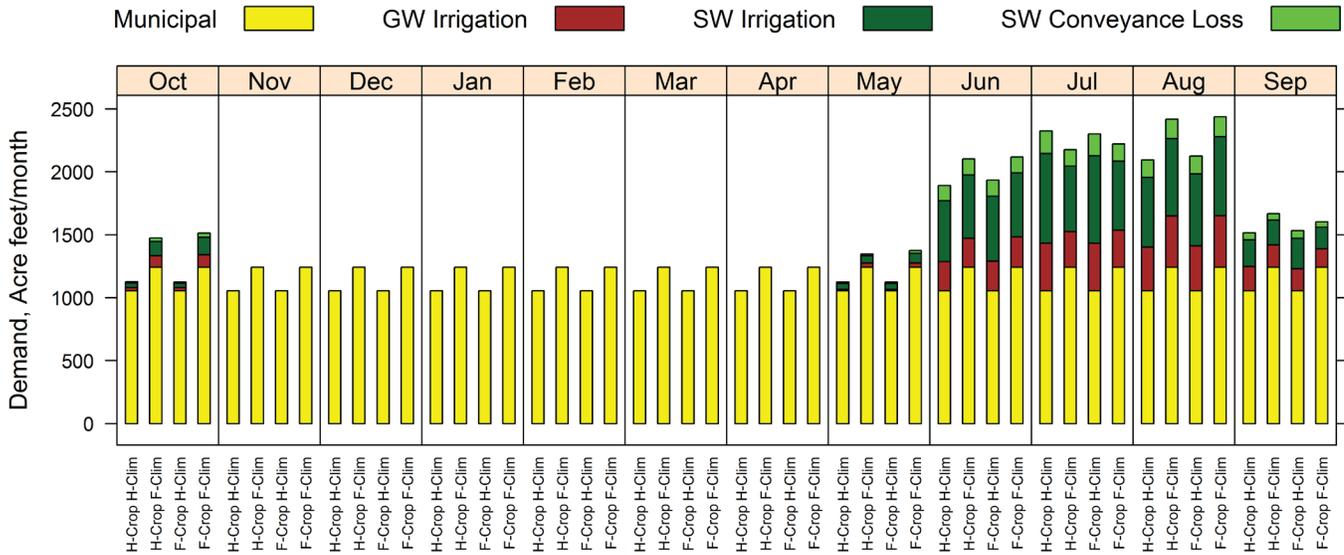


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

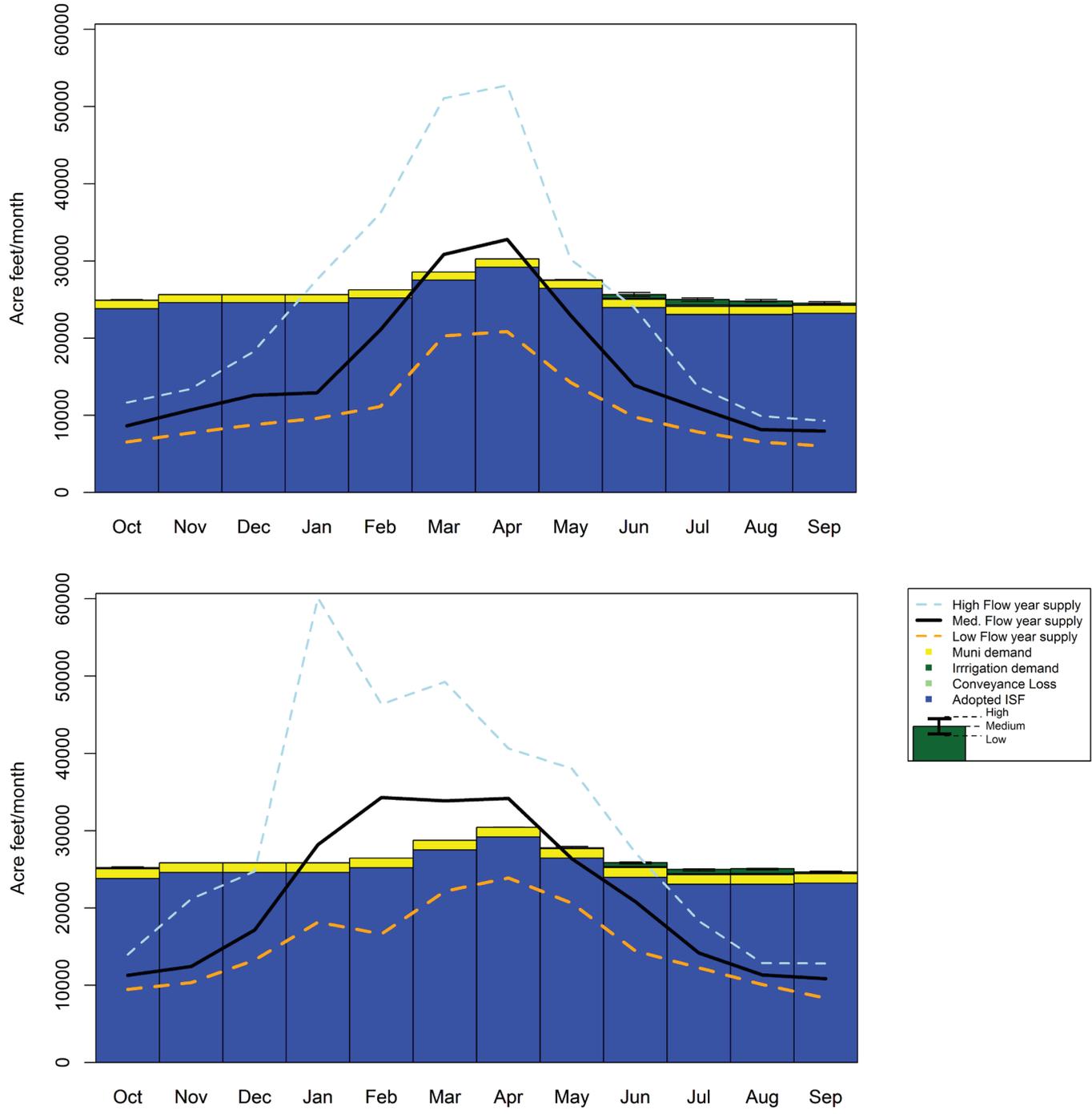


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND

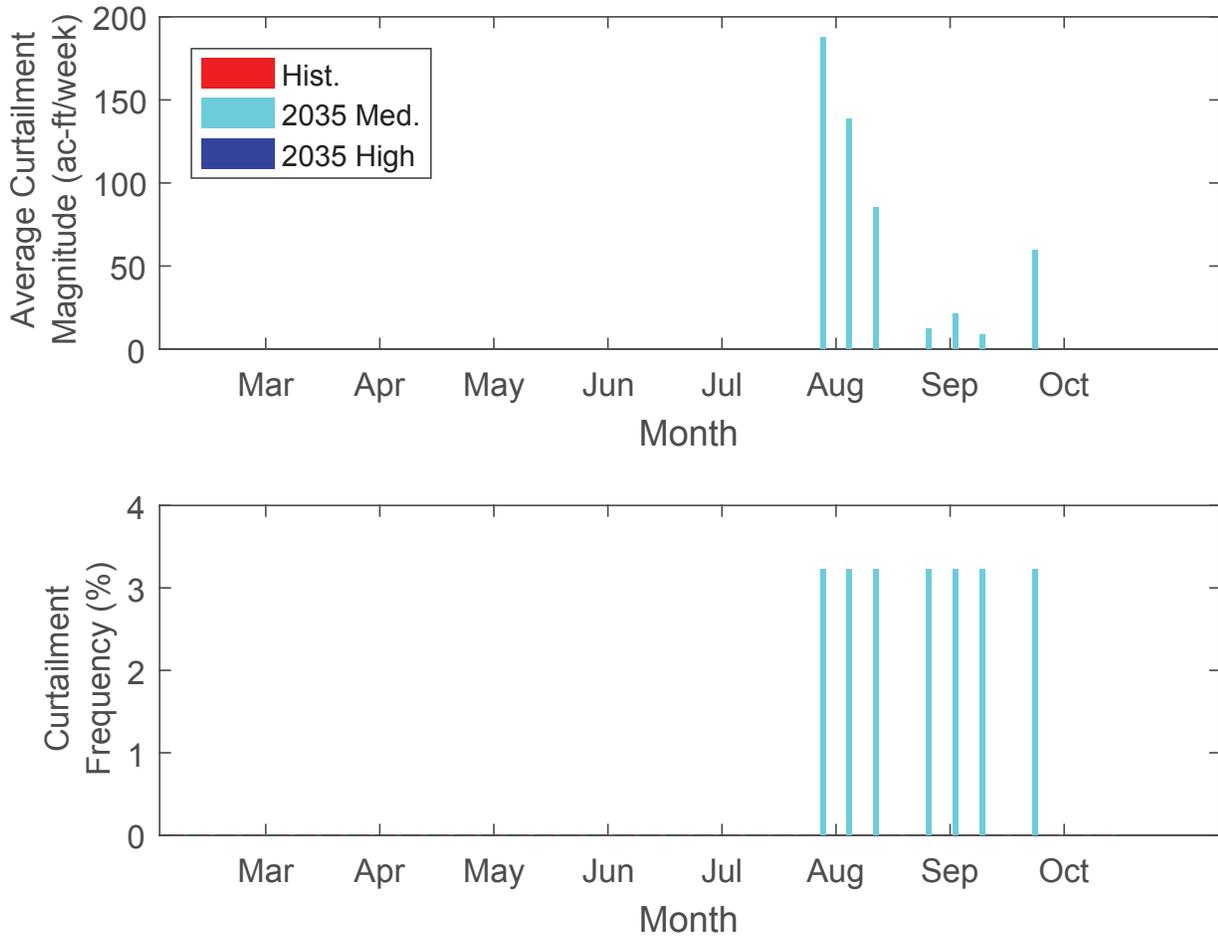


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

CURTAILMENT



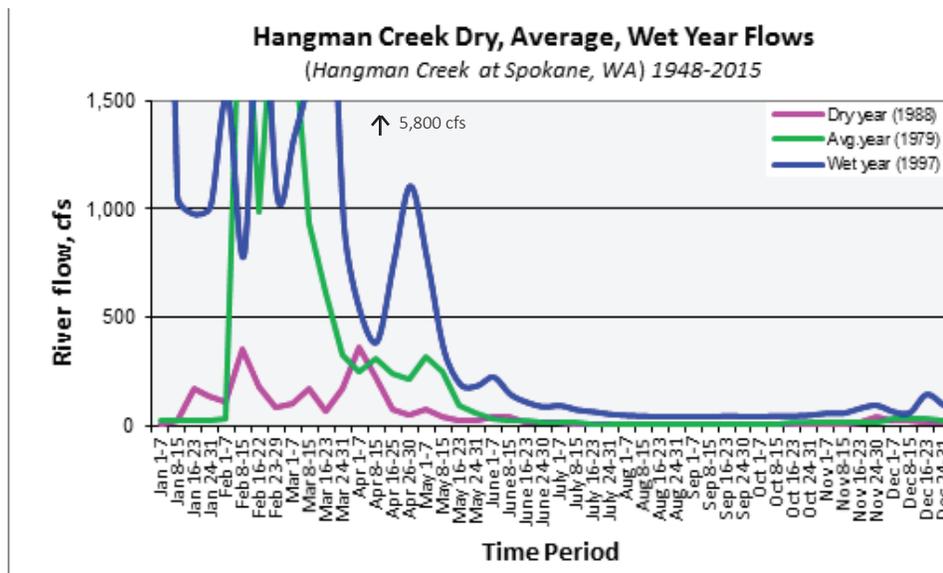
Modeled historical (1981-2011) and forecast (2035) median curtailment magnitude (ac-ft per week) (top panel) and curtailment frequency (%) (bottom panel) in this WRIA. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

- The tributary surface water supply forecast for Hangman is less certain as it is characterized by a combination of increases of increases and decreases during the months of January through July, depending on climate scenario.
- Unlike many other watersheds in eastern Washington, municipal demands are larger than irrigation demands in Hangman watershed.
- Assuming no change in irrigated acreage, irrigation demand is projected to increase for all months during the irrigation season. This is response to climate change while crop mix changes are resulting in some increased demand in July and August demands.
- Municipal demand is forecasted to grow 26% by 2035.

### MANAGEMENT CONTEXT

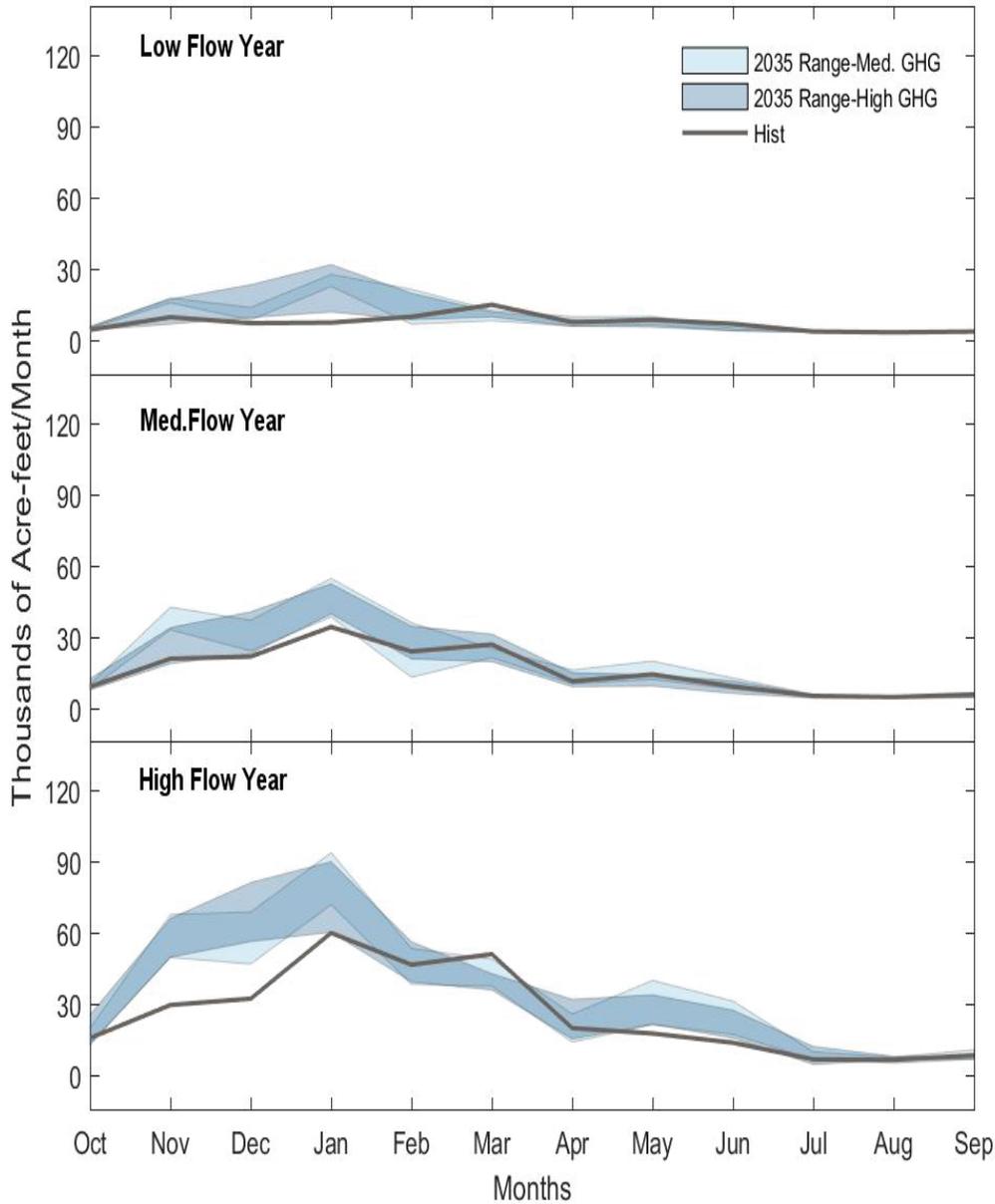
Adjudicated Areas	Crystal Springs
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Management Area	NO (For additional information on groundwater decline areas within this WRIA, see Module xx.)

<sup>1</sup>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.

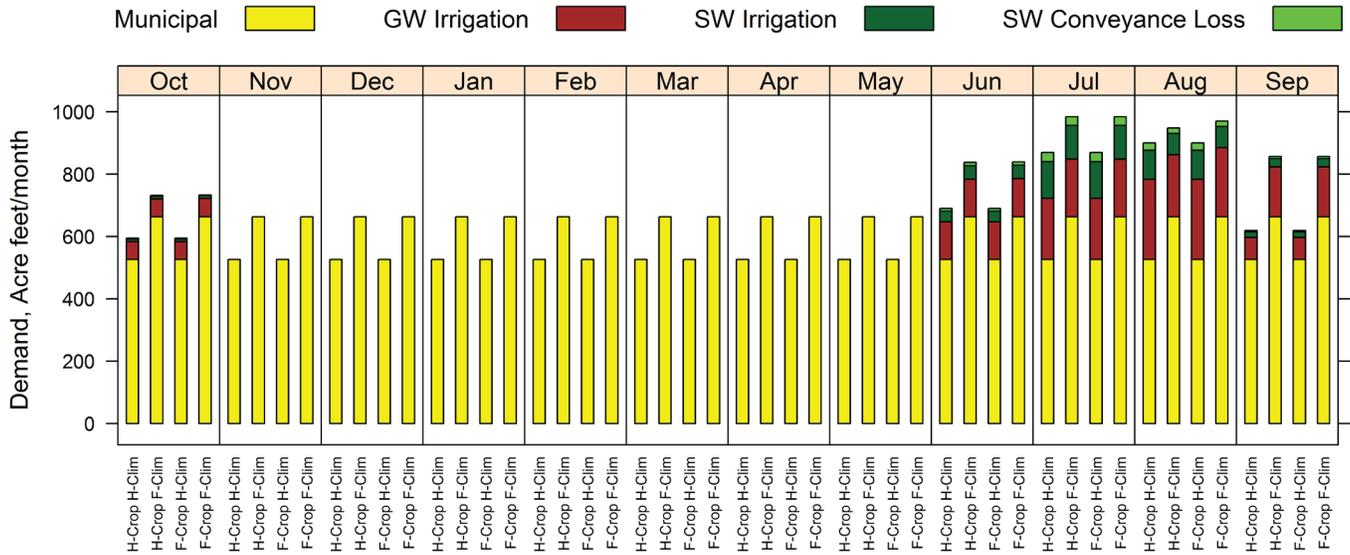


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

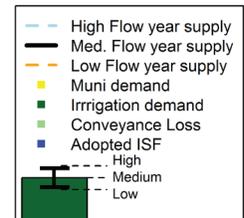
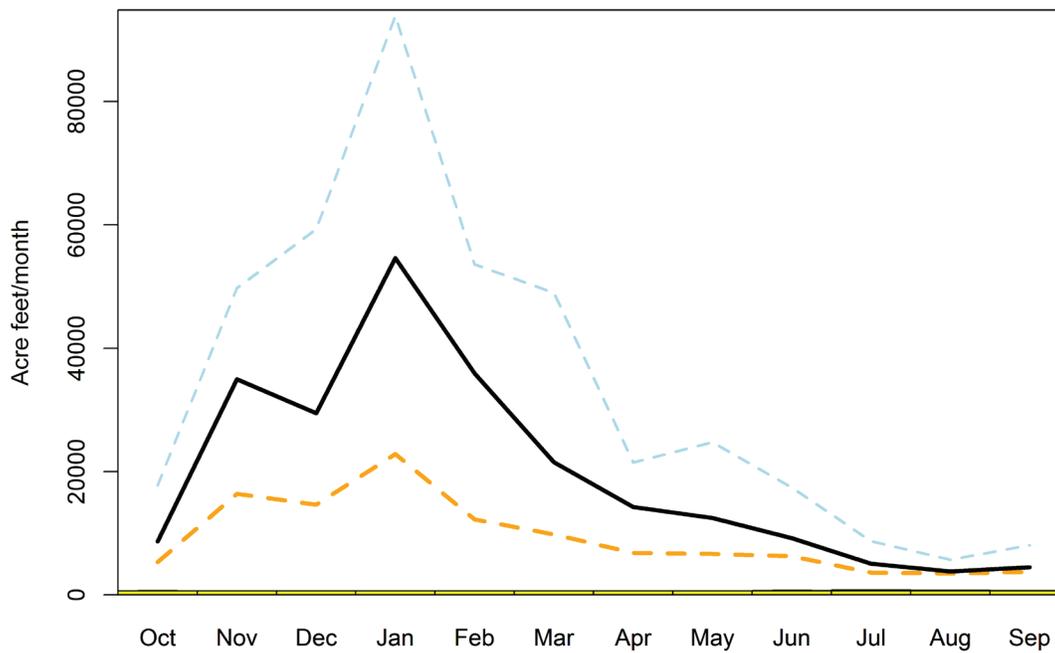
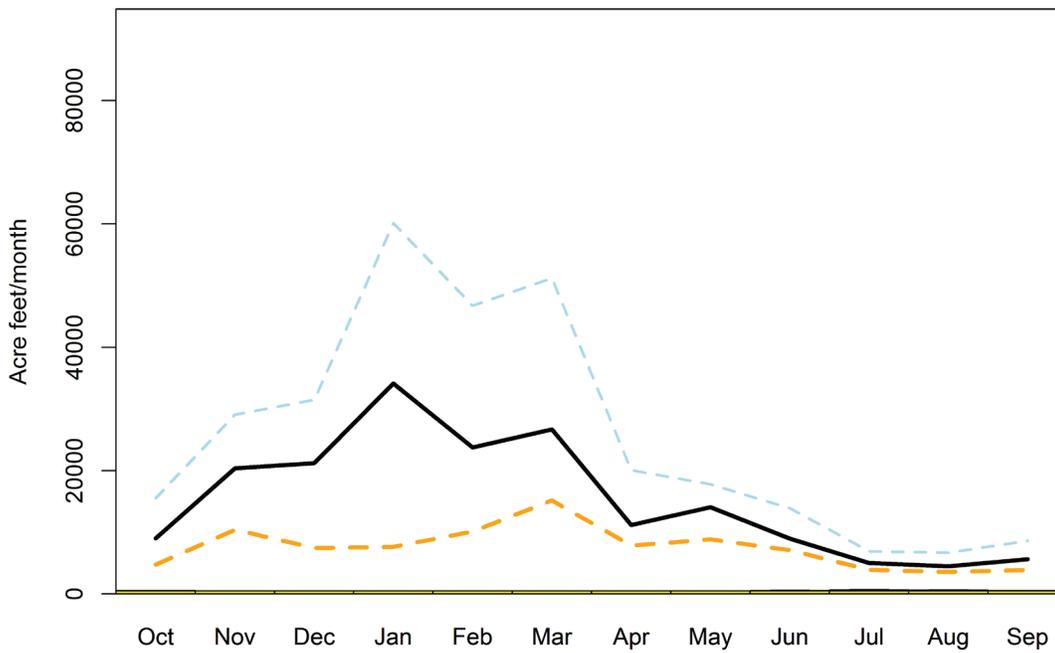


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



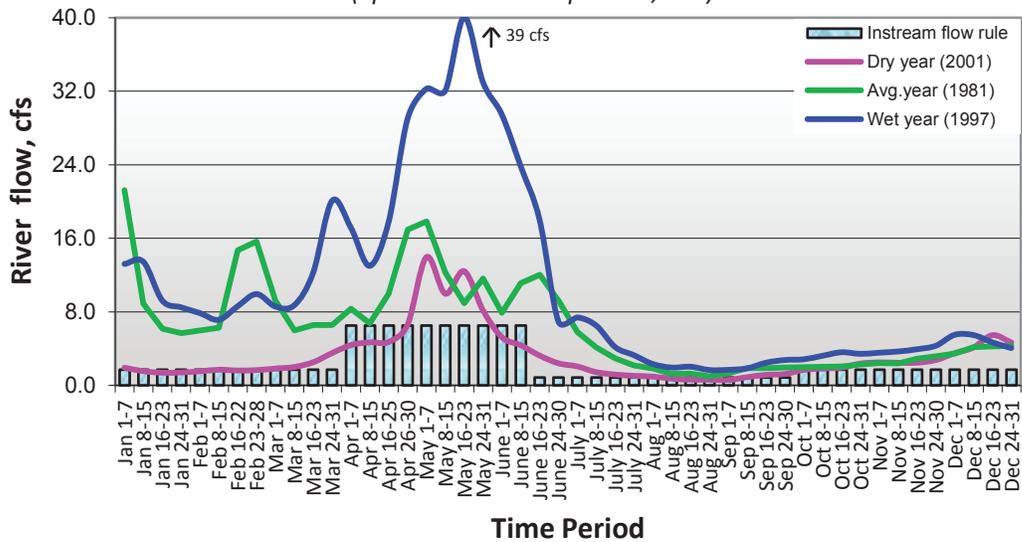
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- The tributary surface water supply forecast for Middle Spokane is characterized by significant increases from October through February, with a mix of increases and decreases in March and mostly decreases in April. June through August supplies are mixed with mostly increases for the 80th percentile supply year and decreases for the 20th percentile supply year.
- Municipal demands are the largest source of water demand in this watershed, and are also one of the largest among all of the WRIsAs in eastern Washington.
- Assuming no change in irrigated acreage, irrigation demands are projected to increase for all months. This is response to climate change while crop mix changes (in isolation) are resulting in mostly unchanged demands.
- Municipal demand is projected to increase by 8% by 2035.

MANAGEMENT CONTEXT	
Adjudicated Areas	Walla Walla River
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-557 WAC). No interruptible rights have been issued to date that are subject to instream flow curtailment.
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

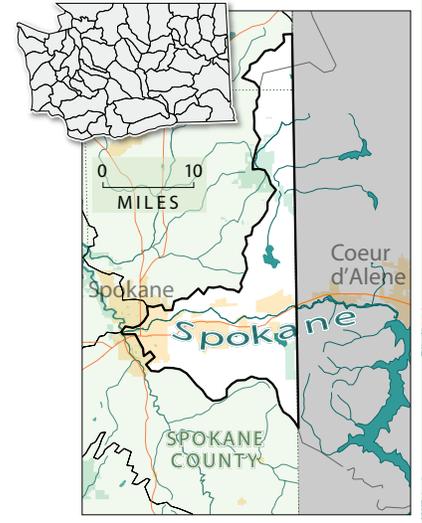
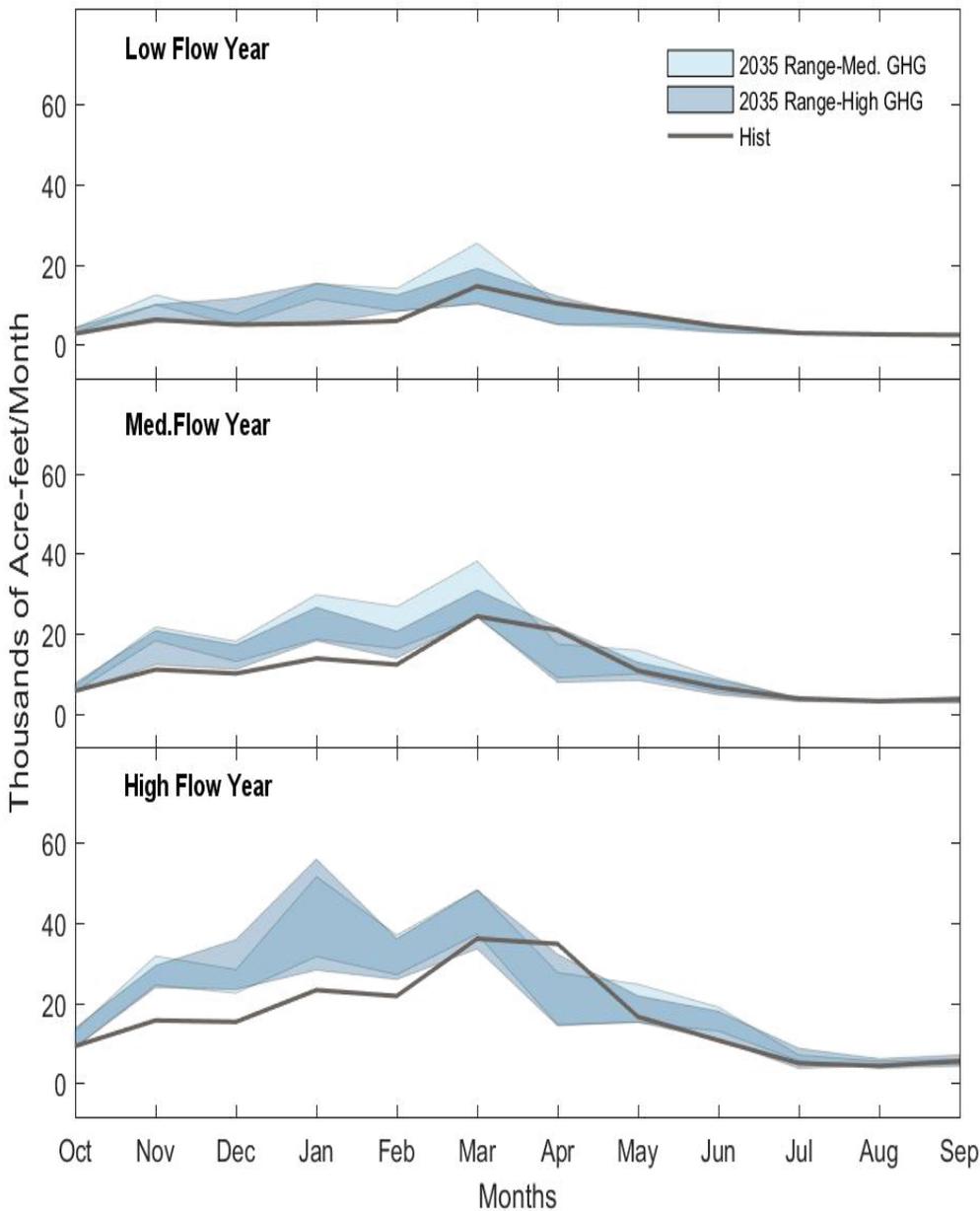
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

Comparison of Dry, Average and Wet Year Flows to Instream Flow Rule (Spokane River at Spokane, WA) 1981-2011

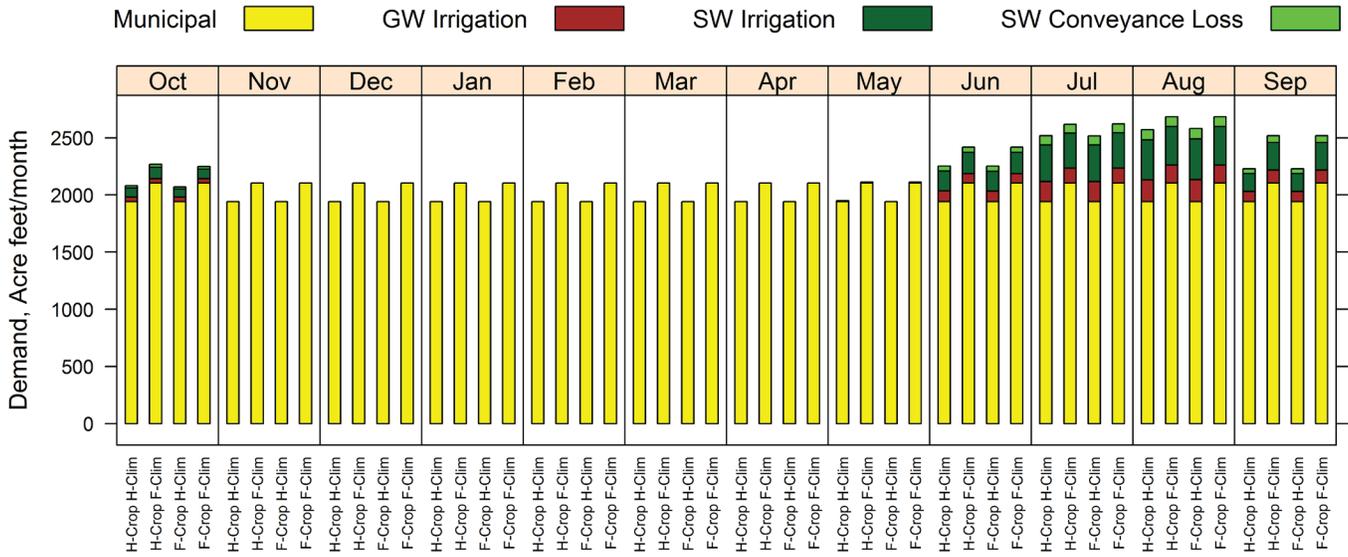


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIsAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

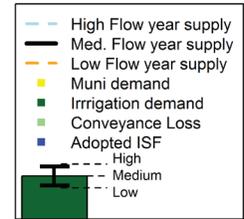
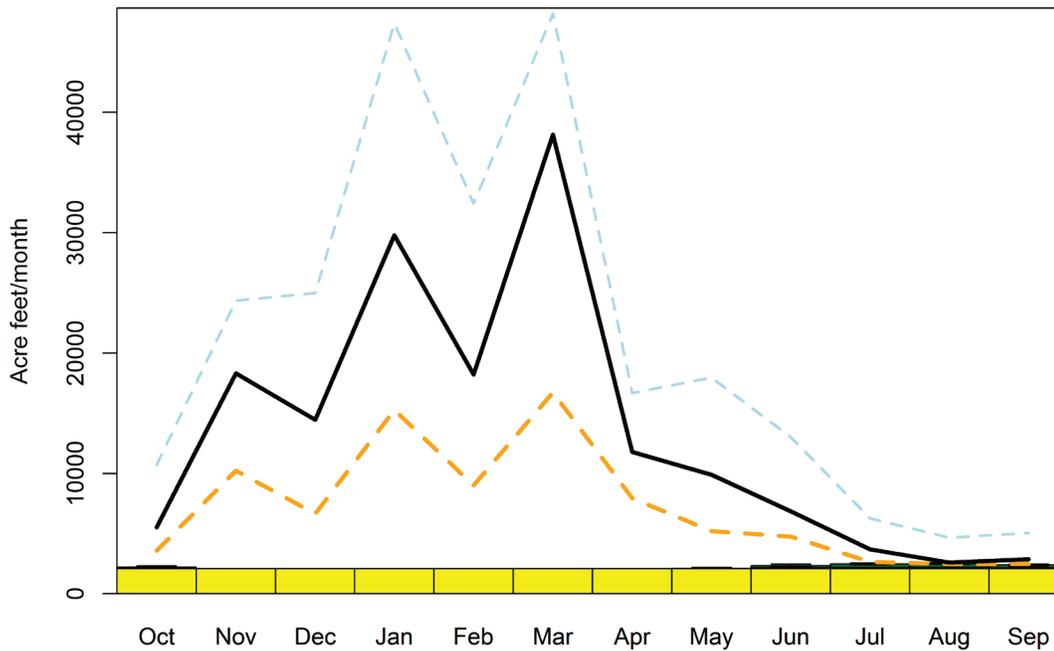
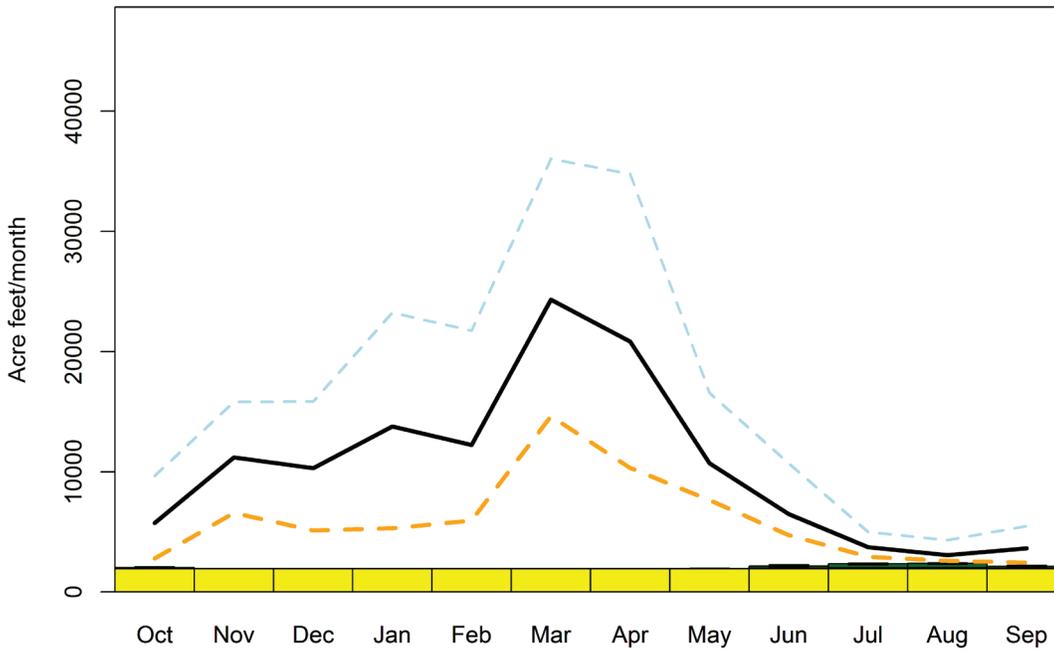


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

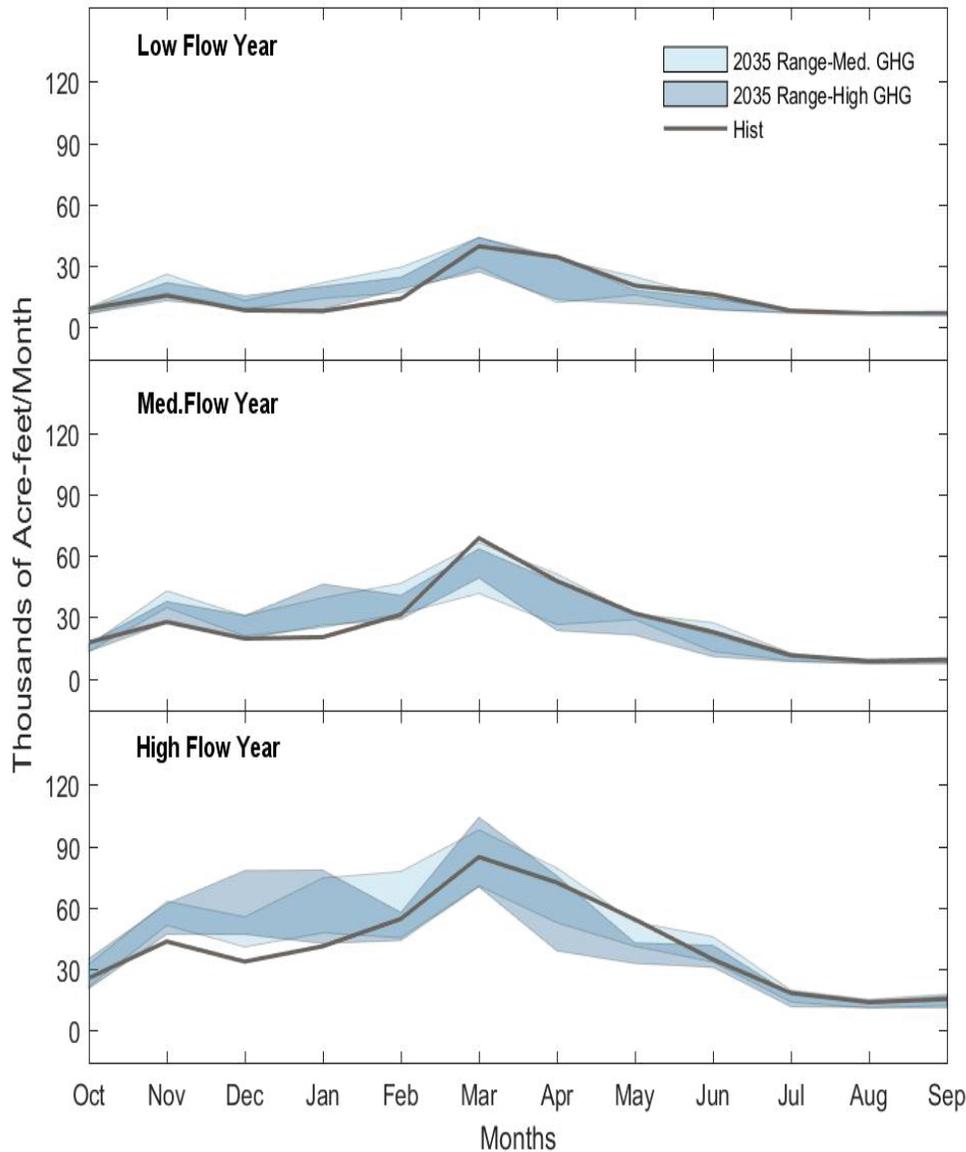
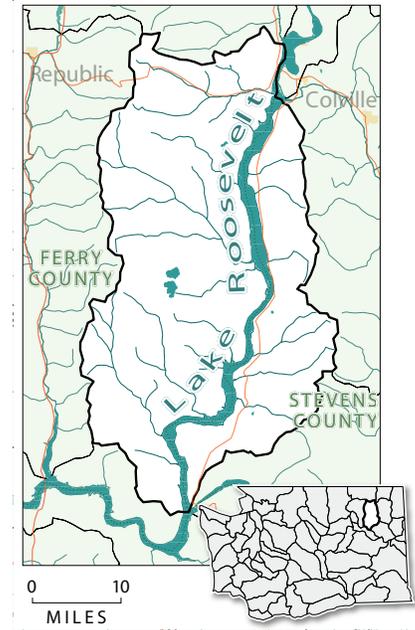
- The tributary surface water supply forecast for Middle Lake Roosevelt is characterized by mostly increases from November through February and decreases from March through July, although the 80th percentile supply years show a combination of increases and decreases in March and June.
- Irrigation is 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 projected to increase for all months except May (which will decrease). This is in response to climate change as crop mix changes (in isolation) are resulting in increased demands in June, September, and October. Decreased demand in May is in response to crop mix changes.
- Municipal demand is forecasted to grow by 8% by 2035, though the total municipal demand will still be fairly small.

MANAGEMENT CONTEXT

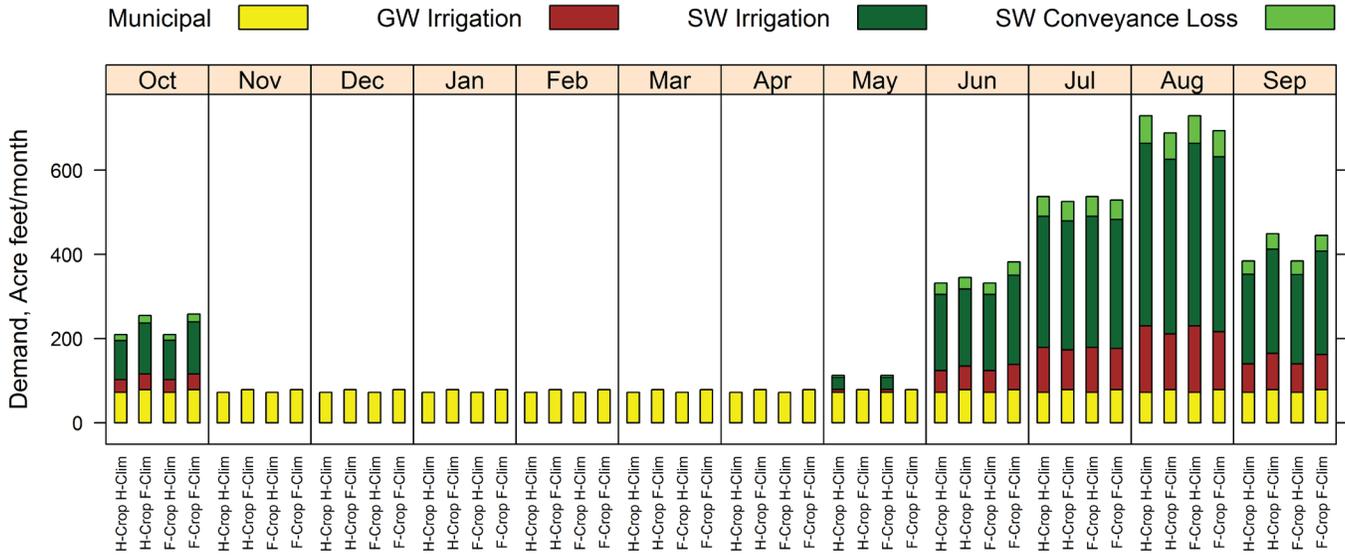
Adjudicated Areas	Quilliascut Creek, Cheweka Creek, Jennings Creek, Magee Creek , Stranger Creek, Harvey Creek, Alder Creek , O-Ra-Pak-En Creek, Corus Creek, Hunter Creek (incomplete)
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

<sup>1</sup>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.

## SUPPLY

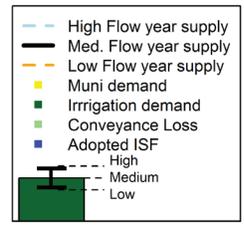
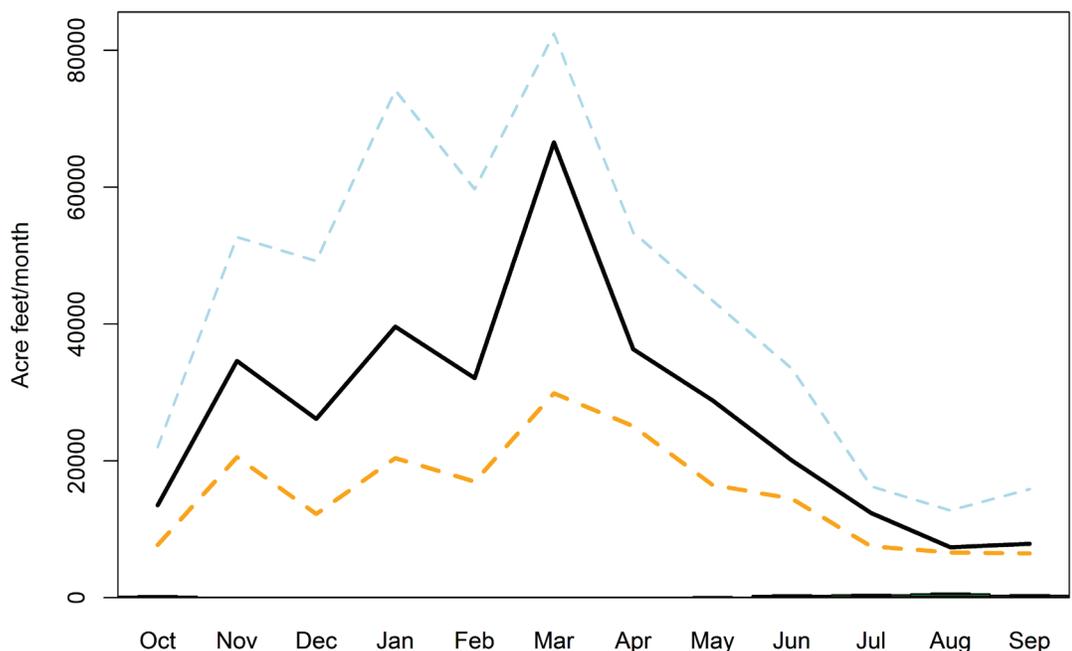
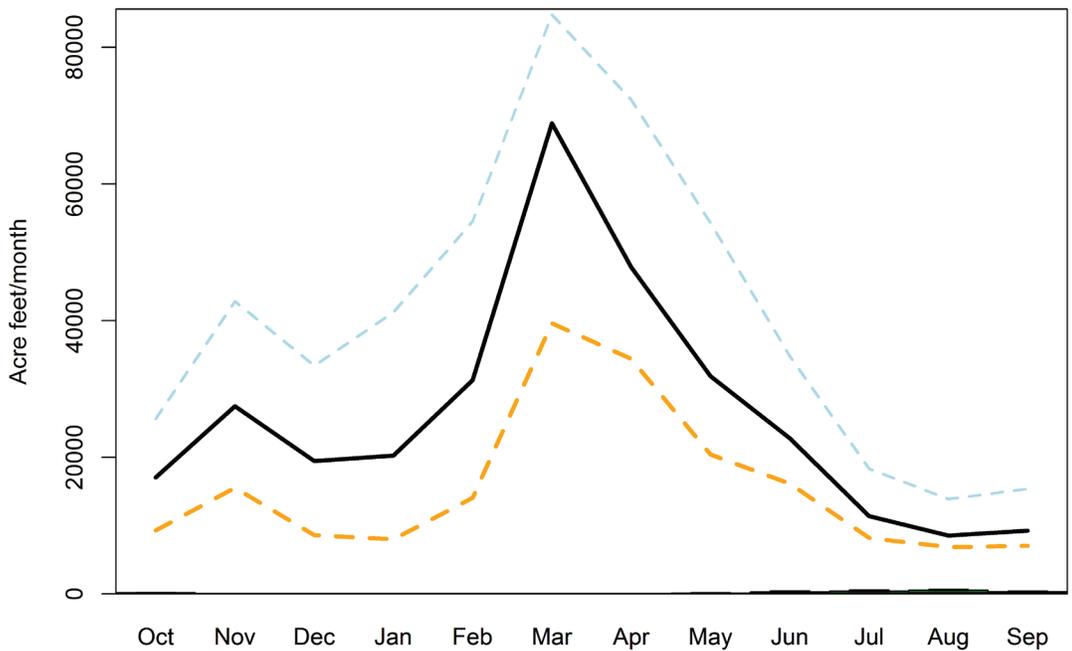


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



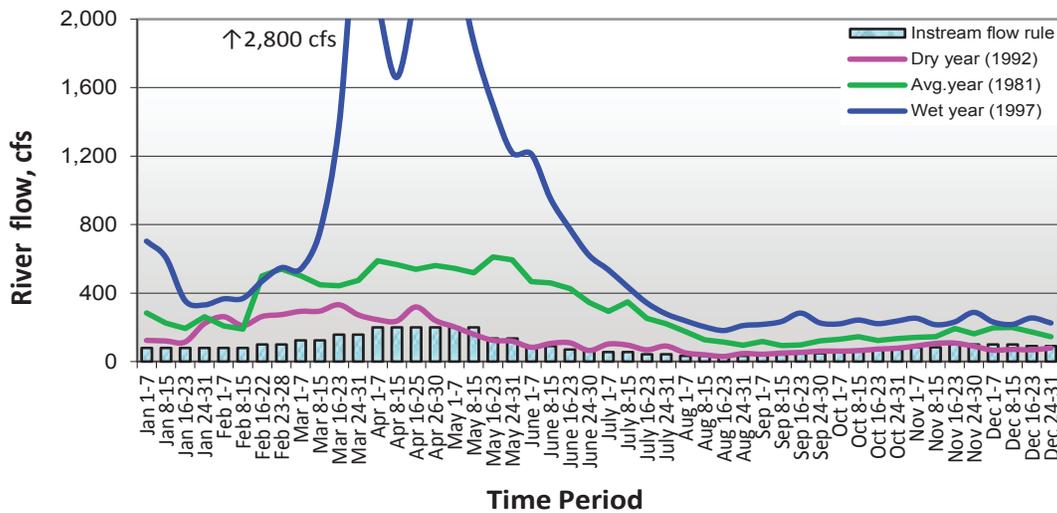
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

- The tributary surface water supply forecast for Colville is characterized mostly by increases in all months, with substantial increases from November through March.
- The primary demands are instream flow requirements and irrigation, with municipal demands that are fairly small.
- Assuming no change in irrigated acreage, irrigation demand is unclear as climate and crop mix changes are results in demand changes of opposite sign, with climate change resulting in increased demands for all months and crop mix changes resulting in decreased demand in all months.
- Municipal demands are forecasted to grow by roughly 6% by 2035, though the resulting demand will still be modest in comparison to other WRIAs of eastern Washington.
- Forecast shows increasing curtailment magnitude and frequency throughout the irrigation season for the Medium Range Green House Gas scenario.
- There is high uncertainty with forecast magnitude as two future scenarios show completely different responses.

MANAGEMENT CONTEXT	
Adjudicated Areas	Sherwood Creek, Deer Creek, Chewelah Creek, Hoffman Creek, Pingston Creek, Bull Dog Creek, Thomason Creek, Narcisse Creek, Grouse Creek, Jumpoff Joe Creek, Jumpoff Joe Lake
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-559 WAC). 85 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 ranged from 0 to 5 years from January to October (83% to 100% reliable), and from 5 to 9 years in November and December (70% to 83% reliable).
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

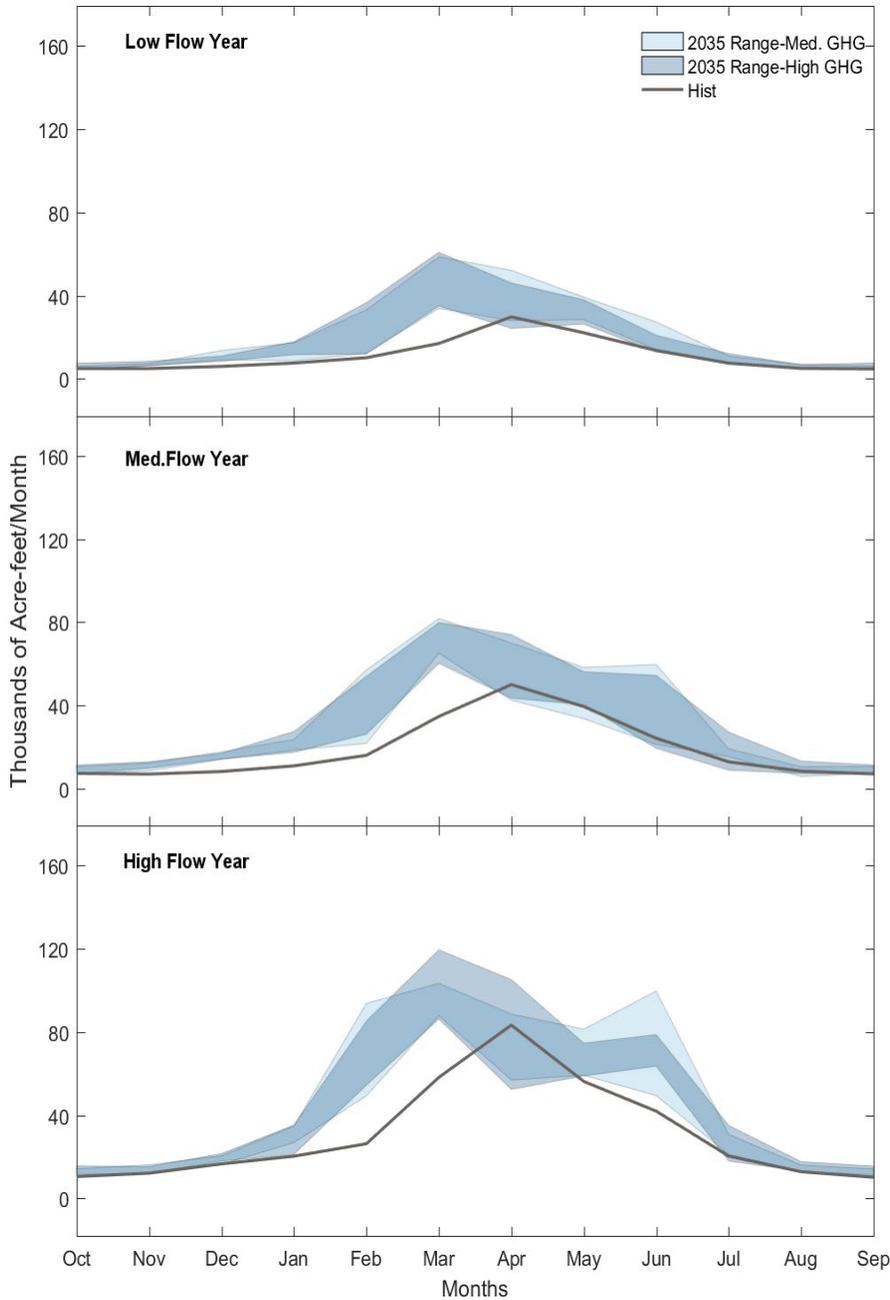
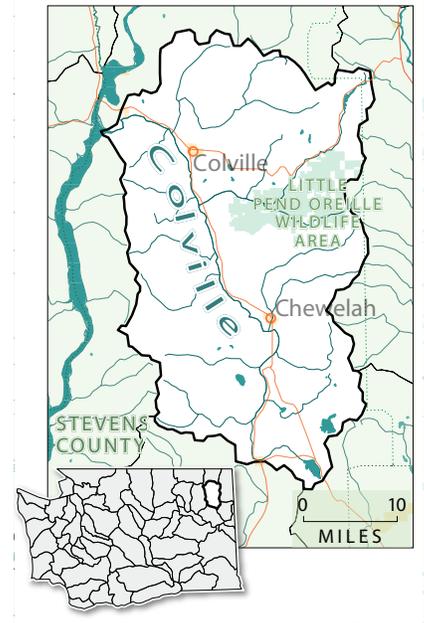
<sup>1</sup>All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

**Comparison of Dry, Average, Wet Year Flows to Instream Flow Rule**  
(Colville River at Kettle Falls, WA) 1981-2011

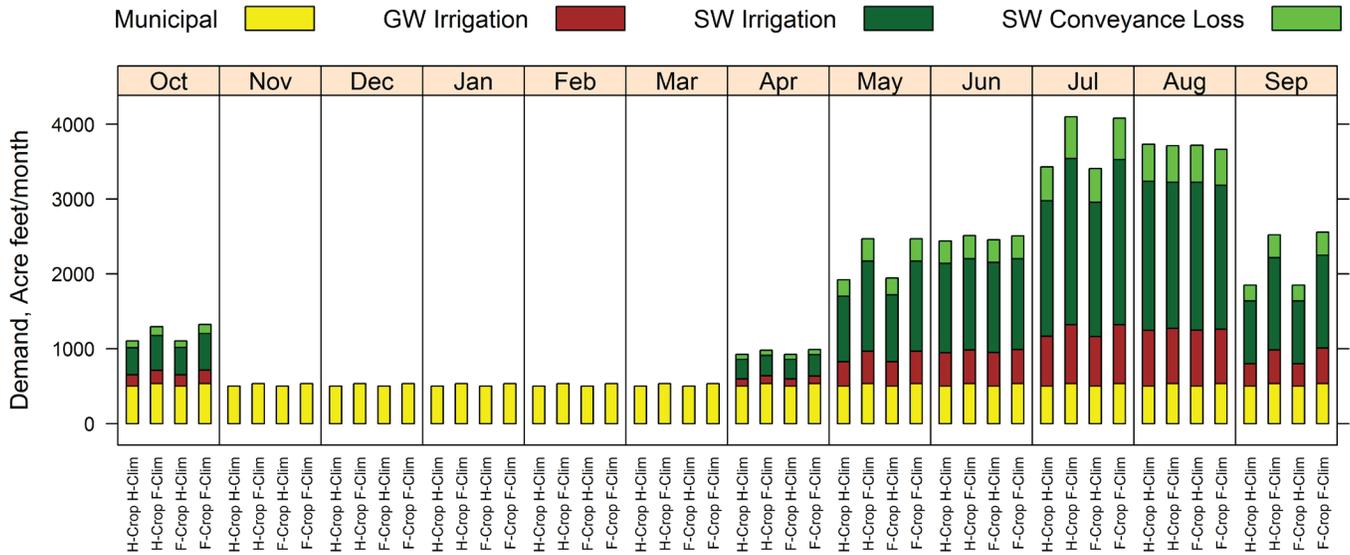


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

## SUPPLY

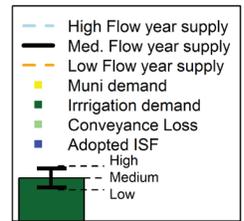
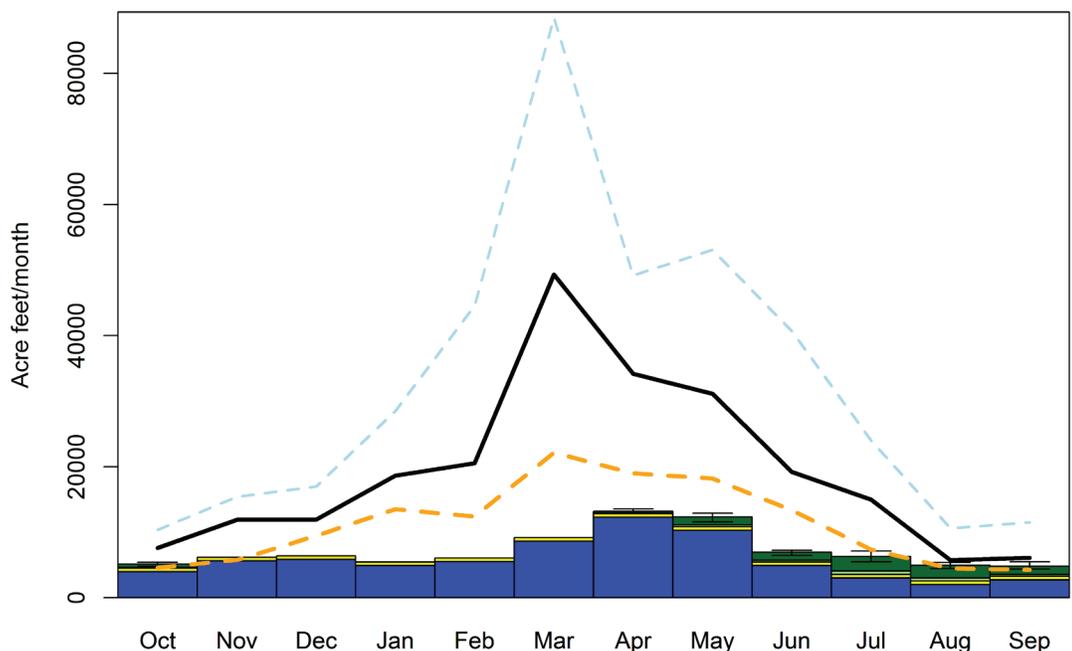
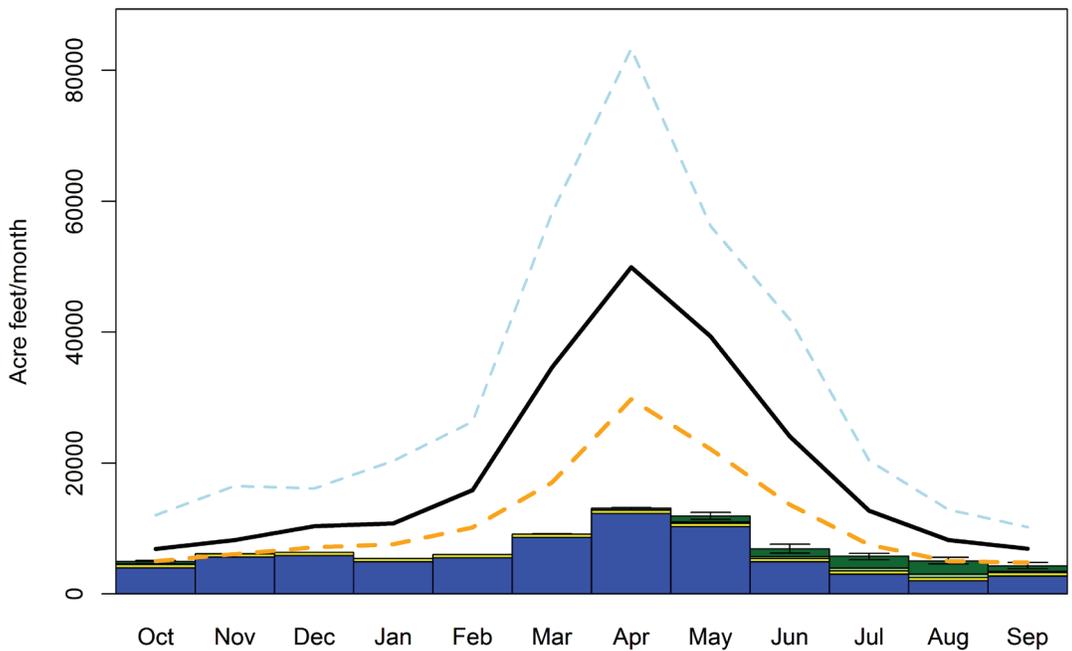


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

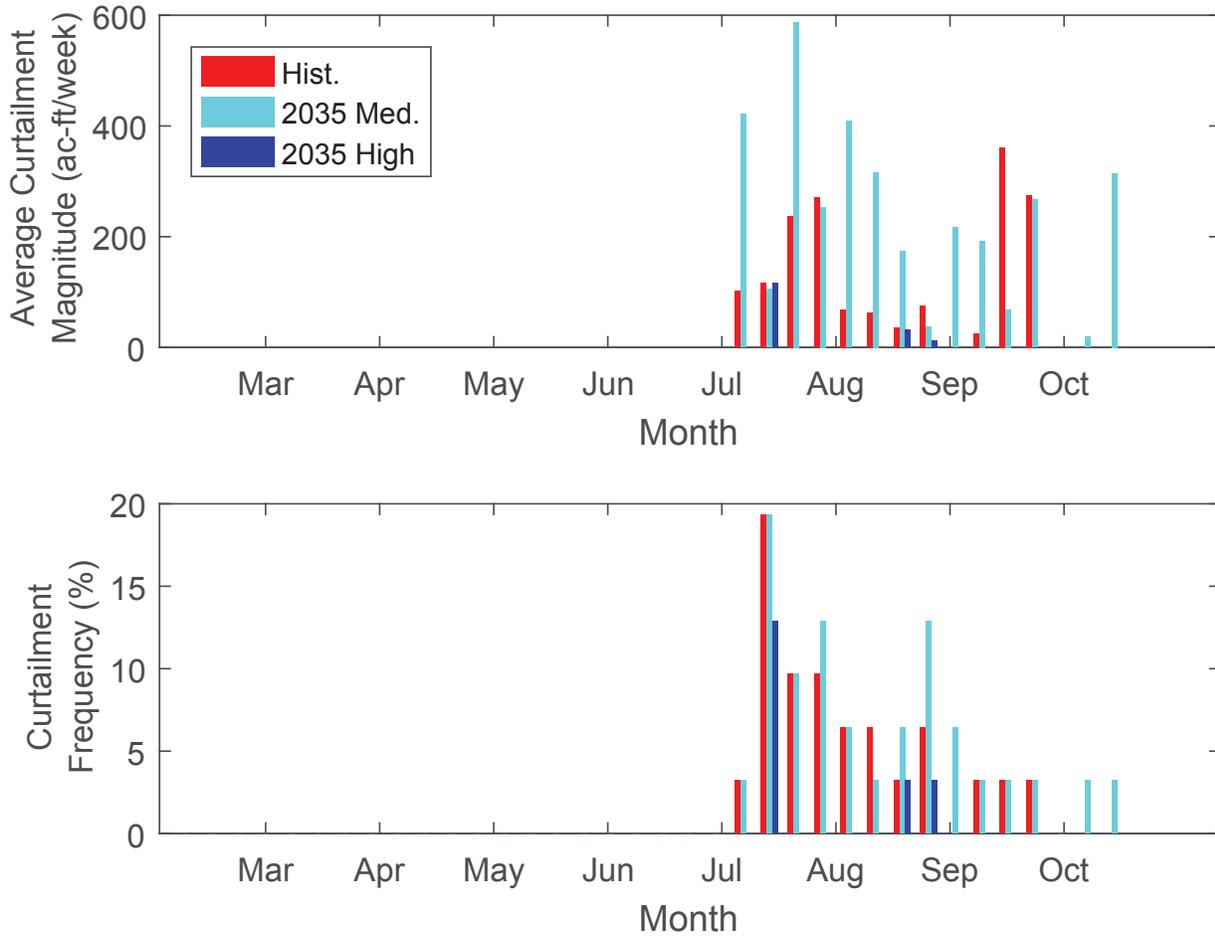


Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b)"H-Crop F-Clim", c)"F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario,"H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.

SUPPLY & DEMAND



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.



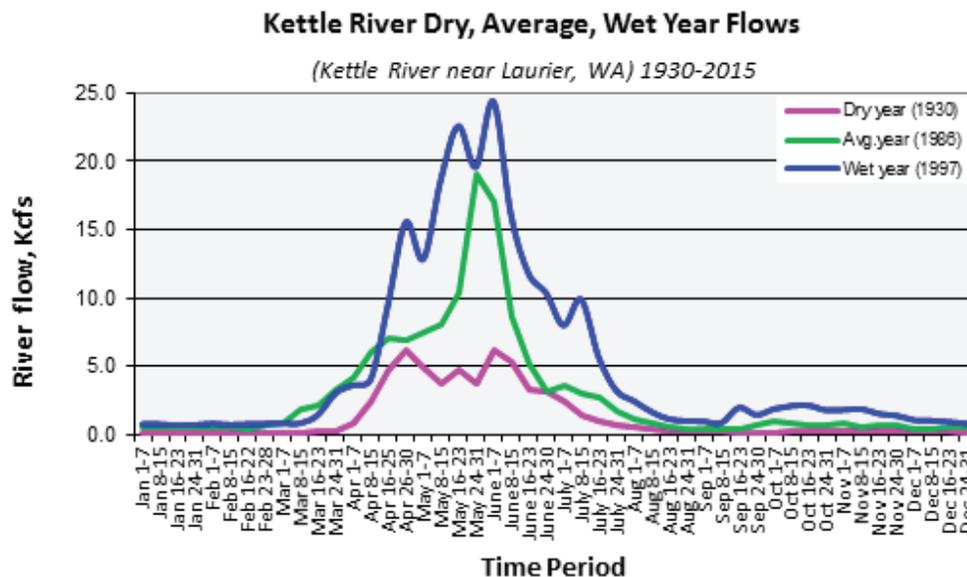
Modeled historical (1981-2011) and forecast (2035) median curtailment magnitude (ac-ft per week) (top panel) and curtailment frequency (%) (bottom panel) in this WRIA. Curtailment is forecasted using the climate change scenario that projects changes in temperature and precipitation closest to the middle of all 5 climate change scenarios considered under each emissions scenario: the “2035 Range- Med. GHG” and the “2035 Range-High GHG” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The median of curtailment magnitude only considers the years which have curtailment. Curtailment frequency shows the percentage of years that observe any amount of curtailment for a particular week.

## MANAGEMENT CONTEXT

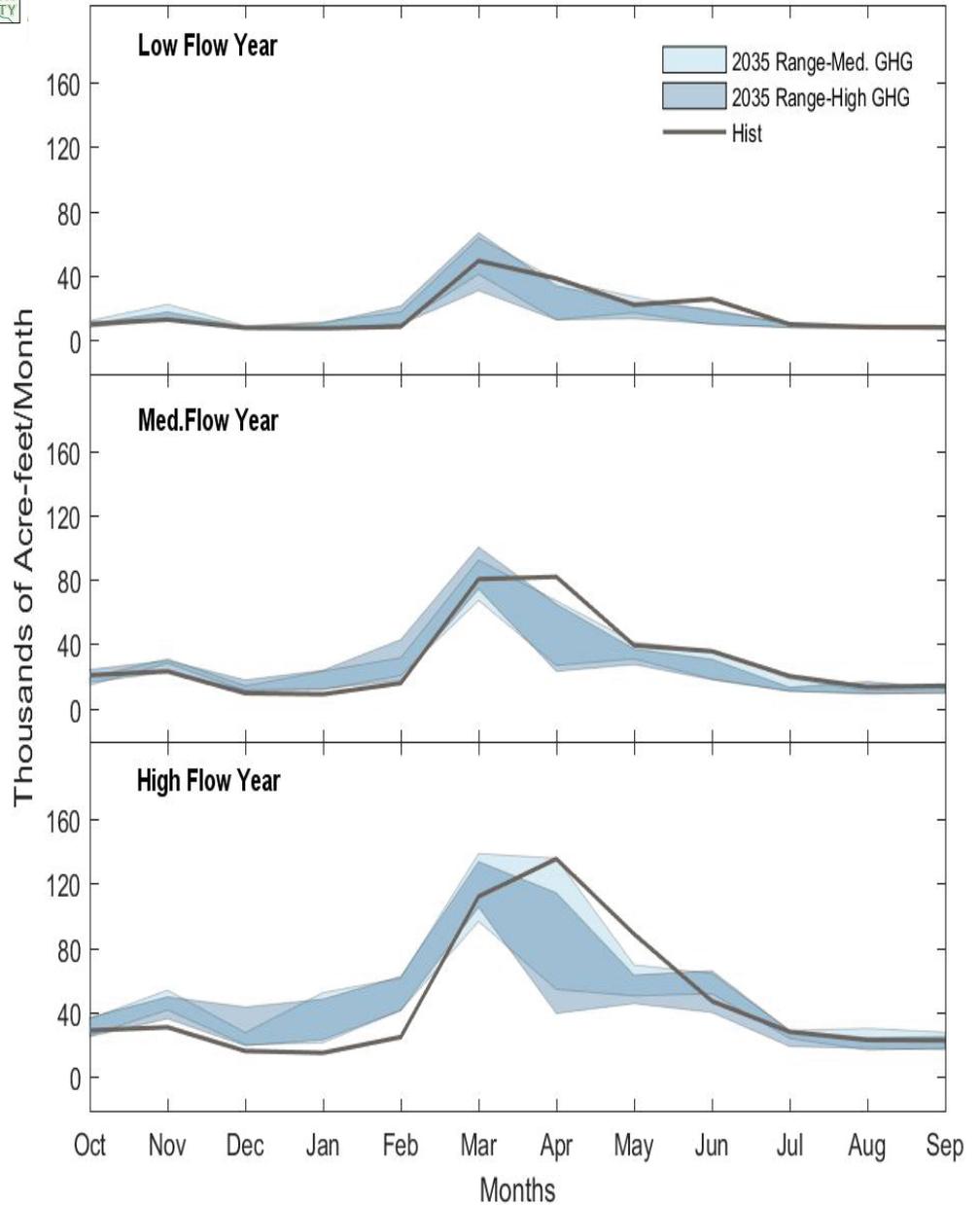
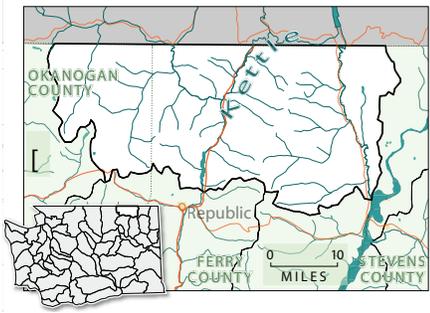
- The tributary surface water supply forecast for Kettle is characterized by mostly increases from November through February and mostly decreases from April through August, with mixed effects in June for the 80th percentile supply year.
- Both irrigation and municipal/domestic demands are quite small.
- Assuming no change in irrigated acreage, irrigation demands are Projected to increase in August and October and decrease in June, July, and September. These changes are due to mixed responses to climate and crop mix changes.
- Municipal demand is forecasted to grow roughly 9% by 2035, though total municipal demand will still be modest.

MANAGEMENT CONTEXT	
Adjudicated Areas	Twin Creek
Watershed Planning	NO (planning terminated at the end of phase 2)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

<sup>1</sup>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.

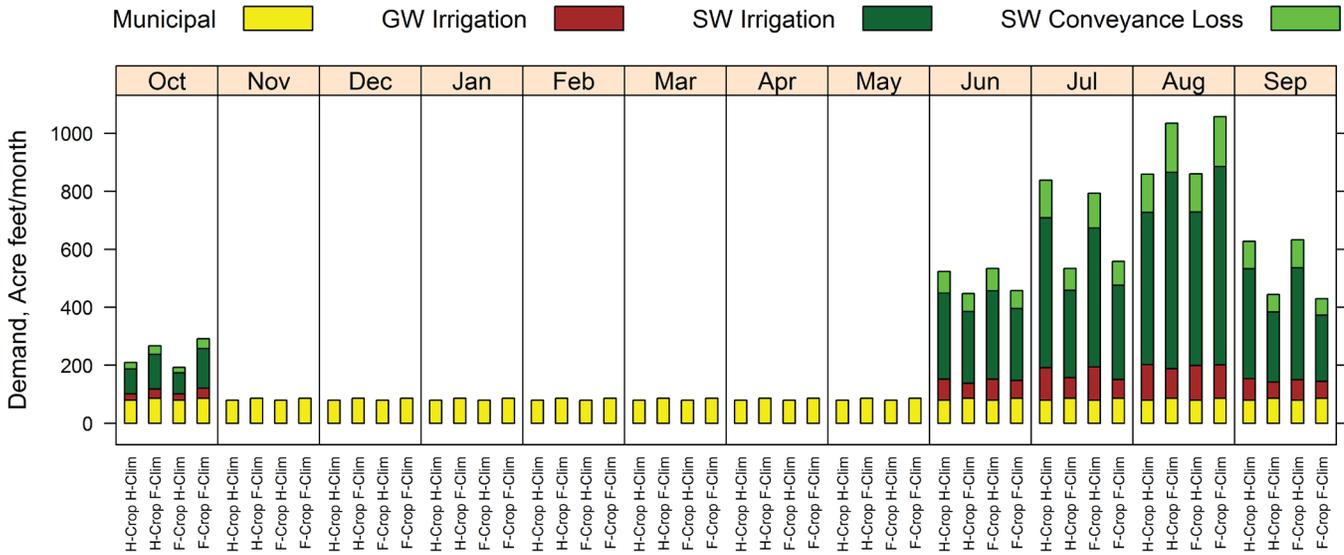


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

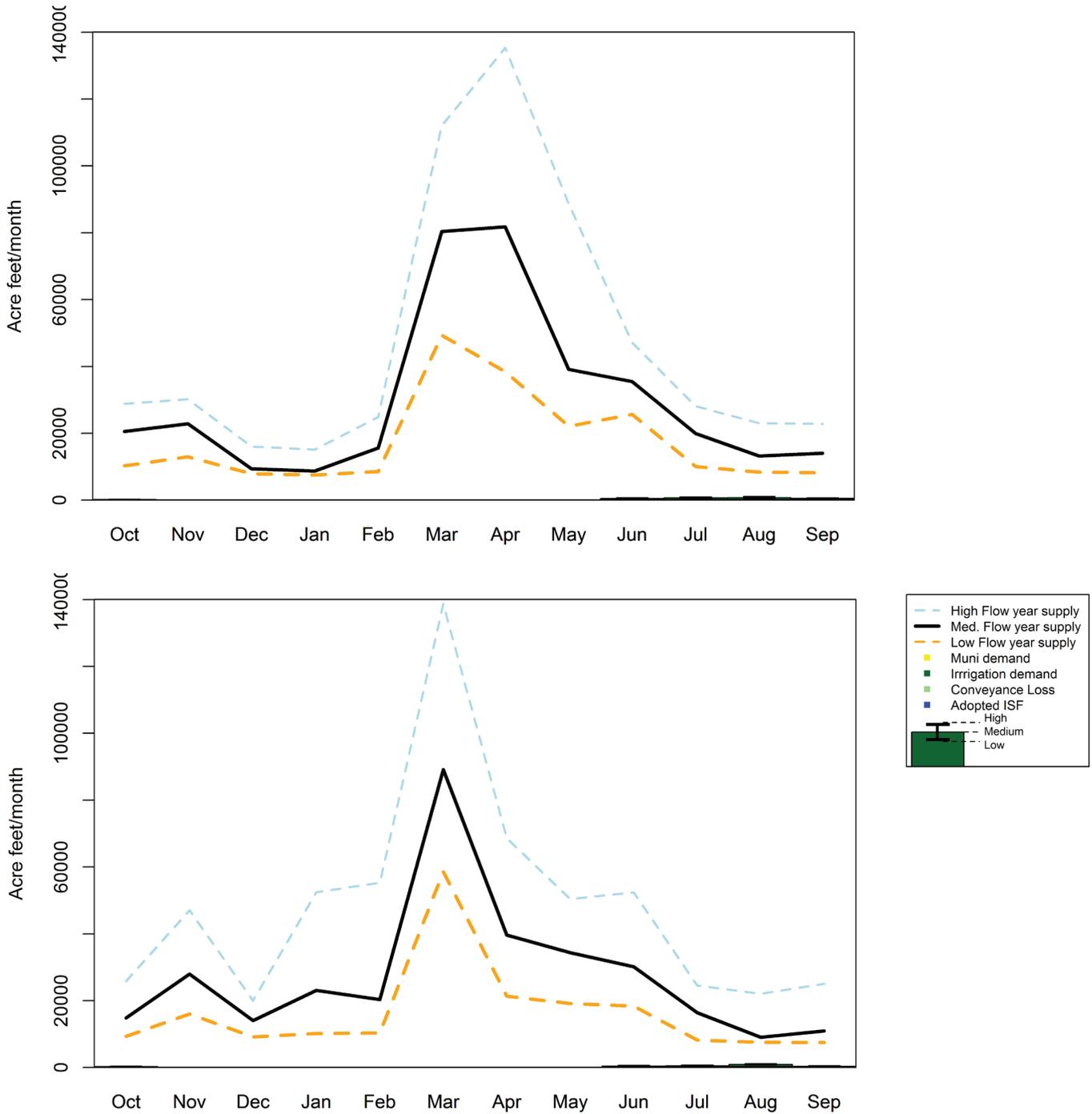


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



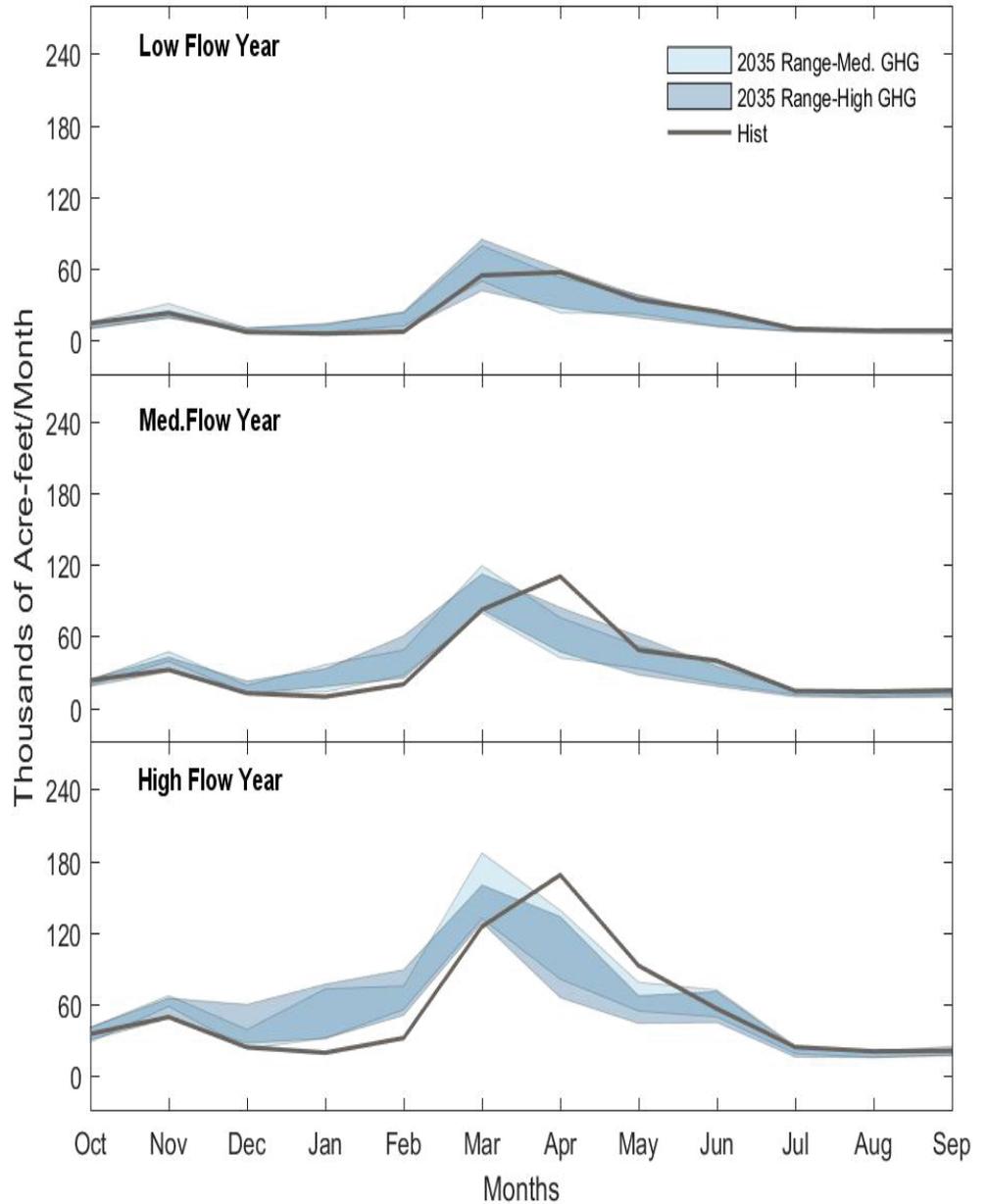
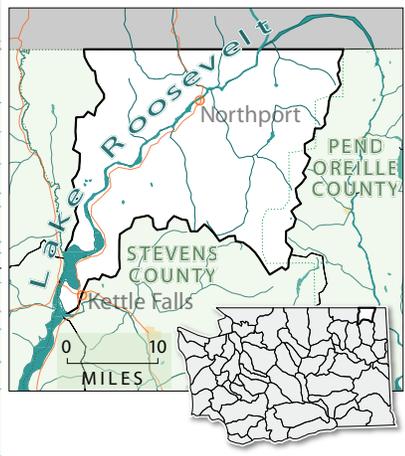
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

# MANAGEMENT CONTEXT

- The tributary surface water supply forecast for Upper Lake Roosevelt is characterized by mostly increases from November through March and decreases from April through August, with mixed effects in June for the 80th percentile supply year.
- Both municipal/domestic and irrigation demands are fairly small.
- Assuming no change in irrigated acreage, irrigation demands are projected to decrease in all months except October, during which it is projected to increase. The effects from changes in climate are mixed with increase in June, September, and October and decrease in rest of the irrigation season. Crop mix changes almost always contributed to decrease in demand.
- Municipal demand is forecasted to grow roughly 8% by 2035, though total municipal demand will still be modest.

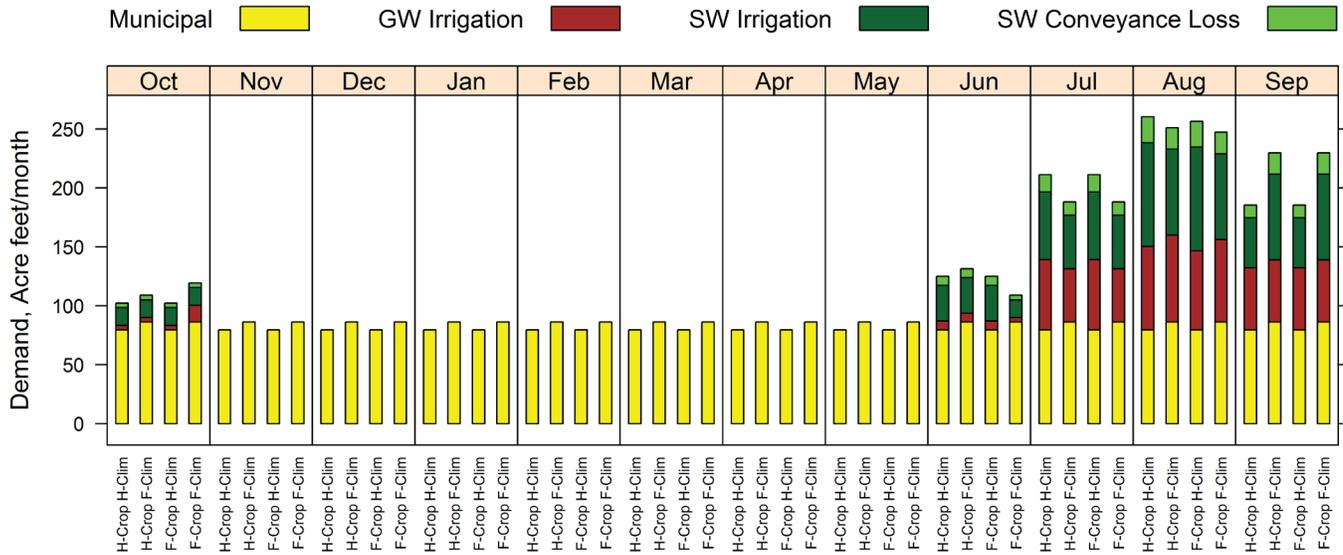
MANAGEMENT CONTEXT	
Adjudicated Areas	NONE
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout spawning and rearing unknown
Groundwater Management Area	NO

<sup>1</sup>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.

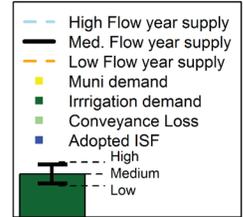
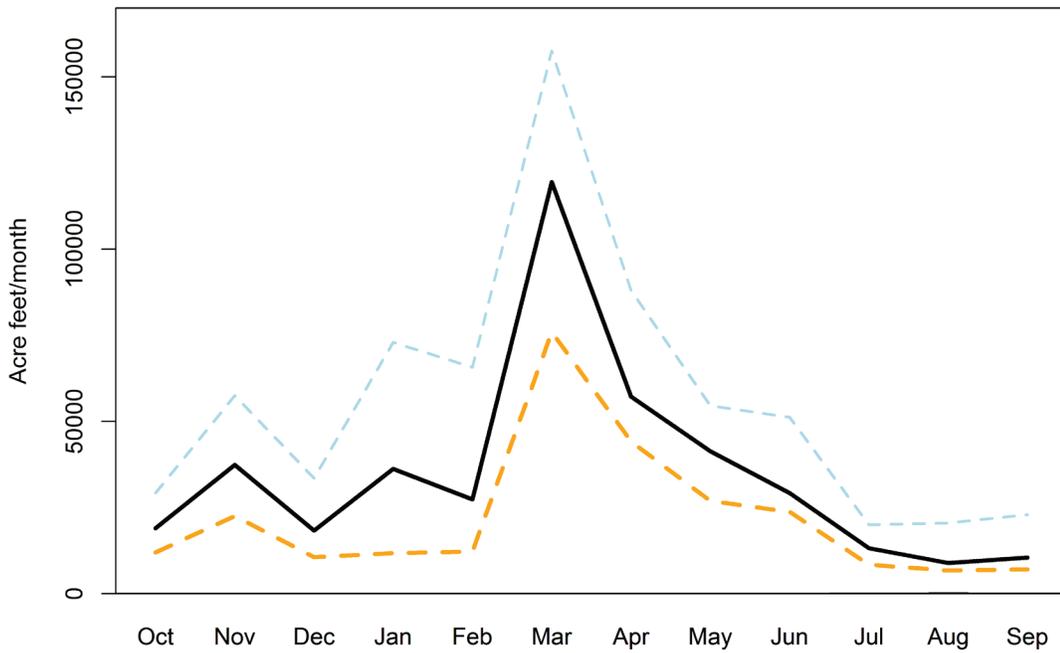
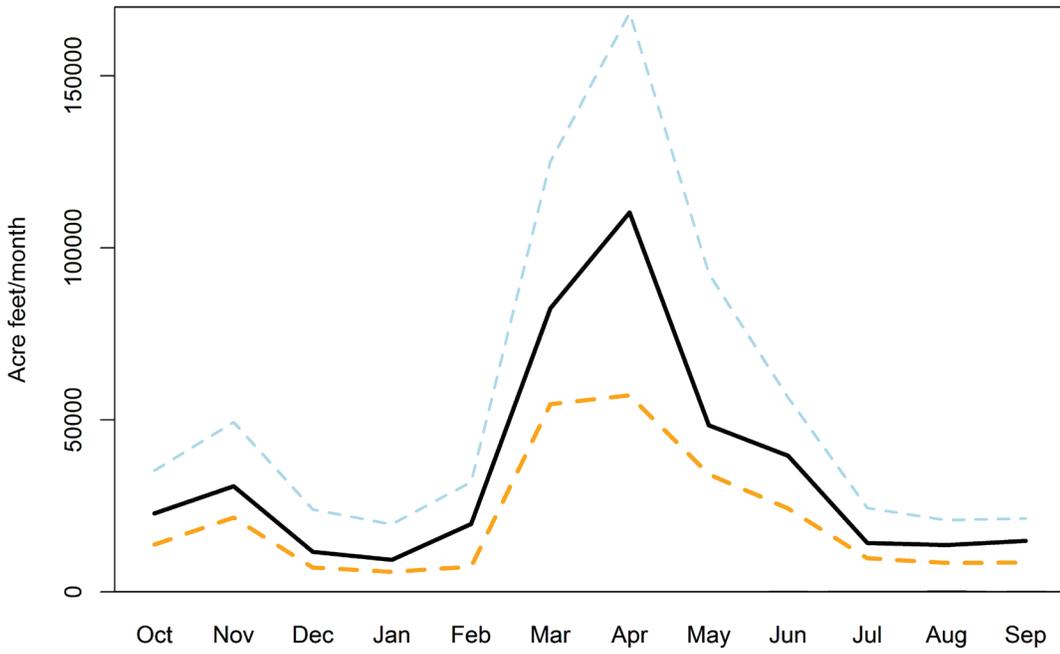


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b)"H-Crop F-Clim", c)"F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario,"H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



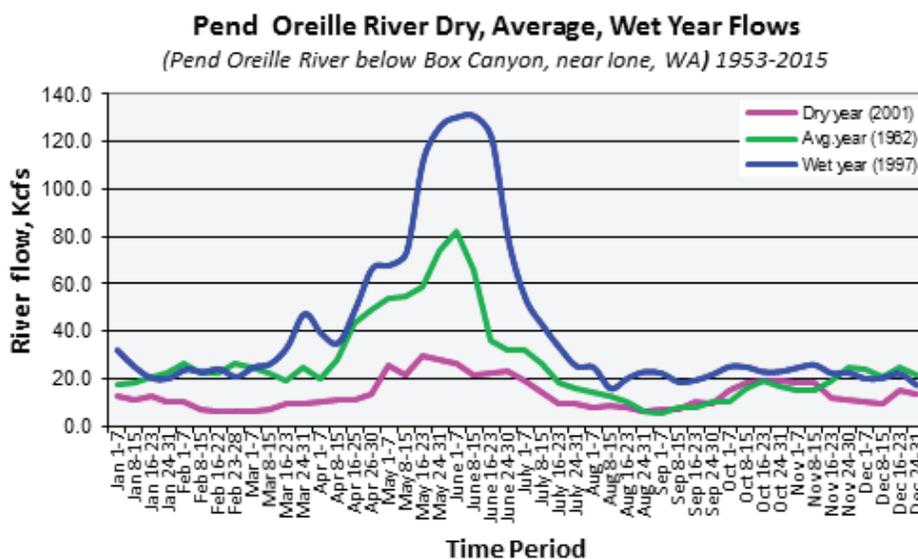
Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

## MANAGEMENT CONTEXT

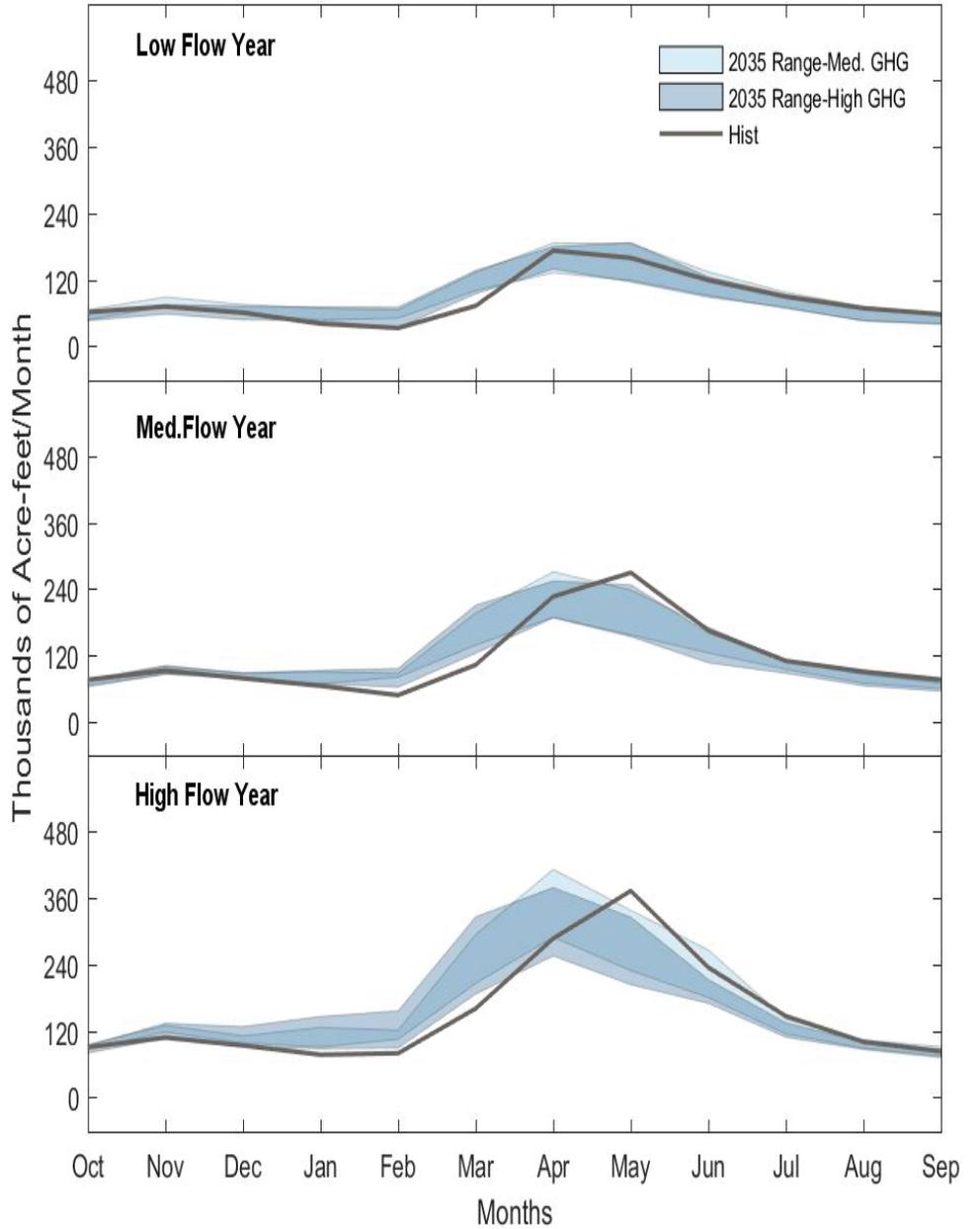
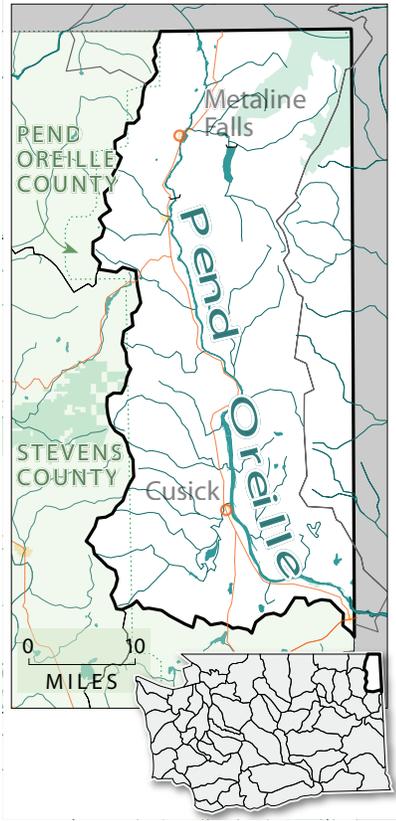
- The tributary surface water supply forecast for Pend Oreille is characterized by mostly increases from November through March and decreases from May through August.
- Municipal demand is the primary source of demand, though small in comparison to watersheds with larger population centers.
- Assuming no change in irrigated acreage, irrigation demands are projected to increase in May, June, August, and October and decrease in July and September. While climate change (in isolation) is resulting in a mix of increases and decreases in demand, crop mix changes are not showing any impact.
- Municipal demand is forecasted to grow 9% by 2035.
- If additional water capacity is provided, agricultural irrigation water demand is not anticipated to increase.

MANAGEMENT CONTEXT	
Adjudicated Areas	Renshaw Creek, Little Calispell Creek, Marshall Lake and Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act <sup>1</sup>	Bull Trout
Groundwater Management Area	NO

<sup>1</sup>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.

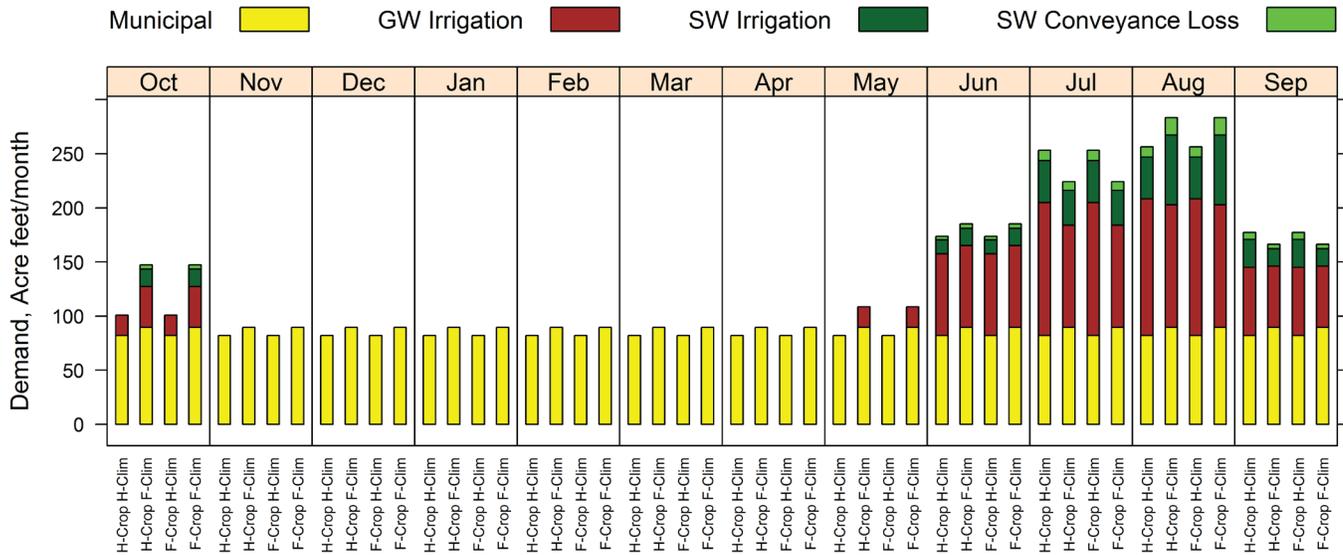


Actual historical flows measured at an existing stream gauge (data obtained from the U.S. Geological Survey [link: <http://waterdata.usgs.gov/wa/nwis>]). The stream gauge selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the year with the highest annual flow on record (Wet year), and the year with annual flow closest to average flow for that gauge. Average flow was calculated as the mean of the central 60% of years on record, ranked by their annual flows, which were assumed to represent “average” years. Only years with sufficient weekly data points to provide a complete flow curve were selected. WRIAs with adopted instream flow rules show those flow requirements as well, for comparison purposes.

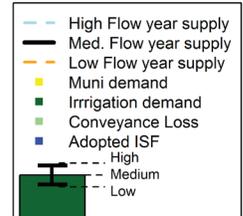
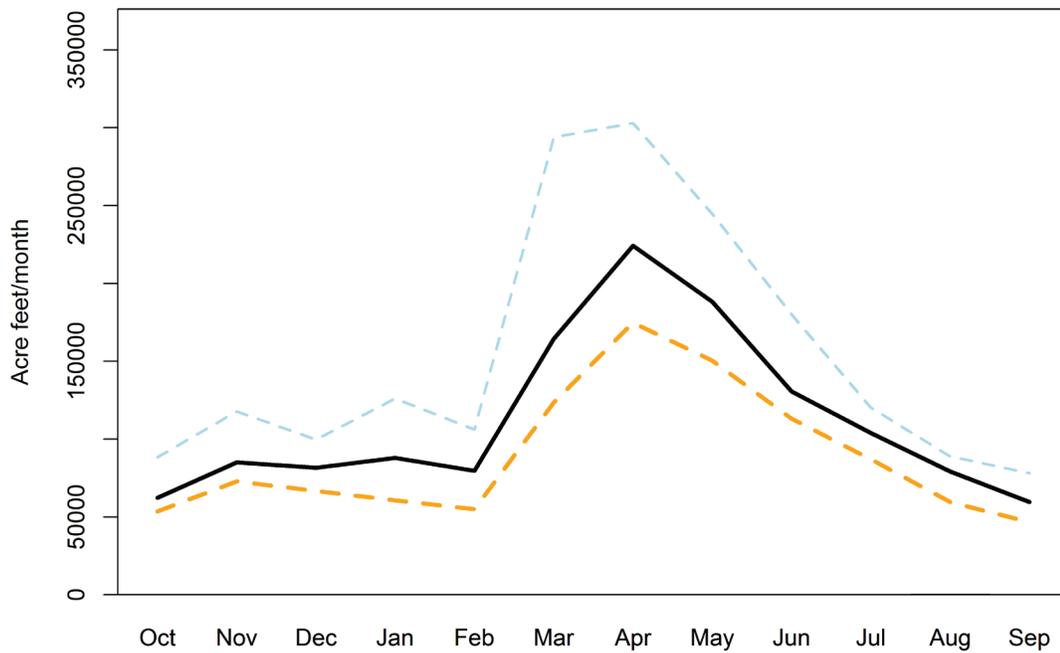
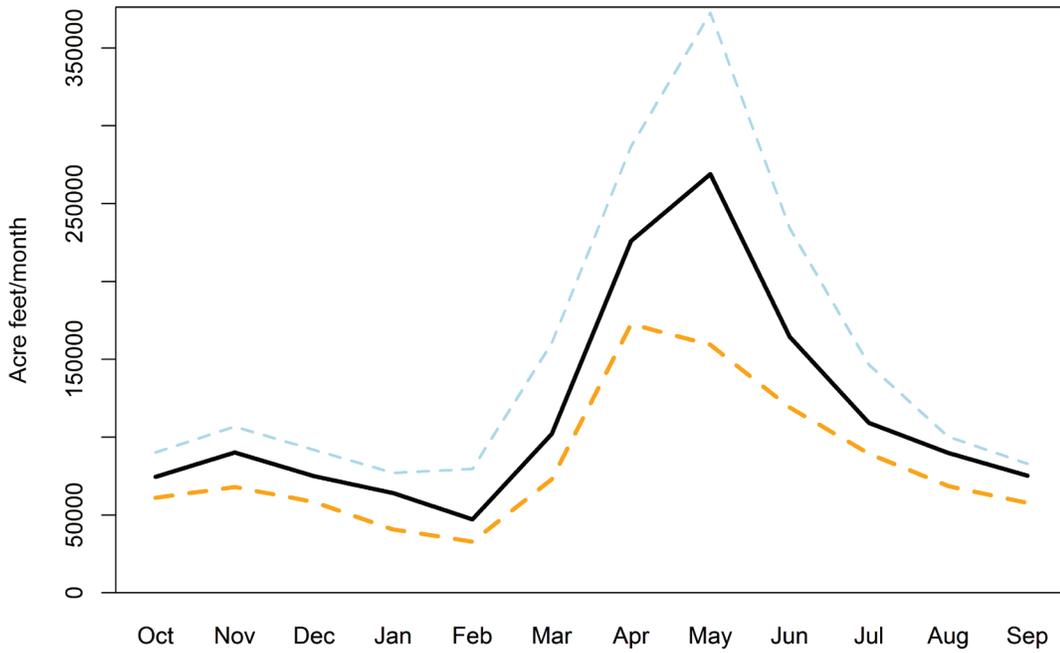


Modeled historical (1981-2011) and forecast (2035) surface water supply generated within the WRIA for low (20th percentile, top), median (middle), and high (80th percentile, bottom) supply conditions. Water supply was forecast under two emissions scenarios: the “2035 Range-Med. GHG” and the “2035 Range-Med. High” values represent supply forecast under IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5, respectively. The spread of each 2035 supply is due to the range of climate change scenarios considered. Supplies are reported prior to accounting for demands, and thus should not be compared to observed flows.

DEMAND



Modeled historical (1981-2011) and forecast (2035) agricultural, municipal, and instream flow water demands within the WRIA. Water demand was forecast under four scenarios combination of: a) "H-Crop H-Clim", b) "H-Crop F-Clim", c) "F-Crop H-Clim", and d) "F-Crop F-Clim" where "H-Crop" represents historic crop mix; "F-Crop" as future crop mix under medium economic scenario, "H-Clim" as historic climate and "F-Clim" values represent demand forecast under IPCC Representative Concentration Pathway (RCP) 4.5 centering 2035. Each bar represents median (50th percentile) demand condition. Ground water (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.



Comparison of surface water supply, surface water agricultural and municipal demands for historical (1981-2011; top panel) and forecast (2035; bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The 80th, 50th, and 20th percentile demand conditions are also shown for agricultural demand using error bars. These results do not consider water curtailment.

## WRIA 32

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Walla Walla Summer Steelhead (ESA Threatened; 2 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Walla Walla Spring Chinook (No ESA Stock; Not a SaSI Stock)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Walla Walla Bull Trout (ESA Threatened; 2 Stocks)	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												

	= No Use
	= Some activity or use occurring
	= Peak activity

## WRIA 35

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snake Fall Chinook (ESA Threatened)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snake Spring Chinook (ESA Threatened; 3 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snake Summer Steelhead (ESA Threatened; 4 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snake Bull Trout (ESA Threatened; 3 Stocks)	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snake River Sockeye (ESA Endangered; Not a SaSI Stock)	Adult In-Migration												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coho (No ESA Stock; Not a SaSI Stock)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

	= No Use
	= Some activity or use occurring
	= Peak activity

# WRIA 37

## Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Fall Chinook (ESA Not Warranted; 2 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Spring Chinook (ESA Not Warranted; 3 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Summer Steelhead (ESA Threatened; 4 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Sockeye (Not ESA listed; Not a SaSI Stock)	Adult In-Migration												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Coho (ESA Not Warranted)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species - SaSI Stock (SaSI)	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Bull Trout (ESA Threatened; 14 Stocks)	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												

	= No Use
	= Some activity or use occurring
	= Peak activity

Fish use charts for WRIs 38 and 39 are available in the 2016 Columbia River Instream Atlas (Ecology Publication in preparation).

# WRIA 45

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Summer Chinook (ESA Not Warrented)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Spring Chinook (ESA Endangered)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Summer Steelhead (ESA Threatened)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Sockeye (ESA Not Warrented)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Coho (Not ESA Listed)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Bull Trout (ESA Threatened; 11 Stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

	= No Use
	= Some activity or use occurring
	= Peak activity

## WRIA 48

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Summer/Fall Chinook (ESA Not Warrented)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Spring Chinook (ESA Endangered)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Summer Steelhead (ESA Threatened)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Coho (Not ESA listed)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Bull Trout (ESA Threatened; 17 stocks)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

	= No Use
	= Some activity or use occurring
	= Peak activity

## WRIA 49

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Okanogan Summer Chinook (ESA Not Warrented)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Okanogan Summer Steelhead (ESA Threatened)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Okanogan Sockeye (ESA Not Warrented)	Adult In-Migration												
	Juvenile Out-Migration												

	= No Use
	= Some activity or use occurring
	= Peak activity