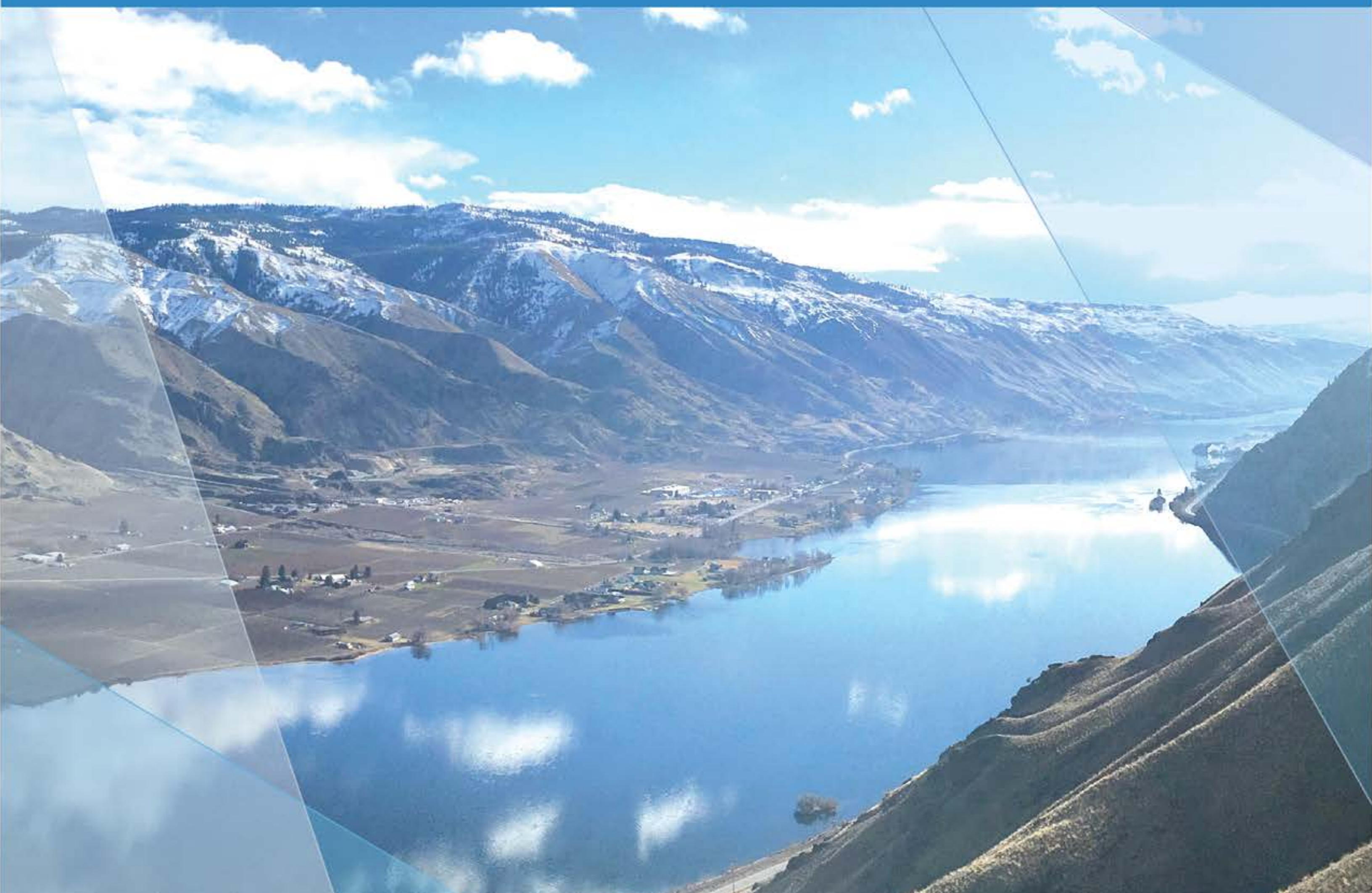
COLUMBIA RIVER BASIN

2021 LONG-TERM WATER SUPPLY & DEMAND FORECAST



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Contact Information

Office of Columbia River Program
Central Regional Office
1250 W Alder Street
Union Gap, WA 989030
Phone: 509-454-4241
Website : http://ecy.wa.gov.

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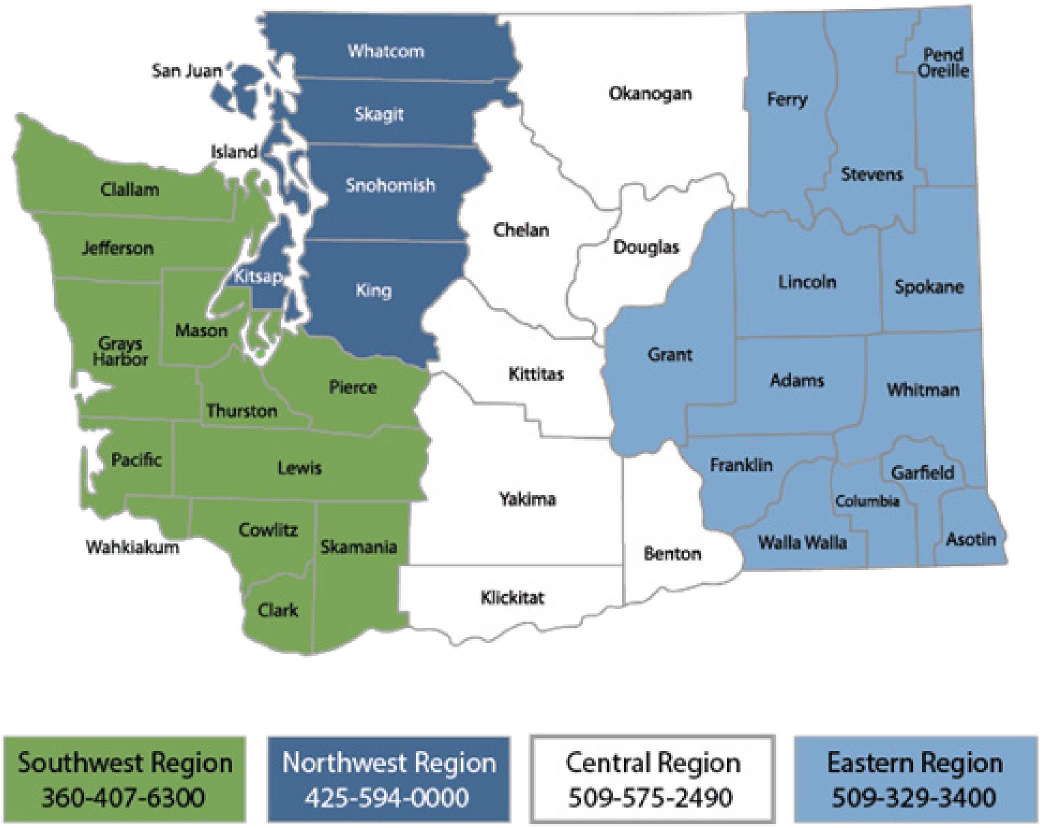

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Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

Columbia River Basin
Long Term Water Supply and Demand Forecast

2021 Legislative Report

Submitted to Washington State Department of Ecology Office of Columbia River Program by:

Washington State University
State of Washington Water Research Center
Center for Sustaining Agriculture and Natural Resources
Biological Systems Engineering
Civil and Environmental Engineering
School of Economic Sciences
PO Box 643002
Pullman, WA 99164-3002

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EXECUTIVE SUMMARY

Meeting Eastern Washington's Water Needs

The Columbia River Basin is the fourth largest watershed in North America in terms of average annual flows, and encompasses nearly 70% of Washington State, mainly east of the Cascade crest. The river is intensively managed to meet a range of competing instream and out-of-stream water demands. Water must also be managed to fulfill the needs of important fish species and meet tribal treaty commitments. Reliable access to water is essential for current and future economic activity and environmental benefits, as well as cultural enhancement across eastern Washington and beyond.

The water supply delivery systems in the Columbia River Basin were built to reliably deliver water under 20th century conditions. As the climate changes, regional population grows, and agriculture responds to these and other trends, the timing and quantity of water supplies and demands are shifting. Washingtonians continue to adapt, changing the ways we use water and how we manage water resources to fulfill our needs.

The primary purpose of the 2021 Long-Term Water Supply and Demand Forecast is to provide a system-wide, quantitative assessment of how future environmental and economic conditions and human responses are likely to influence water supplies and demands over the next 20 years. In this way, the 2021 Forecast provides the foundation for understanding how vulnerabilities might change in the future, informing Washingtonians' efforts to enhance the resilience of the Columbia River system and of our communities.

Overview of Forecast Methods

In collaboration with the Washington Department of Ecology's Office of Columbia River, Washington State University (WSU) and its partners (University of Utah and Aspect Consulting) applied a range of methods to quantify expected changes in water supplies and demands by 2040 (Table ES-1). We used integrated hydrological, crop production, and river operations computer models to evaluate expected changes in surface water supply and agricultural water demand, given a range of possible climate change, crop production, and water capacity futures. We estimated expected changes in residential water demand based on population growth projections and explored potential changes in hydropower production based on that industry's projections of electricity needs. Additionally, we synthesized an independent study on climate change impacts on low flows to explore changes that could affect important fish species. We also evaluated trends in groundwater levels in different aquifer layers across eastern Washington. The results are provided for four different geographic scopes (Figure ES-1, Table ES-1), fulfilling the following specific objectives:

- **Columbia River Basin:** Estimate climate-driven 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 demands for each of eastern Washington's 34 Water Resource Inventory Areas (WRIAs).
- **Washington's Aquifers:** Evaluate groundwater trends in four different aquifer layers within the Columbia Plateau Regional Aquifer System (CPRAS) plus aquifers outside CPRAS, for each of 16 groundwater subareas in eastern Washington.
- **Washington's Columbia River Mainstem:** Estimate changes in supplies in the context of the Mainstem's legal, regulatory, and management schemes.

The Washington State Legislature has mandated that the 20-year forecast be updated every five years[1]. Since 2011, when the team first used computer-based models, we have incorporated substantial improvements to the Forecast as climate science, modeling methods and the conditions across the Columbia River Basin have evolved. New or improved aspects unique to this 2021 Forecast include:

- *Better inclusion of plausible changes in temperature and precipitation extremes,* with the inclusion of an expanded set of 34 climate change scenarios.

1 RCW 90.90 https://app.leg.wa.gov/rcw/default.aspx?cite=90.90

			Methods	Geographic Scopes
SUPPLIES	Surface water		Integrated modeling of historical (1986-2015) and multiple future scenarios (2026-2055). Climate change impacts also modeled through 2070 (2056-2085)	• Columbia River Basin (including focus on eastern Washington) • Washington's Watersheds • Columbia River Mainstem
SUPPLIES	Groundwater		Trends analysis using existing well depth data	• Washington's Aquifers
DEMANDS	Out of Stream	Agricultural	Integrated modeling of historical (1986-2015) and multiple future scenarios (2026-2055). Climate change impacts also modeled through 2070 (2056-2085)	• Columbia River Basin (including focus on eastern Washington) • Washington's Watersheds
DEMANDS	Out of Stream	Residential	Data-based estimates of per capita use and population growth projections Only municipal and self-supplied domestic uses	• Eastern Washington • Washington's Watersheds
DEMANDS	Instream	Flows for Fish	Independent simulation modeling study (Mauger et al. 2021[a])	• Washington's Watersheds
DEMANDS	Instream	Flows for Fish	Compared integrated modeling results to flow regulations	• Columbia River Mainstem
DEMANDS	Instream	Hydropower	Review existing data and information from power entities	• Columbia River Basin

[a] Mauger, G.S., M. Liu, J.C. Adam, J. Won, G. Wilhere, J. Atha, L. Helbrecht, and T. Quinn. 2021. New Culvert Projections for Washington State: Improved Modeling, Probabilistic Projections, and an Updated Web Tool. Report prepared for the Northwest Climate Adaptation Science Center. Climate Impacts Group, University of Washington.

Table ES-1. *Summary of the components of the 2021 Forecast, the methods used to estimate changes by 2040, and the geographic scopes for which results are presented and discussed.*

- ***Deeper exploration of climate change impacts on water supply and demand,*** by adding a longer term, 50-year outlook through 2070.
- ***Deeper analysis of trends in groundwater levels that highlight future vulnerabilities in groundwater supply,*** due to an expanded analysis of available depth to water data from existing wells.
- ***More detailed analysis of seasonal residential water demand,*** with use of monthly data from municipal water providers' water system plans.
- ***More accurate and credible estimates of surface water supply and agricultural water demand,*** resulting from updated and improved data and model calibration.
- ***More detailed simulations of crop water requirements and irrigation needs,*** thanks to improvements in the integrated hydrology and crop production computer model.
- ***Finer scale estimates of interruptions to water users and their impacts on curtailment, crop yields, and instream flow deficits,*** by incorporating more detailed water rights information in curtailment modeling, and exploring additional model outputs.
- ***Data-driven evaluation of the potential impacts of double cropping on agricultural water demand,*** through new analyses of remotely sensed data and of double cropping in warmer agricultural counties across the western states.
- ***A new evaluation of projected changes in low flows that could lead to vulnerabilities for fish species,*** thanks to an independent study on climate change impacts on low flows in Washington State.
- ***More detailed exploration of factors that could significantly affect the demands for electricity from hydropower,*** including transition to electric vehicles, expansion of data centers and future policies and renewable energy targets in Washington State.

These enhancements help the Forecast hone in on the vulnerabilities arising from expected future changes in water supply and demand, and improve our confidence in the results.

Future Vulnerabilities Associated with Changes in Water Supplies and Demands

The 2021 Forecast focused on identifying the vulnerabilities that eastern Washington may face as the climate changes, population grows, and agriculture, hydropower, and other demands for water change.

The availability of water to meet all instream and out-of-stream demands is vulnerable to expected changes in climate and population growth in eastern Washington, even though the amounts of annual surface water supplies and agricultural water demands in the region are expected to be relatively stable. Our key findings highlight the four main types of changes that are leading to vulnerabilities across eastern Washington.

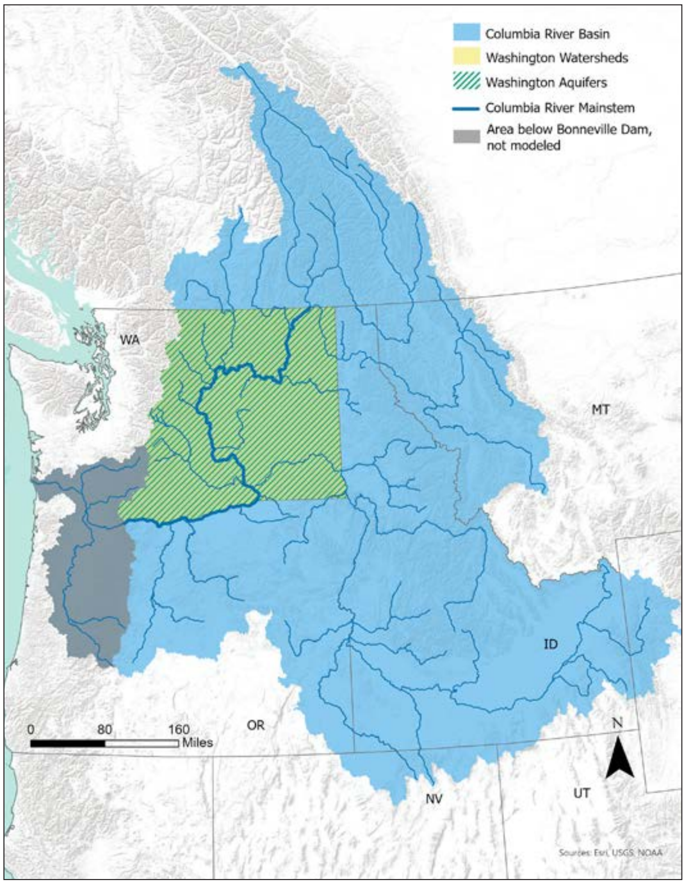

Figure ES-1. Long-term water supplies and demands were forecast through 2040 and beyond, and results are provided for four different geographic scopes: Columbia River Basin, Washington's Watersheds, Washington's Aquifers, and the Columbia River Mainstem.

KEY FINDING 1

The timing of surface water supplies is shifting earlier in the season, especially in the snowmelt-dominated Cascades watersheds. In general, annual supplies are, at most, forecast to increase slightly. Driven by the increasing temperatures and more frequent climatic extremes expected by 2040, however, the early (wet) periods are getting wetter and the late (dry) periods are getting drier, which may have important implications for meeting demands. In some watersheds, these changes are also reflected between years, where supplies in dry years are decreasing and supplies in wet years are increasing.

Vulnerabilities in future water supplies arise from:

- A shift in the timing of water supply, with the center of timing of water supplies shifting on average 22 (±2) days earlier by 2040, and likely increasing the possibility for water supplies and demands to be out of sync.
- Shifts in availability within a water year, with historically wet months (November through May) experiencing a 14.9% (± 2.5%) increase in water supply, and historically dry months (June through October) experiencing a-28.5% (± 2.6%) decrease in water supply by 2040 (Table ES-2).

KEY FINDING 2

Future changes in population and in agriculture in eastern Washington could lead to increases in instream and out-of-stream demands for water. Though climate change alone could result in slight declines in agricultural water demand, population growth, trends in demands for electricity, and planned water development projects could lead to an overall increase in demands for water.

Vulnerabilities, driven by climate-driven changes in water supply are exacerbated by expected changes in water demands. As with supply-driven vulnerabilities, annual agricultural water demand masks the areas of concern, as it is expected to decline slightly (-1.7% ± 0.7%) by 2040 (Table ES-3). However, this pattern is not uniform across eastern Washington, as some watersheds are expecting significant increase in agricultural water demand by 2040 (see Key Finding 4). In addition, the Office of Columbia River (OCR) estimates that 250,000 ac-ft of water may become available by 2040 for out-of-stream uses, as a result of planned water supply projects. If this full amount is used for irrigation, this would lead to an average increase in agricultural water demand by 2040 of 7.5 (± 0.7%) (Table ES-3).

SUPPLY – WASHINGTON PORTION OF THE COLUMBIA RIVER BASIN			
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040
Median year (50th percentile)	16.3	16.7 (± 0.32)	2.0% (± 2.0%)
Wet Season (November - May)	11.5	**13.2 (± 0.29)**	**14.9% (± 2.5%)**
Dry Season (June - October)	4.8	**3.5 (± 0.13)**	**-28.5% (± 2.6%)**

Table ES-2. *Modeled water supply in the historical (1986-2015) and forecast (2040) periods for the Washington portion of the Columbia River Basin, distinguishing between the dry and wet season. The median (50th percentile) supply estimates are included as reference. Throughout, values between parentheses represent confidence intervals around the average of future values, obtained under different climate scenarios. The percent change reflects the difference from the historical to the forecast (2040) values, and is accompanied by confidence intervals associated with climate uncertainty. Changes highlighted in orange and blue are decreases and increases in supply (expected to be associated with decreasing and increasing water availability), respectively, which are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future.*

Expected increases in residential water demand by 2040 are also significant (24% on average across eastern Washington; Table ES-3). While residential water demand overall is a relatively small portion of out-of-stream demands, the expected increase will likely exacerbate the supply-driven vulnerabilities in specific areas, as these demand increases are also variable across the region (see Key Finding 4). Though significant uncertainty remains around which factors will actually drive future demand for electricity, it is clear that demand for hydroelectric power is likely to increase, with estimates ranging from 5% to 34% by 2040. This will place further pressure on limited supplies, as does the continued restoration efforts at the federal, state and local level to ensure instream water demands (such as instream flows) are met as well.

Convergence of decreasing water supplies with increasing agricultural and residential water demands are expected to occur fairly consistently during July and August along the Columbia River Mainstem. This convergence is reflected in the expected increase in frequency of instream flow deficits—that is, the frequency with which flows are expected to be insufficient to meet regulatory instream flow requirements—which at some locations could increase over 35% by 2040.

The water demands described so far do not address areas of currently unmet water requirements suggested by other studies, and declining groundwater (see Key Finding 3) poses additional risks to other water uses. These demands at risk of not being met can reach 13.4 million ac-ft per year for the Columbia River Mainstem during an extreme drought year, and an additional 1.4 to 2.3 million ac-ft per year for fully meeting tributary instream flows, interruptible and proratable water rights, and replacing declining groundwater supplies across eastern Washington (see details in the *Vulnerabilities Across the Columbia River Basin* section of the Legislative Report). The combination of these existing unmet demands with expected changes in water supplies and demands in the future, heighten the need to work collaboratively to address vulnerabilities across eastern Washington and beyond.

KEY FINDING 3

Groundwater levels are declining in most aquifer layers and groundwater subareas across eastern Washington. As with surface water supplies and demands, these declines are not uniform across the region, yet in some subareas and in some aquifers reach as much as-7.0 (± 0.4) ft per year. These declines will likely limit the options to meet demands by moving from surface water to groundwater sources. It may also increase the need to replace current groundwater sources with surface water in the future.

Many groundwater subareas are vulnerable due to declining trends in groundwater levels and the shallowness of the available saturated thickness (the depth to water in a groundwater well, relative to the depth at which water is withdrawn) (Figure ES-2). Each of those subareas will face unique challenges due to the particular combination of changes in groundwater supply and water demands that it is expected to experience, at which locations, and by when. For example, the Okanogan and the Walla Walla groundwater subareas are expected to see significant

OUT-OF-STREAM DEMANDS – WASHINGTON PORTION OF THE COLUMBIA RIVER BASIN			
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040
Median agricultural water demand	3.01	2.96 (± 0.021)	-1.7% (± 0.6%)
Residential water demand	0.19	0.23	22%
Median agricultural water demand + residential water demand	3.20	3.19 (± 0.021)	-0.3% (± 0.7%)
Median agricultural water demand + residential water demand + planned water supply projects	3.20	3.44 (± 0.021)	7.5% (± 0.7%)

Table ES-3. *Expected changes in out-of-stream water demands by 2040 in the Washington portion of the Columbia River Basin. The "median agricultural water demand" estimate considers median climate change impacts, and is assumes that the extent of agricultural acreage remains constant between the historical (1986-2015) and forecast (2040) time periods. The "median agricultural water demand + residential water demand" scenario adds the expected increases in residential water demand. The "median agricultural water demand + residential water demand + planned water supply projects" scenario adds the 250,000 ac-ft of additional water that could be available for out-of-stream uses by 2040 through water development projects. Values between parentheses represent confidence intervals around the average of future values, due to the range of demand values obtained under 34 different climate scenarios. These confidence intervals were maintained in all three scenarios, since we were unable to quantify the uncertainty in the estimate of residential demand or available water. The percent change reflects the difference from the historical to the forecast values, and is accompanied by confidence intervals associated with climate uncertainty. Changes highlighted in blue and orange are decreases and increases in demand, respectively, which are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future.*

reductions in available saturated thickness within 10 years. The Okanogan subarea is also expected to experience significant increases in agricultural water demand (see Key Finding 4). On the other hand, Rock-Glade is expected to see decreases in agricultural water demand, but is expected to experience some of the largest increases in residential consumptive water use in some places (see Key Finding 4), while potentially seeing opposing trends in wells accessing the Wanapum and Saddle Mountain layers (negative and positive, respectively). Similarly, the Odessa and Yakima subareas likely will not see increases in agricultural water demand, but are expected to see some of the largest increases in summer residential consumptive use (see Key Finding 4).

These fairly consistent groundwater declines coincide with vulnerabilities expected due to changes in surface water supplies (see Key Finding 1). This convergence suggests that finding opportunities to prepare for and mitigate the impacts of future changes in water supplies needs to explore options other than finding alternative sources.

KEY FINDING 4

Local increases in out-of-stream demands are expected, converging with local decreases in water supply, such as in the Yakima River Basin. The combination of lower supplies at critical times and locally increasing demands leads to increasing frequency of instream flow deficits and resulting prorationing or curtailments.

The types of vulnerabilities that our region is expected to face due to changes in water supply in the future (see Key Findings 1 and 3) are generally common across all of eastern Washington. However, the degree to which these changes are expected, and the convergence of expected changes in supply and in the different out-of-stream demands for water vary significantly across watersheds.

The Yakima River Basin is an important example of such convergence. The upper watersheds (WRIAs 38 and 39) are expected to experience increases in agricultural water demand (Figure ES-3), while at the same time expecting decreasing water supplies in low supply years (Figure ES-4). The independent study we summarized also highlighted The Cascades WRIAs due to expected decreases in low flows as snowmelt shifts earlier in the year and spring temperatures increase.

TIME TO AN EXPECTED 25% DECLINE IN AVAILABLE SATURATED THICKNESS IN AT LEAST ONE AQUIFER LAYER

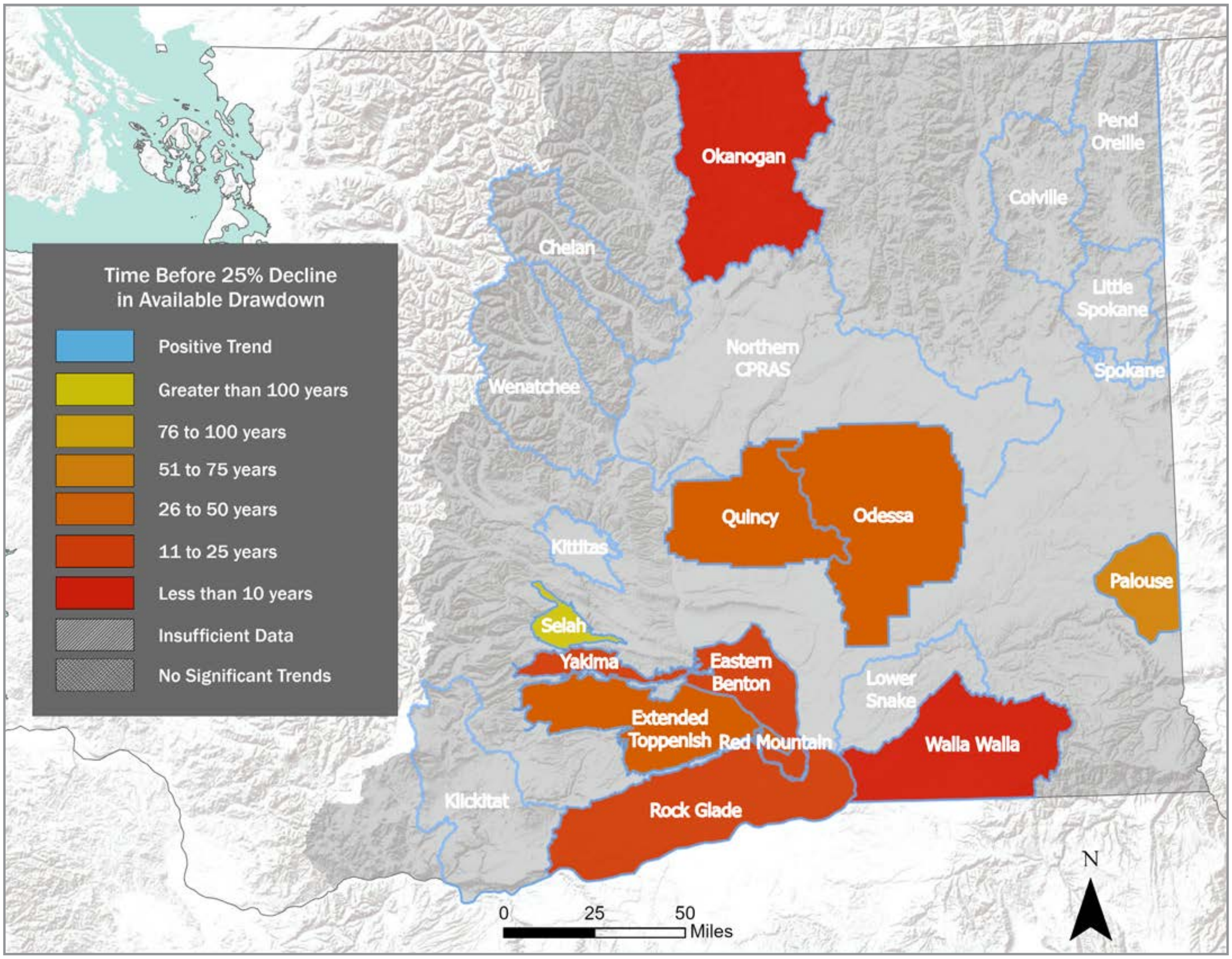

Figure ES-2. Time (in years) until the average available saturated thickness has declined by 25% in at least one aquifer layer in each groundwater subarea. These times are based on declines in available saturated thickness in different aquifer layers, as we show the most vulnerable aquifer layer for each subarea; that is, the time until 25% decline in available saturated thickness may reflect the vulnerability related to declines in the Grande Ronde layer for some subareas, for the Wanapum layer for other subareas, and the Overburden layer for other subareas (for more details see the Forecast Results for Aquifer Layers *section).*

The patterns of expected increases in residential water demand are different to those of agricultural water demand. For example, the Lower Yakima watershed (WRIA 37) is considered vulnerable because of the overlap between expected increases in summer residential water demand (Figure ES-5) coinciding with steep decreases in supply in the summer months (Figure ES-6). Though overall residential water demand in eastern Washington is only about a quarter the magnitude of agricultural water demand, these results warrant serious attention. Increases in summer residential demand of over 20% are expected to occur in WRIAs showing declining summer supplies and that include municipalities using surface water sources (such as WRIA 37). Similarly, WRIAs with the largest expected increases in summer demand lie over aquifer layers with declining groundwater levels (see Key Finding 3), while also including municipalities using groundwater sources.

We conclude that numerous WRIAs in eastern Washington are vulnerable to expected changes in the timing and variability of water supply combined with changes in some type of out-of-stream water demand. Each WRIA has a unique combination of challenges to adapt to in the future, depending in part on the specific balance of changes in supply and demand that lead it to be vulnerable.

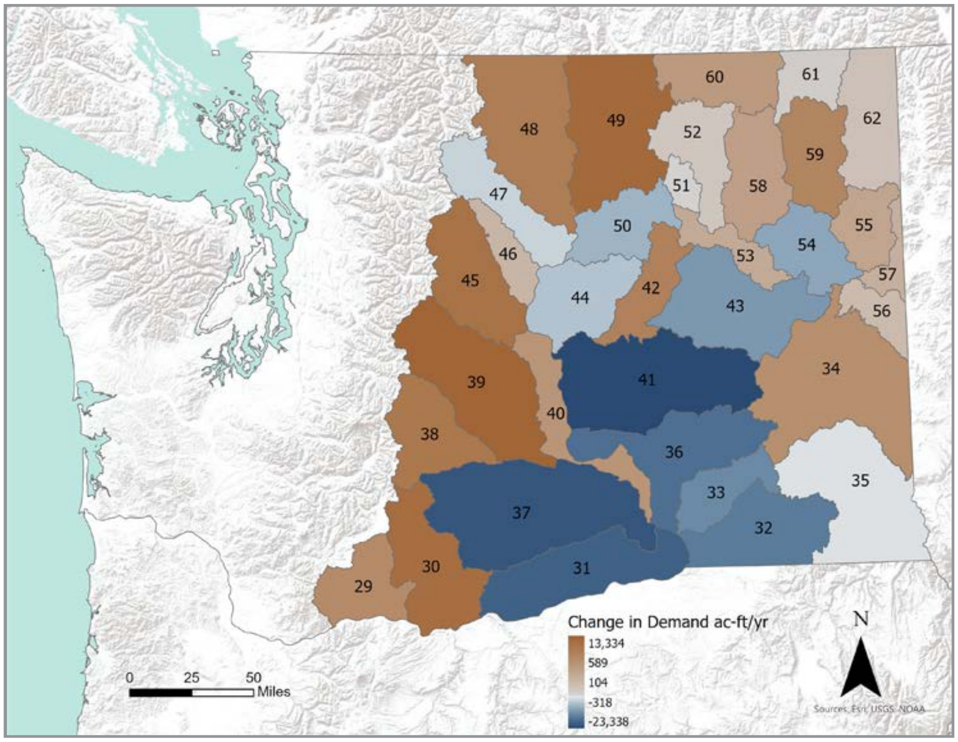

__Figure ES-3__. Expected change in agricultural water demand between the historical (1986-2015) and forecast (2040) time periods, summarized by WRIA. Changes in demand are expressed in acre-feet per year.

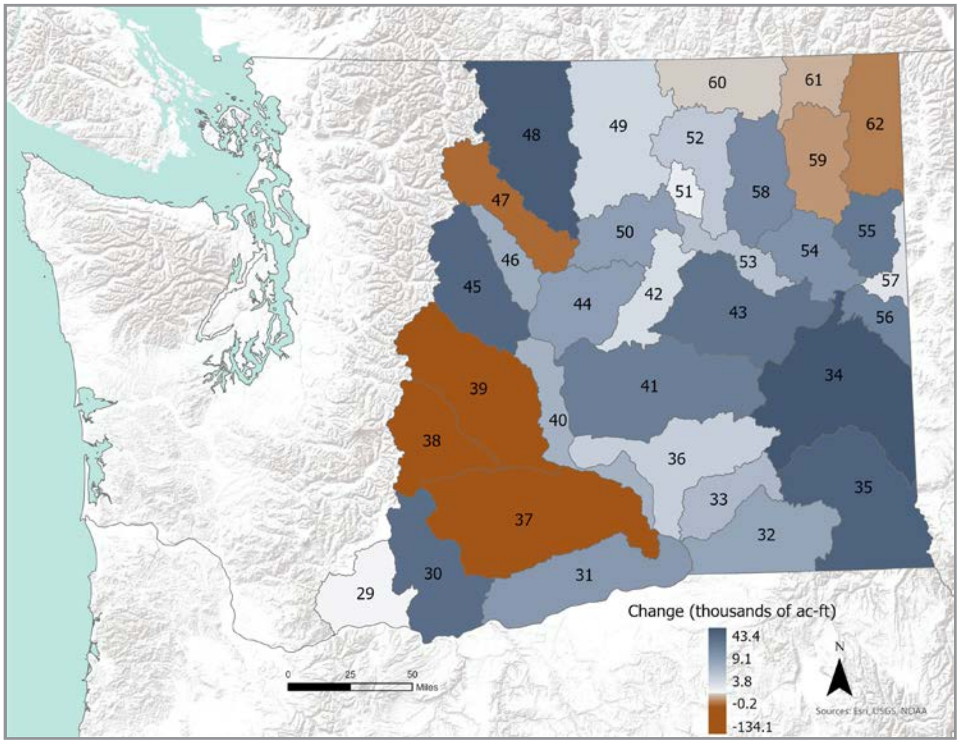

__Figure ES-4__. Changes in annual water supply expected during low flow years (20th percentile) by 2040, in thousands of acre-feet. WRIAs are colored based on the magnitude of change in annual water supply between historical (1986-2015) and forecast (2026-2055) time periods. Future supplies were represented by the median of 34 climate change scenarios. Note that one value is given for WRIAs 37, 38 and 39, and one value is given for WRIAs 44 and 50, reflecting the sum of changes in those groups of WRIAs.

EXPECTED CHANGES IN RESIDENTIAL CONSUMPTIVE USE AND SURFACE WATER SUPPLY DURING SUMMER MONTHS

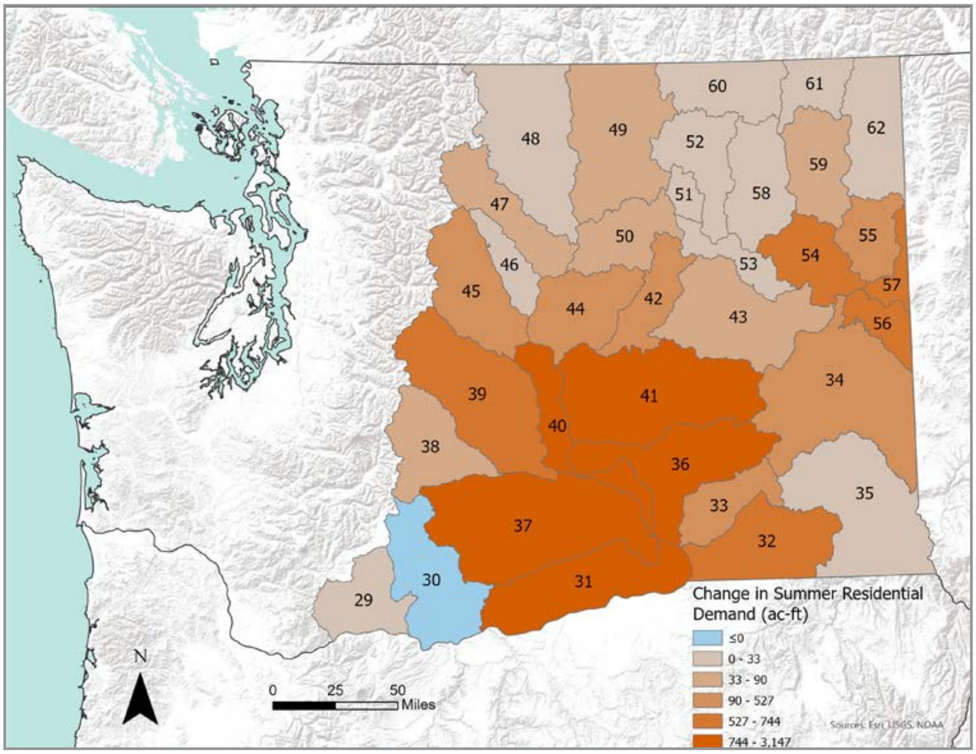

Figure ES-5. Change in residential consumptive water use during summer months (June, July and August) from 2020 to 2040, expressed in ac-ft, summarized by WRIA.

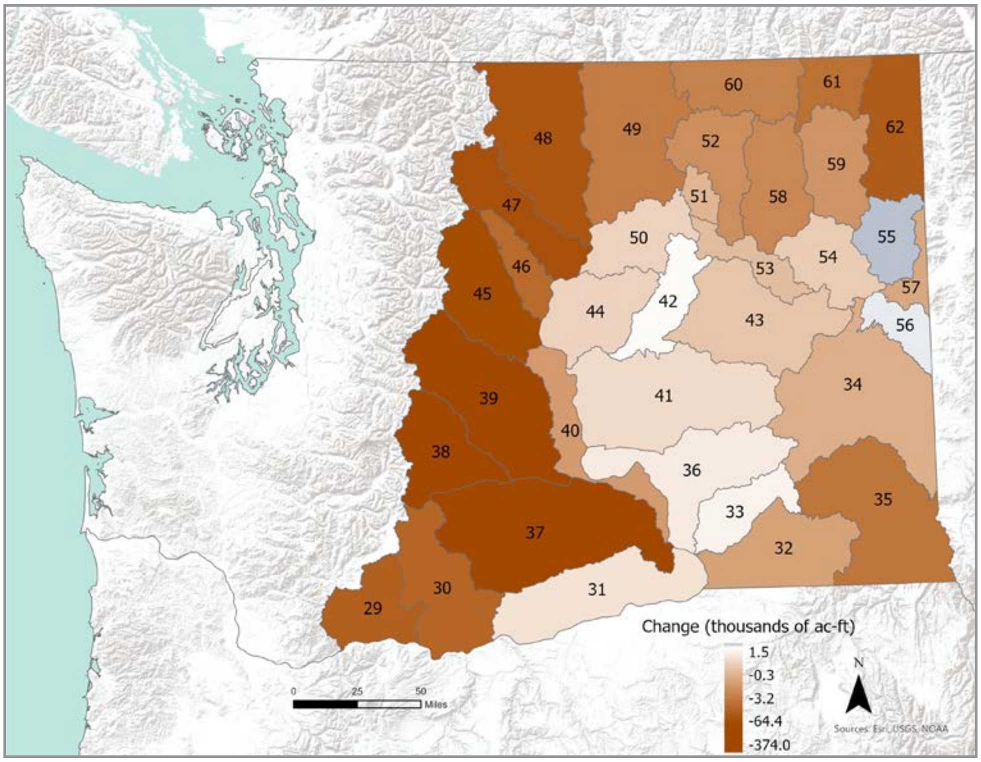

Figure ES-6. Change in surface water supply during summer months (June, July and August) from historical (1986-2015) to forecast (2040) periods, by WRIA. Changes in demand are expressed in thousands of acre-feet per year. One value is given for WRIAs 37, 38, and 39, reflecting the sum of changes in those WRIAs. Likewise, one value is given for WRIAs 44 and 50, reflecting the sum of changes in those WRIAs.

Other Findings

The 2021 Forecast explored a variety of additional factors contributing to changes in water supplies and water demands, a range of possible alternative futures, and the possible implications of these changes. A series of other important findings also arose from these explorations, including the following:

- Annual supply across eastern Washington is expected to increase slightly through 2040, from 16.3 million ac-ft per year to 16.7 million ac-ft per year. This slight increase in supply (2.0% ± 2.0%) is the net effect of an 14.9% (± 2.5%) increase in the early (wet) season supply, and a-28.5% (± 2.6%) decrease in the (dry) late season supply.
- An average decrease of-1.7% (± 0.7%) in agricultural water demand is expected in eastern Washington by 2040. This is the net effect of an 9.4% (± 1.9%) increase in the early irrigation season demands, and a-9.8% (± 1.2%) decrease in the late season. The two future changes in agricultural production we explored—earlier planting dates and changes in crop mix—had counteracting effects, having little overall impact on agricultural water demands.
- Current estimates suggest double cropping occurs on approximately 121,000 acres, or 6% of total irrigated acres in eastern Washington. More than half of these acres are in Grant and Franklin Counties. Our analysis of potential double cropping suggests that increases in summer temperatures will outweigh any benefits from longer growing seasons, and further double cropping in eastern Washington is likely to be negligible.
- The shift in timing of water supplies could range from as much as 23 days earlier by 2040 in the central and southern Cascades WRIAs, to as little as 2 days in the Lower Snake (WRIA 33). This range is closely linked to the proportion of a WRIA's supply that comes from snowmelt, which is much higher in the Cascades WRIAs.
- Cascades WRIAs are expecting the greatest decreases in minimum flows, quantified using a common low-flow metric representing the minimum flow that has a 10% chance of occurring any given year (called 7Q10). Minimum flows in the Cascades WRIAs could be reduced by as much as-15.6 cfs. The lower elevation areas in the heart of central Washington, on the other hand, are expecting slight increases (approximately 1 cfs) by 2040.
- The patterns of change in the frequency of curtailments expected by 2040 vary from WRIA to WRIA. However, there is a trend towards increasing frequency of curtailment by 2040, during the summer months (June, July, and August) across all WRIAs with adopted instream flow rules, with curtailments expected as many as 14 additional years (out of 30) in some weeks and under some climate change scenarios. For example, curtailment frequency in the Wenatchee watershed (WRIA 45) during August is expected to increase from 10 years out of 30 historically to 23 years out of 30 by 2040.
- Reduced irrigation due to curtailment generally caused reductions in yields of forage and high value perennial crops. The magnitude of the yield reduction for crops experiencing curtailment was generally greater under future (2040) conditions than under historical (1986-2015) conditions. The forecast reductions in yield were on the order of 20-25% larger than under historical conditions, though in the Yakima (WRIAs 37, 38, 39) loss in yields could triple.
- Instream flow deficits along the Columbia River Mainstem could occur as many as 10 additional years (out of 30) by 2040, mainly in July and August. In late July, instream flow deficits could increase in frequency from 16 out of 30 years historically to 24 out of 30 years, while in August they could increase from 23 out of 30 years to 30 years out of 30 for most control points along the Columbia River Mainstem. In the spring, on the other hand, water supply is expected to increase, improving the ability of flows to meet instream flow requirements, and reductions in the expected frequency of instream flow deficits. However, these reductions in frequency are relatively minor.

The 2021 Forecast also provides detailed information on the expected changes in water supplies and demands for each WRIA and aquifer layer in eastern Washington. This information can more specifically and directly inform local, watershed, or county level water management decisions.

Conclusion

Where vulnerabilities due to changes in surface water supply exist, expected increases in demands will tend to make them more acute. This is particularly likely in places that may already be experiencing declining groundwater levels. Given the patterns of water demand changes across eastern Washington, numerous watersheds are expected to experience either an increase in agricultural water demand or an increase in residential water demand. Therefore, each watershed will have a rather unique combination of challenges to adapt to. These vulnerabilities will express themselves more obviously during low flow years. The expected increases in frequency of instream flow deficits and curtailment during July and August are a reflection of the impacts of these changes on water supplies and demands.

This 2021 Forecast confirms the findings of the 2016 Forecast and improves our understanding of expected changes in future surface and groundwater supplies and instream and out-of-stream demands. Our results have re-affirmed the importance of understanding the impacts of climate change on the timing and location of water supplies, and how these supply changes interact with changes in agricultural and residential water demands. The generally declining groundwater trends also re-affirm the need to pursue further integration of groundwater into future Forecasts, to better understand these interactions.

In this way, the Forecast results can support insights and understanding relevant to water management that will help Washingtonians prepare for changes in water availability expected in the future. We envision groups with diverse perspectives using the Forecast to understand what vulnerabilities are most acute, and which actions are most likely to make a difference to sustainably meeting the region's water demands, helping us maintain and enhance eastern Washington's economic, environmental, and cultural prosperity for the next 20 years and beyond.

Columbia River at Wanapum Pool

MEETING EASTERN WASHINGTON'S WATER NEEDS

The Columbia River Basin is the fourth largest watershed in North America in terms of average annual flows, and encompasses nearly 70% of Washington State, mainly east of the Cascade crest. The river is intensively managed to meet a range of competing demands. Water is diverted to support an important agricultural economy as well as growing communities and industries. A series of dams along the Columbia River generate hydropower and provide flood control as well as recreation at its reservoirs. The river basin is home to native peoples and water must be managed to fulfill the needs of important fish species and tribal treaty commitments. Reliable access to water is essential for current and future economic activity and environmental benefits, as well as cultural enhancement.

Water supply and demand changes from year to year and across the region. These changes are due to responses to variations in precipitation, temperature, and snowpack dynamics, as well as variations in crop production, irrigation methods, residential needs, and other factors. The water supply delivery systems in the Columbia River Basin were designed and built to reliably deliver water under 20th century conditions. As the climate changes, regional population grows, and agriculture responds to these and other trends (Figure 1), the timing and quantity of water supplies and demands are shifting. Washingtonians continue to adapt to these shifts, changing the ways we use water (such as through water conservation or more efficient irrigation technologies) and how we manage water resources to fulfill our needs (such as reservoir operations or managed aquifer recharge). These adaptations can either increase the system's vulnerabilities in the future or buffer the effects of the climate-driven shifts by helping avoid critical water shortages and reducing the need for water use curtailments.

To prepare for the future we need to understand the nature of the expected changes. We can apply what we know about the Columbia River system and use available tools to help us envision the range of possibilities that the future may hold. The primary purpose of the 2021 Long-Term Water Supply and Demand Forecast is to provide a system-wide, quantitative assessment of how future environmental and economic conditions and human responses are likely to influence water supplies and demands over the next 20 years. This assessment highlights where vulnerabilities in water availability are worsening, bringing focus to where and when actions would be needed to mitigate expected impacts. Similar to the 2006[1], 2011[2] and 2016[3] Forecasts, this 2021 Forecast provides information to help legislators, water managers, and the Office of Columbia River (OCR; Box 1) plan for future conditions that will likely be quite different from those we have experienced in the past. Such plans can guide actions such as investing in water supply projects that have the greatest chance of meeting instream and out-of-stream demands under future conditions. In this way, the 2021 Forecast provides the foundation for understanding how vulnerabilities might change in the future, informing Washingtonians' efforts to enhance the resilience of the Columbia River system and of our communities.

1 Golder Associates Inc. and Anchor Environmental. 2006. Water Supply Inventory and Lwong-Term Water Supply and Demand Forecast. Publication No. 06-11-043. Washington Department of Ecology, Olympia, WA. 995 pp. Available online at: https://apps.ecology.wa.gov/publications/SummaryPages/0611043.html

2 Washington State University and State of Washington Water Research Center. 2011. 2011 Washington State Legislative Report. Columbia River Basin Long-Term Water Supply and Demand Forecast. Publication No. 11-12-011. Washington Department of Ecology, Olympia, WA. 204 pp. Available online at: https://apps.ecology.wa.gov/publications/SummaryPages/1112011.html

3 Hall, S.A., J.C. Adam, M. Barik, et al. 2016. 2016 Washington State Legislative Report. Columbia River Basin Long-Term Water Supply and Demand Forecast. Publication No. 16-12-001. Washington Department of Ecology, Olympia, WA. 216 pp. Available online at: https://fortress.wa.gov/ecy/publications/SummaryPages/1612001.html

Columbia River near Lincoln Rock State Park, north of Wenatchee

BOX 1

The Office of Columbia River

The Office of Columbia River (OCR) was formed in 2006 as a result of Chapter 90.90 RCW.

AUTHORIZING STATUTE

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 long-term water supply and demand forecast by November 15, 2006, and shall update the report every five years thereafter.

VISION

Preserve and enhance the standard of living for the people of Washington by strengthening the state's economy, and restoring and protecting the Columbia Basin's unique natural environment.

MISSION

Aggressively pursue development of water supplies to benefit both instream and out-of-stream uses.

This mission includes the development of 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.*

Long Term Water Supply and Demand Forecasting

Every five years, the Office of Columbia River is required to issue an updated water supply and demand forecast to provide the most current analysis of the forces influencing water resources in the Columbia River Basin. With each Forecast significant methodological improvements are made to better identify future changes in supply and demand.

The first Forecast, published in 2006, used existing data to estimate water use in eastern Washington and made projections of water use through 2025 based on water rights applications and historical trends in water use.

CLIMATE CHANGE

By the 2040s, Washington can expect:

- *Higher temperatures*
- *Wetter, warmer winters*
- *More rain and less snow*
- *Reduced snowpack, especially at low and mid elevations*
- *Earlier snowmelt*
- *Warmer, drier summers, deeper droughts*
- *Greater heat stress*
- *More frequent extreme weather events*

POPULATION GROWTH

By the 2040s, Washington can expect:

- *17% higher population across the state*
- *Stable fertility rates and increasing mortality rates (as baby boomers age)*
- *Over two-thirds of the state's population increase are due to net migration into the state*
- *13% higher population across eastern Washington*

TRENDS IN AGRICULTURE

By the 2040s, Washington can expect:

- *Longer growing season*
- *Greater rate of accumulation of growing degree days*
- *Increased photosynthesis in many crops*
- *Earlier planting dates*
- *Earlier flowering in tree fruit and specialty crops*
- *More frequent heat stress events in summer*

Figure 1. *Expected changes that will influence future water supplies and demands. These expected trends inform the scenarios explored in this 2021 Forecast.*

Beginning with the 2011 Forecast, our team employed computer-based models to forecast water supply and agricultural demand 20 years into the future. These models allow us to better integrate our understanding of what factors influence water supply and demand, such as climate change, future regional and global economic conditions, and state-level water management actions. Since then we have incorporated substantial improvements as climate science, modeling methods and the conditions across the Columbia River Basin have evolved.

The basic modeling framework includes a series of integrated biophysical models that mathematically describe the movement of water through the landscape, crop growth processes, and their dependence on available water, and routing of water through the stream and river network of the Columbia River Basin (Figure 2A). This integrated set of models allows us to explore the current situation and compare alternative futures or scenarios including how expectations of future climate, economic conditions or water management decisions would affect water supply and demand and other output variables.

For this 2021 Forecast, we have continued to improve the models, data, and important variables considered (see the *Overview of the 2021 Forecast* section, below). These efforts have allowed us to streamline the process for obtaining results (Figure 2). In turn, the streamlined process has allowed us to explore additional future scenarios, such as an expanded range of possible future climates, and to evaluate new outputs, such as the potential impacts of water deficits on crop yields and instream flows. These improvements also set the stage for future explorations of additional scenarios that may be important to a range of decision-makers across eastern Washington.

In addition to improvements in the integrated modeling framework, we have also employed more extensive data and sophisticated methods to estimate other types of supply and demand, in particular in analyses of groundwater trends, residential demands, and an evaluation of vulnerabilities for fish. These improvements provide a clearer picture of the vulnerabilities facing the region, as water supplies and demands across the Columbia River Basin change.

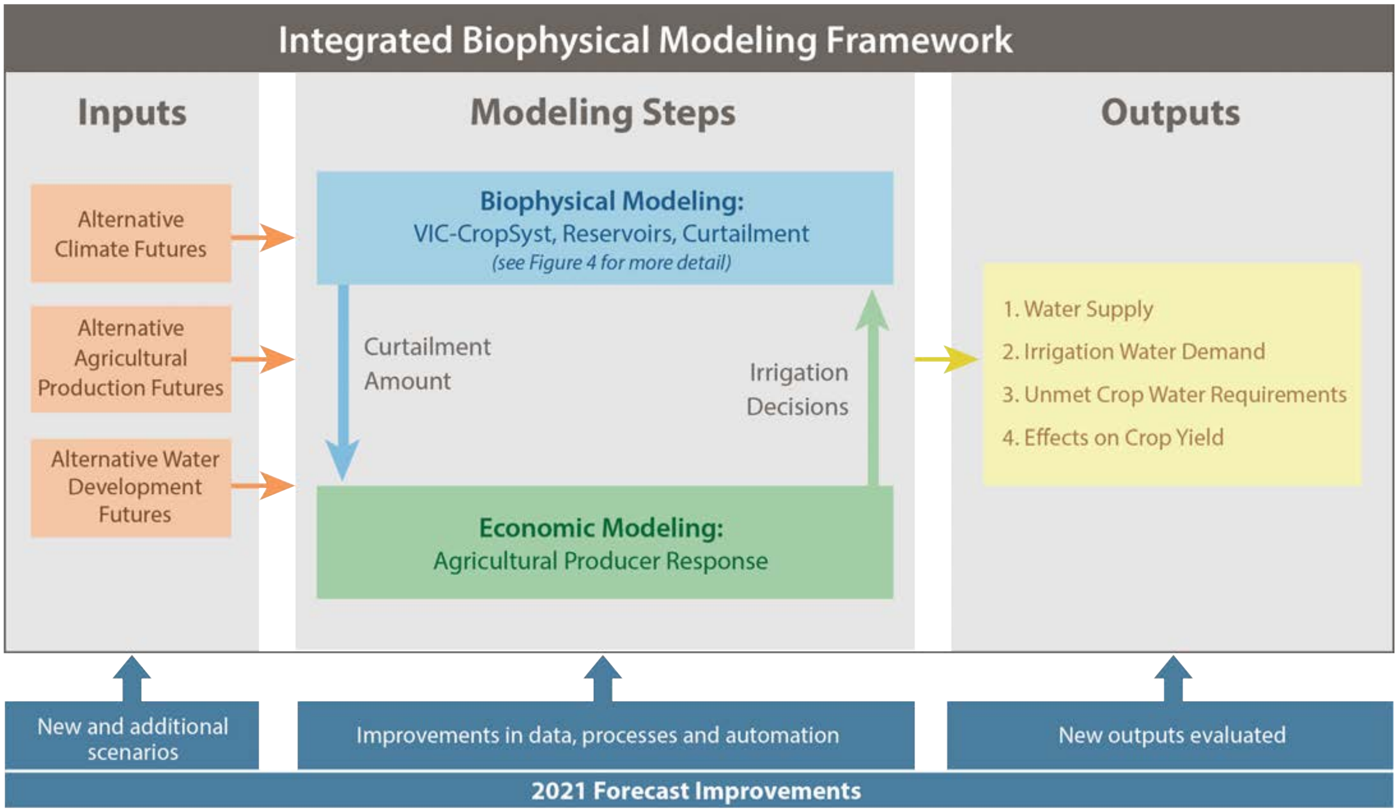

Figure 2. *Integration of biophysical modeling (surface water supply, crop dynamics and climate) with economic and policy modeling. The bottom panel highlights key improvements made in this 2021 Forecast.*

How We Organized this Report

The first section of this 2021 Legislative Report, titled *Overview of Forecast Methods*, starts with a high-level overview of the approach we used, and is followed by a deeper dive into the methods we used to evaluate each type of supply and demand. Next, the *Future Vulnerabilities Associated with Changes in Water Supply and Demand* section describes the findings of the 2021 Forecast, organized around four geographic scopes. In each of these four geographic subsections we discuss the expected changes in water supplies and demands 20 years into the future. Each subsection ends with a discussion of the vulnerabilities in water availability that emerge or are likely to be exacerbated by these expected changes, with a focus on that particular geographic scope (more details on the four geographic scopes can be found in the *Overview of Forecast Methods* section). Finally, in the *Conclusion*, we integrate our findings across all four geographic scopes to highlight the potential future vulnerabilities in water availability for the region, as well as provide recommendations for future improvements to the Forecast itself.

In an effort to provide information to decision-makers in Washington State, this 2021 Forecast includes two additional sections that include more detailed results that can be useful at a local level. The *Forecast Results for Individual WRIAs* section consists of a set of pages specific to each of eastern Washington's 34 WRIAs (Water Resource Inventory Areas), with figures representing surface water supply and demands. The following section, *Forecast Results for Aquifer Layers*, provides an overview of the four aquifer layers within the Columbia Plateau Regional Aquifer System (CPRAS), plus a fifth area outside the CPRAS. Each layer has a dedicated set of pages with tables, figures and maps representing trends in groundwater supplies and available saturated thickness, and summaries for 16 groundwater subareas in eastern Washington.

For more information regarding the technical aspects of the 2021 Forecast, this Legislative Report is followed by a *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast* (Ecology Publication No. 22-12-001, to be published in early 2022).

Columbia River at the Gorge/Cave B Winery

OVERVIEW OF FORECAST METHODS

Forecasting water availability in the Columbia River Basin is multi-faceted, as is any effort made to assess changes in water supplies and demands that takes into consideration both biophysical and human dimensions. Our team has expertise in the different and interconnected water supplies and demands, and the data and methods available to quantify the conditions in this complex water system. In this section, we provide an overview of the methods we used to estimate expected changes in each type of supply and demand, as well as a further look into data- and model-based scenarios we might face in the future. The *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast* will provide further technical details.

This Forecast considers surface water and groundwater supply (Table 1) and estimates four types of demands, including water needs to meet the out-of-stream demands of agricultural and residential sectors, and to meet the instream needs of fish species and hydropower production (Table 1). In collaboration with the Office of Columbia River, Washington State University (WSU) and its partners (University of Utah and Aspect Consulting) applied a range of methods to quantify expected changes in these supplies and demands by 2040 (Table 1). The results are based on different sources of data, and can inform decisions that apply across different geographies. Therefore, the results are provided for four different geographic scopes (Figure 3, Table 1), fulfilling the following specific objectives:

- **Columbia River Basin:** Estimate climate-driven 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 demands for each of eastern Washington's 34 Water Resource Inventory Areas (WRIAs).
- **Washington's Aquifers:** Evaluate groundwater trends in four different aquifer layers within the Columbia Plateau Regional Aquifer System (CPRAS) plus outside CPRAS for each of 16 groundwater subareas in eastern Washington.
- **Washington's Columbia River Mainstem:** Estimate changes in supplies in the context of the mainstem's legal, regulatory, and management schemes.

			Methods	Geographic Scopes
SUPPLIES		Surface Water	Integrated modeling of historical (1986-2015) and multiple future scenarios (2026-2055). Climate change impacts also modeled through 2070 (2056-2085)	• Columbia River Basin (including focus on eastern Washington) • Washington's Watersheds • Columbia River Mainstem
SUPPLIES		Groundwater	Trends analysis using existing well depth data	• Washington's Aquifers
DEMANDS	Out of Stream	Agricultural	Integrated modeling of historical (1986-2015) and multiple future scenarios (2026-2055). Climate change impacts also modeled through 2070 (2056-2085)	• Columbia River Basin (including focus on eastern Washington) • Washington's Watersheds
DEMANDS	Out of Stream	Residential	Data-based estimates of per capita use and population growth projections Only municipal and self-supplied domestic uses	• Eastern Washington • Washington's Watersheds
DEMANDS	Instream	Flows for Fish	Independent simulation modeling study (Mauger et al. 2021[a])	• Washington's Watersheds
DEMANDS	Instream	Flows for Fish	Compared integrated modeling results to flow regulations	• Columbia River Mainstem
DEMANDS	Instream	Hydropower	Review existing data and information from power entities	• Columbia River Basin

[a] Mauger, G.S., M. Liu, J.C. Adam, J. Won, G. Wilhere, J. Atha, L. Helbrecht, and T. Quinn. 2021. New Culvert Projections for Washington State: Improved Modeling, Probabilistic Projections, and an Updated Web Tool. Report prepared for the Northwest Climate Adaptation Science Center. Climate Impacts Group, University of Washington.

***Table 1.** Summary of the components of the 2021 Forecast, the methods used to estimate changes by 2040, and the geographic scopes for which results are presented and discussed.*

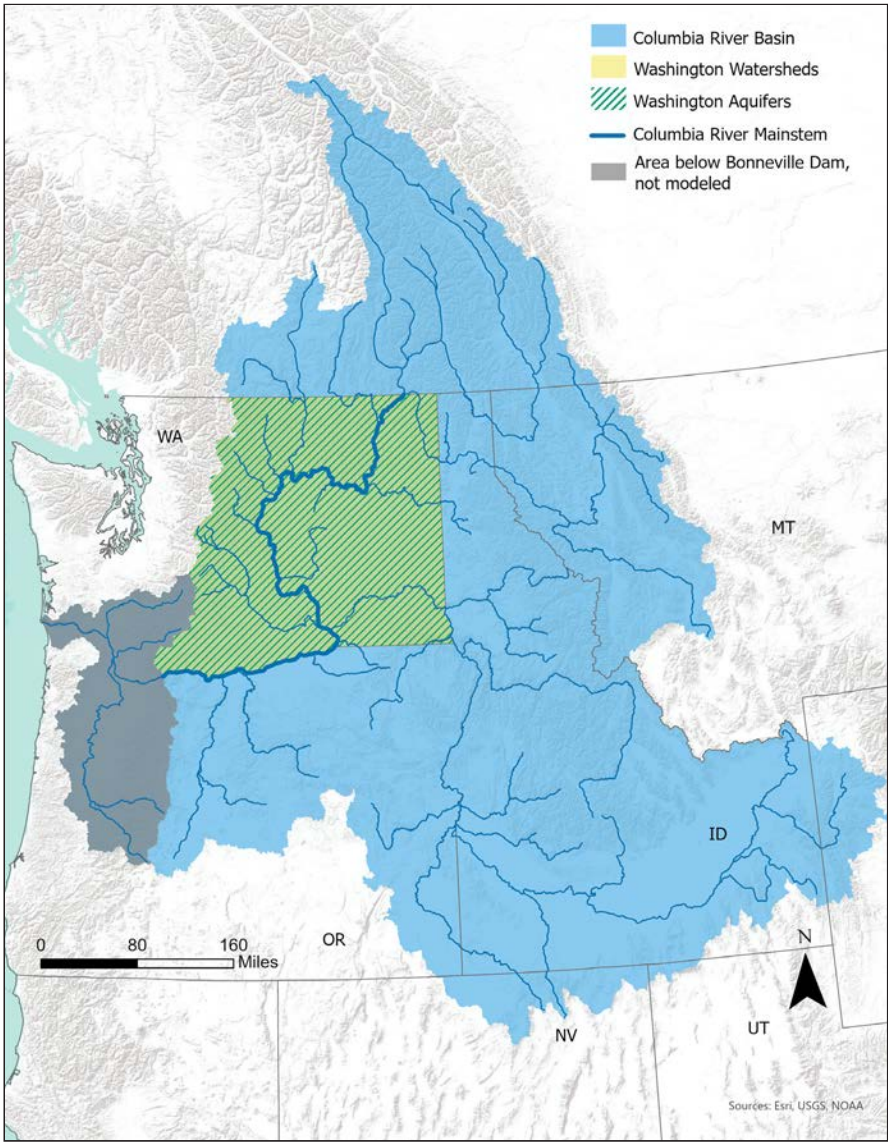

Figure 3. *Long-term water supplies and demands were forecast through 2040 and beyond, and results are provided for four different geographic scopes: Columbia River Basin, Washington's Watersheds, Washington's Aquifers, and the Columbia River Mainstem.*

Similar to the 2016 Forecast, the 2021 Forecast:

- Integrated hydrological, crop production, and river operations (dams and reservoirs) models to evaluate expected changes in water supply and agricultural water demand (Figure 4, diagram);
- Estimated changes expected in residential water demand (formerly called municipal water demand) based on expected changes in population, focused on the Washington State portion of the Columbia River Basin;
- Explored potential changes in hydropower production based on that industry's projections of electricity needs;
- Explored a range of climate change scenarios (34 possible climate futures), crop production scenarios (changing planting dates and crop mixes), and the effect of water projects under development on water capacity; and
- Assumed groundwater is generally not limiting, as we currently do not have the models necessary to integrate groundwater with surface water modeling (though we evaluate this assumption via the groundwater trends analysis; see the *Water Supply Forecast for Washington's Aquifers* section).

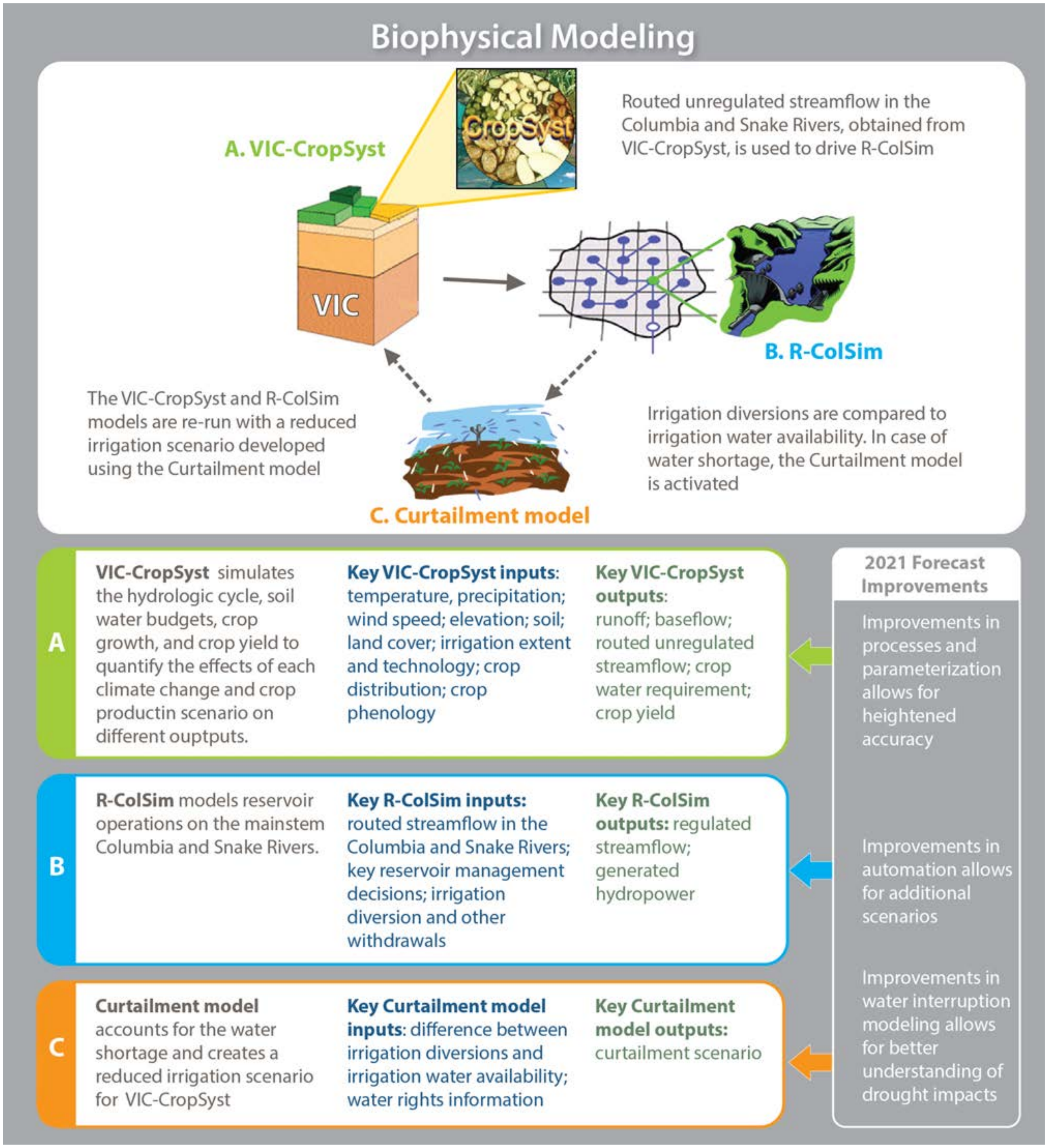

Figure 4. *Biophysical modeling framework for forecasting surface water supply and agricultural water demand across the Columbia River Basin. The diagram represents the basic modeling framework used since the 2011 Forecast. The diagram is accompanied by brief descriptions of each modeling component (Panels A, B, and C), and highlights of key improvements made in this 2021 Forecast.*

New or improved aspects unique to this 2021 Forecast (Figure 4) include:

- *Better inclusion of plausible changes in temperature and precipitation extremes* that could be particularly impactful on water supply and demand. We modeled water supply and demand under an expanded set of 34 climate change scenarios. This larger set of climate change scenarios were developed using 17 different global climate models, each run under two alternative greenhouse gas scenarios[4]. Through this set of climate change scenarios, our team was able to better capture the range of possible climate futures.

4 The greenhouse gas emissions scenarios are called Representative Concentration Pathways (RCPs) by the Intergovernmental Panel on Climate Change (IPCC). The two scenarios used here are RCP 4.5, considered a moderate increase in emissions, and RCP 8.5, considered a high increase in emissions.

- *Deeper exploration of climate change impacts on water supply and demand.* Along with the statutory mandated results for the 20-year forecast (through 2040), we used results from a longer term, 50-year outlook (through 2070) to help elucidate the continued trends in water supply and demand changes in response to changing climatic factors.
- *Deeper analysis of trends in groundwater that highlight future vulnerabilities in groundwater supply.* This analysis focusing on Washington State groundwater trends provides a foundation for integration of surface and groundwater supply modeling in future Forecasts, and complements the surface water supply results.
- *More detailed analysis of seasonal residential water demand.* We gathered information and data from large "Group A" water providers'[5] water system plans to obtain monthly estimates of residential water demand, allowing us to explore the summer overlap of potential increased demands with reduced supplies.
- *More accurate and credible estimates of surface water supply and agricultural water demand,* thanks to updated and improved land cover, irrigation extent and leaf area index values based on remotely sensed data and derived data products coupled with an extensive calibration of key parameters in the integrated VIC-CropSyst model. We used agriculture inventory and field trials data to calibrate the crop parameters of all major crops in eastern Washington, particularly those for fruit trees and forage. Additionally, we calibrated key soil parameters that influence the movement of water through the soil and drainage into streams using observations from 213 streamflow gauges.
- *More detailed simulations of crop water requirements and irrigation needs. Through fully coupling the hydrological (VIC) and crop production (CropSyst) models we were able to use the full functionality of the stand-alone CropSyst model, rather than the simplified version used previously.*
- *Finer scale estimates of interruptions to water users and their impacts on curtailment, crop yields, and instream flow deficits.* Curtailment modeling in this Forecast is based on a more detailed set of water rights that considers instream flow provisions that are included in water rights documents for individual rivers in eastern Washington. In addition, the assignment of interruptions is targeted to the place of use, producing tighter estimates of curtailment. Further, we then modeled crop yields and changes to instream flow deficits should the expected curtailments be implemented in watersheds with adopted instream flow rules.
- *Data-driven evaluation of the potential impacts of double cropping on agricultural water demand,* now and in 2040. We leveraged a related project to provide remotely-sensed estimates of current double cropping extent, and modeled the impacts of this practice on irrigation water demand. Analysis of existing data from other states across the western United States, which demonstrate similar climatic characteristics to those Washington State may experience in the future, provided support for evaluating future changes to double cropping in Washington by 2040.
- *A new evaluation of projected changes in low flows that could lead to vulnerabilities for fish species.* We incorporated into our findings existing projections of low flows by 2040, developed by the University of Washington's Climate Impacts Group (Mauger et al. 2021), to help understand changes in flows that could pose further challenges for fish.
- *More detailed exploration of factors that could significantly affect the demands for electricity from hydropower.* We reviewed available information on the transition to electric vehicles, expansion of data centers, and the adoption of additional renewable energy targets.

These enhancements help the results hone in on the vulnerabilities arising from expected future changes in water supply and demand, as well as improving our confidence in the results of the 2021 Forecast.

5 "Group A" municipal water providers are defined by the Washington Department of Health's Office of Drinking Water as systems having 15 or more service connections or serving more than 25 people for 60 or more days per year.

Integrated Modeling of Surface Water Supply and Agricultural Demand

Water supplies and demands are interrelated. Out-of-stream diversions reduce supply downstream. However, 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 supply water downstream. We simulated surface water supply and out-of-stream demands with an integrated set of computer models that together quantify the relationships between climate, hydrology, water supply, irrigation water demand, crop productivity, economics, residential water demand, and water management. This set of computer models integrates and builds upon three existing models—VIC, CropSyst (now coupled into VIC-CropSyst v3.0), and R-ColSim—that have been used independently in numerous studies to simulate conditions in the Columbia River Basin (for a brief description of each model, its inputs and outputs, see Figure 4).

Modeling Decisions

The integrated model VIC-CropSyst v3.0 uses daily precipitation and temperature observations from across the portion of the Columbia River Basin that is upstream of the Bonneville Dam, including upstream areas in other states and British Columbia, for the 1986-2015 water years (October 1985 through September 2015) to generate baseline simulations of historical conditions for each location. To forecast future conditions, the model uses projected daily weather information from the 2026 to the 2055 water year (referred to in this Forecast as 2040, the year at the center of the 30-year range), as well as from the 2056 to 2085 water year (referred to as 2070). These projections have been developed for 34 different climate change scenarios, representing 17 different climate models run under two alternative greenhouse gas emissions scenarios (RCPs 4.5 and 8.5). The climate change scenarios were adapted for our region by Dr. John Abatzoglou and colleagues[6]. Increased carbon dioxide concentrations were also used as inputs to VIC-CropSyst, affecting crop growth and water use under future scenarios.

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 future climate scenario on regional streamflow, on crop water requirements, and on crop yields (Figure 4). The supply modeling focused on surface waters and shallow subsurface/surface hydrologic interactions (the trends in deep groundwater in eastern Washington described in the *Evaluating Trends in Groundwater Supply* section are not yet integrated with surface water dynamics). The demand modeling focused on irrigation. This use represents the majority of out-of-stream water use in the Columbia River Basin (Table 2) and supports irrigated agricultural production, a prominent driver of Washington's economy.

We explored changes in surface water supply and agricultural demand under four sets of conditions:

- A **historical scenario**, whose inputs are historical climate conditions, historical planting dates and historical crop mixes.
- A **climate change scenario**, whose inputs include future climate conditions, yet retain historical planting dates and crop mixes, isolating the effect of climate change.
- A **mixed future scenario**, whose inputs include both future climate conditions and future (earlier) planting dates, while retaining historical crop mixes.
- A **full future scenario**, whose inputs include future climate conditions, future planting dates and future crop mixes.

The planting date and crop mix conditions are described fully in the *Exploring Effects of Management Responses* section, below.

6 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 Northwest Knowledge Network are available online at: https://climate.northwestknowledge.net/MACA/.

Source	Millions Gallons Per Day	Percent of All Uses
Irrigation	2411	81.15%
Public Supply	317	10.67%
Industrial	135	4.53%
Aquaculture	48	1.63%
Self-supplied Domestic	20	0.68%
Livestock	20	0.68%
Mining	15	0.49%
Thermoelectric	5	0.17%
All Uses	**2971**	**100%**

***Table 2.** Water withdrawals in eastern Washington in 2015. Data estimated by the U.S. Geological Survey (Fasser 2018[7]). This is the most recent estimate available. The USGS updates their reports every five years, and the 2020 values are not yet available.*

Any simulation modeling effort requires that the modelers select datasets and make modeling decisions that define what conditions each modeled scenario represents. There are also known limitations to how well the available datasets and parameters reflect real conditions. Understanding these conditions and limitations is critical for interpreting the results of the simulations, and using them effectively to inform particular water management decisions. The main data sources and modeling decisions made while modeling water supply and agricultural water demand were:

- Irrigation demands were modeled assuming that the land base for irrigated agriculture remained constant between the historical (1986-2015) and the future timeframe (2026-2055). Increasing the irrigated acreage in the region is dependent on additional water development and new water rights (see the *Planned Water Supply Projects* section for details on our exploration of such an increase).
- OCR continues to invest in water development projects in the Odessa Special Study Area (Figure 5). Therefore, the irrigated agriculture acreage in the Odessa Subarea that was assumed to be served by groundwater in the historical period was assumed to depend on surface water by 2040.
- We simulated the growth and development of over 100 different field and pasture crops, tree fruit, and other perennials (Table 3), capturing the diversity of eastern Washington's crop mixes. Detailed parameterization of crop growth parameters focused on 25 crop types that account for the majority of agricultural acreage in eastern Washington (Table 3). We then strategically applied these crop growth parameters to the remaining crop types.
- The historical (1986-2015) simulations used recent crop mapping information from the United States Department of Agriculture's (USDA) Cropland Data Layer (CDL; 2018 dataset) for areas outside of Washington, and used the Washington State Department of Agriculture's (WSDA; 2018 dataset) more precise data for areas inside the state.
- Each crop within Washington was identified as irrigated or not and assigned a type of irrigation based on information in the WSDA dataset. Since the USDA dataset used for the surrounding states does not include this information, we applied the most common decisions within Washington to the same crops outside of Washington. High-value crops such as corn, fruit, and potatoes were considered to be always irrigated.
- We projected the future crop mix by extending recent changes (between 1990 and 2019) in the relative acreage of various types of crops through to 2040 (see *Crop Mix* section).

7 Fasser, E.T., 2018, Water use in Washington, 2015: U.S. Geological Survey Fact Sheet 2018-3058, 4 p., https://doi.org/10.3133/fs20183058.

- We 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. Dam management captured within R-ColSim[8] included operations for power generation, flood control, instream flow targets, and stream flow regulation.

- We obtained water supply under the different modeled scenarios from the unregulated streamflow outputs of VIC-CropSyst, and the regulated streamflow outputs of R-ColSim (Figure 4). We obtained agricultural water demand under those same scenarios from the crop water requirement outputs of VIC-CropSyst, plus estimates of conveyance losses (Figure 4).

Field Crops		Vegetables and Field Fruits	Forage	Tree Fruit and Other Perennial Crops
Winter Wheat	Dry Peas	Sweet Corn	Alfalfa	Apple
Spring Wheat	Canola	Mint	Grass Hay	Cherry
Spring Barley	Oats	Onions	Clover Hay	Pear
Potato	Dry Beans	Radish		Hops
Field Corn	Triticale	Green Peas		Grape – Wine
Lentils	Sod Grass (for seed)			Blueberry

Other crops simulated in the historical and future crop mixes:

Field Crops: Durum Wheat, Sugar Beet, Rye, Buckwheat, Sunflower, Millet, Sorghum, Soybeans, Speltz, Chickpea, Mustard, Camelina, Safflower, Beet Seed, Corn Seed, Pea Seed, Flax Seed, Sugar Beet Seed, Sunflower Seed, Rape Seed, Other Small Grains.

Vegetables and Fruits: Asparagus, Carrots, Squash, Garlic, Spinach, Green Beans, Herbs, Turnips, Watermelon, Broccoli, Cabbage, Cauliflower, Cucumber, Lettuce, Peppers, Potatoes, Pumpkin, Greens, Dill, Carrot Seed, Spinach Seed.

Pasture Crops: Pasture, Pasture Grass, Bluegrass Hay, Timothy, Rye Grass, Vetch, Barley Hay, Alfalfa Seed, Bluegrass Seed, Ryegrass Seed, Fescue Seed, Other Hays.

Tree Fruit and Other Perennial Crops: Peach or Nectarine, Plum, Apricots, Grapes, Grape – Juice, Caneberry, Cranberry, Strawberries, Other Orchards, Silviculture, Christmas Trees, Poplar, Daffodil, Tulip, Green Manure, Yellow Mustard, Clover, Wildflowers, Sudangrass, Nursery Silviculture, Nursery Orchard, Nursery Ornamental, Walnuts, Conifer Seed.

Table 3. *Field crops, fruits and vegetables, forage, tree fruit, and other perennial crops simulated in the historical and future crop mixes. The crops listed in the table represent the crop types for which we did detailed parameterizations of crop growth under locally appropriate management conditions, using agriculture inventory statistics and field trials data, reviews of existing literature, and communications with local experts. The bottom panel lists the other crops that we simulated in this Forecast. These crops were not parameterized individually, due to either their relatively low occurrence in the region or to their similarity to one of the 25 crops that were parameterized in detail. We simulated these crops using the parameters developed for the crop that they most closely resemble.*

8 R-ColSim is a version of the ColSim model that maintains all the functions of the original ColSim model, but that is written into the R programming language to allow for a fully-automated simulation of regulated flows.

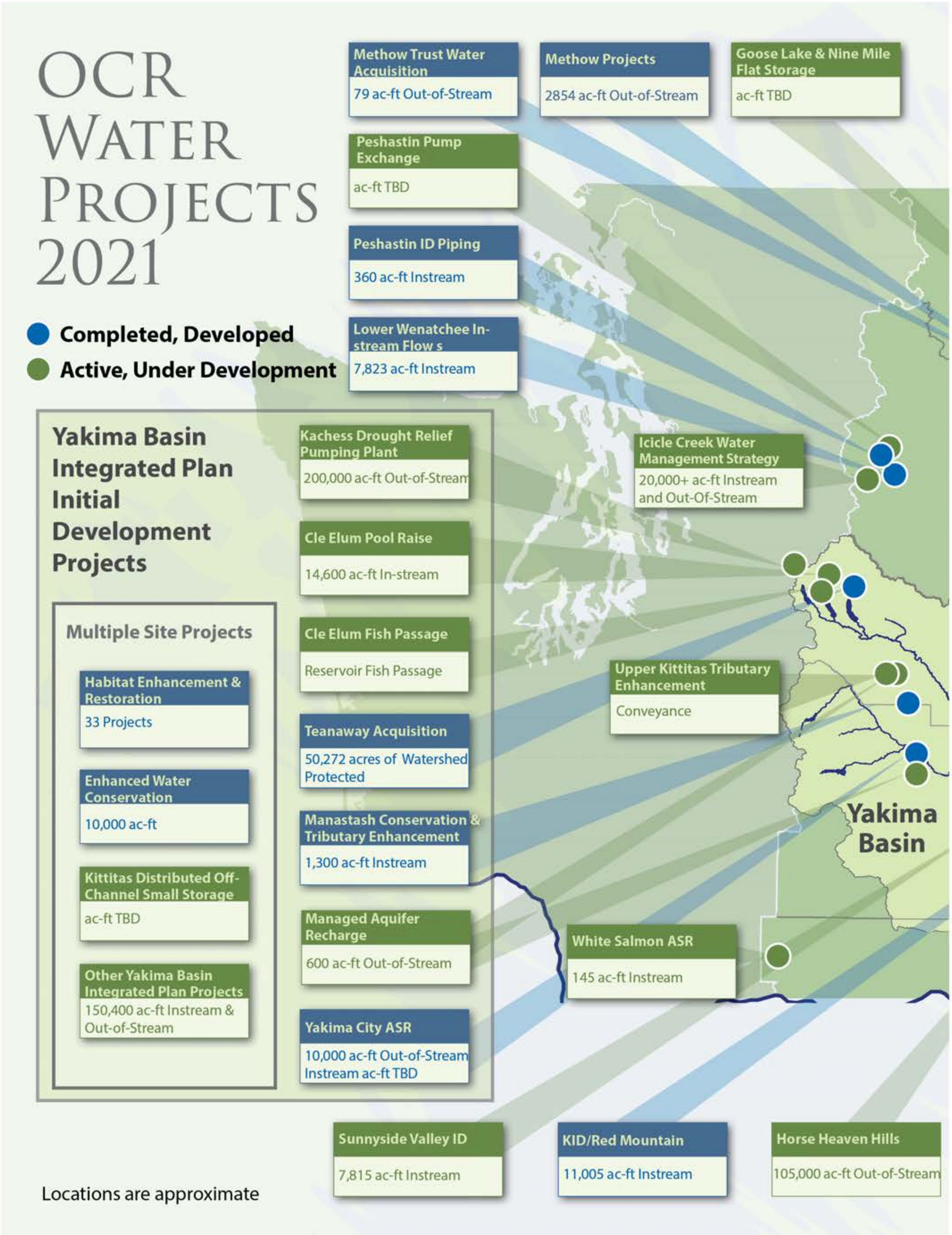

Figure 5. *Projects funded by the Office of Columbia River.*

Region-Wide Projects

Conservation Commission Irrigation Efficiency
7,823 ac-ft Instream

Conservation Commission Retiming
ac-ft TBD

Regional Aquifer Storage and Recover
ac-ft TBD

Donations
28,854 ac-ft Instream

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THE OFFICE OF COLUMBIA RIVER
DEPARTMENT OF ECOLOGY
State of Washington
Water for Families, Farms, and Fish

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Exploring Effects of Management Responses

Planting Dates

Planting date for annual crops can change from year to year in response to climatic factors. As temperatures warm, farmers may be able to plant their annual crops earlier, which will affect the timing of crop growth, and therefore the timing of their demand for water. In our integrated modeling framework, planting date can be modeled in one of two ways:

- A set date is given and the planting date is always the same, independent of the climate conditions for that particular year (static mode); or
- Planting date is calculated for each year as a function of the temperature during the planting season (dynamic mode).

If we use the dynamic mode, planting date would be modeled earlier for the future climate scenarios, due to warmer temperatures. This earlier planting date contributes to an earlier irrigation season with the potential for earlier water rights interruption during low flow years. However, if the dynamic mode is used, planting date is different for each year, making it difficult to determine to what extent planting date was affecting the irrigation season, the net irrigation demand, and the timing and frequency of water rights interruption.

Instead, we decided to use the static mode so that we could isolate the effects that planting date have on the water demand and curtailment results, focusing specifically on annual crops, grass hay and clover hay. We used historical planting date when modeling historical supply and demand, and then explored two planting date options in the model runs using future (2040) climate:

- Historical planting date, which isolates the effects of climate change alone on water supply and demand; and
- Projected future planting date, estimated to occur one week earlier than historically. This future planting date was added to the future climate inputs, so results reflect effects of future planting date in addition to those of climate change.

It is important to note that the use of these options are not predicting how planting date will change. Changes in planting date are the result of farmers' decisions, and are influenced in complex ways by field conditions, the water right's season of use, and other factors. Instead, the intent in using these two planting date options is to quantify the impacts that a realistic change in the future planting date could have on water demand and on curtailment of interruptible water rights.

Crop Mix

We analyzed the historical changes in crop mix statistically, and forecast those trends through 2040. Using survey data from USDA NASS[9] that reports state-level planting acres for each crop from 1999 to 2019, we developed statistical equations that quantified how crop acreage changed over time. We then extended these trends beyond 2019, giving us an estimate of the proportions of different crops at the state level in 2040 (Figure 6). Once we had the estimates of crop mix in 2040, we assigned them to each modeling grid cell based on the crop types currently occurring in that grid cell. The new, relative proportions of each crop type expected in 2040 was considered the future crop mix.

As with planting date, we explored two crop mix options in the model runs using future (2040) climate, and historical and future planting dates:

- Historical crop mix, combined with future climate and historical planting date, first, and then combined with future climate and future planting date; and
- Projected future crop mix. This future crop mix was added to the future climate and future planting date inputs, so results reflect the effects of future crop mix in addition to those of climate change and an earlier planting date.

This approach to quantifying a future crop mix scenario assumes that historical trends in the relative acreage of crop types, as well as the relative profitability of each crop (which is the main driver of those changes) will continue into the future. This approach would have limited utility if the factors that influence crop mix in the future are different

9 USDA National Agricultural Statistics Service (2017). NASS- Quick Stats. USDA National Agricultural Statistics Service. https://data.nal.usda.gov/dataset/nass-quick-stats. Accessed: various dates in 2020.

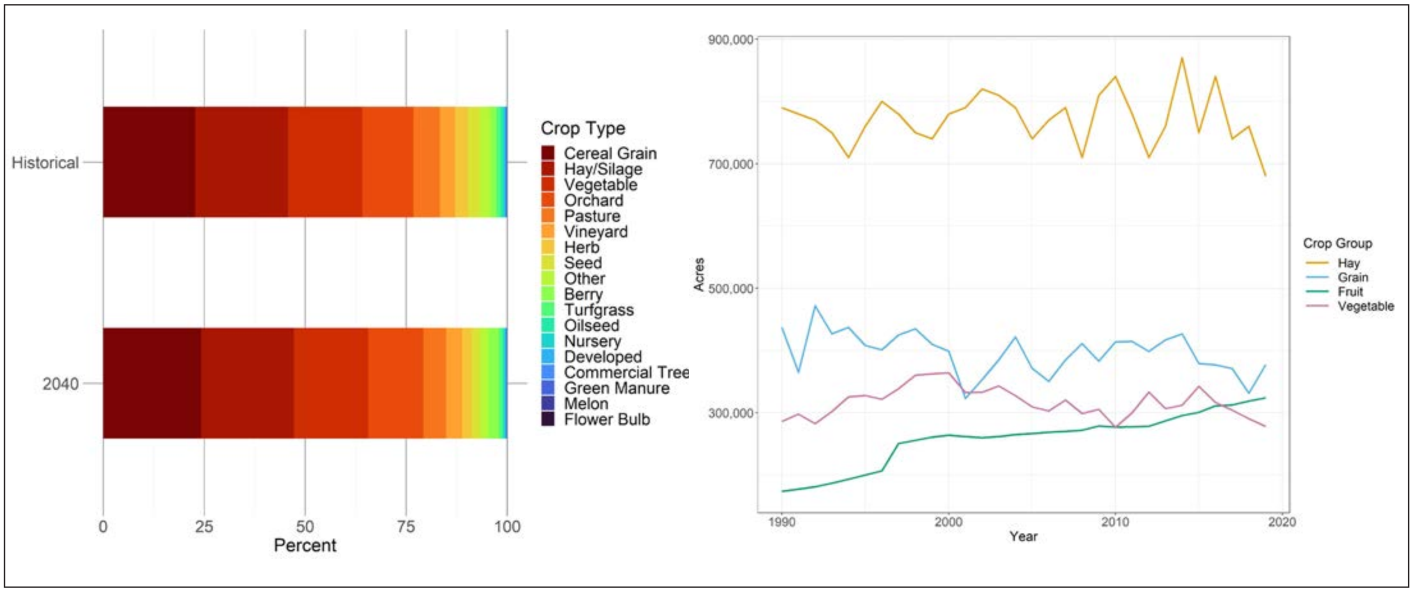

Figure 6. *Estimated proportions of different crops in Washington, used as inputs to the integrated modeling of agricultural water demand (left) and irrigated acres of certain crop groups of particular interest for this analysis (right). The historical (2020) crop mix was estimated using USDA NASS survey data, and the 2040 crop mix was estimated based on a statistical analysis of trends in different crops between 1999 and 2019.*

to those that drove crop mix in the recent past. However, given that we are making projections to the relatively near future, we considered this the most relevant approach.

Water Use Curtailment and Instream Flow Deficits

The modeling results for surface water supply and agricultural water demand described above are calculated without limiting irrigation if supply is insufficient to meet all demands. To determine whether the agricultural water demand can be fully met, supply and demand need to be compared to each other, within the context of the regulatory environment. Understanding to what extent water supply is sufficient, and whether that is expected to change by 2040, is important information for decision-makers.

To explore this issue, we modeled the frequency and magnitude of curtailments in four eastern Washington watersheds with water rights that are interruptible in favor of established instream flows: Wenatchee (WRIA 45), Methow (48), Okanogan (49), and Colville (59) (Box 2). We also modeled the proration frequency and rate in the Yakima River Basin (WRIAs 37, 38, 39). Based on these results, we then evaluated how crop yields would be affected by such curtailments and prorationing, now and in the future. Finally, we modeled instream flow deficits at the nine dams along the Columbia River Mainstem in Washington State: Chief Joseph, Wells, Rocky Reach, Rock Island, Wanapum, Priest Rapids, McNary, John Day and The Dalles. Minimum average weekly flows for instream uses are established at these locations under Washington Administrative Code (WAC) 173-563-040(1).

WRIA Level Curtailment

In individual WRIAs we used a curtailment model that identifies, on a weekly basis, when the water supply left over after accounting for agricultural and residential demands is insufficient to meet instream flow requirements (Figure 4). Each such week was counted as a curtailment period, and these counts are then summarized into a historical or forecast curtailment frequency by aggregating them across the appropriate 30-year time window (1986-2015 or 2026-2055).

When instream supply in those WRIAs fell below the instream flow rule, we calculated curtailment magnitude as the surface water demand from interruptible water rights (Box 2). The exception is the Yakima River Basin (WRIAs 37, 38, and 39), where the water rights system is different to all other watersheds in Washington (Box 2). In this basin, we simulated curtailment using Yakima RiverWare, which compares modeled water supply (historical or forecast) to the Yakima River's flow targets, and applies curtailment rules designed around the specifics of the prorationing system that regulates water use in this Basin. In all cases curtailments were calculated on a weekly basis.

BOX 2

Types of Curtailment in Eastern Washington

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 2021 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 an 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. The interruptible curtailment analysis in the 2021 Forecast, using a curtailment model, focused on these interruptible water rights. We identified interruptible rights by their instream flow provision, rather than by their priority date, as we had done in the past. This approach led to many more interruptible water rights being included in the curtailment analysis. In addition, when determining the irrigated area impacted by a particular curtailment, we used the acreage associated with the water right's place of use and the crop growing there, more accurately reflecting actual and potential water rights interruption.

Non-interruptible curtailment: Water rights that are not subject to instream flow targets are called non-interruptible water rights, also described as "junior to senior water calls." These water rights may still be subject to curtailment, given that a senior water right holder can call on individual junior water rights holders to cease withdrawals, if and when their water availability is affected. The Forecast team is compiling available data to explore these non-interruptible curtailments.

Figure A. Surface water users in the Yakima Basin. Credit: Washington Department of Ecology.

Prorationing: 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 5, 1905; proratable water rights have a priority date of May 5, 1905; and junior water rights have a priority date after May 5, 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 prorationed portion of their entitlements. This prorationing 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 prorationing analysis in the 2021 Forecast, using the model Yakima RiverWare, focused on the proratable water rights. When prorationing is in effect, the junior right holders are curtailed in full and receive no water.

- For more information see Washington Department of Ecology's website at https://ecology.wa.gov/Regulations-Permits/Compliance-enforcement/Water-use-compliance/Curtailing-water-use.

Curtailment Impacts on Crop Yields

The WRIA level curtailment and prorationing frequency results for the Wenatchee (WRIA 45), Methow (48), Okanogan (49), and Yakima (37, 38, 39) provided the basis for estimates of the impact of curtailment on crop yields. We did not include the Colville watershed (59) in this analysis as there are only 57 acres of interruptible water rights in this watershed, which was below our 100 acres minimum. We re-ran VIC-CropSyst v3.0 using the water available for agricultural irrigation when curtailment occurred. This reduced amount of water available for irrigation was considered to represent deficit irrigation rather than fallowing. That is, less water was allocated to each field, rather than the full needs of crops being met on some fields, while other fields were left fallow. In this way, we quantified how the reduced irrigation water amounts led to changes in yields of selected groups of important regional crops.

In these three WRIAs, as well as in the Yakima watershed (WRIAs 37, 38 and 39) we explored changes in crop yields due to reduced irrigation under the same four sets of conditions for which we explored changes in agricultural water demands and curtailment frequency and magnitude: a historical scenario, a climate change scenario, a mixed future scenario (climate change and future planting date), and a full future scenario (climate change, future planting date, and future crop mix).

In this way we quantified a range of crop yield changes that provide information on the impacts of reduced irrigation on crop yields, as well as the interacting effects of climate change and other production management responses on those impacts.

Instream Flow Deficits on the Mainstem

The approach taken to estimate the frequency of instream flow deficit along the Columbia River Mainstem was conceptually similar to that used in individual WRIAs. Since curtailment has only happened once on the Columbia River Mainstem (in 2001), it is challenging to correctly parameterize the model to accurately reproduce curtailment frequency. Therefore, we decided to focus on the occurrence of instream flow deficits rather than curtailment frequency. An occurrence of instream flow deficit is a week when water supply at a particular location on the Columbia River Mainstem is insufficient to meet instream flow requirements, once agricultural and residential demands have been accounted for. As with the WRIA curtailment frequencies, we summarized these instances of instream flow deficit as the frequency of occurrence across the 30-year time period.

Double Cropping

Increasing temperatures in the Columbia River Basin are leading to a longer growing season (as measured by frost-free days). Temperatures throughout the growing season are also increasing. These changes may allow producers to practice double cropping in annual crops, growing a second crop in the same field within the same growing season. In the 2016 Forecast, we calculated an initial, coarse estimate of the potential impacts that increasing use of double cropping might have on agricultural water demand. We made some basic assumptions around what crops are most likely to be double cropped, assumed some expectations about the maximum extent producers might double crop, and how much water the second crop is expected to need. However, it became clear that data to validate or modify these assumptions would lead to a better understanding of double-cropping patterns across eastern Washington and the potential impacts of this practice on agricultural water demand. Therefore, in this 2021 Forecast we explored more sophisticated, data-driven approaches.

Satellite-Imagery Based Estimates of Current Double Cropping

We leveraged funding provided by the U.S. Geological Survey (USGS) through the Washington Water Research Center to estimate the acreage currently being double cropped using remotely sensed data (from 2016 to 2018) that tracks changes in the greenness in field crops. The satellite imagery can capture the cyclical nature of greenness, where a single cropping system will show one peak in greenness during a growing season while a double-cropped system will show a peak followed by a harvest event, a second peak, and a final harvest event (Figure 7). Through these approaches and in partnership with the Washington State Department of Agriculture (WSDA), we estimated the amount of double cropping currently occurring in eastern Washington. We then used VIC-CropSyst v3.0 to estimate the water demand of these double-cropped systems, which is expected to be higher than for related single-crop systems. This remote sensing analysis was progressing alongside the integrated modeling of water supply and agricultural water demand across the whole region. Therefore, the additional water demand represented by crops that are currently double-cropped is not included in the historical estimates of agricultural water demand discussed in the *Agricultural Water Demand* sections, but are the focus of the relevant portion of the *Potential Impacts of Double Cropping* section. For further details on this methodology and the datasets used, see the *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast*.

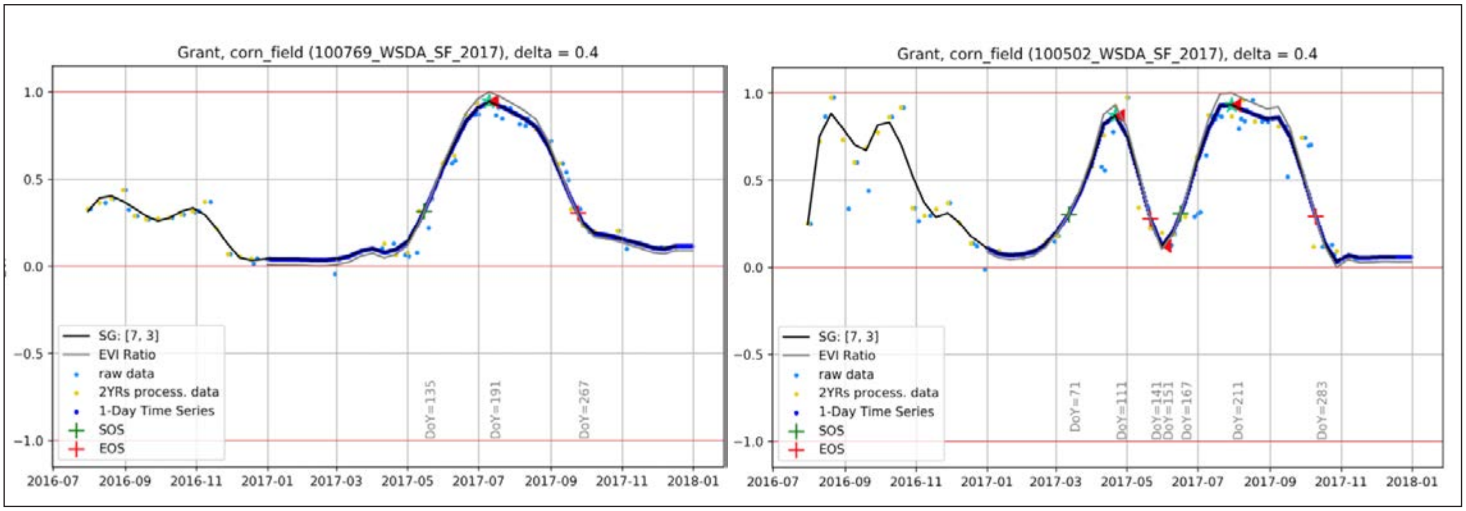

Figure 7. Schematic of greenness cycles for a single-cropping system (left) and for a double-cropped system (right). These curves were obtained from time series of Enhanced Vegetation Index (EVI) obtained from Sentinel-2 optical data.

Estimates of Potential Future Double Cropping

To determine the possible futures of double cropping in Washington State, we analyzed data from highly diverse, surface-water irrigated agricultural systems in Washington, Oregon, Idaho, California and Arizona. We purposefully included areas that are warmer, on average, than Washington is today. We used National Agriculture Statistical Service Census of Agriculture, county-level data from the last four censuses (2002, 2007, 2012, and 2017) to calculate the ratio of irrigated harvested acres to total irrigated cropland area for those counties that have at least 15,000 irrigated cropland acres. This cropping intensity ratio (CI) gives an indirect measure of how many fields in a given area are double cropped. If 10% of acres in a county are double cropped, and all other acres are single cropped, that county will have a CI value of 1.1. We then explored the relationship between climate in those counties, as measured by growing degree days and the length of the growing season, and their cropping intensity. We found that a statistically significant relationship exists between climate and CI. We then used this climate-CI relationship to estimate how much double cropping might occur in Washington under warmer future climate conditions.

Growers' Survey

We surveyed a sample of growers and irrigation districts throughout eastern Washington to confirm instances of double cropping estimated with satellite-based imagery, and to investigate the possible ways respondents expect double cropping and other growing practices might change in response to lengthening growing seasons. The survey included questions related to historical and potential future double cropping and cover cropping, historical crop types and potential future changes in crop types, and whether their ability to double crop is limited by water rights and availability. Survey responses provide helpful context for interpreting the double-cropping projections for eastern Washington counties through 2040.

Planned Water Supply Projects

An important simplification when modeling the agricultural water demand is that the extent of irrigated acres across the region is initially considered fixed. That is, we used the same irrigated extent as input to both the historical and future model runs. This is not a completely realistic assumption. The possibility of increasing the overall irrigated acreage depends mainly on water becoming available to irrigate additional acres. The mission of OCR is to "aggressively pursue development of water supplies" (Box 1). Therefore, we used information on OCR's planned water supply projects to explore the effect that relaxing this constraint could have on agricultural water demand.

Ongoing and planned water supply projects could make as much as 250,000 acre-feet of water available as agricultural irrigation water (the dominant out-of-stream use) by 2040, according to OCR. It is important to note that this amount does not reflect the entirety of all ongoing and planned water supply projects, which also consider water supply needs of instream and other out-of-stream uses, as well as planning horizons that exceed 2040.

Evaluating Trends in Groundwater Levels

There are hydrological interconnections between surface and groundwater, and both sources contribute to fulfilling different water demands. As a necessary step towards incorporating accurate estimates of groundwater supply into the Forecast, which the integrated modeling cannot currently model, we systematically compiled well depth and depth to water data available across eastern Washington. We focused on the spring high water level in each well, and used the resulting dataset to:

- Perform a trend analysis that quantifies declining groundwater, by aquifer layer, based on all wells where a sufficient time series of data exists;
- Perform a vulnerability assessment based on projected trends in depth to water relative to depth at which groundwater is withdrawn (called available saturated thickness); and
- Identify critical data gaps, and use this to target opportunities for initiating or resuming monitoring in existing wells.

The trend analysis and the vulnerability assessment are included in this Legislative Report. The identification of critical data gaps and the resulting effort to fill those gaps are described in the associated *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast*.

We carried out the analysis of trends in groundwater using the following criteria:

- Only wells with at least ten records of spring high water level within the 1975 to 2020 time frame and at least eight records after 2000 were considered to have sufficient data to determine historical trends. We first evaluated the quality of the data, adjusting for airline breaks and other factors noted as abnormalities by the Department of Ecology staff responsible for the monitoring.
- We statistically analyzed trends in spring high water level for each well individually (Figure 8, left panel).
- We estimated trends using both the full 1975-2020 time period, and again using only data collected since 2000. This second approach allowed us to estimate more recent trends and evaluate whether trends are changing.
- We interpolated the trend analysis results from individual wells to estimate the rate of groundwater declines for each aquifer layer across each groundwater subarea. The analyses focused on the four main aquifer layers of the Columbia Plateau Regional Aquifer System (CPRAS, Figure 8, right panel): Overburden, Saddle Mountains Basalt, Wanapum Basalt and Grande Ronde Basalt, as well as locations outside of the CPRAS. We interpolated the trends within 16 subareas: Chelan, Eastern Benton, Extended Toppenish, Kittitas, Klickitat, Northern CPRAS, Odessa, Okanogan, Palouse, Quincy, Red Mountain, Rock Glade, Selah, Spokane, Walla Walla, and Yakima.
- We projected the rates of groundwater decline obtained through the 2000-2020 trend analysis out to 2040 and estimated the number of years to a 25%, 50%, and 75% decline in available saturated thickness. These projections provide an initial evaluation of how vulnerable each groundwater subarea might be to running out of water in this timeframe, should the trends over the last 20 years continue into the future. We converted the projected declines in spring high water level into changes in available saturated thickness. Available saturated thickness is quantified as the height of the water column above the pump intake in the spring prior to turning on pumps at the start of the irrigation season (Figure 8, left panel). We based the conversion to available saturated thickness on average well depths in the corresponding aquifer layer and subarea as well as on assumptions about the height of pump intake placement relative to the reported well bottom (Figure 8, left panel).

The results of this vulnerability assessment can further inform well monitoring plans that seek to address the critical data gaps that we identified (see the *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast*). Ultimately, progress in this area may ensure that sufficient data are available to support full integration of groundwater and surface water modeling in future Forecasts.

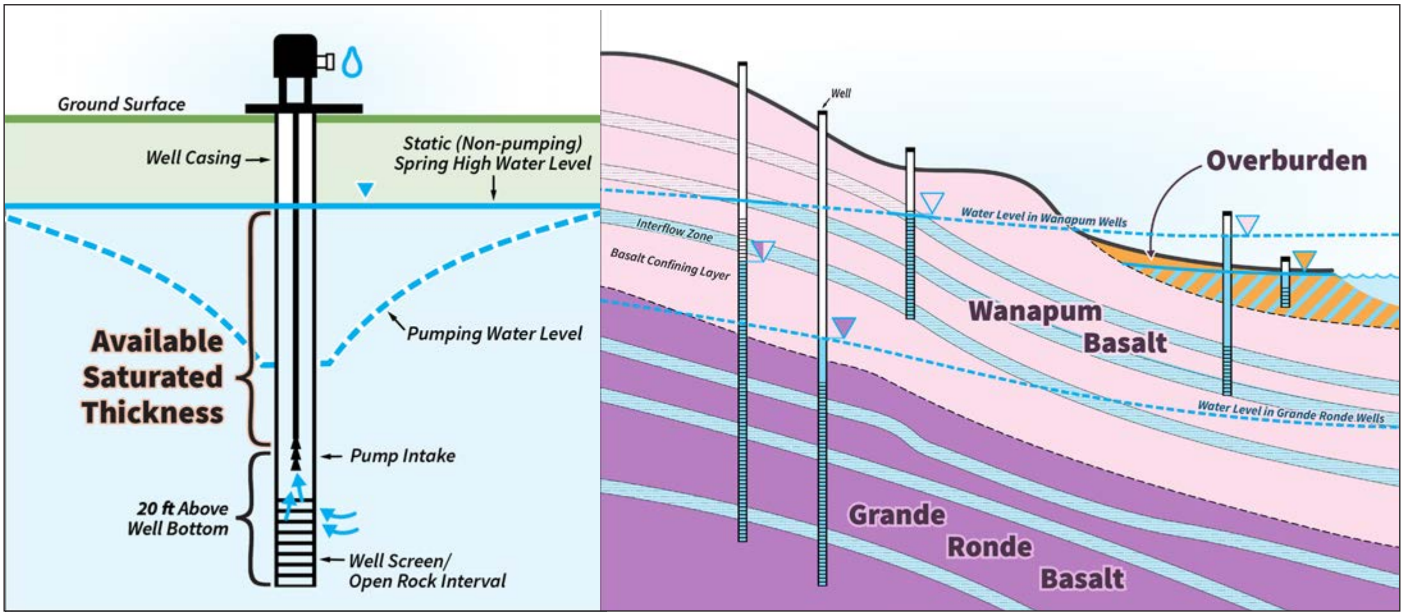

Figure 8. Diagrams representing a well pumping groundwater in eastern Washington (right), and the four main basalt aquifer layers of the Columbia Plateau Regional Aquifer System (CPRAS), with examples of how wells access those aquifer layers (right). The data used in the trend analysis represent the spring high water level, and trends were summarized within each aquifer layer (that is, using wells that access the same aquifer layer, shown by the color of the downturned triangle beside each well). The vulnerability assessment is based on the available saturated thickness.

Forecasting Residential Water Demand

Residential water use refers to water that is used in or around the home, and does not include water used for industrial or commercial purposes. We considered residential water use[10] to include:

- Water from public or private community water providers (excluding any water supplied by these providers for non-residential uses), plus
- Self-supplied domestic water in areas outside municipal boundaries.

This type of water use represents approximately 11% of all water demands in eastern Washington ("public supply" plus "self-supplied domestic," Table 2). Though this is a much smaller portion of water demand than agriculture in the Columbia River Basin, it is important for supporting the continued prosperity of the region. The Washington State Supreme Court's "Hirst decision" in 2016 and subsequent legislation has led to added focus on water availability for residential water users in Washington State, and on the need to more rigorously evaluate these uses and the implications for water management. Providing a more detailed analysis of residential water demands was therefore prioritized above estimating commercial and industrial water use in this Forecast.

We made three main improvements in estimating residential water demand in this 2021 Forecast: we used improved population growth projection data, moved from annual to monthly estimates of municipal and domestic demand, and separately estimated indoor and outdoor consumptive water use. Additional data choices and decisions include:

- Assessing residential demand only within Washington State. Residential demand includes water provided by large municipal water providers (municipal) and self-supplied water (domestic).
- Quantifying or aggregated residential demand at three levels: by municipality, by county, and by WRIA.
- Calculating per capita water use using historical water demand data collected from 45 municipalities and 21 counties in eastern Washington. We aggregated the per capita water-use estimates from the municipal and county

10 The 2016 Forecast provided estimates of municipal water demand, which included U.S. Geological Survey data on "self-supplied" and "public-supplied" sources. This 2021 Forecast uses more detailed data from specific municipal water providers, in addition to the USGS "self-supplied" data which serves as a proxy for estimating all other domestic home water use. We therefore replaced the term "municipal water demand" with "residential water demand," which better reflects the combination of municipal demand plus domestic demand, while allowing us to distinguish these two types.

levels for each WRIA as the area-weighted average. We then calculated current residential water demand at each level by multiplying recent per capita water use by the corresponding population size for that level.

- Municipal data were mostly available at monthly resolution, while county level data were available annually. We converted the annual data to monthly values by using estimates of mean monthly water-use patterns for the appropriate county. This step allowed us to account for seasonal changes in water use.
- Gathering municipal-level data from large, Group A water providers' most recent comprehensive water system plans obtained from the Washington Department of Health. Different plans included data from different time windows, although all were published within the last twenty years (2000 to 2019).
- Using the most recent five-year average values of per capita water use for domestic self-supplied categories reported in the U.S. Geological Survey's (USGS) 2015 Water Use Report[11] to estimate county-level water demand.
- While there are several types of water users covered generally under both municipal and domestic categories (e.g., single family home users, multi-family home users, permit-exempt well users), these specific types were not assessed individually in this Forecast.
- Calculating historical population values using data from a combination of comprehensive water system plans (for municipalities) and from the Washington Office of Financial Management (OFM) Small Area Estimates Program reports (for counties and WRIAs) for 2000 to 2019[12].
- Estimating future water demand as the current per capita demand multiplied by the projected population value. These population projections were based on statistically extending the population growth trends from historical data (2000-2019) through to 2040 (for municipalities) or on population projections provided by the OFM for 2020 to 2040.
- Assuming that domestic consumptive water use was primarily locally derived, self-supplied groundwater. We then calculated this variable by assuming that 10% of indoor water use and 80% of outdoor water use is used consumptively[13], the remainder being non-consumptive use (90% and 20%, respectively).
- Deriving assumptions of municipal consumptive water use from source water withdrawal and wastewater discharge information. This approach uses more recent and reliable wastewater return data, and allowed us to differentiate between rural domestic and municipal water use.
- Growth in rural water demand (self-supplied) will likely be met by groundwater supplies, but wells are expected to be shallow. Depending on the hydraulic connectivity of the location, groundwater use could impact surface water flows.

The analysis detailed above allowed us to provide more realistic estimates of residential water demand, historically and forecast for 2040, and improve our understanding of seasonal patterns of water use in eastern Washington.

Forecasting Hydropower Demand

As in previous Forecasts, our approach to estimating the demand for water needed instream to fulfill the state or region's demand for hydropower was to extensively review existing data and information from the Northwest Power and Conservation Council and other power entities in the Northwest. This helped us to understand the sector's current electricity demands, and their expectations of changes in electricity demands by 2040. These expectations of future demands, and the contribution that hydropower may make to fulfilling those demands, depend on a range of conditions and decisions, both within and outside the control of managers and policy makers. We explicitly explore and discuss some of the major factors expected to have a significant influence on future needs for hydropower. We reviewed existing projections in demand for electricity with a specific focus on Washington State (though in some cases this review extended across the Columbia River Basin) to answer two main questions:

11 The 2015 USGS Water Use Report data were accessed via https://water.usgs.gov/watuse/data/data2015.html (see ScienceBase link under *Data Release*).

12 Washington State Office of Financial Management. Data retrieved from the Small area estimates program: https://ofm.wa.gov/washington-data-research/population-demographics/population-estimates/small-area-estimates-program

13 Culhane, T. and Nazy, D. 2015. Permit-Exempt Domestic Well Use in Washington State. Publication No. 15-11-006. Washington Department of Ecology, Olympia, WA. 33 pp. Available online at: https://apps.ecology.wa.gov/publications/SummaryPages/1511006.html

- Does the electricity production sector expect additional demand for hydropower by 2040?
- How is climate change expected to impact evaporation of water from existing and any potential new reservoirs?

To answer the first question, we explored a series of major factors expected to have a significant influence on future demand for electricity by 2040. These factors formed the basis for four electricity demand scenarios:

- Population increases in the region,
- Large-scale adoption of electric vehicles,
- Expansion of data centers and chip manufacturing facilities, and
- Renewable energy and other relevant laws in place or being considered in Washington State.

Available reports that we 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. We also assessed federal information from the U.S Energy Information Association (EIA) in conjunction with data from the Washington State Department of Commerce (WSDOC) and Washington State Department of Licensing (WSDOL). In addition, we examined state legislation, newspaper articles, and websites 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, we made every effort to include the most recent information.

Forecasting Instream Water Demand for Fish

Our approach to assessing how future changes in water supplies and demands might affect the instream needs of fish was two-fold. For tributaries to the Columbia River, we synthesized results from a relevant, independent study evaluating climate change impacts on low flows in Washington (Mauger et al. 2021[14]). For the Columbia River Mainstem, we used the adopted state and federal instream flows to represent instream water demands to fulfill the needs of fish species, and explored whether historical and future water supplies are sufficient to meet those flow requirements. Additional information related to fish and instream water needs is provided for those WRIAs with adopted instream flow rules (the *Forecast Results for Individual WRIAs* section).

Climate Change Impacts on Low Flows

Changes in surface water supply and demand can help us determine times and locations where fish might be at risk due to low flows. However, they do not directly describe how low flows might change by 2040, and how these changes could impact efforts to ensure sufficient instream flows to meet the needs of fish. An independent modeling study led by the University of Washington's Climate Impacts Group (Mauger et al., 2021) focused on low flows specifically. We synthesized key results from the Mauger led study as a preliminary step towards better understanding expected changes in low flows.

Mauger and colleagues' study focused on water years 1982 to 2011 as the historical time period, and water years 2030 to 2059 as the future time period, which in this case is centered on the year 2045. They used 12 climate scenarios (12 global climate models run under one greenhouse gas emissions scenario, RCP 8.5). These global scenarios were used as inputs to a regional-scale dynamic model that downscales the future climate variables to Washington State in a way that better captures the effect that more local factors have on climatic variables. These dynamically downscaled data were then used to run the VIC hydrologic model[15], and estimate a range of streamflow metrics.

It is important to reinforce that the Mauger led study, though it overlaps with the 2021 Forecast in the use of the VIC model and the climate change scenarios explored, is independent of the Forecast's modeling effort. Mauger and

14 Mauger, G.S., M. Liu, J.C. Adam, J. Won, G. Wilhere, J. Atha, L. Helbrecht, and T. Quinn. 2021. New Culvert Projections for Washington State: Improved Modeling, Probabilistic Projections, and an Updated Web Tool. Report prepared for the Northwest Climate Adaptation Science Center. Climate Impacts Group, University of Washington.

15 The VIC model is the same hydrologic model used as part of WSU's integrated modeling framework to forecast water supplies and agricultural water demands. However, in this independent, low flow study, the VIC model was used as a stand-alone model, not integrated with CropSyst, as is done in the Forecasts.

colleauges' work is substantially different due to the downscaling methods used, the output metrics, and the time windows, so the results are not directly comparable to the 2021 Forecast integrated modeling results. However, since Mauger and colleagues evaluated metrics that more directly relate to the needs of fish (streamflows, as opposed to water supply), their results can complement the 2021 Forecast results, providing insights into where in eastern Washington future changes in low flows may lead to vulnerabilities for fish species due to climatic changes.

Comparing Mainstem Water Supply to Instream Flow Requirements

We first compared Washington State instream flows (WA ISF[16]), and the Federal Columbia River Power System Biological Opinion instream flows (FCRPS BiOp[17]) to modeled historical and forecast surface water supplies (before accounting for out-of-stream water demands) at Priest Rapids, McNary, and Bonneville Dams. We chose these two regulatory schemes 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 water permit (in the case of the FCRPS BiOp). We used the current adopted instream flows both for the historical and forecast periods.

We then used the curtailment model (Figure 4, Panel C) to quantify instream flow deficits after the out-of-stream demands (agricultural and residential) have been accounted for. This comparison resulted in an initial identification of the times of the year when the remaining water supply in the Columbia River Mainstem would be insufficient to fulfill instream flow requirements, and the changes expected in those times by 2040.

Forecast Limitations

Every Forecast has limitations, and this one is no exception. There are a number of key aspects that the team was unable to explore due to limited resources, insufficient data, or the need for scientific tools that are not yet available. Some of these, such as groundwater not being fully integrated with the surface water modeling due to model limitations, or commercial and industrial water use not being quantified due to having to prioritize resources, were discussed in the relevant sections above.

Beyond these topic-specific limitations, there are also broader limitations to the Forecast as a whole. Of particular note are future events which could have significant impacts on water supply and demand in Washington, which were not investigated in this Forecast. Here we highlight two important aspects that were not addressed, identified with input received during the public comment period (see the *Gathering Feedback* section), and provide a few resources that further discuss each issue (Box 3).

The Columbia River Treaty and Columbia River Operations: Any modifications made to the federal Columbia River Treaty between the U.S. and Canada could have wide-reaching impacts on operations of U.S. facilities on the Columbia River, and on water supplies and demands. Negotiations, which were authorized by the U.S. State Department in 2016, have been less active in recent years, although the U.S. and Canadian negotiating teams held 10 rounds of negotiations between 2018 and 2020[18]. Lawmakers from the Pacific Northwest have recently initiated efforts to prioritize these negotiations in the coming years[19]. One area where the Forecast models could shed light is in quantifying how changes in operations of the Treaty dams may impact the frequency and magnitude of interruption of junior irrigation water rights along the Columbia Mainstem. Other important externalities that were not considered include the potential for breaching of the Snake River Dams or changes in response to the Columbia River System Operations Environmental Impact Statement[20]. As discussions and details of proposed changes become clearer, it may be possible to model specific "what if" scenarios reflecting those changes in the 2026 Forecast.

Water Conservation: We did not consider the potential for water conservation by either municipal or agricultural users to alleviate some of the supply and demand vulnerabilities that may be encountered in the future. Conservation has many benefits for municipal water suppliers. It defers costly upgrades in pumps, reservoirs, and pipelines to

16 RCW 173-563 https://apps.leg.wa.gov/wac/default.aspx?cite=173-563

17 FCRPS BiOp https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/federal-columbia-river-power-system-biological-opinion. Additional information on the Federal Columbia River Power System available at https://www.usbr.gov/pn/fcrps/index.html

18 Columbia River Treaty Review. CRS Report R43287, Prepared for Members and Committees of Congress. Congressional Research Service. December 2020. https://crsreports.congress.gov/product/pdf/R/R43287

19 https://defazio.house.gov/sites/defazio.house.gov/files/Col.%20River%20Treaty%20Ltr%20President%20Biden%206.29.21%20FINAL.pdf

20 https://www.nwd.usace.army.mil/CRSO/Final-EIS/

the future, it reduces operation and maintenance costs, and it ensures limited water rights for municipalities are maximized. However, many conservation efforts also lead to increases in overall consumptive use. While some strategies, such as restricting outdoor water use can reduce consumptive use, most municipal conservation efforts (reducing pipe leaks, low flow appurtenance retrofit programs) reduce non-consumptive use, water that currently returns to the streams or aquifers. If these reductions in non-consumptive use allow more houses to be hooked up to municipal systems, the ultimate effect is an increase in consumptive use. The same is true in an agricultural irrigation setting. Research has shown that irrigation efficiency generally results in higher crop yields, but in some cases may reduce water availability to downstream surface water users and instream flows for fish, and reduce groundwater recharge. The extent to which irrigation efficiency increases versus decreases water availability for other users depends on a large number of local characteristics, making modeling of conservation a complex challenge to overcome in future Forecasts. Therefore, quantifying the fate of conserved water before incentivizing conservation is prudent, so a fair weighing of the balanced benefits and consequences can be considered.

BOX 3

Additional Resources

The Columbia River Treaty:

- United States: Information and a means to make inquiries can be found at https://www.state.gov/columbia-river-treaty/. A 2020 review is provided by the Congressional Research Service: https://crsreports.congress.gov/product/pdf/R/R43287

- Canada: Information can be found at https://engage.gov.bc.ca/columbiarivertreaty/. The Government of British Columbia also provides access to their technical studies: https://engage.gov.bc.ca/columbiarivertreaty/review/technical-studies/

Complexity of Irrigation Efficiency:

- AgClimate.net blog article by Keyvan Malek, Civil and Environmental Engineering, Cornell University. November 9, 2018. **Irrigation Efficiency: What Do the Researchers Say?** https://www.agclimate.net/2018/11/09/irrigation-efficiency-what-do-the-researchers-say/

- AgClimate.net blog article by Keyvan Malek, Civil and Environmental Engineering, Cornell University. September 30, 2019. **Are Efficient Irrigation Technologies a Winning Solution in the Yakima River Basin?** https://www.agclimate.net/2019/09/30/are-efficient-irrigation-technologies-a-winning-solution-in-the-yakima-river-basin/

- Ward, F.A. and Pulido-Velazquez, M., 2008. **Water conservation in irrigation can increase water use.** Proceedings of the National Academy of Sciences, 105(47), pp.18215-18220. https://www.pnas.org/content/pnas/105/47/18215.full.pdf (also discusses some residential aspects)

- Grafton, R.Q., Williams, J., Perry, C.J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S.A., Wang, Y., Garrick, D. and Allen, R.G., 2018. **The paradox of irrigation efficiency.** Science, 361(6404), pp.748-750. https://science.sciencemag.org/content/sci/361/6404/748.full.pdf

Municipal Conservation:

- Olmstead, S.M. and Stavins, R.N., 2009. Comparing price and nonprice approaches to urban water conservation. Water Resources Research, 45(4). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2008WR007227

- Qaiser, K., Ahmad, S., Johnson, W. and Batista, J., 2011. Evaluating the impact of water conservation on fate of outdoor water use: a study in an arid region. Journal of Environmental Management, 92(8), pp.2061-2068. https://www.sciencedirect.com/science/article/pii/S0301479711000971 (subscription required)

Gathering Feedback

Feedback received during the 2016 Forecast process, including the recommendations captured in the *Next Steps – Building Towards the 2021 Forecast* section, was essential for planning for this 2021 Forecast. So too were responses to the many presentations that research team members and OCR staff have given on the Columbia River Long-Term Supply and Demand Forecast to diverse groups in the intervening years. OCR's Columbia River Policy Advisory Group (PAG), which represents a range of stakeholder interests, continued to provide input to OCR on the approach, priorities, and relevant policy issues. The PAG helps OCR identify and evaluate water resources and water supply policy issues.

In the intervening years, OCR, WSU and its partners have also convened and met regularly with a State Caucus, comprised of sister state agencies in Washington with interests relating to water and water resource management, including the Washington State Departments of Agriculture, Commerce, Health, Fish and Wildlife, Natural Resources, and the Washington Conservation Commission, as well as representatives from other programs within the State Department of Ecology (water resources and environmental assessment programs).

Access to relevant datasets has also been critical to the ongoing development and evaluation of the Forecast, particularly supporting more detailed groundwater supply and residential water demand estimates. These connections have been facilitated by the State Caucus, and by targeted outreach to agricultural, municipal, tribal, and federal entities.

In the development of the 2021 Forecast, input from stakeholders was received through two public workshops held virtually in June 2021. During these meetings the team presented and discussed draft results, and requested actionable feedback from participants. The draft Legislative Report was also available online from June 2 to July 2, 2021, and comments were accepted during that month-long open public comment period. A number of comments suggested that further clarity was needed on certain aspects related to the scope, scale and principles that guided this 2021 Forecast, or pointed to errors made during the compilation of the Legislative Report. We have sought to provide that clarity and correct those mistakes in this report. Other comments reflected people's perspective on this body of work, and on what they would like to see included in the Forecast, which provide valuable input to OCR and the research team as recommendations come forward and future plans are made for the 2026 Forecast. Many of these comments have informed the *Next Steps—Building Towards the 2026 Forecast* section. Finally, all comments received during the public workshops and during the open comment period were compiled, and a detailed response to each comment is included in the *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast* (anticipated publication date: January 2022).

Columbia River and view of East Wenatchee

FUTURE VULNERABILITIES ASSOCIATED WITH CHANGES IN WATER SUPPLIES AND DEMANDS

This 2021 Forecast is focused on identifying the vulnerabilities that the Columbia River Basin may face as the climate changes, as the population in the Pacific Northwest grows, and as agriculture, hydropower, and other demands for water change. By quantifying key metrics pertaining to water supplies and demands under alternative futures or scenarios, we help identify opportunities that may exist to prepare for the impacts of future changes. We analyzed those changes in our water supplies and demands that are likely to be most impactful by 2040. In some cases, looking further ahead to the outlook by 2070 helped highlight the longer-term changes driven by changing climatic factors.

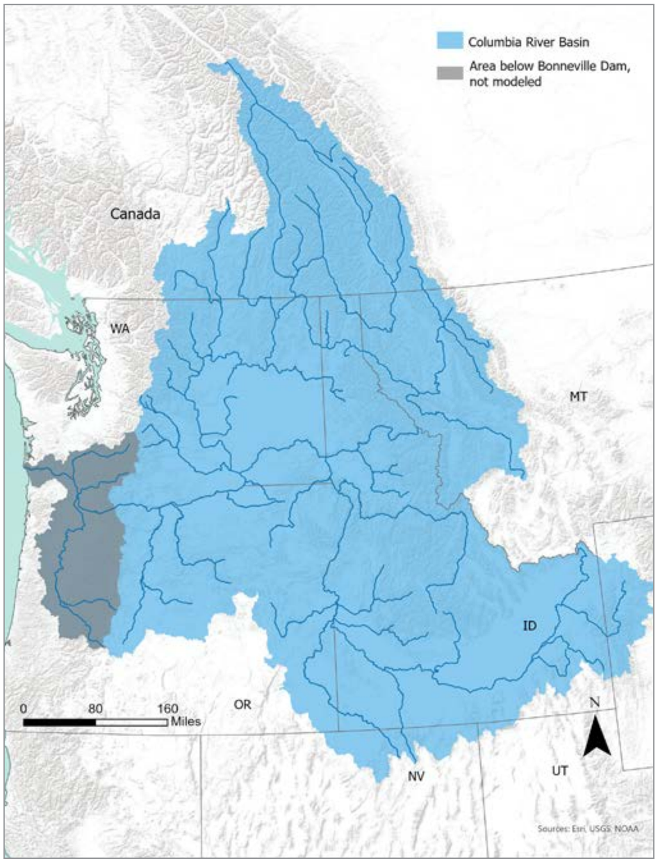

Figure 9. *The Columbia River Basin geographic scope.*

Here we take an in-depth view at the results. First, we discuss future changes in water supply and demand expected by 2040 across the whole Columbia River Basin upstream of Bonneville Dam (Columbia River flows below Bonneville Dam were not modeled as part of the 2021 Forecast). Where appropriate, we focus on the Washington portion of the Basin (see the *Water Supply and Demand Forecast for the Columbia River Basin* section). Second, we explore in more detail the patterns of change across different watersheds and aquifers in eastern Washington, highlighting places across the state where changes are expected to be more acute or may be related to particular conditions (see the *Water Supply and Demand Forecast for Washington's Watersheds* and the *Water Supply Forecast for Washington's Aquifers* sections). Third, we explore key aspects of water supply and demand for the Columbia River Mainstem in Washington, given the importance of the Columbia River itself in water use and water management in Washington State (see the *Water Supply and Demand Forecast for Washington's Columbia River Mainstem* section). Not all types of water supplies and demands are equally explored for all geographic scopes (for example, we explore instream water demand for fish only in the *Water Supply and Demand Forecast for Washington's Watersheds* and the *Water Supply and Demand Forecast for Washington's Columbia River Mainstem* sections). However, each scope targets specific types of changes in water availability, and identifies particular vulnerabilities that arise from future changes. Therefore, we complete each of these four sections of results by highlighting the vulnerabilities our region faces due to changes wrought by climate change and population growth, with the intent of informing discussions around how our agricultural production, water management and other systems could adapt.

Water Supply and Demand Forecast for the Columbia River Basin

The Columbia River Basin extends across seven states and one province, with British Columbia, Idaho, Montana, Washington and Oregon being the major water contributors to Columbia River flows (Figure 9). Projected changes in climate are expected to lead to notable changes in the timing of water supplies across the Columbia River Basin. The alternative scenarios we assessed can help inform what changes we can expect by quantifying the effects of those scenarios on water supplies and demands.

Surface Water Supply

The comparison between estimated future surface water supply (2040) and the historical supply (1986-2015) for the Columbia River Basin (see Box 4 for a description of how the model results were synthesized to allow for these comparisons) highlighted that, in general, annual supplies are, at most, forecast to increase slightly. However, **forecast changes to timing of seasonal supply may have important implications for meeting demands**. Specifically, we found that:

- Annual supply across the Columbia River Basin is expected to increase slightly through 2040, from around 129 million ac-ft per year to 133 million ac-ft per year (Table 4). This slight increase in supply (3.3% ± 1.8%) is statistically different from the historical value, given the variation in results across climate change scenarios.
- In high supply years, when those managing dams and other infrastructure may face challenges due to high water amounts, annual supply across the Basin is also expected to increase slightly (4.0% ± 1.5% by 2040; Table 4). However, this trend weakens somewhat by 2070 (3.8% ± 1.8% by 2070; Table 4).
- In low supply years, when meeting the multiple demands for water in the region is more challenging, annual supply across the Basin is expected to remain fairly stable, at around 104 million ac-ft per year (Table 4).
- The timing of supply will shift, with the overall timing of annual supplies shifting on average 22 (±2) days earlier by 2040, and likely increasing the possibility for water supplies and demands to be out of sync (Figure 10).
- The relatively small changes expected in annual supplies mask an average increase in unregulated surface water supply of 18.9% (±2.9%) between November and May, and a-16.0% (±2.0%) decrease, on average, between June and October (Table 5).
- The decrease during the drier months is even more marked in the Washington portion of the Columbia River Basin, where water supply from June through October is expected to decrease-28.5% (± 2.6%) by 2040, and as much as-41.1% (± 2.8%) by 2070 (Table 5).
- While somewhat less extreme, the increase during the wetter months of the year in the Washington portion of the Basin is also noteworthy, and will likely pose management challenges. This increase is expected to reach 14.9% (±2.5%) by 2040, and 21.8% (±2.8%) by 2070 (Table 5).

SUPPLY - Entire Columbia River Basin					
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040	2070 Forecast (million ac-ft)	% change by 2070
Low supply year (20th percentile)	104	104.5 (± 1.70)	0.5% (± 1.6%)	104.4 (± 2.14)	0.4% (± 2.1%)
Median year (50th percentile)	128.5	**132.7 (± 2.26)**	**3.3% (± 1.8%)**	**134.0 (± 1.82)**	**4.3% (± 1.4%)**
High supply year (80th percentile)	162.7	**169.2 (± 2.47)**	**4.0% (± 1.5%)**	**168.9 (± 2.87)**	**3.8% (± 1.8%)**
SUPPLY - Washington Portion of the Columbia River Basin					
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040	2070 Forecast (million ac-ft)	% change by 2070
Low supply year (20th percentile)	11.6	11.8 (± 0.26)	1.4% (± 2.2%)	11.6 (± 0.33)	0.4% (± 2.9%)
Median year (50th percentile)	16.3	16.7 (± 0.32)	2.0% (± 2.0%)	**16.8 (± 0.36)**	**3.1% (± 2.2%)**
High supply year (80th percentile)	23.8	**24.8 (± 0.48)**	**4.2% (± 2.0%)**	**25.1 (± 0.53)**	**5.6% (± 2.2%)**

***Table 4.** Modeled annual water supply in the historical (1986-2015) and forecast (2040 and 2070) periods for the entire Columbia River Basin (top rows) and for the Washington portion of the Columbia River Basin (bottom rows). Estimates are presented for low (20th percentile), median (50th percentile), and high (80th percentile) supply years. Values between parentheses represent confidence intervals around the average of future values, obtained under different climate scenarios (for details see Box 4). The percent change reflects the difference from the historical to the forecast (2040 or 2070, respectively) values, and is also accompanied by confidence intervals associated with climate uncertainty. Changes highlighted in blue are increases in supply (expected to be associated with increasing water availability) that are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future.*

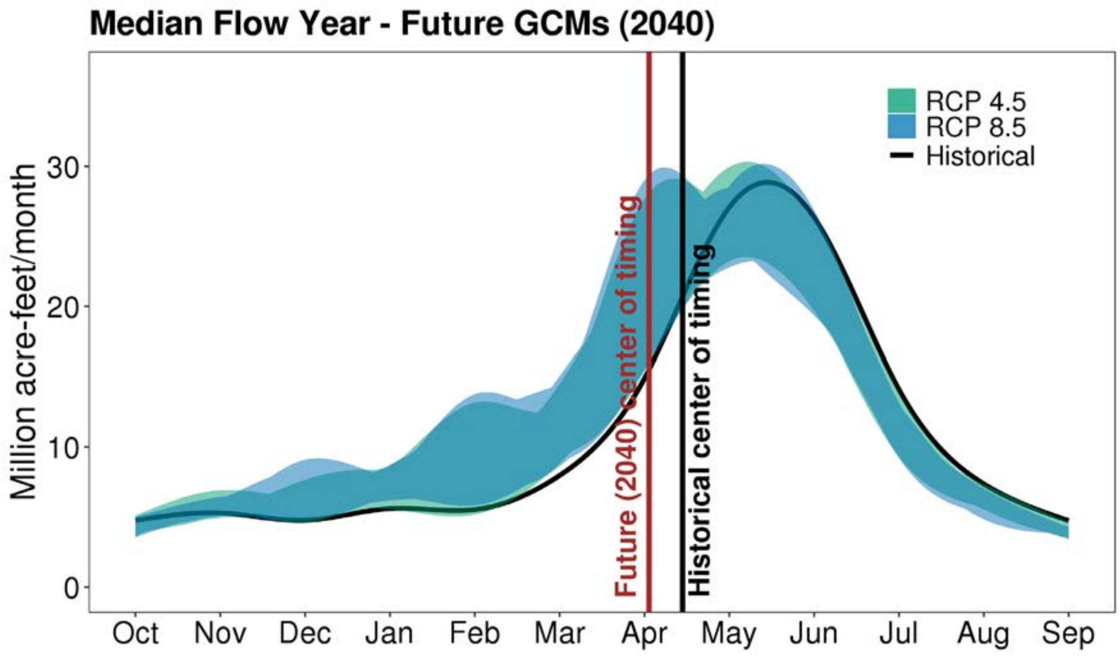

Figure 10. *Expected change by 2040 in timing of water supply in the Columbia River Basin. The water supply timing in the historical (1986-2015) and forecast (2040) time periods was calculated using a center of timing approach, and was quantified at Bonneville Dam. Historical supply for a median (50th percentile) supply year is shown in the black line, and the range of possible future (2040) supplies under different greenhouse gas emissions scenarios are shown in the blue and green shading (for further details see caption in Figure 12). Historical and future center of timing dates are shown in the black and crimson lines, respectively. Future center of timing date is the median value of all 34 climate change scenarios.*

SUPPLY - Entire Columbia River Basin					
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040	2070 Forecast (million ac-ft)	% change by 2070
Median year (50th percentile)	128.5	**132.7 (± 2.26)**	**3.3% (± 1.8%)**	**134.0 (± 1.82)**	**4.3% (± 1.4%)**
Wet Season (November - May)	71.2	**84.6 (± 2.05)**	**18.9% (± 2.9%)**	**92.5 (± 1.69)**	**30.0% (± 2.4%)**
Dry Season (June - October)	57.3	**48.1 (± 1.15)**	**-16.0% (± 2.0%)**	**41.4 (± 1.36)**	**-27.7% (± 2.4%)**
SUPPLY - Washington Portion of the Columbia River Basin					
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040	2070 Forecast (million ac-ft)	% change by 2070
Median year (50th percentile)	16.3	16.7 (± 0.32)	2.0% (± 2.0%)	**16.8 (± 0.36)**	**3.1% (± 2.2%)**
Wet Season (November - May)	11.5	**13.2 (± 0.29)**	**14.9% (± 2.5%)**	**14.0 (± 0.32)**	**21.8% (± 2.8%)**
Dry Season (June - October)	4.8	**3.5 (± 0.13)**	**-28.5% (± 2.6%)**	**2.9 (± 0.13)**	**-41.1% (± 2.8%)**

Table 5. *Modeled water supply in the historical (1986-2015) and forecast (2040 and 2070) periods for the entire Columbia River Basin (top rows) and for the Washington portion of the Columbia River Basin (bottom rows), distinguishing between the dry and wet season. The median (50th percentile) supply estimates (from Table 4) are included as reference. Values between parentheses represent confidence intervals around the average of future values, obtained under different climate scenarios (for details see Box 4). The percent change reflects the difference from the historical to the forecast (2040 or 2070, respectively) values, and is also accompanied by confidence intervals associated with climate uncertainty. Changes highlighted in orange and blue are decreases and increases in supply (expected to be associated with decreasing and increasing water availability), respectively, that are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future.*

As was already discussed in the 2016 Forecast, the shift in the timing of water supply occurs in response to warming temperatures that result in a smaller snowpack (as less precipitation falls as snow and more as rain) and an earlier snowmelt. This shift towards greater supply earlier in the year becomes even clearer as supplies are forecast further into the future (2070 in Figure 11). In addition, the improved data and methods used in this 2021 Forecast allowed the models to better capture how the year-to-year variability in water supply is expected to change: the expected changes in water supplies during high and low supply years more clearly reflect our current understanding of this increasing variability between years. The use of a greater range of future climate projections (34 versus the 10 used in 2016) also better capture the expectations of future supply than in the 2016 Forecast. In the future, we should expect increasing variations within a year, with wetter wet seasons and drier dry seasons. We should also expect more frequent extremes, both in terms of highs and lows, each having their associated management challenges. However, these patterns also pose opportunities for addressing future impacts, given that the overall supply will likely remain stable.

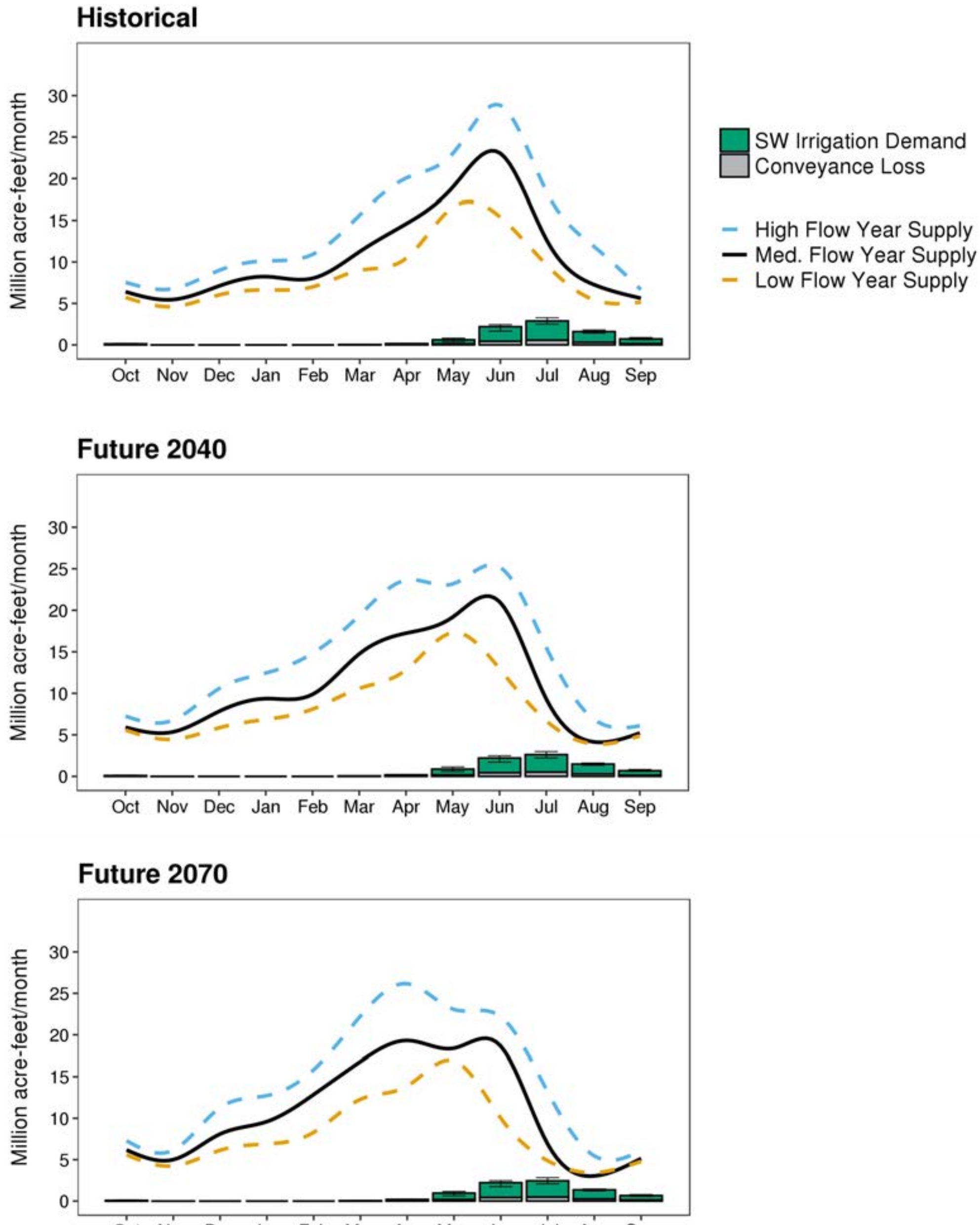

Figure 11. Comparison of regulated surface water supply and agricultural water demands for the historical (1986-2015; top panel) and forecast (two future time periods: 2040 in the middle panel; 2070 in the bottom panel) periods across the entire Columbia River Basin, including portions of the basin outside 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 2040 and 2070 forecast panels, all values represent the median of 34 different climate scenarios (see Box 4 for details).

BOX 4

How Model Projections of Supply and Agricultural Water Demand are Synthesized in the 2021 Forecast

To compare surface water supply in 2040 to historical water supply it is useful to have one number of acre-feet representing "historical", and one number for 2040. However, it is important to remember that the single value varies from year to year (called interannual variability). Similarly, it is important to understand how much uncertainty there is related to the 2040 number, as models cannot make 100% accurate predictions of supply 20 years into the future (called climate uncertainty). We estimated climate uncertainty by using 17 climate models and two greenhouse gas emissions scenarios, which provide a range of 34 values for 2040.

The 2021 Forecast results we provide are:

1. A single number for historical values,
2. A single number for future values, and
3. A confidence interval accompanying each future value, to quantify the climate uncertainty.

Since each time period (historical and future) is calculated based on a 30-year window (1986-2015 and 2026-2055, respectively), we also provide information on interannual variability. Alternative values (both for historical and future conditions) for low, median and high supply years capture this interannual variability.

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

Historical supply = 128.5 million ac-ft. This is the median value of supply for the period 1986-2015. The integrated model takes weather information and simulates monthly supply over that 30-year period. For each month, the 30 flow values are ordered from smallest to largest, and the values in the 15th and 16th position are averaged to provide the median value. The 12 median values from each month are then added to get the median value of supply for the 30-year period. Finally, these 34 supply values are averaged to get future flow during a median supply year.

Interannual variability in historical supply = from 104 million ac-ft (20th percentile) to 162.7 million ac-ft (80th percentile). Once the supply values for each month across the 30 years are ranked, the value in the 6th position (driest 20% of years) and the value in the 24th position (wettest 20% of years, or "driest" 80%) are selected. The 20th and 80th percentile flows for each of the 12 months are then added to get the 20th and 80th percentile annual flows, respectively. These values provide a range in interannual variability.

Future supply = 132.7 million ac-ft. This is the average of the 34 median values of supply (from each of the 34 climate scenarios) for the period 2026 to 2055. As with historical supply, weather data from a climate scenario goes into the integrated model, and the monthly supply over the forecast period (2026-2055) is calculated. For each of the 12 months in a year, the 30 flow values are ordered from smallest to largest and the values in the 15th and 16thposition are averaged to get the median value. This process is repeated for all 34 climate scenarios. Finally, the 34 median values are averaged to get future flow during a median supply year.

Interannual variability in future supply = from 104.5 million ac-ft (20th percentile) to 169.2 million ac-ft (80th percentile). These are calculated in the same way as for historical supply: once the supply values for each month across the 30 years from one climate scenario are ranked, the 6th (20th percentile) and the 24th (80th percentile) values are selected. The 20th and 80th percentile flows for each of the 12 months are added to get the 20th and 80th percentile annual flows for each of the 34 climate scenarios. Finally, the 34 20th percentile flows and the 34 80th percentile flows are averaged to get the range in interannual variability.

Climate uncertainty = from 130.4 to 135.0 million ac-ft. There are 34 climate scenarios, and therefore 34 median values of annual supply. To obtain the single future supply value to compare to the historical supply value, those 34 median values are averaged, as described above. In addition, a confidence interval that represent the climate uncertainty is calculated based on how different those 34 median values are. In this case, the confidence interval is ±2.3 million ac-ft, suggesting that we can be 90% certain that the average future flow during a median supply year is between 130.4 and 135.0 million ac-ft.

Surface Water Supplies Entering Washington

The forecast changes in surface water supply entering Washington are similar to those estimated for the entire Columbia River Basin: annual water supply entering Washington is generally expected to experience slight increases through 2040. These increases are generally consistent across years for the Similkameen, Columbia, Spokane and Snake Rivers (Figure 12). Supplies entering Washington through the Kettle, Pend Oreille, Clearwater, John Day and Deschutes Rivers, on the other hand, are expected to remain stable in the future (Figure 12).

As was discussed above, **noteworthy changes arose when we explored shifts in the seasonality of supplies, which are expected to generally occur earlier in the year** (Figure 12, insets). The general slight increases in annual supply is likely the net effect of expected increases in supply during the wetter portions of the year, and expected decreases in supply during the drier portions of the year, as can be seen in a river's seasonal supply graph (inset panels, Figure 12). During November through May, the range of expected supply values under future climate change scenarios in 2040 are above the historical supply values for the Columbia River (top inset, Figure 12). On the other hand, from June through September, expected future supplies are below the historical values, with the exception of high supply years (top inset, Figure 12).

Agricultural Water Demand

Agricultural demand is the largest out-of-stream water demand in the Columbia River Basin. We estimated "top of crop" agricultural water demand, which represents the amount of water that is applied to a crop to meet its water needs. We also estimated conveyance losses, using certain assumptions around losses during delivery, which vary across different watersheds.

Our results suggest that across the whole Basin annual agricultural demand will remain fairly stable in the future, though declining slightly. However, **agricultural water demand is likely to increase early in the season and decrease later in the season, and show larger extremes, both highs and lows, among years**. These changes in agricultural water demand, as well as changes in these results for different locations in eastern Washington (see the *Water Supply and Demand Forecast for Washington's Watersheds* section) highlight times and places where these changes could exacerbate challenges in meeting these water demands.

The agricultural water demand results across the entire Columbia River Basin highlight the following:

- Demand for agricultural irrigation water across the entire Columbia River Basin is expected to decline slightly, on average, by 2040 (-1.2% ± 0.6%) and continue declining through 2070 (-4.1% ± 0.9%; Table 6). This slight decline is consistent for low, median and high demand years (Table 6), and is driven by changes in climate (these estimates are based on historical planting dates and historical crop mix).
- When the focus narrows to the Washington portion of the Basin, results suggest the decrease in agricultural water demand driven by climate change is somewhat larger. These declines are more noticeable in high demand years (-2.6% ± 0.6% and-6.2% ± 0.9% for 2040 and 2070, respectively; Table 6).
- The two future changes in agricultural production that we explored—earlier planting date and changes in crop mix— have counteracting effects on these climate-change driven baseline projections. When planting date is modeled as occurring one week earlier, the expected decrease in agricultural water demand in eastern Washington is slightly larger (-2.0% ± 0.7%, as opposed to-1.7% ± 0.7%; Table 7). And when projections of changes in crop mix are included in the simulations as well, the decrease from historical demand is actually smaller than what would be expected with climate change effects only (-1.1% ± 0.7%, as opposed to-1.7% ± 0.7%; Table 7).
- Changes in the seasonality of agricultural water demand are much more significant. The demand during the first half of the irrigation season (March-June) is expected to increase by 9% to 13% by 2040, depending on the agricultural production scenarios considered. The demand during the second half of the season is expected to decrease by a similar amount (10% to 12%) by 2040 (Table 7).
- The expected changes in magnitude of agricultural water demand early and late in the season appear to be more significant than the overall shift in timing. The center of timing of agricultural water demand across the Columbia River Basin is expected to shift 3 (±0.5) days earlier as the climate changes (Figure 13). This is a much more modest shift in timing than the expected shift in water supply's timing (Figure 10), highlighting the risk that supplies and demands will be further out of sync in the future.

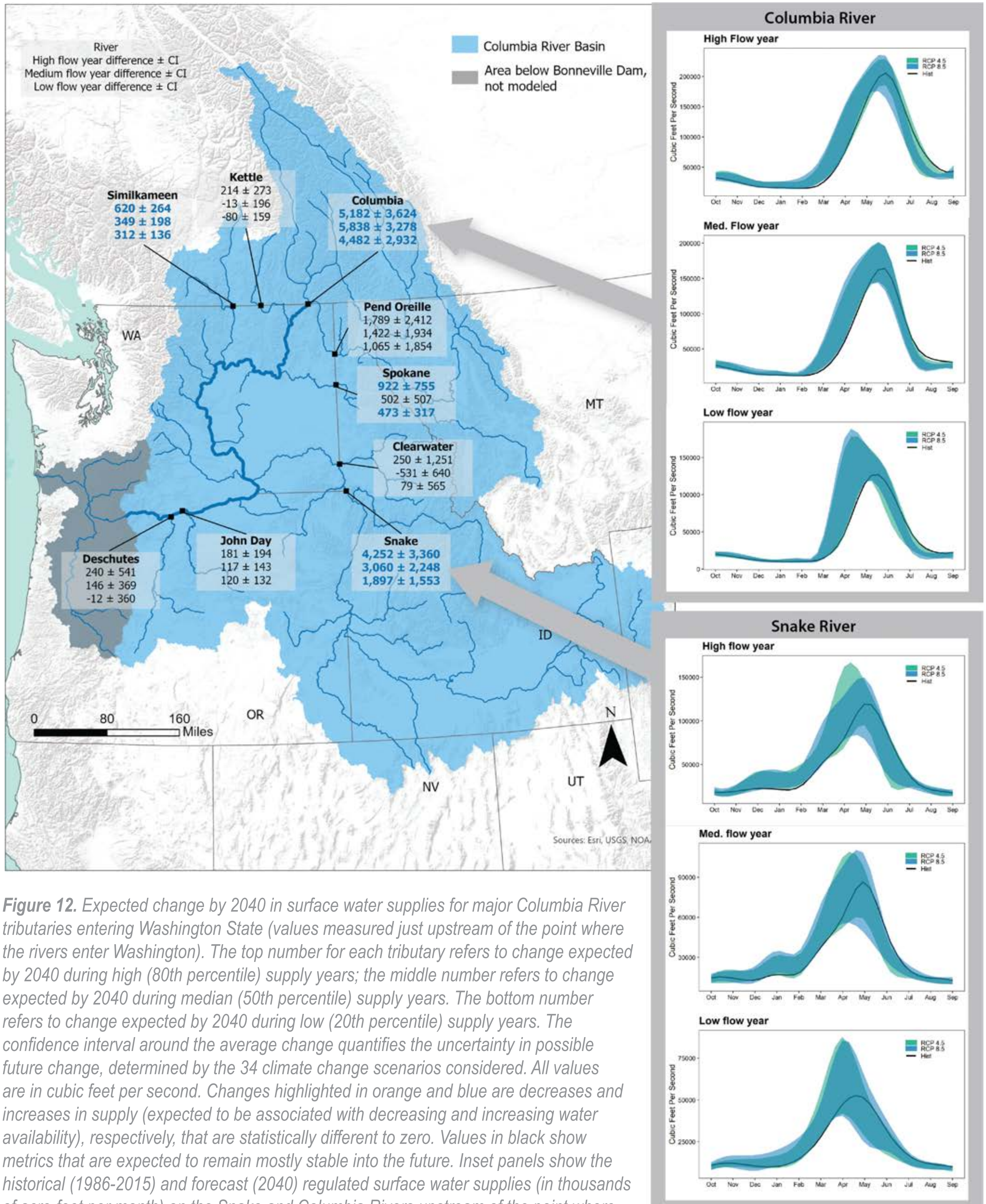

__Figure 12.__ Expected change by 2040 in surface water supplies for major Columbia River tributaries entering Washington State (values measured just upstream of the point where the rivers enter Washington). The top number for each tributary refers to change expected by 2040 during high (80th percentile) supply years; the middle number refers to change expected by 2040 during median (50th percentile) supply years. The bottom number refers to change expected by 2040 during low (20th percentile) supply years. The confidence interval around the average change quantifies the uncertainty in possible future change, determined by the 34 climate change scenarios considered. All values are in cubic feet per second. Changes highlighted in orange and blue are decreases and increases in supply (expected to be associated with decreasing and increasing water availability), respectively, that are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future. Inset panels show the historical (1986-2015) and forecast (2040) regulated surface water supplies (in thousands of acre-feet per month) on the Snake and Columbia Rivers upstream of the point where they enter Washington State for low (20th percentile; bottom graph in each inset panel), median (50th percentile; middle graph in each inset panel), and high (80th percentile; top graph in each inset panel) supply years. The spread of forecast (2040) supply is due to the range of climate change scenarios considered.

AGRICULTURAL DEMAND - Entire Columbia River Basin					
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040	2070 Forecast (million ac-ft)	% change by 2070
Low demand year (20th percentile)	8.16	8.02 (± 0.095)	-1.8% (± 1.2%)	7.88 (± 0.091)	-3.5% (± 1.1%)
Median demand year (50th percentile)	9.45	9.34 (± 0.060)	-1.2% (± 0.6%)	9.06 (± 0.081)	-4.1% (± 0.9%)
High demand year (80th percentile)	10.64	10.45 (± 0.067)	-1.8% (± 0.6%)	10.19 (± 0.094)	-4.3% (± 0.9%)
AGRICULTURAL DEMAND - Washington Portion of the Columbia River Basin					
	Historical (million ac-ft)	2040 Forecast (million ac-ft)	% change by 2040	2070 Forecast (million ac-ft)	% change by 2070
Low demand year (20th percentile)	2.62	2.58 (± 0.024)	-1.7% (± 0.9%)	2.51 (± 0.033)	-4.4% (± 1.3%)
Median demand year (50th percentile)	3.01	2.96 (± 0.021)	-1.7% (± 0.7%)	2.86 ± 0.029)	-5.1% (± 1.0%)
High demand year (80th percentile)	3.43	3.34 (± 0.021)	-2.6% (± 0.6%)	3.21 (± 0.030)	-6.2% (± 0.9%)

Table 6. *Modeled agricultural water demand excluding conveyance losses (known as "top of crop"), in the historical (1986-2015) and forecast (2040 and 2070) periods, for the entire Columbia River Basin. The extent of agricultural acreage was kept constant in all cases, as was the planting date and the crop mix. 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, due to the range of demand values obtained under difference climate scenarios (for details see Box 4). The percent change reflects the difference from the historical to the forecast (2040 or 2070, respectively) values, and is also accompanied by confidence intervals associated with climate uncertainty. Changes highlighted in blue are decreases in demand (expected to be associated with increasing water availability) that are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future.*

AGRICULTURAL DEMAND - Washington Portion of the Columbia River Basin							
	Historical (million ac-ft)	Future (2040) Climate, Historical Planting Date, Historical Crop Mix		Future (2040) Climate, Future Planting Date, Historical Crop Mix		Future (2040) Climate, Future Planting Date, Future Crop Mix	
Median year (50th percentile)	3.01	2.96 (± 0.021)	-1.7% (± 0.7%)	2.95 (± 0.021)	-2.0% (± 0.7%)	2.98 (± 0.021)	-1.1% (± 0.7%)
Early Season (March -- June)	1.26	1.38 (± 0.024)	9.4% (± 1.9%)	1.41 (± 0.024)	12.2% (± 1.9%)	1.42 (± 0.024)	13.0% (± 1.9%)
Late Season (July -- October)	1.75	1.58 (± 0.022)	-9.8% (± 1.2%)	1.54 (± 0.020)	-12.2% (± 1.2%)	1.56 (± 0.021)	-11.1% (± 1.2%)

Table 7. *Modeled agricultural water demand excluding conveyance losses (known as "top of crop"), in the historical (1986-2015) and forecast (2040) periods, for the Washington portion of the Columbia River Basin, distinguishing between early and late in the irrigation season. Three alternative futures were explored: (a) only including future climate change projections, (b) also including a shift to earlier planting dates (by one week) as temperatures warm and growing seasons lengthen, and (c) adding projected changes in crop mix. The extent of agricultural acreage was kept constant in all cases. The median (50th percentile) demand estimates (from Table 6) are included as reference. Values in parentheses represent confidence intervals around the average of future values, obtained under different climate scenarios (for details see Box 4). The percent change reflects the difference from the historical to the forecast values, and is also accompanied by confidence intervals associated with climate uncertainty. Changes highlighted in orange and blue are increases and decreases in demand (expected to be associated with increasing water availability), respectively, that are statistically different to zero. Values in black show metrics that are expected to remain mostly stable into the future.*

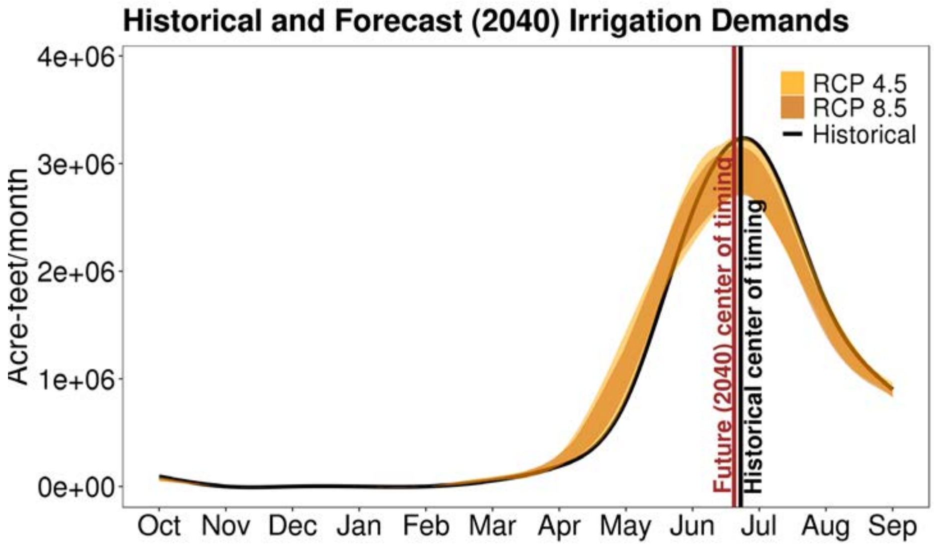

Figure 13. *Expected change by 2040 in timing of agricultural water demand in the Columbia River Basin. The timing of water demand in the historical (1986-2015) and forecast (2040) time periods was calculated using a center of timing approach, and was quantified at Bonneville Dam. Historical agricultural water demand for a median (50th percentile) demand year is shown in the black line, and the range of possible future (2040) demands under different greenhouse gas emissions scenarios (using historical planting dates and historical crop mix) are shown in the two tones of orange shading. Historical and future center of timing dates are shown in the black and crimson lines, respectively. Future center of timing date is the median value of all 34 climate change scenarios.*

The slight decline expected in agricultural water demand across the region is consistent with past Forecast results, though the size of the decrease is smaller than the 2016 estimate. This difference may reflect the improvements in the data and models we used in this 2021 Forecast, which better captured the dynamics on the ground. As discussed above for the annual supply results, though, a key point is that these regional annual demand values are the net effect of increases in demand early in the season, and decreases later in the season. The early-season increases are due to the accelerated growth and development of crops, driven by warmer temperatures in the future. However, this effect is compensated by late-season decreases in demand, as many crops complete their cycles or are harvested earlier (reducing their irrigation demand), and because most crops are expected to use water more efficiently under increased carbon dioxide concentrations.

Over the long term, producers will make changes in their agricultural production systems. A combination of two such possible changes, earlier planting dates and changes in crop mix, appear to counteract each other, maintaining the overall small decline in agricultural water demand.by 2040. Though crop mix will likely continue to be dominated by grain crops and hay, increasing acreage will likely be dedicated to fruit and vegetable crops. Overall, these changes are likely to lead to a less water-efficient mix of crops, explaining the effect of crop mix changes on agricultural water demand.

It is worth highlighting that there are other factors that could lead to future agricultural water demand that is greater than we estimated. We assumed a constant irrigated acreage in the region. However, if additional water supply development is allocated to support an increase in the land base for irrigated agriculture, future agricultural water demand would be greater than estimated here (see the *Potential Impacts of Planned Water Supply Projects* section). These estimates also do not include possible increases in agricultural water demand due to double cropping, though estimates of these practices in Washington suggest approximately 6% of total irrigated acres in Washington State are double cropped (see the *Potential Impacts of Double-Cropping* section). We also assumed no changes in irrigation efficiency or other water conservation measures, whose effect on demand over large areas is more complex than would at first appear (see *Forecast Limitations* section). Finally, it is important to note that **this overall decline in agricultural water demand for the entire Columbia River Basin masks significant variations across the region**. We explored these patterns in eastern Washington, and found that decreases in agricultural water demand in some of Washington's watersheds, mainly in central and south central Washington, were compensated by increases in other watersheds, mainly in eastern Cascades WRIAs (see the *Water Supply and Demand Forecast for Washington's Watersheds* section).

Potential Impacts of Double Cropping

During the production of the 2016 Forecast, interest and concern were voiced about the potential impact of an increase in double cropping in eastern Washington on agricultural water demand. Double cropping was seen as a possible response to increased growing season lengths as the climate warms. In this 2021 Forecast, we explored this question in depth, looking to better understand and quantify how much double cropping is occurring currently, and what are reasonable expectations of how double-cropped acres might change by 2040. We found that:

- **Current double cropping acreage could add over 238,000 ac-ft to the historical agricultural water demand values.**
- **Future changes in double cropping are likely to be negligible, and therefore would have little additional impacts on future agricultural water demand.**

Satellite-Imagery Based Estimates of Current Double Cropping: The analysis of Sentinel 2 satellite imagery from 2016 to 2018 resulted in a current double cropping estimate of 120,976 acres, or 6% of total irrigated acres in eastern Washington State. These acreages translate to a cropping intensity of 1.06. More than half of the double-cropped extent was identified in Grant and Franklin Counties (accounting for over 30% and 20% of irrigated acres, respectively). We used VIC-CropSyst v3.0 to model water demand for common double crop types (for example, green peas/sweet corn, or winter wheat/buckwheat). Our estimates suggest that the annual water demand for an acre of land that is double cropped is 44% greater than the demand if that same acre has a single crop. Applying these water demand estimates to the acres that are currently double cropped suggests that our historical water demand values underestimate demand by 238,660 ac-ft per year.

The cropping intensity values across eastern Washington are higher than those calculated from the Census of Agriculture data (see details below). Our satellite-imagery based estimates include cover crops in the double-cropped acres, while the census data do not include cover crops. Cover crops can have a satellite imagery signature that is similar to that of other types of double cropped fields. Given that cover cropping is also associated with additional water use, it is appropriate to consider potential increases in cover cropping extent in the future alongside increases in harvested crops.

Understanding Patterns in Warmer Areas to Inform Future Double Cropping Estimates: The analysis of double cropping for irrigated crops in western states (Arizona, California, Idaho, Oregon and Washington) using county-level data from the Census of Agriculture to estimate cropping intensity—the ratio of total harvested irrigated acres to irrigated extent—showed that two outcomes associated with a warming climate had different and opposite effects on the extent of double cropping. A longer growing season was positively associated with rates of double cropping. On the other hand, higher temperatures during the growing season (as measured by growing degree days—an agriculture-relevant measure of accumulation of temperature over time, which influences crop growth and development) were negatively related with double cropping rates. That is, the longer the growing season, the more double cropping you could expect, but that may be countered by warmer summer temperatures, which tend to lead to less double cropping. The statistical analysis, using a multi-variate regression that accounted for other factors as well, quantified these relationships. We found that:

- A 1% increase in growing degree days leads to a ***decrease*** in cropping intensity (or rate of double cropping) of 0.189%.
- A 1% increase in frost-free days (which bounds the growing season) leads to an increase in cropping intensity of 0.197%.

Based on these results, an increase in double cropping due to climate change would only be predicted to occur if growing season increased proportionally more than the growing degree days. In fact, the opposite is true. Climate simulations (RCP 4.5 and 8.5) for Grant, Walla Walla, and Benton Counties all show growing degree days increasing between 23% and 35% by 2040, while the growing season is projected to lengthen by at most 15%. In contrast, there are parts of western Washington where the growing season is predicted to increase more than growing degree days. We therefore conclude that climate change is not expected to lead to an increase in double cropping in eastern Washington.

Looking at rates of double cropping in warmer parts of California and Arizona helps put an upper bound on potential rates of double cropping in Washington, should it be possible to find areas where the growing season lengthens without the increases in temperature that would then depress double cropping. About 95% of counties in the sample have cropping intensity values between 0.8 and 1.2 (Figure 14). The highest levels of double cropping found in major irrigated agricultural counties in these states are in the range of 35% (cropping intensity of 1.35). However, such cases have conditions that are unlikely to be met in the future anywhere in eastern Washington: relatively mild temperatures in both summer and winter, leading to very long growing seasons, with relatively cool summers (that is, they do not experience significant heat in summer that would depress the potential for double cropping). Most counties in eastern Washington have cropping intensity values between 0.95 and 1.05 (Figure 14). If a location had the right conditions for a longer growing season without an associated high summer heat peak, then the highest increase in double cropping that could reasonably be expected in eastern Washington appears to be around 15%. However, more modest increases are much more likely.

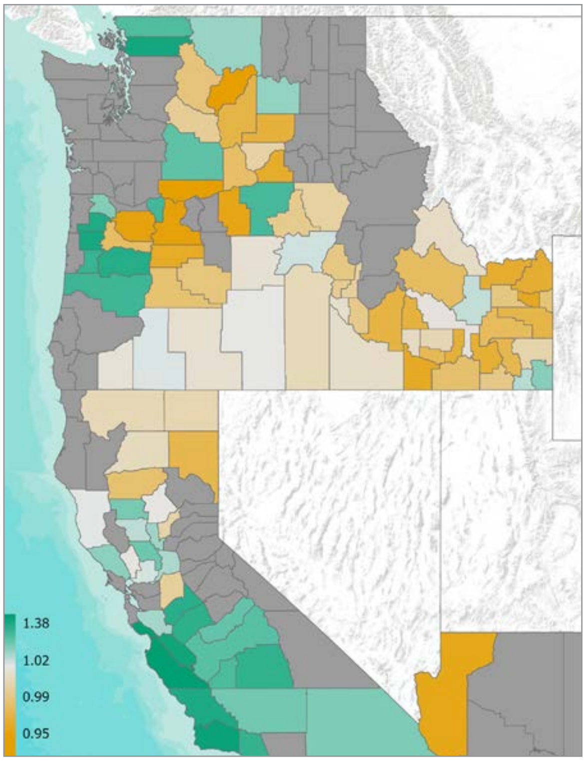

Figure 14. *Cropping intensity—the ratio of total harvested irrigated acres to irrigated extent—of irrigated crops by county, averaged over the last four waves of the Census of Agriculture (USDA NASS: 2002, 2007, 2012, and 2017).*

Growers' Survey: Responses to the surveys carried out with producers in eastern Washington indicated that current double cropping is limited due to high availability of land and limited availability of water rights, suggesting that lack of water availability will likely limit the expansion of double cropping as growing seasons lengthen. These inferences, obtained through a very different method, combined with the conclusions described above, suggest that changes in double cropping are unlikely to be a major driver of changes in agricultural water demand in eastern Washington in the future.

Potential Impacts of Planned Water Supply Projects

A key modeling decision was made to keep the overall irrigated acreage constant between the historical (1986-2015) and forecast (2040 and 2070) time periods. However, OCR estimates that 250,000 ac-ft of water may become available by 2040 for out-of-stream uses, due to planned water supply projects. **If we assume that this full amount is used in**

AGRICULTURAL DEMAND - Washington Portion of the Columbia River Basin			
	Historical (million ac-ft)	**2040 Forecast** (million ac-ft)	**% change by 2040**
Median demand year (50th percentile)	3.01	**2.96 (± 0.021)**	**-1.7% (± 0.7%)**
Median demand year + planned water supply projects	3.01	**3.21 (± 0.021)**	**6.6 (± 0.7%)**

Table 8. *Impact of adding 250,000 ac-ft from planned water supply projects to modeled agricultural water demand for the Washington portion of the Columbia River Basin by 2040. The "median demand year" scenario is based on maintaining the extent of agricultural acreage constant between the historical (1986-2015) and forecast (2040) time periods (from Table 6). The "median demand year + planned water supply projects" scenario assumes that the 250,000 ac-ft of additional water that could be available for out-of-stream uses by 2040 is all allocated to additional irrigation. Values between parentheses represent confidence intervals around the average of future values, due to the range of demand values obtained under difference climate scenarios (for details see Box 4). The percent change reflects the difference from the historical to the forecast values, and is also accompanied by confidence intervals associated with climate uncertainty. Those confidence intervals were maintained in both scenarios, since we were unable to quantify the uncertainty in the estimate of available water. Changes highlighted in orange and blue are increases and decreases in demand (expected to be associated with decreasing and increasing water availability), respectively, that are statistically different to zero.*

irrigation by 2040, then the agricultural water demand would increase by this amount. In this case, the change in agricultural water demand would, on average, overwhelm the projected small decline expected by 2040 (Table 8). This approach provides a very coarse estimate of the potential impacts of planned water supply projects in eastern Washington. However, it highlights how changes in investment and water management can change the trends in agricultural water demand from negative to positive.

Residential Water Demand

We estimated residential water demand for the Washington portion of the Columbia River Basin only. **Almost all eastern Washington WRIAs are expected to see increases in population through 2040.** The rate of such growth varies significantly across WRIAs, from close to zero in Nespelem (WRIA 51) and Upper Crab-Wilson (43), to approximately 30% in Hangman (56), Upper Yakima (39) and Moses Coulee (44), 40% in Chelan (47), and close to 50% in Esquatzel Coulee (36). Since we estimated changes in residential water demand as the per capita consumption times the size of the population, these projected changes in population drove the estimates of increases in residential demand, and their variations across eastern Washington (see the *Water Supply and Demand Forecast for Washington's Watersheds* section). Specifically:

- Total residential consumptive demand for eastern Washington will reach over 226,221 ac-ft per year by 2040, compared to close to 185,503 ac-ft per year in 2020. This represents an increase of approximately 22% (Table 9).
- The portion of the increase in residential demand arising from increases in municipal use was proportionately larger than the portion arising from increase in domestic use (23% vs 17%, respectively; Table 9).
- Residential water demand during the summer months (June, July and August) accounted for 38% of total annual residential demand.
- Of the residential water demand during the summer months, 67% was estimated to be for outdoor water use.

As with agricultural demand estimates above, these residential demand values do not include potential improvements due to water conservation measures, which could reduce forecast residential water demand.

RESIDENTIAL DEMAND - Washington Portion of the Columbia River Basin			
	Historical - 2020 (ac-ft per yr)	2040 Forecast (ac-ft per yr)	% Change
Municipal	156,089	191,726	23%
Domestic	29,413	34,496	17%
Residential (total)	**185,503**	**226,221**	**22%**

Table 9. *Historical (2020) and forecast (2040) residential water demand for the Washington State portion of the Columbia River Basin, including municipal and domestic demands. Changes highlighted in orange are increases in demand (expected to be associated with decreasing water availability).*

Hydropower Demand

Our extensive review of existing data and information from power entities in the Northwest highlighted the magnitude of the potential increase in demand for electricity generally, and hydropower specifically, by 2040. **The estimated increase in hydropower demand by 2040 could range from 5% to 34%.** We explored how population growth, expansion of the use of electric vehicles, and data centers contribute to this range of values, and further discuss the potential impact of Washington legislation on future changes.

Additional Hydropower Demand by 2040

There will be a demand for additional electricity by 2040 in the state of Washington as population growth, technology (such as expanded use of electric vehicles and data centers), and the need to reduce greenhouse gas emissions lead society towards an increasing dependence on electricity. Our review of regional power entities' data and information and our exploration of different scenarios suggest that demand for electricity overall may increase between 10% and 47% by 2040 (Table 10). If we assume that the correlation that has existed over the last 20 years between total electricity demand and hydropower demand will continue through to 2040, then this additional demand would translate into an increase in demand for hydropower of between 5% and 34% (Table 10). However, whether or not this additional electricity demand will actually translate to demand for additional hydropower will depend on existing laws, policies, and trends, as well as the regulatory changes over the next 20 years. This includes the potential for policies that may limit expansion of hydropower production in Washington State, and potential changes to the Columbia River Treaty (see the *Forecast Limitations* section).

To explore the potential effect of future laws and regulatory changes, we focused on Washington State's Senate Bill (SB) 5116. This bill, signed into law on May 7, 2021, would exclude new and expanded hydroelectric facilities from being recognized as contributing towards Washington's goal to become greenhouse-gas neutral. Therefore, to be recognized, additional hydropower would need to be supplied through pump storage projects, achieving efficiencies, or other improvements in existing hydroelectric generating facilities.

In addition to the above constraints, any effort to achieve greenhouse gas neutrality would require that non-emitting power sources would need to replace 1,084,000 MWh of natural gas and 362,000 MWh of coal-fired generation, in addition to fulfilling demands for additional electricity by 2040 (Figure 15). Another 865,000 MWh comes from nuclear energy supplied by the Columbia Generating Station (current operating license expiration: December 2043).

HYDROPOWER DEMAND - Entire Columbia River Basin						
		Generation Demand (KWh)			Percent Change	
		2019	2040 - Low	2040 - High	2040 - Low	2040 - High
Scenario 1 Population Growth	Total Electricity Demand	106,463,608	117,410,322	137,592,463	10	29
	Hydroelectric	66,026,861	69,175,073	75,468,376	5	14
Scenario 2 Population Growth + Electric Vehicles	Total Electricity Demand	106,463,608	118,697,840	140,746,676	11	32
	Hydroelectric	66,026,861	72,329,286	76,755,894	10	16
Scenario 3 Population Growth + Electric Vehicles + Data Centers	Total Electricity Demand	106,463,608	130,523,840	156,514,676	23	47
	Hydroelectric	66,026,861	88,097,286	88,581,894	33	34

Table 10. *Expected changes in demand for electricity and hydropower by 2040 in the Columbia River Basin, based on data and information from public utilities in the region. The "low" and "high" alternatives are calculated based on the range of existing projections in population growth (all scenarios), in expected adoption of electric vehicles (scenarios 2 and 3), and expected expansion of data centers (scenario 3).*

It is difficult to say with confidence how utilities will meet greenhouse gas neutrality goals. A report released by the Washington State Department of Commerce (WSDOC 2020[21]) described how utilities met the goals set forth by the Energy Independence Act (EIA). Utilities which serve 80% of the Washington State population met their 15% transition goal of 2020 by increasing generation from wind by 62% and hydropower by 8%. It is unclear to what extent these utility companies will be able to further improve efficiencies for future goals. This could mean that greenhouse-gas neutral goals will be more commonly met with carbon credits or further transition to renewables.

21 WSDOC (2020). EIA 2020 Report Summary and Detail. Washington State Department of Commerce. Available online at https://www.commerce.wa.gov/wp-content/uploads/2020/06/Energy-EIA-2020-Report-Summary-and-Detail.pdf, accessed May 18, 2021.

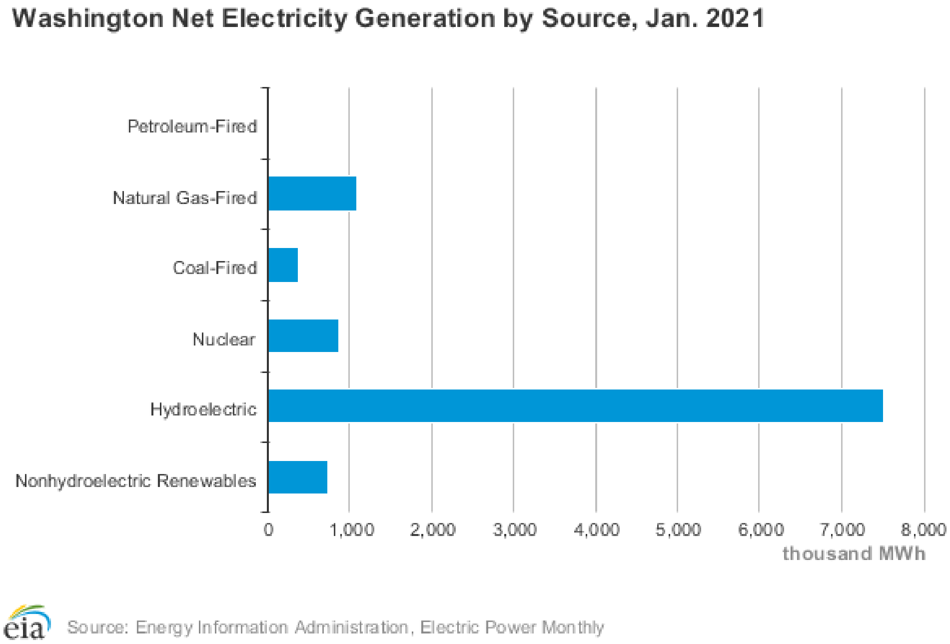

Figure 15. *Washington's net electricity generation by source, produced by the Energy Information Administration in January 2021. Available online at https://www.eia.gov/state/?sid=WA#tabs-4, accessed May 18, 2021.*

Climate Change Impacts on Evaporative Losses

Water losses due to evaporation and seepage from off-channel pump storage facilities are expected. For instance, the Goldendale Pump Storage Project proposed by Rye Development would generate 25,500 MWh for up to 20 hours. The Sierra Club opposes the project because it is estimated that it will require 2.93 billion gallons of Columbia River water initially to fill, and as much as 1.2 million gallons each year to make up for water lost through evaporation and leakage, which is equivalent to about 9,000 ac-ft to fill and 3.7 ac-ft per year in losses. Other pump storage projects like Shell's Pearl Hill Project are closed-loop systems where water will be stored in a large tank. Evaporation losses would be negligible (assuming the tank is enclosed), although there could be additional small losses when the water is released back to the downstream pond. Therefore, evaporation losses from new facilities would likely be fairly small, though projects with larger surface area to volume ratios might result in larger losses.

Climate change could impact hydropower generation in two additional ways. First, increasing temperatures and longer, drier summers will lead to additional evaporation from existing facilities. A 1-inch increase in evaporation from a full Lake Roosevelt, for example, would consume an additional 6,800 acre-feet of water. And second, hydroelectric generation requires substantial head to provide efficient power generation. Unfortunately, it was not possible to estimate these increased demands, due to a lack of historical measurements and unknowns related to future operations (such as potential changes under the Columbia River Treaty).

Vulnerabilities Across the Columbia River Basin

The vulnerabilities in the Columbia River Basin in the future arise not from overall reductions in water availability—since annual supplies are generally expected to increase slightly—but rather from shifts in availability within a water year, with historically wet months getting wetter, and historically dry months getting drier. In some places, these shifts are accompanied by variations from year to year, such that water supplies are generally expected to decrease in low supply years and to increase in high supply years, heightening the challenges of either managing for all the demands for water or managing large water supplies (see the *Water Supply and Demand Forecast for Washington's Watersheds* section).

These vulnerabilities, driven by expected changes in future water supply, are exacerbated by expected changes in water demands. The slight decreases expected in agricultural water demand, that could potentially have alleviated the supply-driven vulnerabilities, are not uniform decreases across the region (see the *Water Supply and Demand Forecast for Washington's Watersheds* section). Similarly, expected increases in residential water demand by 2040 are

Water Use or Demand Currently Unmet or Not Reliably Met		
Water Use or Demand	**Estimated Volume (acre-feet)**	**Source**
Unmet Columbia River Instream Flows[a]	13,400,000	Ecology data, McNary Dam, 2001 drought year
Unmet Tributary Instream Flows[b]	26,600 to 654,500	Ecology data, tributaries with adopted instream flows, on average, and for a drought year (generally 2001)
Unmet Columbia River Interruptibles[c]	40,000 to 292,000	Ecology Water Right Tracking System
Water Use or Demand that May be Met with Surface Supplies by 2040		
Yakima Basin Water Supply (pro-ratables, municipal/ domestic and fish)[d]	450,000	Yakima Integrated Water Resource Management Plan (April 2011)
Alternate supply for Odessa Subarea within the Columbia Basin Project[e]	185,000	Odessa Final Environmental
Remaining groundwater supplies in the Odessa Subarea at risk (largely outside the Columbia Basin Project)[f]	307,000	Odessa Final EIS (August 2012), demand without a current plan for surface water replacement
Agricultural water demand at risk due to declining groundwater supplies (other than in the Odessa Subarea)[g]	993,719	WRTS database, WSDA crop extent, extent of declining groundwater trends
Residential water demand at risk due to declining groundwater supplies (other than in the Odessa Subarea)[h]	81,904	Estimated residential demand, extent of declining groundwater trends

a 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 remains the only year since WAC 173.563 was enacted when Columbia River flows were not met and interruptible water users were curtailed.

b 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. Note that unquantified instream flow demand also exists in tributaries without adopted instream flow rules. 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.

c The range of values for Columbia River interruptibles at risk of curtailment includes both the experienced curtailment from the 2001 drought, and the full water right value at risk of curtailment, which OCR estimated in 2019 to be 291,435 ac-ft.

d Multiple water projects are under development in the Yakima River Basin, as part of the Yakima Integrated Water Resource Management Plan, and are expected to lead to decreases in the estimated volume needed. Examples include: Yakima City Aquifer Storage and Recovery (ASR), Cle Elum Pool Raise, and the Kachess Drought Relief Pumping Plant (see Figure 5).

e Of the 190,000 irrigated acres in the Odessa Subarea, the 2012 Odessa Final Environmental Impact Statement includes water supply projects to replace groundwater with surface water to serve 87,700 acres. At an assumed water duty of 3 ac-ft/acre, this translates to 264,000 ac-ft, The planned Lake Roosevelt Incremental Storage Releases, the Odessa Subarea Special Study, and coordinated conservation water savings within the Columbia Basin Project would account for approx. 224,000 ac-ft of surface water replacement, and should be completed by 2040. The difference of 40,000 ac-ft will be made up and accounted for by return flows with Columbia Basin Project operations and is not a new diversion from the Columbia River, therefore this quantity is subtracted from the unmet demand. Currently 13,000 acres of Odessa Subarea lands are receiving Columbia Basin Project surface water; at an assumed water duty of 3 ac-ft/acre, this reduces the unmet demand by 39,000 ac-ft.

f Of the 190,000 irrigated acres in the Odessa Subarea, 102,300 acres of irrigated lands dependent on groundwater do not have a surface water replacement plan in place at this time, and are therefore at risk due to declining groundwater. With an assumed water duty of 3 ac-ft/acre, this demand was estimated as 307,000 ac-ft.

g The estimate of the agricultural water demand at risk due to declining groundwater is based on the acreage irrigated from a groundwater source (based on combining WSDA crop extent with WRTS data on source) that occurs over groundwater subareas with documented declines (obtained from the groundwater trends analysis), and an assumed average irrigation rate of 3 ac-ft/ac. Due to the greater extent of the groundwater trends analysis in this 2021 Forecast relative to the 2016 Forecast, the irrigated acreage at risk has almost doubled from the previous estimate (331,240 ac in 2021, vs. 147,176 ac in 2016). 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.

(Table continued on bottom of next page)

significant. While residential water demand overall is a relatively small portion of out-of-stream demands across the Columbia River Basin, the expected increase will likely exacerbate the supply-driven vulnerabilities in specific areas across the region (see more detail in the *Water Supply and Demand Forecast for Washington's Watersheds* section). And though significant uncertainty remains around which factors will actually drive future demand for hydropower, it is clear that demand is likely to increase, placing further pressure on limited supplies.

In addition, the water demands quantified so far do not address areas of currently unmet water requirements suggested by other studies, while declining groundwater (see the *Water Supply Forecast for Washington's Aquifers* section) poses additional risks to other water uses (Table 11). The combination of existing unmet demands, both for meeting instream flow requirements and for out-of-stream uses, and of expected changes in water supplies and demands in the future, heighten the need to work collaboratively to address vulnerabilities in water availability across the Columbia River Basin, including eastern Washington.

Water Supply and Demand Forecast for Washington's Watersheds

Within Washington State numerous management decisions are made at the scale of individual watersheds, or within counties (Figure 16). Hydrological processes do not respect jurisdictional boundaries, so the 2021 Forecast continues to summarize results of the integrated modeling within watersheds. We used Washington State's Water Resource Inventory Areas (WRIAs) to summarize the results of the integrated modeling of surface water supply and agricultural water demand. Supplies are those generated within the watershed, excluding supplies from the mainstem Columbia and Snake Rivers (for insights on the contributions of the Columbia River Mainstem see the *Water Supply and Demand Forecast for Washington's Columbia River Mainstem* section). In addition, we carried out detailed forecasts for residential (municipal plus domestic) demand (see the *Residential Water Demand* section, below), and for curtailment of interruptible water rights, to determine when and how frequently water rights could expect to be interrupted in favor of instream flow (ISF) requirements (see the *Curtailments for WRIAs with Adopted Instream Flow Rules* section, below).

Figure 16. *Washington's Watersheds geographic scope: Water Resource Inventory Areas (WRIAs) in eastern Washington, and their relation to county boundaries.*

h The estimate of the residential water demand at risk due to declining groundwater is based on (a) the demand in municipalities using 100% groundwater that are within a subarea with declining groundwater (based on the population and per capita use), and (b) an area weighted estimate based on the percent of each county that is within a subarea with declining groundwater, which was then multiplied by the demand of the county. 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.

Table 11. *Water demands in the Washington portion of the Columbia River Basin that are at risk, either because they are currently not being met reliably (top portion of the table), or may be met from surface water supplies by 2040 (bottom portion of the table). These estimates are based on existing information, obtained from other plans, databases and sources. These are conservative estimates meant to highlight demands that could be at risk of curtailment or at risk due to declining groundwater, and therefore existing supply sources may not be able to reliably meet those demands.*

Surface Water Supply

Major Tributaries into Washington's Columbia River Mainstem

Major tributaries make sizeable water supply contributions to the Columbia River as it makes its way from the Canadian border to Bonneville Dam. The expected changes in **annual surface water supply generated within these tributary watersheds vary, as expected climatic changes are not uniform across the region**. In many cases supplies are expected to remain stable or increase, with some watersheds expecting decreases under certain conditions.

Tributaries that are expected to consistently see increasing water flows by 2040 are the Okanogan, Wenatchee, Crab Creek, Palouse and Klickitat Rivers, while the Kettle, Methow and Deschutes Rivers are consistently expected to remain stable (Figure 17). The remaining major tributaries are generally expected to see increases in water flows by 2040, at least during high flow years. Four major tributaries, however, are expected to see significant decreases in water flows under low flow conditions: the Snake, Yakima, Chelan and Colville Rivers. Of these four, the Yakima River is expected to see decreasing flows in low and median flow years, and the Colville River is expected to experience decreasing annual supplies under all conditions (low, median and high flow conditions).

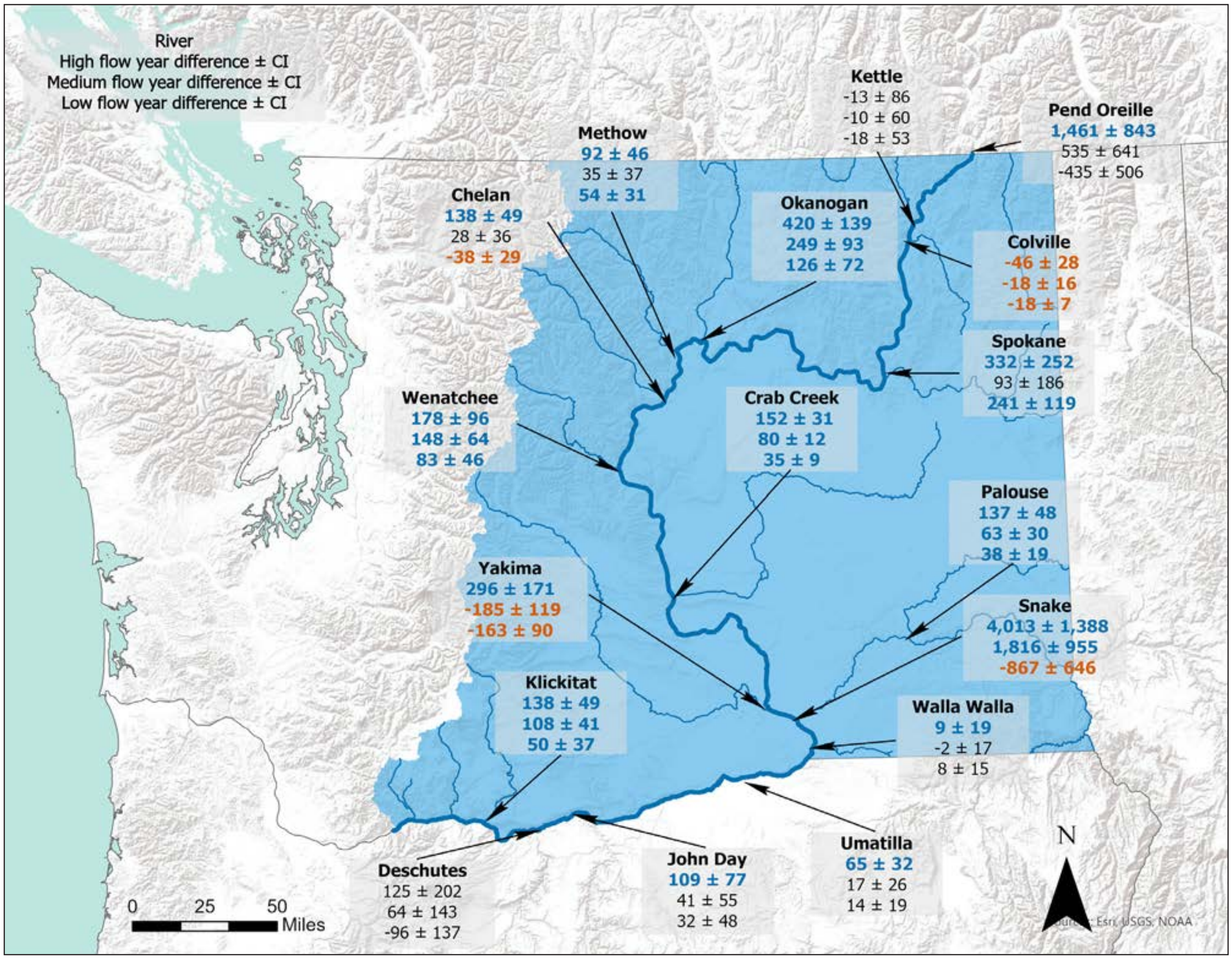

Figure 17. Expected change by 2040 in surface water flows (prior to accounting for demands) where tributaries join Washington's Columbia River Mainstem (above Bonneville Dam). The three numbers for each river refer to forecast (2040) surface water supply for a high (80th percentile; top), median (50th percentile; middle) and low supply year (20th percentile; bottom), averaged across 34 climate change scenarios (confidence interval around that average in parentheses). Changes highlighted in orange and blue are decreases and increases in supply (expected to be associated with decreasing and increasing water availability), respectively, that are statistically different to zero. All values are in cubic feet per second.

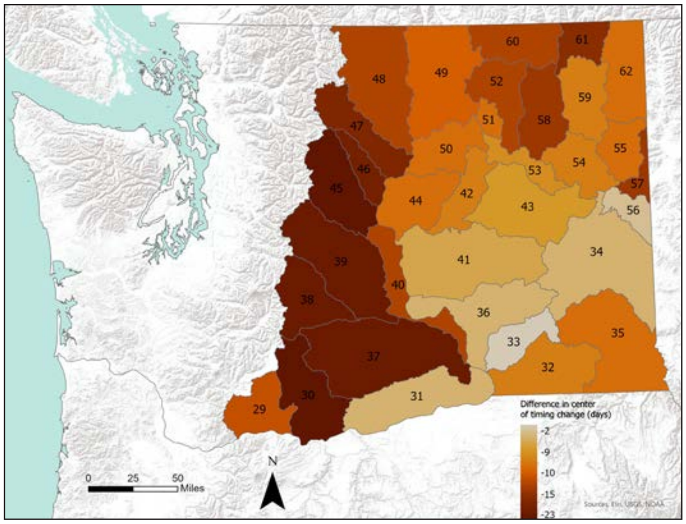

Figure 18. Changes in the timing of water supply expected during high flow years (80th percentile) by 2040. We quantified the shift based on the change, in number of days, of the center of timing of supply from the historical (1986-2015) to the forecast (2040) period (using the median of 34 climate change scenarios). Note that one value is given for WRIAs 37, 38 and 39, and one value is given for WRIAs 44 and 50, reflecting the sum of changes in those groups of WRIAs.

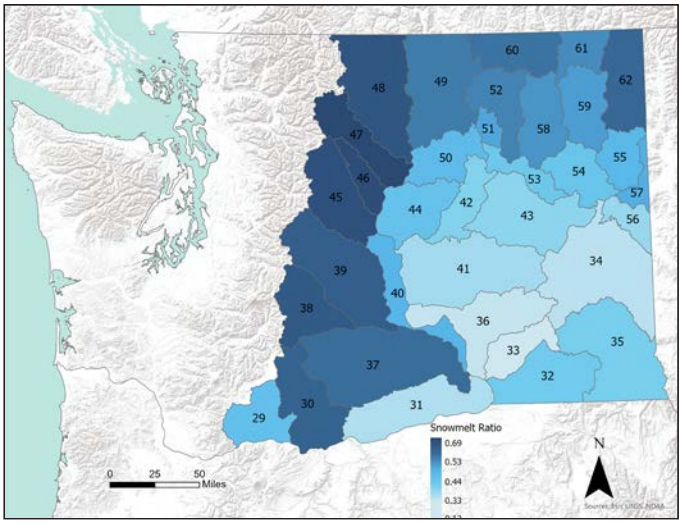

Figure 19. Historical (1976-2005) snowmelt ratio, obtained from an independent dataset. The snowmelt ratio reflects the relative contributions of snowmelt and rainfall to streamflow. The higher the ratio, the greater the contribution from snowmelt.

Water Supply across Washington's Watersheds

At the watershed scale, the results highlight that the **main change in surface water supply by 2040, driven by changes in climate, is similar to what is expected for the entire Columbia River Basin: a shift in timing of water supply to earlier in the water year**. In addition, some watersheds across eastern Washington are also expected to experience either increases in supply during high flow years or decreases in supply during low flow years, or both.

Most of eastern Washington's WRIAs are expected to experience the shift in timing of surface water supply to earlier in the water year, though the magnitude of the shift will likely vary by watershed. This change in timing is driven by warming temperatures and their effect on snowpack and snowmelt, which is consistent with previous Forecasts and other studies. The center of timing of water supplies are expected to shift as much as 23 days earlier by 2040 in some watersheds, notably those in the central and southern Cascades (Figure 18). These rivers receive a high proportion of their supply from snowmelt (measured as the snowmelt ratio; Figure 19), yet are temperate enough that temperature increases lead directly to earlier snowmelt, with the resulting shift to earlier water supply patterns. The northern and northeastern WRIAs are colder, so although they also have high snowmelt contributions (Figure 19), they are less sensitive to expected increases in temperatures by 2040. Therefore, the shift in timing of supply is not as large in these watersheds (Figure 18). Finally, the low elevation WRIAs in the heart of central Washington and into the Columbia River Gorge, where snowmelt contributions are also lower, are expected to experience the smallest shifts in timing, which can be as little as two days in some cases (Figure 18).

The biggest increases in supply during high flow years (80th percentile) under future climates (2040) are expected in the watersheds draining from the Cascade Mountains, particularly those in the central and southern Cascades, as well as the Palouse (WRIA 34; Figure 20). Less pronounced increases in water supplies during high flow years are expected in some of the watersheds in the heart of central Washington, particularly the Lower Crab and Upper Crab-Wilson (WRIAs 41 and 43) (Figure 20).

During low flow years (20th percentile), the Yakima River WRIAs (37, 38 and 39) are expecting the largest reductions in annual water supply under future climates (2040), followed by the Chelan (WRIA 47), Pend Oreille (62) and Colville (59) (Figure 21). The rest of the WRIAs in eastern Washington could experience no change or even increases in water supply in low flow years, though there does not appear to be consistent patterns across the region (Figure 21).

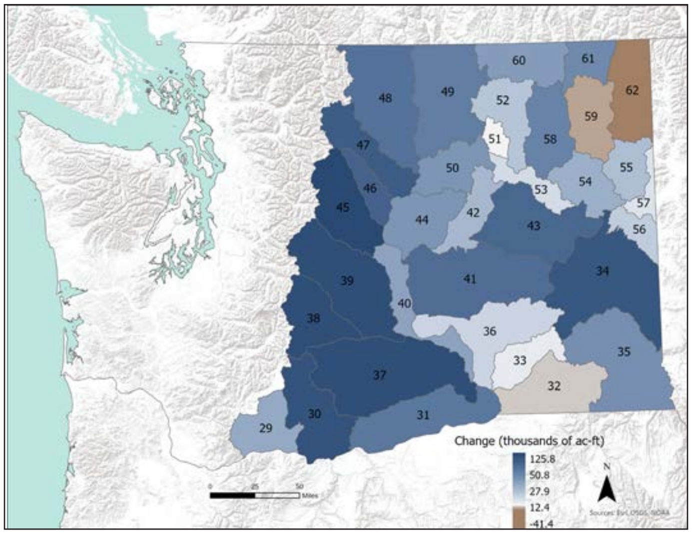

Figure 20. Changes in annual water supply expected during high flow years (80th percentile) by 2040, in thousands of acre-feet. WRIAs are colored based on the magnitude of change in annual water supply between historical (1986-2015) and forecast (2026-2055) time periods. Future supplies were represented by the median of 34 climate change scenarios. Note that one value is given for WRIAs 37, 38 and 39, reflecting the sum of changes in those WRIAs.

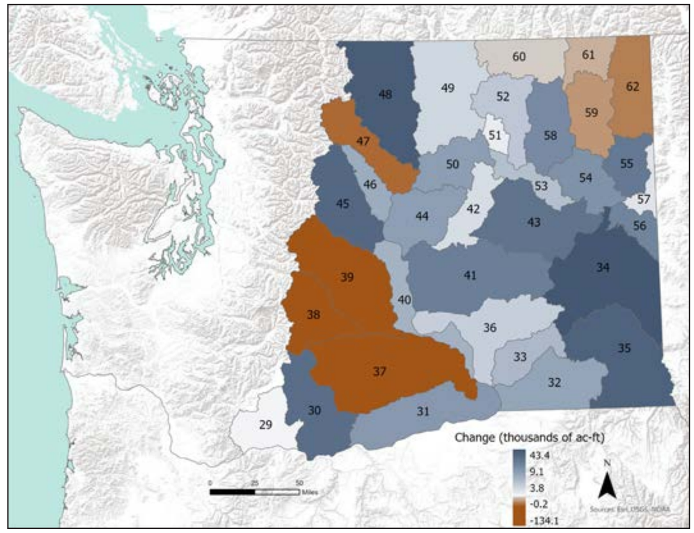

Figure 21. Changes in annual water supply expected during low flow years (20th percentile) by 2040, in thousands of acre-feet. WRIAs are colored based on the magnitude of change in annual water supply between historical (1986-2015) and forecast (2026-2055) time periods. Future supplies were represented by the median of 34 climate change scenarios. Note that one value is given for WRIAs 37, 38 and 39, and one value is given for WRIAs 44 and 50, reflecting the sum of changes in those groups of WRIAs.

Agricultural Water Demand

Historically, agricultural water demand has been greatest in the WRIAs in south-central Washington (Lower and Upper Yakima, WRIAs 37 and 39; Rock-Glade, 31), the WRIAs in the heart of central Washington (Lower Crab, 41; Esquatzel Coulee, 36) through to the Walla Walla (32), as well as Okanogan (49) (Figure 22). These patterns remain fairly consistent under future climate change scenarios, both in 2040 and even 2070. **Only some WRIAs are expected to experience significant increases in agricultural water demand by 2040. These WRIAs are found mainly in the eastern Cascades**, and include the Klickitat (WRIA 30), the Upper Yakima (39), the Wenatchee (45), the Methow (48), and the Okanogan (49) (Figure 23). WRIAs in the heart of central Washington and along the Columbia River Gorge, as well as the Lower Yakima (37), are expected to experience decreases in agricultural water demand by 2040 (Figure 22). These patterns of change are expected to continue through to 2070.

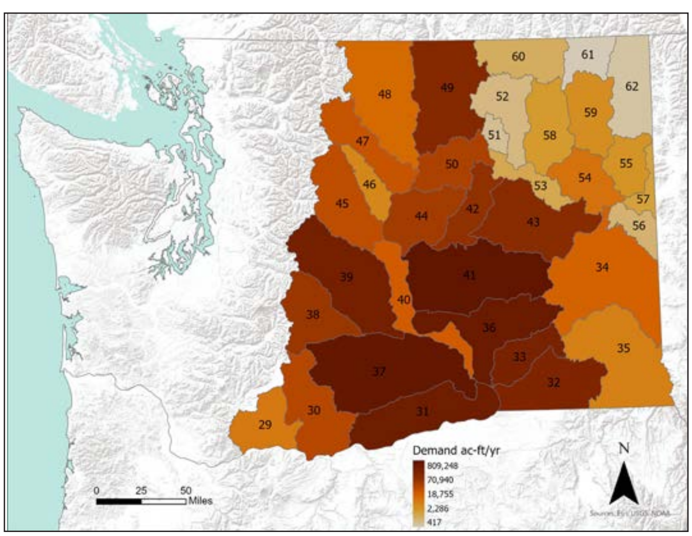

Figure 22. Historical (1986-2015) agricultural water demands across eastern Washington's Water Resource Inventory Areas (WRIAs). Demand is expressed in acre-feet per year.

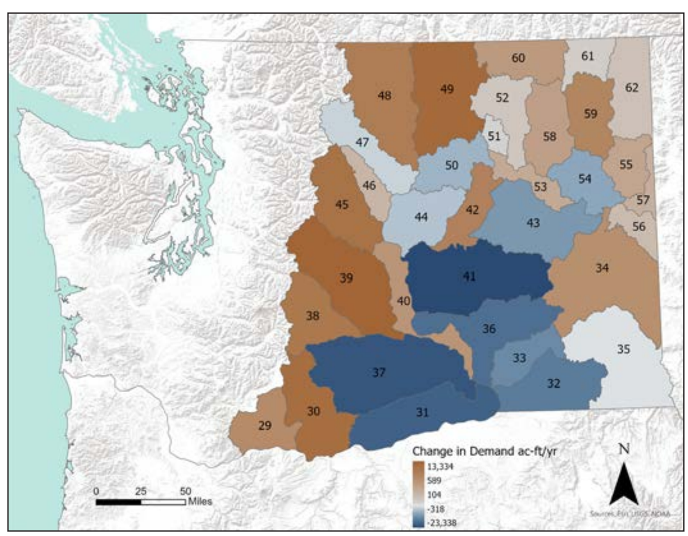

Figure 23. Expected change in agricultural water demand between the historical (1986-2015) and forecast (2040) time periods, summarized by WRIA. Changes in demand are expressed in acre-feet per year.

When the expected changes in agricultural water demand are expressed relative to the magnitude of historical water demand, a notable pattern emerges across WRIAs with expected increases in demand. The highest relative increases in agricultural water demand by 2040 and by 2070 are mostly concentrated in the WRIAs in the northeastern portion of the state, most of which have fairly modest agricultural water demand values, historically.

Residential Water Demand

Most areas in eastern Washington are forecast to see increases in residential water demand by 2040. However, forecast residential water demand by 2040 is expected to vary across WRIAs and jurisdictions, as is the rate of expected changes. Of the 45 municipalities for which we obtained data, the municipal water systems projected to use the largest volumes of water by 2040 are located in Spokane (40,360 ac-ft per year), Richland (28,873 ac-ft per year), Pasco (25,231 ac-ft per year), Kennewick (15,089 ac-ft per year), Moses Lake (14,955 ac-ft per year), and Yakima (10, 916 ac-ft per year) (Figure 24). These municipalities are somewhat correlated with the counties expected to be the largest domestic water users by 2040: Franklin (25,579 ac-ft per year), Grant (21,530 ac-ft per year), Benton (13,290 ac-ft per year), Yakima (10,121 ac-ft per year), and Stevens (6,814 ac-ft per year) (Figure 24).

When the municipal and domestic water demand results are aggregated and presented by WRIA, the WRIAs expected to experience the largest increases in consumptive residential water use include the Esquatzel Coulee (WRIA 36, 64%), Lower Snake (WRIA 33, 43% increase), and Lower Crab (WRIA 41, 38%), followed by Rock-Glade (WRIA 31, 26%), Alkali-Squilchuck (WRIA 40, 24%), Moses Coulee (WRIA 44, 22%) and Foster (WRIA 50, 22%) (Figure 25). Many of these areas already have high domestic or municipal water use (or both). It is notable that while the Spokane region has some of the highest water use, their expected change in consumptive use is not as great as other WRIAs in eastern Washington.

The finer resolution data used in this 2021 Forecast allowed us to explore two aspects of residential water demand that are particularly informative in determining future vulnerability in water availability. Estimating monthly residential water demand allowed us to explore seasonal water use. It may be more difficult to meet all water demands where expected increases in demands during the summer months (June, July and August) by 2040 co-occur with decreasing surface water supply during those months.

We found that the low-elevation WRIAs at the heart of central Washington and adjacent Cascades (WRIAs 31, 36, 37, 40 and 41) are expected to see the greatest increases in summer consumptive demand, followed by the WRIAs around Spokane (54, 56 and 57). For the most part, northern WRIAs are expected to see the least change (Figure 26). Of the WRIAs expected to see large changes in summer consumptive demand, the Lower Yakima (WRIA 37) stood out because it may also experience strong decreases in summer supplies (Figure 27). Alkali-Squilchuck (40) and the Lower and Middle Spokane (54 and 57) are expected to experience more moderate decreases in summer supplies, while still

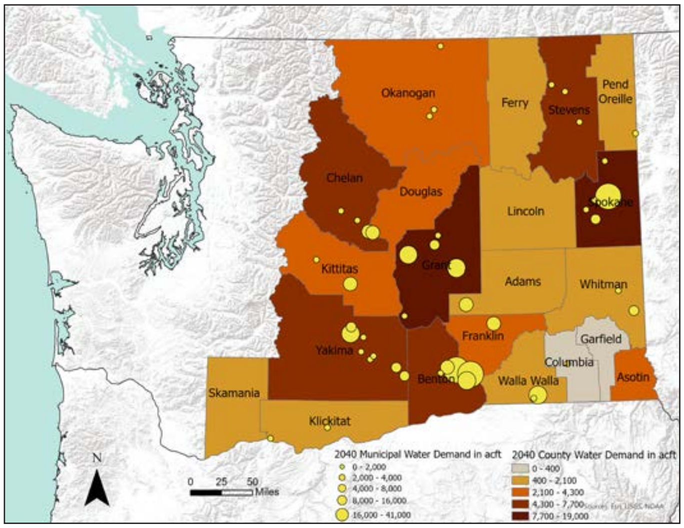

Figure 24. Total annual residential water demands for 2040 for domestic users (shaded areas) and municipalities (yellow circles).

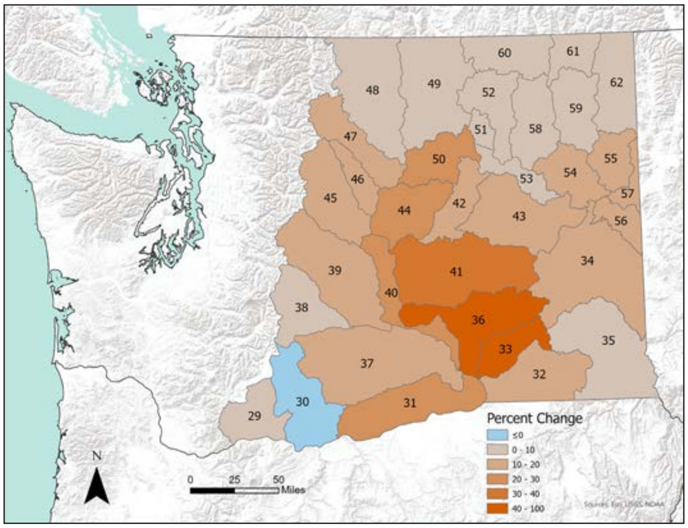

Figure 25. Change in total annual residential consumptive water use from 2020 to 2040, expressed as a percent of 2020 use, summarized by WRIA.

experiencing increasing summer residential demand. Residential water users in these WRIAs may be more vulnerable if they are using shallow groundwater connected to surface water, or if they have water systems that rely on surface water sources. In particular, the Lower Yakima (37) has at least four water systems (Yakima, Richland, Ellensburg, and Cle Elum) that use surface water to meet municipal demands. Rock-Glade (31) has at least one municipal water system (Kennewick) that relies in part on surface water sources, though this WRIA is expected to experience very slight decreases in surface water supply. Finally, the remaining WRIAs expecting large increases in summer consumptive demand (WRIAs 36, 41, and 56) are not expected to see even moderate decreases in summer supplies (Figure 27), and therefore are likely to less vulnerable.

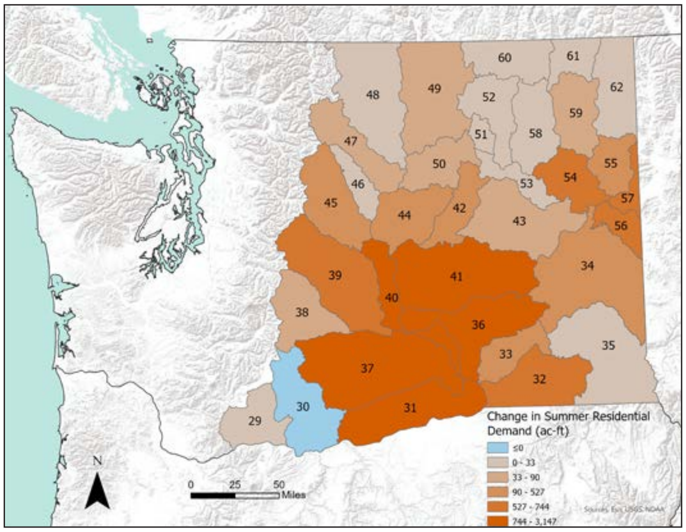

Figure 26. Change in residential consumptive water use during summer months (June, July and August) from 2020 to 2040, summarized by WRIA.

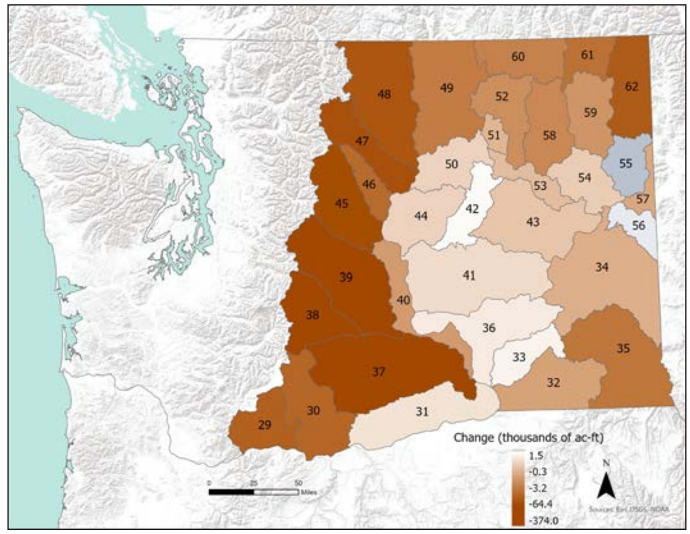

Figure 27. Change in surface water supply during summer months (June, July and August) from historical (1986-2015) to forecast (2040) periods, by WRIA. Note that one value is given for WRIAs 37, 38 and 39, and one value is given for WRIAs 44 and 50, reflecting the sum of changes in those groups of WRIAs.

While increased withdrawals may exacerbate declining streamflow conditions in some cases, most of the water used for residential (municipal or domestic) purposes comes from groundwater. Therefore, we also identified municipal water systems that may be vulnerable due to declining groundwater availability. Eight of the 27 municipal water systems we had data for that occur within the groundwater subareas we studied (see the *Water Supply Forecast for Washington's Aquifers* section) are completely groundwater dependent, are expecting summer demands to increase by more than 25% by 2040, and likely access at least one aquifer layer that is experiencing an overall decline (Table 12).

We further explored water availability for future growth in fast-growing cities and towns by distinguishing between municipal and domestic water use. Municipal water providers rely on their inchoate rights to meet future water demands.

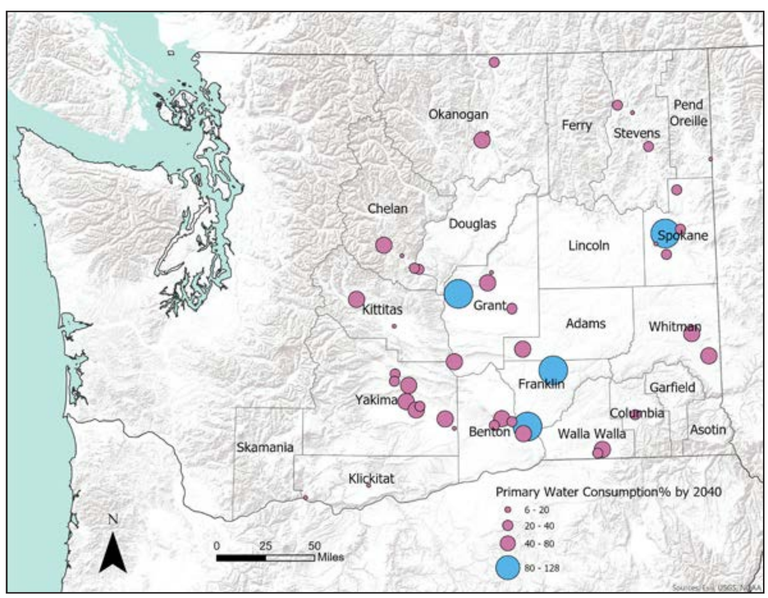

Figure 28. Percent of available water rights used by 2040 for sampled water provider systems.

WRIA the Water System Is In	Water System Location	Type of Water Source	Aquifer Layers with Declining Trends	Expected Change (%) in Municipal Consumptive Use by 2040
30	Goldendale	GW	3	-7
31	Kennewick	SW/GW	3	28
32	College Place	GW/IN	4	19
32	Dayton	GW	4	14
34	Colfax	GW	1	1
34	**Pullman**	**GW**	**1**	**25**
36	**Connell**	**GW**	**2**	**83**
37	**Benton City**	**GW**	**3**	**29**
37	**Grandview**	**GW**	**3**	**27**
37	Sunnyside	GW	3	23
37	West Richland	GW/IN	1	54
37	Yakima	SW/GW	4	-8
37	**Zillah**	**GW**	**3**	**46**
39	Ellensburg	SW/GW	2	21
41	**Moses Lake**	**GW**	**2**	**38**
41	**Quincy**	**GW**	**2**	**101**
42	Soap Lake	GW	2	-20
45	Leavenworth	SW/GW	0	14
45	Wenatchee	GW	0	26
49	Omak	GW	1	4
49	Oroville	GW	1	2
55	**Deer Park**	**GW**	**1**	**28**
57	Spokane	GW	0	13
59	Chewelah	GW	0	24
59	Colville	GW	0	-6
59	Kettle Falls	GW	0	2
62	Newport	GW	1	13

Table 12. *Municipal water systems occurring within the studied groundwater subareas. Details provided for each municipality include water sources that supply those municipalities, expected changes in municipal consumptive use by 2040, and the number of aquifer layers likely accessed by each municipality that show decliming trends in water levels (see* Forecast Results for Aquifer Layers *section for details on groundwater trends). Municipal water systems shown in bold may be particularly vulnerable due to declining groundwater.*

We found that 14 municipal systems are forecast to be using less than 25% of their existing water rights (as reflected in existing primary water rights registered in the Washington Department of Ecology's Water Rights Database) by 2040 (Figure 28). Twenty-one systems are forecast to be using 25-50% of their water rights, and six systems would be using 50-75% of their water rights by 2040. Four additional systems, serving Connell, Quincy, Pasco, and Airway Heights, are estimated to be using over 75% of their water rights by 2040, such that their existing water rights might be taxed under future water demand scenarios. Of these four systems, three (Connell, Quincy, and Pasco) have already documented that they are actively looking for additional (pending) water rights, and the fourth (Airway Heights[22]) has initiated water purchase agreements with a neighboring municipal water supplier.

22 See http://cawh.org/home/showdocument?id=20386

Instream Water Demand for Fish

Drought, as well as the potentially drier summers expected in the region under future climates, pose risks to fish, including listed species such as salmon, steelhead and bull trout. Critically low flows may be a risk in themselves. Low flows can also lead to warmer water, further impacting these cold-water fish species. Interesting insights around expected changes in low flows under future climates arise from Mauger and colleagues's (2021) independent study, which can help managers and policy makers determine where fish species and associated restoration efforts may be vulnerable to such changes in low flows. We synthesized some of those results, in collaboration with the author.

Our synthesis focused on two of the streamflow metrics that Mauger and colleagues studied, namely 7Q10 and 7Q2. The 7Q10 is a commonly used low-flow metric that quantifies the annual minimum 7-day average streamflow (or discharge, commonly represented with the letter Q) with a 10-year recurrence interval (hence the label 7Q10). This metric can be interpreted as presenting the value of the minimum flow (expressed as an average over seven days) that has a 10% chance of occurring any given year. Similarly, the 7Q2 quantifies the annual minimum 7-day average streamflow with a 2-year recurrence interval, or the minimum flow (expressed as an average over seven days) that has a 50% chance of occurring any given year.

Historically (1982 to 2011) in eastern Washington, the minimum flows expected with a 10% or 50% chance (7Q10 and 7Q2, respectively) are highest in the watersheds draining from the Cascade Mountains, followed by WRIAs draining other mountainous regions across the Washington portion of the Columbia River Basin. The lowest minimum flows occur in the lower elevation areas in the WRIAs at the heart of central Washington (Figures 29 and 31).

When exploring expected changes in 7Q10 and 7Q2 under future climate scenarios, by 2040, the patterns of expected changes are different between the WRIAs in mountainous versus low elevation areas in the heart of central Washington. **Mountainous WRIAs are expected to see decreases in annual minimum flows, with the largest decreases occurring in the Cascade Mountains** (Figures 30 and 32), where the earlier snowmelt and higher spring evaporation and transpiration lead to less water available in the summer to support baseflows. Decreases in annual minimum flows are less pronounced in the lower elevation WRIAs along the Columbia River Gorge, as well as the WRIAs draining from mountainous regions in the northeast and southeast of the state (Figures 30 and 32). On the

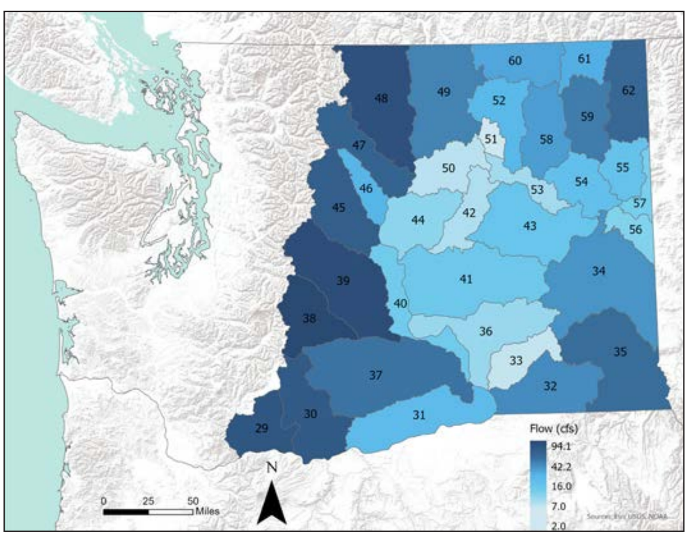

__Figure 29__. Historical (1982-2011) annual minimum 7-day average streamflow with a 10-year recurrence interval (7Q10) across Washington State's WRIAs. Map produced for this 2021 Forecast using data obtained from Mauger et al. (2021).

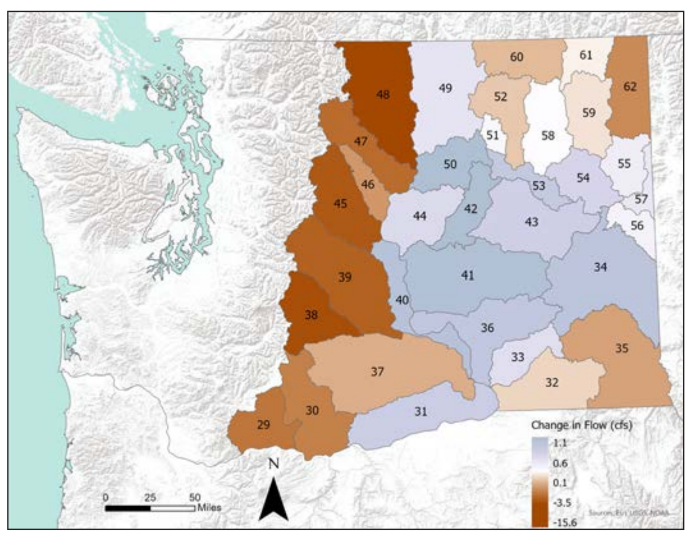

__Figure 30__. Expected changes in annual minimum 7-day average streamflow with a 10-year recurrence interval (7Q10) across Washington State's WRIAs, between the historical (1982-2011) and the projected future (2030-2059) time periods. Future projections summarize results from 12 climate change scenarios, developed using dynamic downscaling, under greenhouse gas emissions scenario RCP 8.5. Map produced for this 2021 Forecast using data obtained from Mauger et al. (2021).

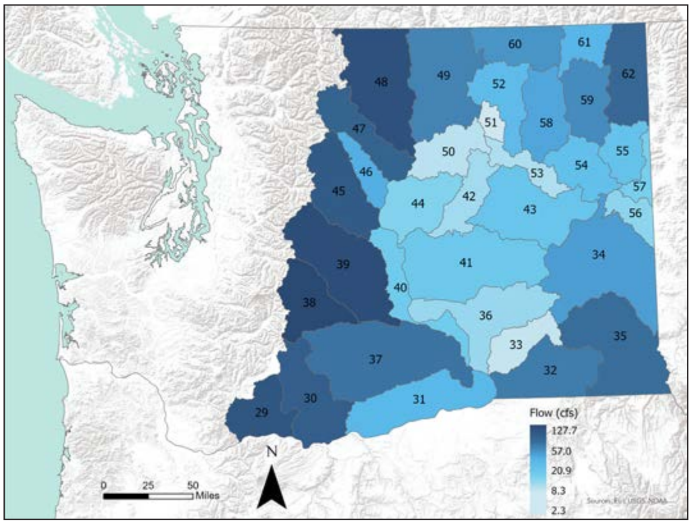

Figure 31. Historical (1982-2011) annual minimum 7-day average streamflow with a 2-year recurrence interval (7Q2) across Washington State's WRIAs. Map produced for this 2021 Forecast using data obtained from Mauger et al. (2021).

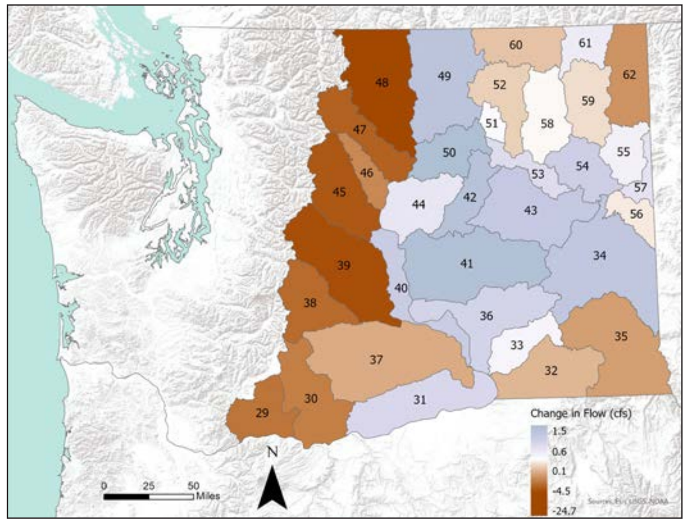

Figure 32. Expected changes in annual minimum 7-day average streamflow with a 2-year recurrence interval (7Q2) across Washington State's WRIAs, between the historical (1982-2011) and the projected future (2030-2059) time periods. Future projections summarize results from 12 climate change scenarios, developed using dynamic downscaling, under greenhouse gas emissions scenario RCP 8.5. Map produced for this 2021 Forecast using data obtained from Mauger et al. (2021).

other hand, WRIAs in the lower elevation areas in the heart of central Washington are expected to see slight increases in these annual minimum flows by 2040 (Figures 30 and 32).

The direction of change (decrease or increase) in 7Q2 for each WRIA is consistent with the above-described patterns for 7Q10. However, slightly more WRIAs show expected decreases or increases in 7Q2 than in 7Q10 (Figures 30 and 32). Mauger and colleagues (2021) also found that the biggest and most consistent decreases in annual minimum flows (both 7Q10 and 7Q2) are expected to occur on the west side of the Cascade Mountains, ranging from approximately-35 to-150 cfs. However, it is important to note that the east-side decreases, which can reach over -15 cfs, are likely to have significant impacts on these streams, which normally have lower flows.

Curtailments for WRIAs with Adopted Instream Flow Rules

There is a trend towards increasing frequency of curtailment by 2040 during the main portion of the irrigation season across all WRIAs with adopted instream flow rules that we modeled (Wenatchee, WRIA 45; Methow, 48; Okanogan, 49; and Colville, 59). However, the patterns of change in the frequency of curtailments vary from WRIA to WRIA (see the *Forecast Results for Individual WRIAs* section for details), with some showing the largest increases mid-season. For example, curtailment frequency in the Wenatchee watershed (WRIA 45) during August is expected to increase from 10 years out of 30 historically to 23 years out of 30 by 2040. Other watersheds can expect fairly even increases throughout much of the irrigation season, and even some decreases in curtailment late in the season; for example, the Methow (48) could see around 5 additional years out of 30 with curtailment much of the season (Figure 33).

The increases in number of years with curtailment (out of 30 years) could reach as much as 14 additional years in some weeks and under some climate change scenarios (for example, in the Wenatchee River, during late July under future emissions scenario RCP 8.5; Figure 33). This pattern is likely a reflection of the expected decreases in water supply expected during the dry season in low flow years, when curtailment is likely to happen, although increases in irrigation demand in WRIAs may also be a contributing factor.

Other WRIAs, most noticeably the Methow (48), could see modest decreases by 2040 in the number of years with curtailment at the end of the irrigation season (Figure 33). Such late-season decreases in curtailment (when they occur) may be due to the expected accelerated development in annual crops due to warmer temperatures, thus reducing late season water demand for irrigation (Figure 33).

Due to the differences in how curtailments occur in the Yakima River Basin, our modeling results do not show seasonality of curtailment. The annual average prorationing rate in the Yakima River Basin, which represents the amount that proratable water rights are curtailed under drought conditions (Box 4), is projected to moderately decrease under future climates, though the frequency of prorationing is expected to increase almost three-fold, from around 20% of years historically to close to 60% of years by 2040.

Details of expected changes in curtailment frequency between historical (1986-2015) and forecasted (2026-2055)

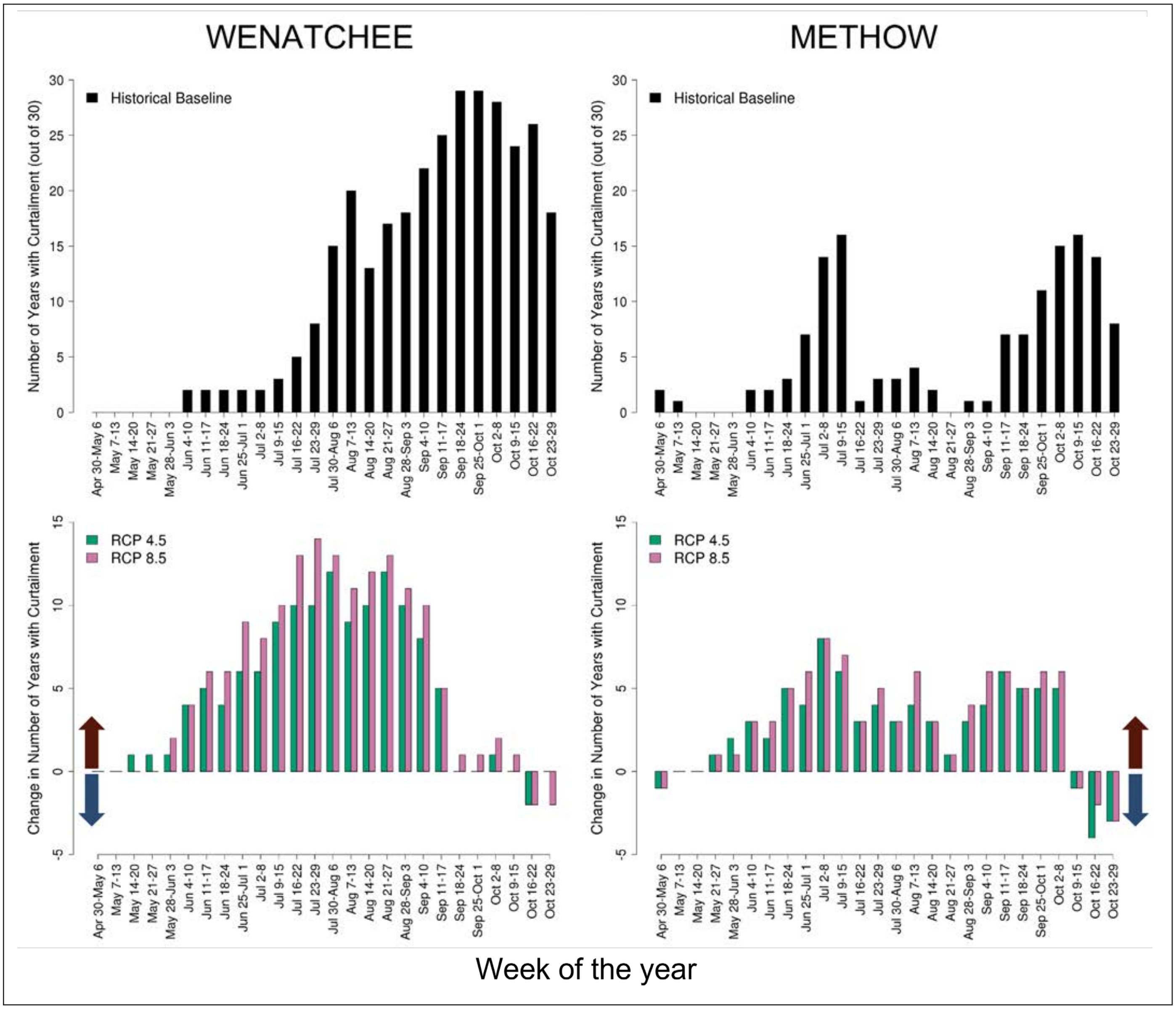

__Figure 33.__ Modeled historical (1986-2015) curtailment frequency (top panels) and change in expected curtailment frequency between historical and forecast (2040) time periods (bottom panels) in the Wenatchee watershed (WRIA 45; left panels) and the Methow watershed (WRIA 48; right panels), expressed as in number of years, out of 30 years, when curtailment occurs. Results for future change in frequency in each watershed are shown for two different greenhouse gas emissions scenarios (RCP 4.5 and RCP 8.5) and reflect the median change expected when 17 climate change scenarios are explored under each emissions scenario. Curtailment frequency was calculated on a weekly basis. Values of change (in the two bottom panels) above the zero line reflect increases in curtailment frequency (brown arrow), and values below the zero line reflect decreases in frequency (blue arrow).

time periods exploring the effects of changes in crop production—earlier planting date, changes in crop mix—that could occur in the region by 2040 are provided for each of these eastern Washington WRIAs in the *Forecast Results for Individual WRIAs* section.

Crop Yield Impacts from Reduced Irrigation

Reduced irrigation had negative impacts on crop yields across the different WRIAs, and for all the different crop groups modeled. The main crop types in the four WRIAs in which we modeled curtailment and its impacts were forages and high value perennials, such as fruit trees, though we also looked at high value annuals and other field crops in the Yakima watershed (WRIAs 37, 38 and 39). **In general, climate change led to larger decreases in crop yields when irrigation was reduced, with only some minor exceptions.** Some general patterns emerged:

- Reductions in yield occurred both under historical (1986-2015) conditions and under the alternative future (2040) conditions, generally seeing greater yield reductions under the high greenhouse gas emissions scenario (RCP 8.5) than under the lower emissions scenario (RCP 4.5) (Figure 34).
- The impacts of climate change on these yield reductions varied across WRIAs. The magnitude of the yield reduction under future (2040) conditions was generally greater than under historical (1986-2015) conditions (Figure 34). The difference between yield impacts in these two time frames varied from a few percentage points to as much as three times the reduction (Figure 34).
- Of the WRIAs and crops modeled, the crop yield impacts under future conditions are only expected to be slightly smaller than under historical conditions for high value perennials in the Wenatchee (WRIA 45) (see the *Forecast Results for Individual WRIAs* section).
- There were little or no differences between the alternative future management scenarios explored. The crop yield reductions obtained when modeling reduced irrigation under future climates, with or without earlier planting dates and future crop mixes, were very similar to each other. This suggests that the most important factors to consider are the effects of a changing climate.

It is important to note that, though the reductions in yields in some crop types and in some WRIAs are significant, reaching as much as a-35% reduction, the acreage affected by these interruptible water rights is generally modest, at most slightly surpassing a quarter of the irrigated acreage within that particular WRIA. Therefore, these reductions in yield do not translate to proportional reductions in production across the whole WRIA.

Vulnerabilities Across Washington's Watersheds

The types of vulnerabilities that our region is expected to face due to changes in water supply in the future are to some extent common across all Washington's watersheds. These changes in supply are driven by changes in timing of water availability within each year and, in some watersheds, the greater variation expected between years. However, the degree to which these changes are expected, and the convergence of these changes in supply with expected changes in the different demands for water are what vary across eastern Washington's watersheds.

The WRIAs in the upper Yakima Basin (WRIAs 38 and 39) are expected to see such convergence. These WRIAs are expected to experience decreasing water supplies in low supply years (Figure 21), while at the same time expecting increases in agricultural water demand (Figure 23). These WRIAs were also highlighted in Mauger and colleagues's (2021) analysis, due to expected decreases in low flows.

Given these patterns, one might expect that other WRIAs could be considered less vulnerable. However, the patterns of expected increases in residential water demand are different to those of agricultural water demand. The Lower Yakima (WRIA 37) and, to some extent, the Alkali-Squilchuck and Lower and Middle Spokane (40, 54 and 57) are also considered vulnerable because of the overlap between steep to moderate decreases in supply in the summer months (Figure 27) coinciding with expected increases in residential water demand (Figure 26). Though overall in eastern Washington residential water demand is only about a quarter the magnitude of agricultural water demand, the expected increases of over 20% in summer water use in WRIAs with declining summer supplies and municipalities using surface water or shallow groundwater sources (WRIA 37 for example) warrants serious attention.

Not surprisingly, the curtailment results highlight that the summer months will likely be when the decreases in future supply and increases in future demands—both residential and agricultural—converge.

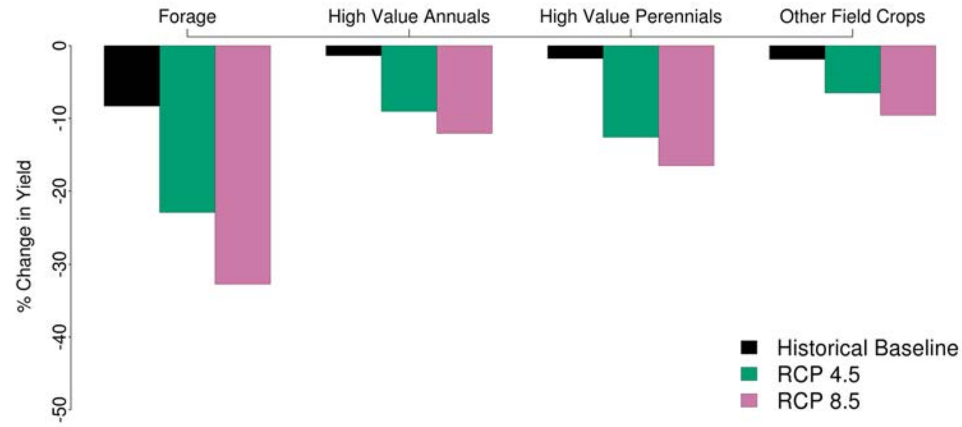

Figure 34. *Change in yield due to reduced irrigation under historical (1986-2015) and future (2040) climate conditions in the Yakima (WRIAs 37, 38, 39). Changes in yields under future conditions are calculated under two alternative greenhouse gas emissions scenarios (RCPs 4.5 and 8.5). Forage includes alfalfa hay and grass hay. High value annuals include onions, potatoes, mint, sweet corn, carrots, oats, dill, grass seed, sunflower, sugar beets, pepper, canola, and yellow mustard. High Value Perennials include blueberries, apples, cherries, peaches, pears, grapes and hops. Other field crops include wheat, peas, barley, corn, and dry beans (for more details see the* Forecast Results for Individual WRIAs *section).*

We conclude that numerous WRIAs in eastern Washington are vulnerable to expected changes in the timing and variability of water supply combined with changes in some type of water demand. Each WRIA has a unique combination of challenges to adapt to in the future, depending in part on the specific balance of changes in supply and demand that lead it to be vulnerable.

Washington Watersheds' Supply and Demand – Detailed Results

Detailed results for individual WRIAs, including modeled historical and forecast water supply, and modeled historical and forecast water demand by type of use, are provided in the *Forecast Results for Individual WRIAs* section. For WRIAs with adopted instream flow rules, this section also includes detailed results on the magnitude and frequency of curtailment, as well as the impacts of curtailment on crop yields, now and in the future. And for WRIAs of particular interest for listed fish species, we include information on historical flows, using data that OCR has compiled, modeled future flow figures, reflecting expected flows by 2040 at the mouth of the tributary once agricultural and residential demands have been accounted for, and a summary of key life cycle stages for fish species of concerned, developed as part of the Washington Department of Fish and Wildlife's Columbia River Instream Atlas[23]. For all WRIAs in eastern Washington, we provide additional information on the management context, as well as a summary of which changes each WRIA is likely most vulnerable to, compared to other WRIAs in eastern Washington. 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). The intent of the *Forecast Results for Individual WRIAs* section is to provide more detailed information on the expected changes in water supplies and demands that can inform WRIA-specific water management decisions.

Water Supply Forecast for Washington's Aquifers

Groundwater sources are accessed from the surface at discrete locations, via wells, and may be hydraulically connected or compartmentalized vertically and horizontally to different degrees, depending on geological and other factors. To accurately represent our findings, and to discuss them in ways that are most relevant for management, we present our results mainly by aquifer layer (defined by Kahle et al. 2011[24], and representing the primary basalt aquifer layers in the Columbia Plateau Regional Aquifer System, or CPRAS). Within each CPRAS aquifer layer, we summarize

23 Scott, T., J. Kohr, R. Granger, A. Marshall, D. Gombert, M. Winkowski, E. Bosman Clark and S. Vigg. 2016. Columbia River Instream Atlas (CRIA), FY2016. A component of the Columbia River Basin 2016 Water Supply & Demand Forecast. November 9, 2016. Funded by Washington Office of the Columbia River, Department of Ecology. 98 Pages.

24 Kahle, S.C., Morgan, D.S., and Welch, W.B., 2011, Hydrogeologic framework and hydrologic budget components of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho: U.S. Geological Survey Scientific Investigations Report 2011-5124, 66 p., http://pubs.usgs.gov/sir/2011/5124/

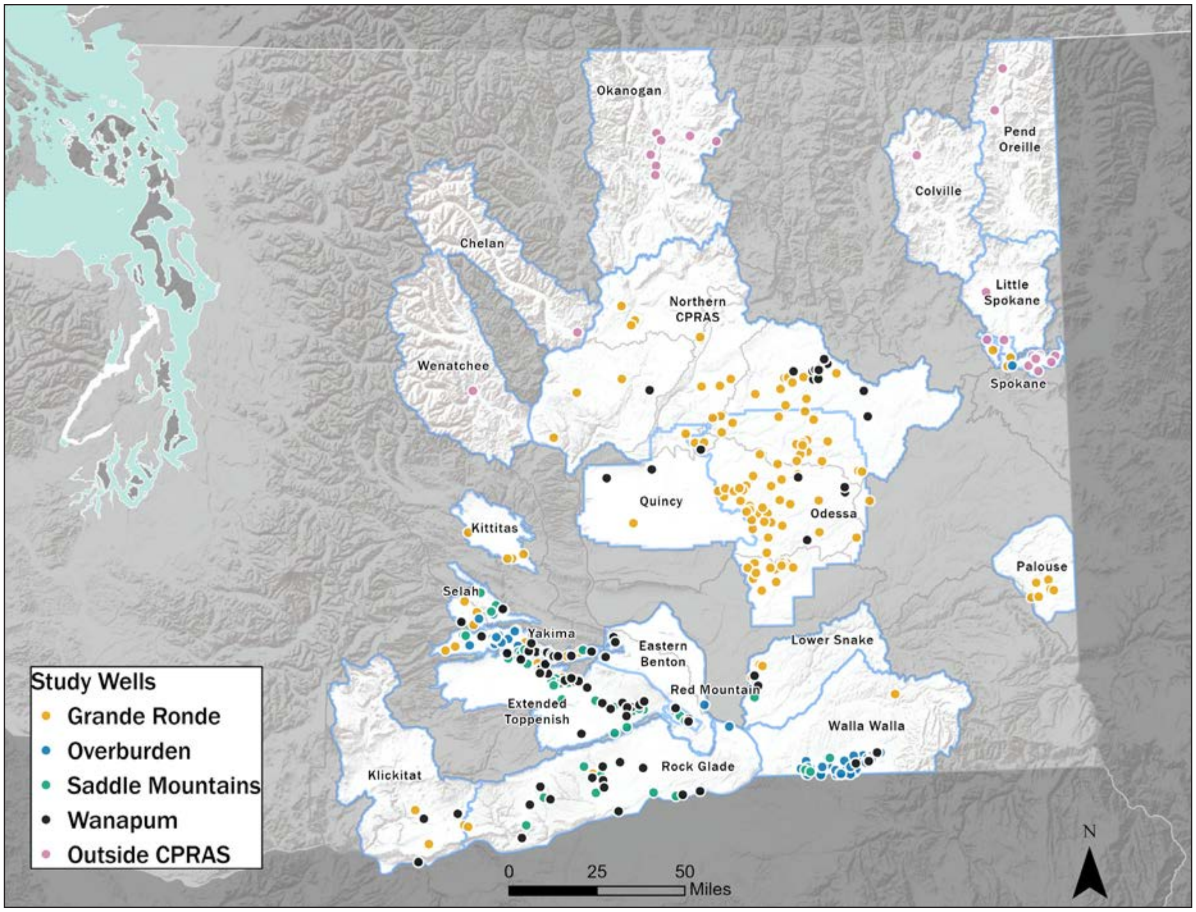

Figure 35. Washington's Aquifers geographic scope, showing the distribution of well locations (circles) used in the groundwater trends analysis. The colors of each well location show which aquifer layer the well accesses if within the Columbia Plateau Regional Aquifer System (CPRAS), or whether the well accesses a source of groundwater outside of the CPRAS.

information from individual wells accessing that layer within subareas across eastern Washington (Figure 35). Some of the subareas we evaluated are outside of the CPRAS domain ("Outside CPRAS"), where detailed hydrogeological studies are either unavailable or limited in extent in comparison to the CPRAS.

Trends in groundwater levels over the last 20 years were predominantly declining across eastern Washington and across all four aquifer layers considered. Groundwater levels are declining due to a combination of overpumping and natural factors, such as decreased replenishment during drought. The specifics of these declines, however, vary by aquifer layer, sometimes even across neighboring wells that access those different aquifer layers. In the Northern CPRAS and Odessa subareas, the declines are more severe in the Grande Ronde than the Wanapum aquifer layers. In the Rock-Glade subarea, the declines are most severe in the Wanapum, followed by the Grande Ronde and then the Overburden, but groundwater levels are increasing in the Saddle Mountains aquifer layer. In the Yakima subarea, the declines are similarly severe in the Wanapum and Grande Ronde aquifer layers. They are least severe in the Overburden aquifer layer. The layers observing the most severe declines also tend to correspond with the most heavily pumped layers in each subarea.

Trends in Groundwater Levels

We analyzed trends in groundwater levels from 2000 to 2020 for individual wells, each associated with the particular aquifer layer it accesses. Where we had at least three wells in a subarea, we interpolated trends within each subarea and aquifer layer.

Overall, the analysis highlighted the complexity of groundwater dynamics in the region, where the steepness of declines in groundwater vary within and across subareas, and among aquifer layers, sometimes showing locally positive trends in close proximity to steep declines. Specifically, we found that:

- The most spatially extensive declines are occurring in the Grande Ronde aquifer layer in the Odessa Subarea, where water levels have declined, on average, at a rate of-3.6 (± 2.5) ft per year (Figure 36).
- The steepest declines have occurred in the greater Yakima area (Eastern Benton [-7.0 ± 0.4 ft per year] and Yakima [-4.2 ± 3.2 ft per year] subareas), and in the Rock-Glade subarea (-5.3 ± 4.4 ft per year), all in the Wanapum aquifer layer (Figure 37). The Extended Toppenish subarea also has steepest declines in the Grande Ronde aquifer layer but there is insufficient data to determine whether the trend is statistically significant. The declines in the Yakima subarea primarily occur in the Black Rock-Moxee Area, those in the Extended Toppenish occur primarily in the southwest flank of Rattlesnake Hills and those in Rock-Glade occur in Horse Heaven Hills, three groundwater hotspots highlighted in the 2016 Forecast.
- There are barriers, such as geologic faults and folds, that restrict horizontal groundwater flow and further compartmentalize aquifers within some subareas including the Yakima and Rock-Glade subareas (Kirk and Mackie, 1993[25]; Packard et al., 1996[26]). This compartmentalization leads to variability in trend analysis results across these subareas. The Rock-Glade WRIA (31) had the widest range of trend values across the different aquifer layers, due to this compartmentalization from faults. This range includes an average positive trend in the Saddle Mountain aquifer layer.
- The Overburden aquifer in the Spokane subarea showed positive trends, on average. While this subarea has passive aquifer recharge projects, these results are insufficient to explicitly link the positive trends with these projects.

These results are based on statistically significant trends from 237 wells, whereas the remaining 429 wells' trends were not statistically significant, which means we were unable to distinguish, with the data available, whether a trend exists. However, the 237 statistically significant trends show a clear pattern of mainly declines in groundwater levels. Options available to mitigate these declining levels vary by aquifer layer. In general, the opportunity to deepen wells depends on whether underlying aquifers have similar declining trends and whether the water quality remains adequate at deeper levels. Managed aquifer recharge projects are most readily implemented in the Overburden aquifer layer; however, this is not where the majority of the declines are occurring. As aquifer storage and recovery (ASR) projects are implemented more widely, aquifer recharge will likely become a more viable mitigation measure in the deeper layers as well. Such ASR projects have thus far been implemented largely at the municipal level.

Future Changes in Available Saturated Thickness

The vulnerability of a particular groundwater source is not only dependent on the rate of decline, but also depends on how much saturated thickness is still available in the aquifer layer. Available saturated thickness indicates how far water levels can decline before they drop below a pump's intake, which is dependent on how deep the pump intakes are installed (Figure 8). We explored the changes in available saturated thickness that would be expected in each aquifer layer and groundwater subarea should the trends in groundwater levels that we quantified continue through 2040. We used the statistically significant trends to evaluate declines in available saturated thickness. We averaged those trends by subarea if a minimum of three wells with significant trends were present. We considered declines of 25% in available saturated thickness as representing a threshold beyond which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use. **Our projections highlighted that the subareas with the largest percent change in available saturated thickness by 2040 are the Okanogan outside the CPRAS (~50%) and the Walla Walla in the Overburden layer (~50%)**.

An alternative way to explore groundwater vulnerabilities is to calculate over what time period a particular location experiencing declining groundwater levels is expected to lose a certain proportion of its available saturated thickness. We calculated the number of years until a subarea reached the three thresholds described above: 25%, 50%, and 75% decline in available saturated thickness. The results suggest that:

25 Kirk, T. K., and T. L. Mackie, 1993, Black Rock – Moxee Groundwater Study, Washington State Department of Ecology Open File Technical Report 93-1, January, 1993.

26 Packard, Hansen, and Bauer, 1996, Hydrogeology and Simulation of Flow and the Effects of Development Alternatives on the Basalt Aquifers of the Horse Heaven Hills, South-Central Washington, U.S. Geological Survey, Water-Resources Investigation Report 94-4068.

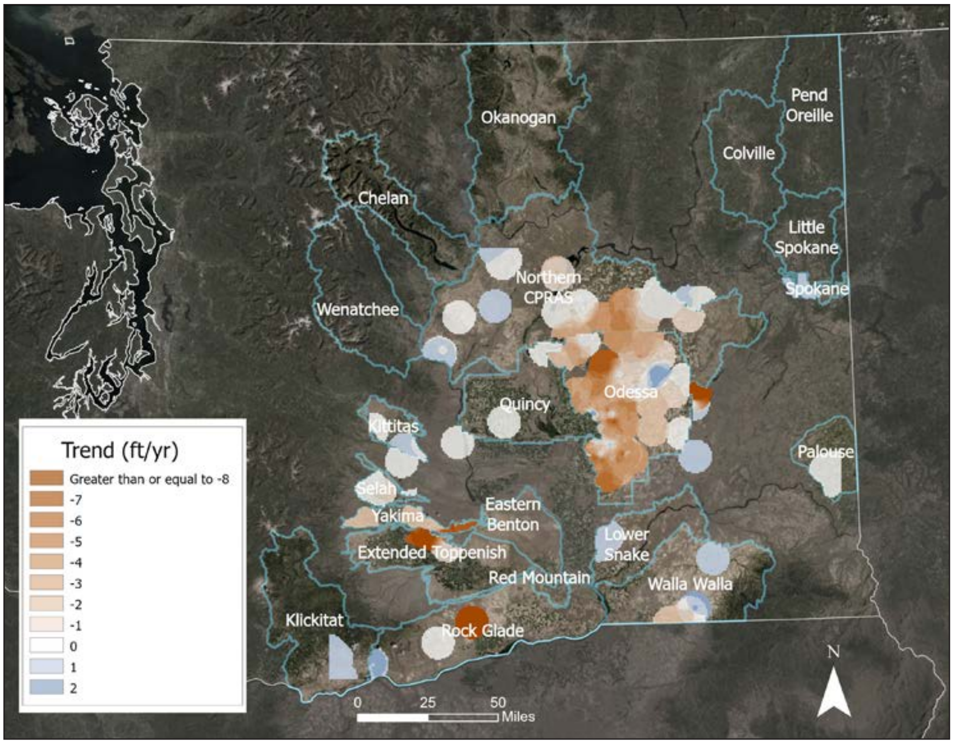

Figure 36. Interpolated trends in groundwater levels in the Grande Ronde Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells (for further details see the Grande Ronde pages in the Forecast Results for Aquifer Layers *section). Areas that do not have interpolated shading lacked adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.*

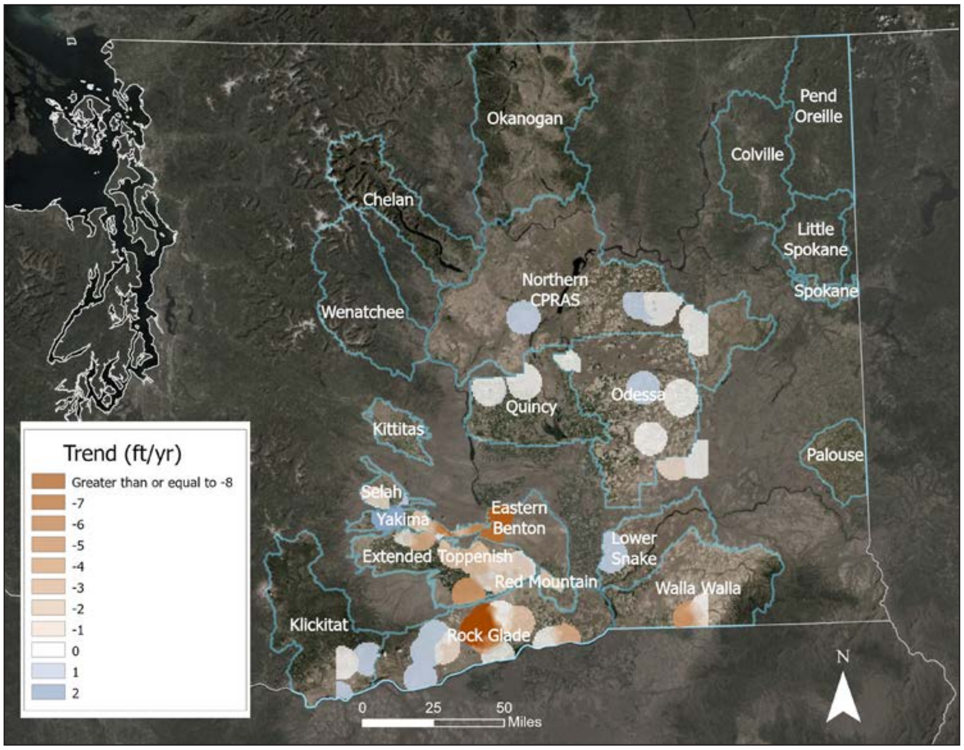

Figure 37. Interpolated trends in groundwater levels in the Wanapum Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells (for further details see the Wanapum pages in the Forecast Results for Aquifer Layers *section). Areas that do not have interpolated shading lacked adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.*

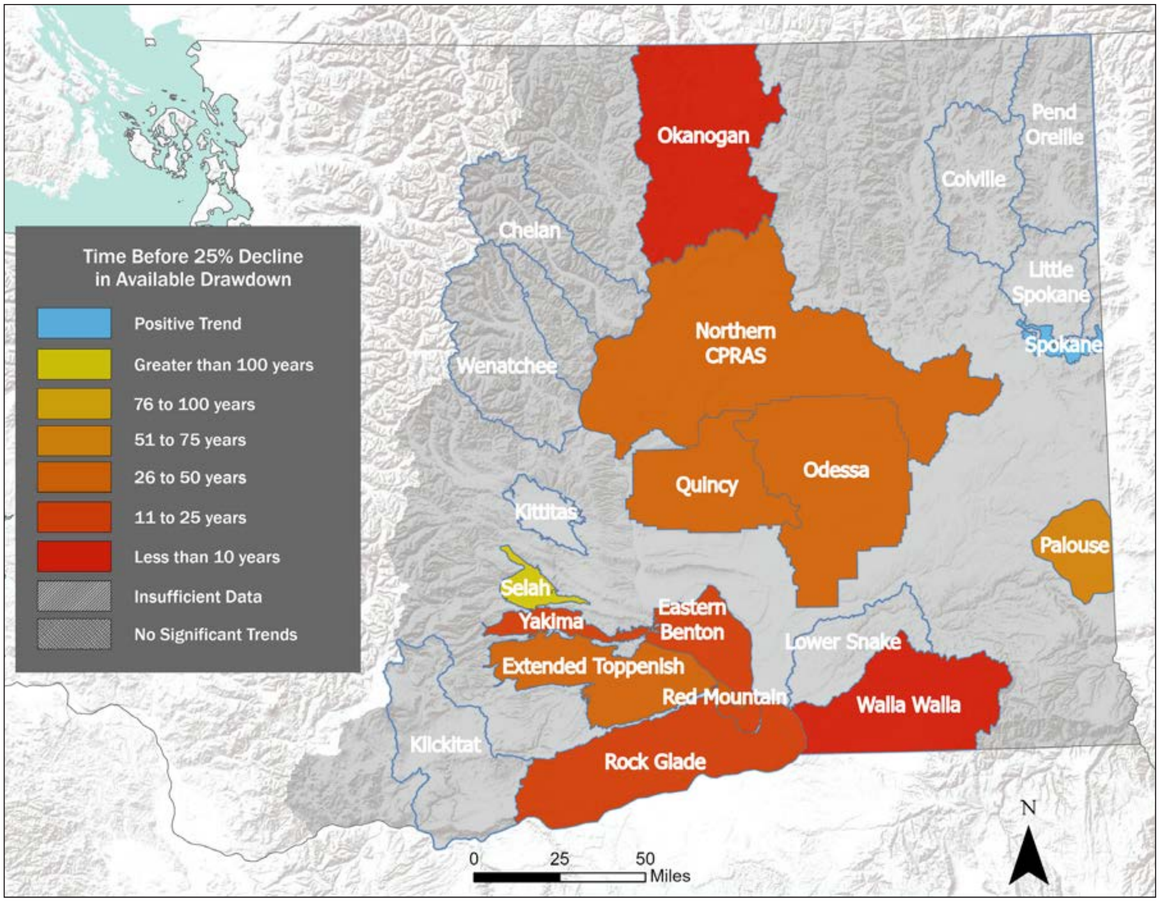

Figure 38. *Time (in years) until the average available saturated thickness has declined by 25% in at least one aquifer layer in each groundwater subarea. These times are based on declines in available saturated thickness in different aquifer layers, as we show the most vulnerable aquifer layer for each subarea; that is, the time until 25% decline in available saturated thickness may reflect the vulnerability related to declines in the Grande Ronde layer for some subareas, for the Wanapum layer for other subareas, and the Overburden layer for other subareas (for more details see the* Forecast Results for Aquifer Layers *section).*

- The Walla Walla subarea in the Overburden aquifer and the Okanogan subarea are expected to have the shortest time to 25% decline, 10 years (Figure 38). The short time period is due mainly to relatively shallow available saturated thickness in these two subareas (40 ft and 30 ft, respectively, in 2020; note that for the Walla Walla, this is less than in other subareas in the Overburden).
- The Rock-Glade and Eastern Benton subareas in the Wanapum aquifer layer also have short timeframes before experiencing 25% declines: 20 years (Figure 38). In this case, the short time frame is due mainly to having the steepest average declining trends, while the 30 years to 25% decline for the Quincy subarea in the Wanapum is due to it having the shallowest available saturated thickness of any layer and any subarea.
- The Northern CPRAS and Odessa subareas in the Grande Ronde aquifer are expected to experience a 25% decline within 40 years (Figure 38). This timeframe was calculated without explicit incorporation of the ongoing Groundwater Replacement Program. Modeling work is required, however, to more fully understand the impacts of the Groundwater Replacement Program in offsetting the current declines in the Odessa subarea.

We did not evaluate changes in available saturated thickness in the Spokane subarea for any aquifer layers and in the Rock-Glade subarea in the Saddle Mountain aquifer layer, as these are the only regions where the trends analysis found positive trends in groundwater levels, on average.

Vulnerabilities Across Washington's Aquifers

The vulnerabilities exposed by the groundwater trends analyses lead to an important conclusion: the overlap between decreasing supplies and increasing demands occurs frequently across eastern Washington. Many groundwater subareas can be considered vulnerable, yet each of those subareas will face unique challenges due to the particular combination of changes in water supply and demand that it is expected to experience, and by when. For example, the Okanogan (WRIA 49) and the Walla Walla (32) are expected to see significant reductions in available saturated thickness within 10 years, which in the Okanogan overlap with significant increases in agricultural water demand. On the other hand, Rock-Glade (31) is expected to see decreases in agricultural water demand, but is expected to experience important increases in residential consumptive water use, while potentially seeing opposing trends in wells accessing the Wanapum and Saddle Mountain layers (negative and positive, respectively). Similarly, the Odessa and Yakima subareas likely will not see increases in agricultural water demand, but have some of the largest residential water users, and are expected to see some of the largest increases in residential consumptive use (particularly the Odessa subarea).

The geographical overlap of areas identified as vulnerable to future changes in surface water supply and that are also identified as vulnerable to future groundwater declines, which is also fairly consistent across all aquifer layers, suggests that finding opportunities to prepare for and mitigate the impacts of these future changes needs to explore options other than finding alternative water supplies.

Washington's Aquifers – Detailed Results

Detailed groundwater results are provided in the *Forecast Results for Aquifer Layers* section. For each subarea within each aquifer layer this section includes details on the direction and magnitude of the trend in groundwater levels (in feet per year), the current available saturated thickness, the expected change in available saturated thickness by 2040, and the timeframes by when each subarea will experience 25%, 50%, and 75% declines in available saturated thickness. This section also includes guidance on how to read and interpret these aquifer- and subarea-specific results (see the *How to Read the Aquifer's Results* guide).

Water Supply and Demand Forecast for Washington's Columbia River Mainstem

Flows on the Columbia River Mainstem within Washington State (Figure 39) 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, recreation opportunities, and water for out-of-stream uses—dominated by agriculture—in proximity to the river.

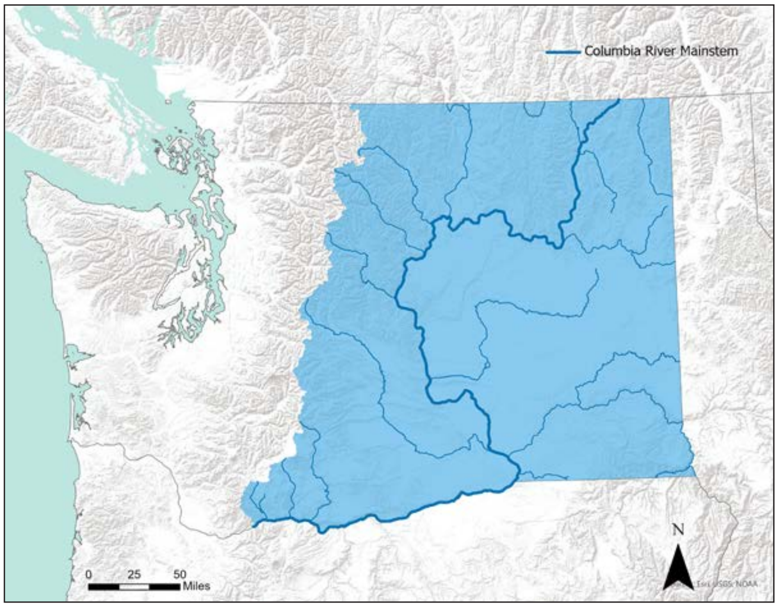

Figure 39. *Washington's Columbia River Mainstem geographic scope.*

Agricultural Water Demand

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 proportion of WRIA-level agricultural water demand was close enough to the Columbia River Mainstem to possibly be supplied by the Mainstem, a corridor on each side of the Columbia River was explored, based on OCR's guidance[27]. Though commonly called the "one-mile corridor," the distance from the Columbia River Mainstem actually varies from the standard one mile, depending on the local geological conditions adjacent to the river. The intent of this corridor is to include water uses that are likely to be hydraulically connected to the Mainstem. The Forecast found that **the overall pattern of agricultural water demand within the one-mile**

27 RCW 90.90.050(2)(a) https://app.leg.wa.gov/rcw/default.aspx?cite=90.90.050

corridor is similar to that of the rest of eastern Washington, with small declines expected in agricultural water demand by 2040. Specifically:

- Both historically and in the future (2040), the majority of the agricultural water demand occurring within the one-mile corridor is concentrated in five WRIAs: Rock-Glade (WRIA 31), Lower Snake (33), Esquatzel Coulee (36), Moses Coulee (44) and Foster (50) (Table 13).
- Three WRIAs have over 50% of their agricultural water demand concentrated within this one-mile corridor: Moses Coulee (WRIA 44), Foster (50) and Upper Lake Roosevelt (61), though note that Upper Lake Roosevelt has among the smallest acreage in the one-mile corridor (Table 13).

		Modeled WRIA agricultural water demand	Modeled agricultural water demand within one mile of the Columbia River Mainstem	Change by 2040 in the proportion of agricultural demand within one mile of the Columbia River Mainstem, under alternative scenarios		
WRIA	WRIA Name	Historical (1986-2015) (ac-ft/year)	Historical (1986-2015) (ac-ft/year)	Climate change only	Climate change + earlier planting date	Climate change + earlier planting date + future crop mix
29	Wind-White Salmon	6,328	383	0%	0%	0%
30	Klickitat	23,731	1,862	-1%	-1%	-1%
31	Rock-Glade	216,490	*23,356*	0%	0%	0%
32	Walla Walla	95,962	4,202	0%	0%	0%
33	Lower Snake	98,821	*26,896*	0%	0%	1%
36	Esquatzel Coulee	483,629	*21,327*	0%	0%	0%
37	Lower Yakima	642,926	176	0%	0%	0%
40	Alkali-Squilchuck	19,155	7,214	-1%	-1%	-1%
41	Lower Crab	809,248	3,515	0%	0%	0%
44	Moses Coulee	39,926	***21,632***	0%	1%	0%
45	Wenatchee	22,907	349	0%	0%	0%
46	Entiat	3,811	1,110	0%	0%	0%
47	Chelan	20,496	5,487	0%	0%	0%
48	Methow	12,377	2,335	-1%	-1%	-1%
49	Okanogan	83,458	7,255	-1%	-1%	-1%
50	Foster	26,955	***20,586***	0%	0%	0%
51	Nespelem	623	33	0%	0%	0%
53	Lower Lake Roosevelt	2,022	973	1%	1%	1%
58	Middle Lake Roosevelt	2,373	833	0%	0%	0%
61	Upper Lake Roosevelt	417	**250**	**-2%**	**-2%**	**-1%**

Table 13. *WRIA-level agricultural water demand occurring within a one-mile corridor of the Columbia River Mainstem in Washington, historically and in the future (2040). Change in the agricultural demand in each WRIA that occurs within the one-mile corridor under three different management scenarios (future climate only; future climate + earlier planting date; future climate + earlier planting date + future crop mix). Numbers in italics highlight the WRIAs which contribute most to agricultural demand within the one mile corridor; numbers in bold emphasize the patterns discussed in the text. Only WRIAs adjacent to the Columbia River Mainstem in Washington are shown.*

- Climate change impacts on agricultural water demand within the one-mile corridor appear to be similar to the impacts discussed for Washington's watersheds. Upper Lake Roosevelt (61) is expected to see a-2% decline in the proportion of the agricultural water demand within the one-mile corridor under some future management scenarios, and all other watersheds are expected to see changes in this proportion of 1% (increase or decrease) or less (Table 13).
- The slight changes in the proportion of agricultural water demand expected in the future (2040) remain stable for the scenarios that also considered changes in agricultural production (earlier planting dates and changes in crop mix) (Table 13).

Overall, our results suggest that the patterns of expected change near the Mainstem will be very similar to patterns of change in each WRIA as a whole. The difference for the one-mile corridor lies in whether the proximity to the Columbia River Mainstem provides additional opportunities for adapting to the changes in water supply expected in the future, and the consequent vulnerabilities.

Instream Water Demand for Fish

The Columbia River is home to multiple species of salmonids listed under the Endangered Species Act (ESA). We explored changes in regulated water supply along the Columbia River Mainstem to identify locations and times when fish might be vulnerable to climate-driven changes in water supply. We used the adopted state (WA ISF) and federal (BiOP) instream flows to represent instream water demands to fulfill the needs of fish species, and determined whether historical (1986-2015) and future (2040 and 2070) water supplies are sufficient to meet those flow requirements, even before all other water demands are accounted for. On a month-to-month basis, modeled **historical and forecasted (regulated) surface water supplies under *average* supply conditions prior to meeting out-of-stream demands were generally sufficient to meet instream flow targets along the Mainstem (with some exceptions), though the patterns of change are concerning** (Figure 40):

- Historically (1986-2015), modeled water supplies at Priest Rapids and McNary Dams would not meet WA ISF targets in August, nor BiOp targets in April, during low (20th percentile) or median (50th percentile) supply years.
- Modeled historical water supplies at Priest Rapids would not meet WA ISF targets in November even in high supply (80th percentile) years. During low supply years, supplies would barely meet targets the rest of the winter, through March, nor the BiOp targets in April and May.
- Modeled historical water supplies at Bonneville Dam would not meet BiOp targets even under high supply conditions in November, and under low supply conditions, these targets would not be met through February.
- By 2040, modeled results suggest that the deficits worsen in July and August. At Priest Rapids and McNary Dams at least one of the flow targets is not met in median supply years in either month, and not even in high supply years in August. At Bonneville, deficits also worsen in the summer, with supplies not being sufficient to meet the BiOp targets in August in median supply years.
- These patterns of unmet flow targets in late summer are expected to persist, and potentially increase slightly, through 2070, where low supply year supplies are also not expected to be sufficient to meet flow targets at Priest Rapids or McNary Dams in June.
- By 2040, increasing water supply in the spring, on the other hand, is expected to improve spring conditions. Water supply is expected to be sufficient to meet WA ISF targets in March at Priest Rapids even under low supply conditions. It is also expected to meet BiOp targets under median supply conditions at Priest Rapids and McNary in April, and even in May at McNary.
- By 2070, spring water supply is expected to be sufficient to meet targets under all supply conditions at all three locations, with the possible exception of meeting BiOp targets in April at McNary.

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. Even though we made this comparison using water supplies ***before*** any out-of-stream demands are accounted for, the changes observed highlight how the shifting of supply to earlier in the spring could worsen the Mainstem's ability to meet instream flow targets in July and August, but could also improve conditions in April and May. This analysis also provides the foundation and complements the findings discussed in the *Instream Flow Deficits along the Columbia River Mainstem* section, below, where out-of-stream demands ***are*** accounted for.

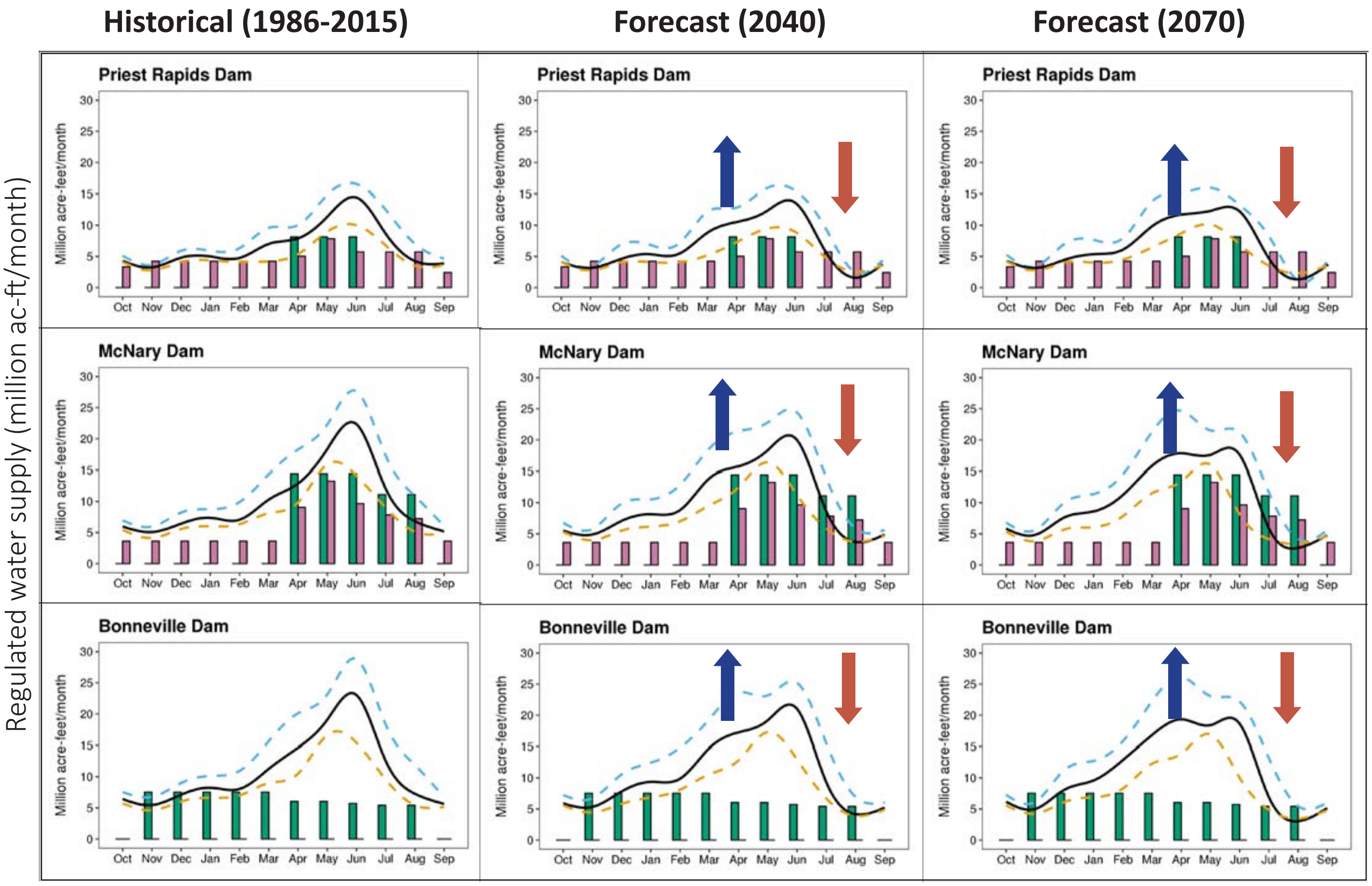

Figure 40. Historical (1986-2015: left column) and forecast (2040: center column; and 2070: right column) regulated surface water supply at Priest Rapids (top row), McNary (center row) and Bonneville (bottom row) Dams for low (20th percentile), median (50th percentile), and high (80th percentile) supply years, averaged across 34 climate change scenarios. Supplies presented are prior to accounting for out-of-stream demands. Also shown are the Washington State instream flow (WA ISF) and federal Biological Opinion (BiOp) flow targets (bars). The brown arrows show where future changes are worsening the Mainstem's ability to meet flow targets, while the blue arrows show where future changes are improving conditions.

Instream Flow Deficits

We estimated the frequency of instream flow deficits along the Columbia River Mainstem by comparing modeled water supplies to their ability to meet regulatory flow targets once out-of-stream demands were accounted for. These estimates were not conditional on whether the threshold of expected supply, as forecast each year on March 1 for March through September, was less than 60 million acre-feet at The Dalles Dam. This is the threshold that would trigger curtailment decisions, and it is calculated based on Ensemble Streamflow Forecasts from the Northwest River Forecasts. Given that this methodology is not part of our integrated modeling framework, and given that our existing methodology does not have an accurate equivalent seasonal expected supply metric, we decided to focus on describing projected changes in the expected deficits in meeting regulatory flow rules given modeled water supplies and demands every year.

Similar to the modeled curtailment results obtained for WRIAs with adopted instream flow rules (see the *Curtailments for WRIAs with Adopted Instream Flow Rules* section, above), modeled results for the different locations along the Columbia River Mainstem suggest that **instream flow deficits could occur much more frequently by 2040 under some scenarios at all locations, mainly during the main portion of the irrigation season.** Instream flow deficits

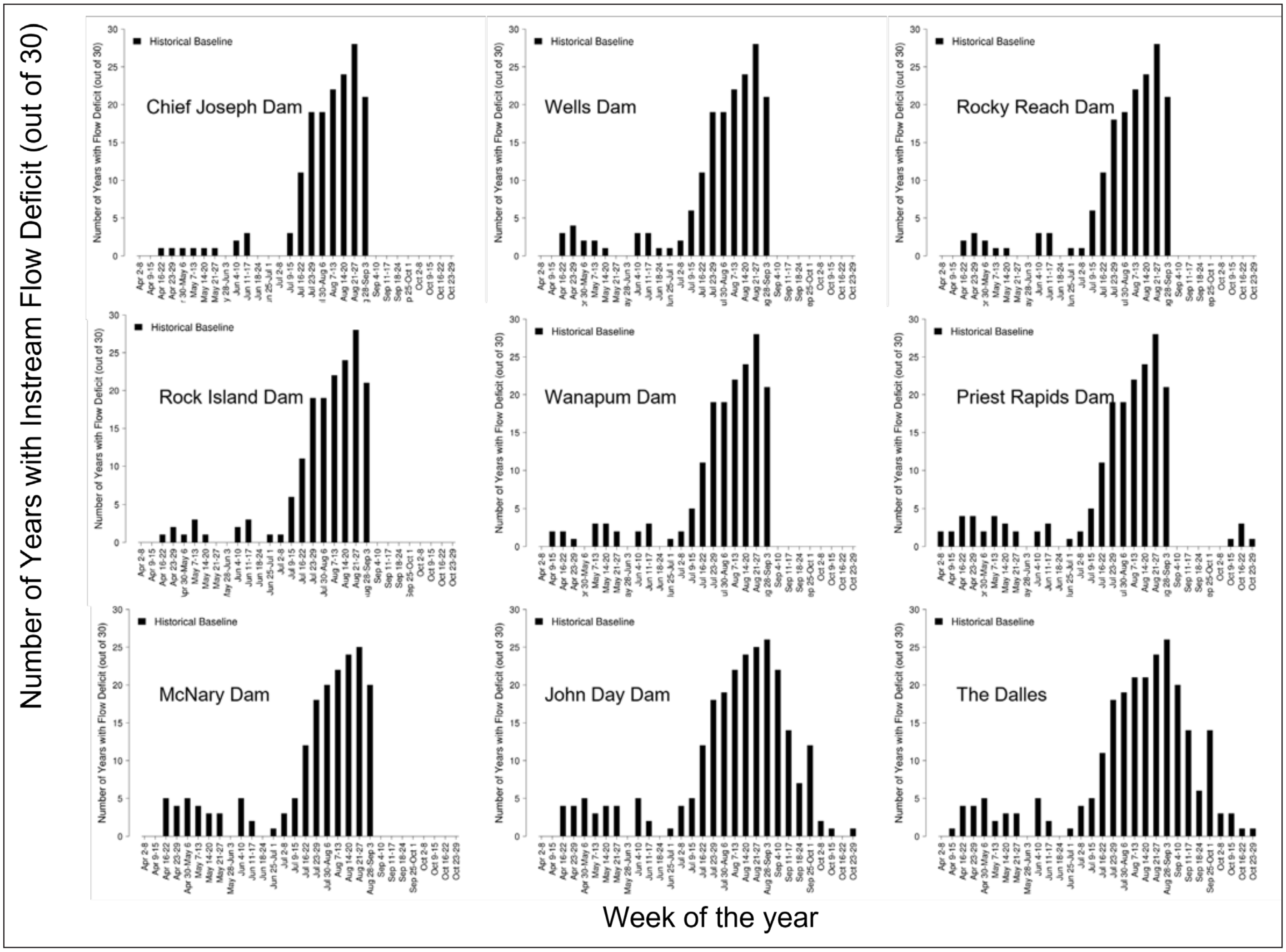

Figure 41. *Modeled historical (1986-2015) frequency of instream flow deficits (quantified as the number of years out of 30 years) at nine locations along the Columbia River Mainstem. The frequency of instream flow deficits was calculated on a weekly basis. These estimates were not conditional on whether the threshold of expected supply that would trigger curtailment decisions on the Mainstem (March through September supply forecast on March 1 to be less than 60 million acre-feet at The Dalles Dam) was reached.*

in late July could increase in frequency from 16 out of 30 years historically to 24 out of 30 years, while in August they could increase from 23 out of 30 years to 30 years out of 30 for most control points along the Columbia River Mainstem (Figures 41 and 42). Smaller increases in the number of years with flow deficits are expected in the earlier and later portions of the irrigation season (through early July, and late August and September, respectively), and smaller decreases (rarely greater than 5 additional years out of 30) are forecast for April and May for most locations, particularly those further downstream (Figure 42). One notable difference across locations is that the furthest downstream locations modeled, John Day and The Dalles Dams, may experience small increases in the frequency of instream flow deficits by 2040 well into October, an increase that is not expected at the locations further upstream (Figure 42).

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 (see *Forecast Limitations* section).

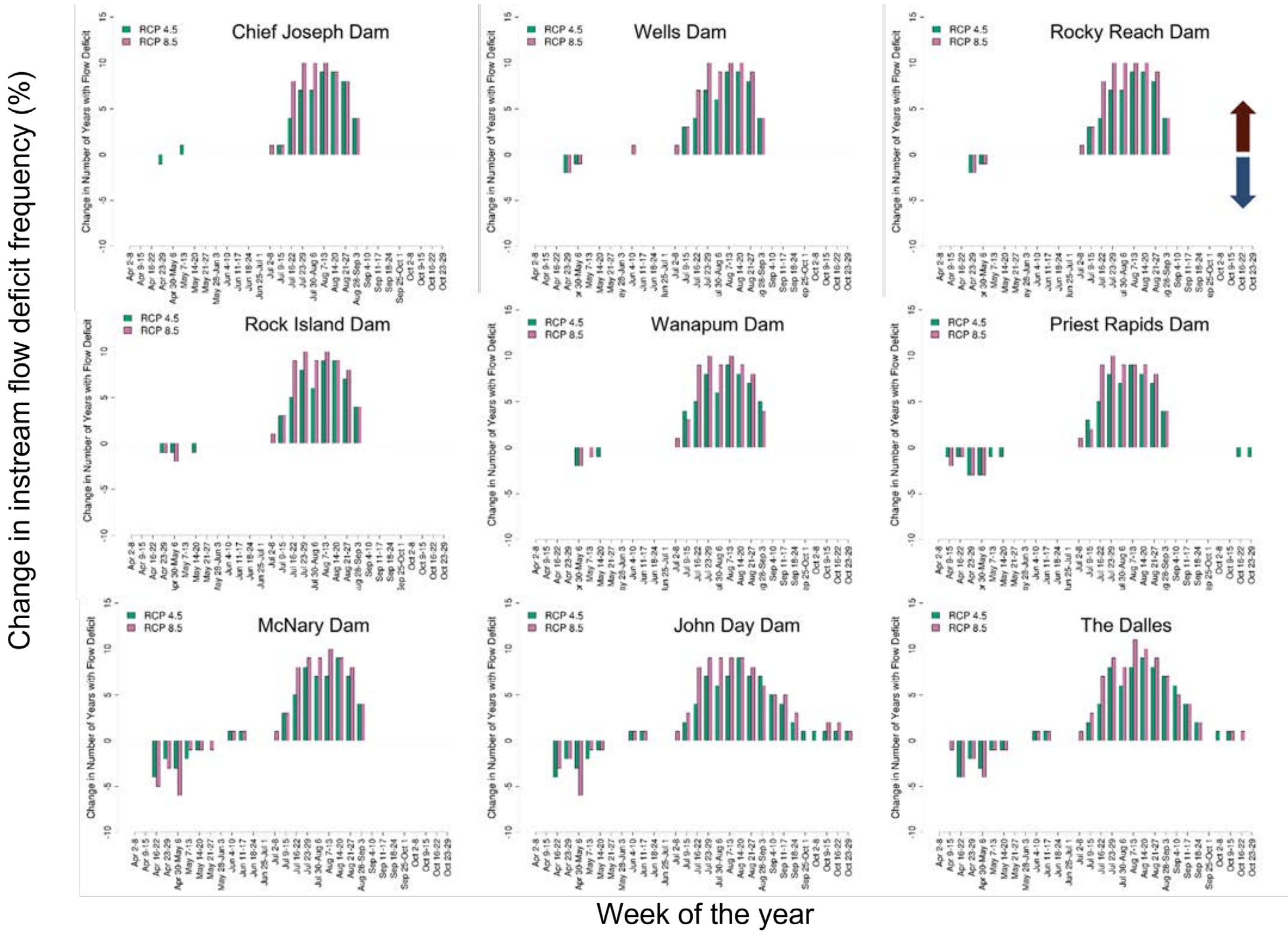

Figure 42. Change in expected frequency of instream flow deficits (quantified as the difference in number of years out of 30 years) between historical (1986-2015) and forecast (2040) time periods at nine locations along the Columbia River Mainstem. Results are shown for two different greenhouse gas emissions scenarios (RCP 4.5 and RCP 8.5) and reflect the median change expected when 17 climate change scenarios are explored under each emissions scenario. The frequency of instream flow deficits was calculated on a weekly basis. Values above the zero line reflect increases in frequency of instream flow deficits (brown arrow), and values below the zero line reflect decreases in frequency (blue arrow).

Vulnerabilities Along Washington's Columbia River Mainstem

Vulnerabilities in water availability in the Columbia River Mainstem mirror those discussed for the Basin as a whole, and for Washington's watersheds: they occur when decreasing water supplies converge in time and space with increasing water demands. In the case of the Mainstem, this convergence occurs primarily, and fairly consistently, during July and August, where decreases in water supplies overlap with increasing agricultural and residential water demands. This convergence is reflected in the expected increase in frequency of instream flow deficits all along the Columbia River Mainstem, an increase that could reach as much as 33% (10 additional years, out of 30) by 2040. It is worth noting that the flow targets used to represent the needs of fish can also be relatively high during these months as well (for example, see McNary Dam in Figure 40).

CONCLUSION

This 2021 Forecast confirms the findings of the 2016 Forecast and improves our understanding of expected changes in future surface and groundwater supplies and instream and out-of-stream demands. Though we cannot answer all questions related to water supply and demand in the Columbia River Basin, the improvements we have made have led to results that consistently and robustly highlight what changes we can expect. These results have re-affirmed the importance of understanding the impacts of climate change on the timing and location of water supply, and how the supply changes interact with changes in agricultural and residential water demands. The generally declining groundwater trends also re-affirm the need to pursue further integration of groundwater into future Forecasts, to better understand these interactions. These are the four main types of changes are leading to vulnerabilities across eastern Washington:

- **The timing of surface water supplies is shifting earlier in the season, especially in the snowmelt-dominated Cascades watersheds.** Driven by the increasing temperatures and more frequent climatic extremes expected by 2040, the early (wet) seasons are getting wetter and the late (dry) seasons are getting drier. In some watersheds, these changes are reflected between years, where supplies in dry years are decreasing and supplies in wet years are increasing.
- **Future changes in population and in agriculture in eastern Washington could lead to increases in instream and out-of-stream demands for water.** Though climate change alone could result in slight declines in agricultural water demand, population growth, trends in demands for electricity, and planned water development projects could lead to an overall increase in demands for water.
- **Groundwater levels are declining in most aquifer layers and groundwater subareas across eastern Washington,** due to a combination of overpumping and natural factors, such as decreased replenishment during drought. As with surface water supplies and demands, these declines are not uniform across the region. However, when compared to the available saturated thickness accessible to most wells, the majority of groundwater subareas are vulnerable due to declining groundwater levels. These declines will likely limit the options to meet demands by moving from surface water to groundwater sources. It may also increase the need to replace current groundwater sources with surface water in the future.
- **Local increases in out-of-stream demands are expected, converging with local decreases in water supply, such as in the Yakima River Basin.** Decreasing water supplies converge with increasing agricultural demand in the upper WRIAs (38 and 39), and with increases in summer residential demand in the Lower Yakima (37). The combination of lower supplies at critical times and locally increasing demands leads to increasing frequency of instream flow deficits and resulting prorationing or curtailments.

In summary, **where vulnerabilities due to changes in surface water supply exist, expected increases in demands will tend to make vulnerabilities more acute. In addition, these vulnerabilities will express themselves more obviously during low flow years, and in places that may already be experiencing declining groundwater levels.**

Given the patterns of water demand changes across eastern Washington, numerous watersheds will likely see their vulnerabilities heightened due to increased demand. **However, most watersheds are expected to experience either an increase in agricultural water demand or an increase in residential water demand.** Therefore, each watershed will have a rather unique combination of challenges to adapt to.

In addition to highlighting unique vulnerabilities across different watersheds, water availability will likely not be equally vulnerable throughout the year. With lower flows and higher demands in the summer months, and as water supplies shift earlier in the season, vulnerability will grow most notably in July and August. The expected increases in frequency of instream flow deficits and curtailment during July and August, though not limited to these months, are a reflection of the impacts of the changes in both water supplies and demands.

Our results highlight the complexity of factors at play in the Columbia River Basin. **Even if models are unable to predict what will actually happen by 2040, these results allow us to explore reasonable and plausible scenarios of change—in climate, in human responses, in management decisions, in regulations and policy.** In this way, the Forecast results can support insights and understanding relevant to water management that will help Washingtonians prepare for changes in water availability expected in the future.

We envision groups with diverse perspectives using the Forecast to understand what vulnerabilities are most acute, and which actions that can be taken are most likely to make a difference to sustainably meeting the region's water demands. Such actions will help maintain and enhance eastern Washington's economic, environmental, and cultural prosperity for the next 20 years and beyond.

Next Steps—Building Towards the 2026 Forecast

Each subsequent Forecast has incorporated improvements to provide a clearer, more accurate, and more robust understanding of expected changes to water supplies and demands in the Columbia River Basin, particularly in eastern Washington. The Legislature's mandate to update the Forecast again in 2026 will provide another opportunity to implement recommendations arising from what we have heard as we have shared the 2021 preliminary and final results, what we have learned so far, and where the critical gaps remain.

In preparation for the 2026 Forecast, OCR is considering a range of potential future improvements. These changes could target gaps in integration of groundwater dynamics, as well as remaining gaps in out-of-stream and instream water demands, further exploration of the effects of water scarcity, opportunities for informing policy and management, improvements in communicating results, and learning from past Forecasts. These potential action areas have been identified with input from interested parties during the June 2021 public comment period. Further refinement and prioritization of these areas will occur in cooperation with the Department of Ecology's Water Resources Program and local, state, federal, and tribal partners.

Integrating Groundwater into Water Supply Forecasting

A high priority improvement is to initiate groundwater modeling to produce forecasts of declining groundwater levels, capture surface-groundwater connectivity, and explore the effects of potential groundwater-related projects and regulation. This improvement may be piloted over an aquifer subarea where a groundwater model has already been implemented or is in development, such as the Columbia Plateau Regional Aquifer System, the Spokane Valley-Rathdrum Prairie, the Yakima Basin, or the Walla Walla watershed. Improvements may also include filling data gaps, such as developing more accurate estimates of the relative contribution of surface water vs. groundwater for irrigation and residential uses. Finally, there is a need to expand the database of groundwater level measurements and ensure these data are accessible and useable.

Improving Water Demand Forecasting

We continue to prioritize improved forecasting of both out-of-stream and instream water demands. Irrigation demands can be improved by capturing post-season demands from cover crops and additional in-season demands such as evaporative cooling. Furthermore, there is interest in a "what if" scenario-based approach that would allow us to examine the effect of changes in water use beyond those that current trends lead us to expect. For example, we could explore changes in crop mix in combination with changes in irrigation technology and other types of conservation. This approach could yield new insight into a broader range of potential changes in the consumptive use of water, and of the potential impacts of these changes.

While smaller in overall water use, residential water forecasting can be improved through detailed estimations of per capita water use, which would allow us to examine, for example, the effects of climate change on outdoor water use, or the effects of water conservation measures. There is also interest in accounting for commercial and industrial water use, which could be important.

Improvements in quantifying instream water demands would continue to be carried out in partnership with other agencies. For example, we plan to partner with and leverage the activities of the Washington Department of Fish and Wildlife and its collaborators to highlight the importance of instream demand and to quantify the impacts of climate change at scales and in ways that can inform decision making around changing vulnerabilities in both the tributaries and the Mainstem. This includes leveraging the work of the Instream Flow Advisory Group's Science Panel (Box 5), and examining potential changes in operations of the Columbia and Snake River dams. Also, coordination with Bonneville Power Authority and other power agencies could refine the hydropower demand assessment and improve integration with the water supply forecast.

Quantifying the Effects of Water Scarcity

Another priority is to continue to improve modeling of water rights interruption, such as more accurately capturing the March 1 interruption decision for the Mainstem, and incorporating junior to senior water calls into the analysis, an effort that was begun as a pilot study as part of the 2021 Forecast (see the *2021 Technical Supplement to the Long-Term Water Supply and Demand Forecast*). To do this, it will be important to improve water master and stream patrolmen records on water rights in areas curtailed by priority calls.

Improved estimates of the effects of water rights interruption, as well as estimates of scarcity due to declining groundwater levels, can be combined with modeling of farm-level responses to drought, which would improve our estimates of the impact of droughts at the farm level and our estimates of how much water is left instream. In addition to understanding the impacts of future droughts, we can explore "what if" scenarios, like, "What happens if droughts occur for two or three years in a row?" This is a different way of examining future climate vulnerability than the approach that has been used in the Forecast to date; instead of analyzing only what Global Climate Models are projecting into the future, we can construct various types of worst-case scenarios and search for thresholds past which impacts are unmanageable. This approach could then be used to explore what potential scenarios of management changes help to avoid or mitigate these impacts.

Informing Policy and Management

While the focus of each Forecast has been on estimating the impacts of climate change on water supply and demand, this modeling framework has strong potential for assessing changes in policy and management, such as changes in reservoir operations arising from the renegotiation of the Columbia River Treaty between the United States and Canada, the Columbia River Systems Operations Environmental Impact Statement, new federal Biological Opinions, and potential breaching of lower Snake River dams. We could also explore how different scenarios for an Upper Columbia River adjudication could influence instream and out-of-stream water demands, reservoir operations, and water rights interruption. Another option is to use the Forecast modeling framework to examine the implications of granting earlier season-of-use for irrigation water rights in response to climate warming and the potential for earlier planting dates. Other types of "what if" scenarios can be focused on exploring changes in policy related to water conservation, land use, and instream demand. Asking these types of "what if" questions is a powerful way to identify both vulnerabilities and solutions, a technique that can be given greater emphasis in future forecasts.

BOX 5

The Future of Instream Flows in Washington State: Science to Inform Policy

Washington's rivers and streams will be stressed by changing climate conditions, and by demands of a growing human population. In 2020, the Washington Department of Fish and Wildlife and the University of Washington Puget Sound Institute formed an Instream Flow Advisory Group to address how Washington will manage and protect instream habitat and water levels, such that instream biota can thrive over the long term. The Group is comprised of representatives from two universities, federal, state, county, and tribal entities, along with key state policy partners. Aiming to inform water policy development in the 2022 State legislative session, the Advisory Group convened a Science Panel of experts to summarize what is known – and what needs to be known – about how these stressors are likely to affect future instream water availability for fish and wildlife in the 21st century.

Supported by the Advisory Group, the Science Panel is addressing the following topics:

1. Characterize the critical stressors that Washington state must address in meeting water needs for people, fish, and wildlife; list anticipated changes associated with those stressors, and describe how those stressors will affect future instream water for fish, wildlife, and people.
2. Identify important scientific knowledge gaps and uncertainties attendant to ensuring sufficient water for fish, wildlife, and people and propose research/monitoring approaches deemed critical for effectively addressing future challenges associated with Washington State water use, and protection of instream water.

The intent is to bridge the widely recognized but rarely spanned 'science-policy gap' via an interactive process that better informs policy makers of relevant science, and helps scientists contribute more effectively to evidence-based policy. Results will be synthesized in a report with supporting materials due out in fall of 2021.

The Forecast could also inform policy and management through combining this framework with other tools. One example is to integrate remotely-sensed monitoring of evapotranspiration (called METRIC) to more accurately represent consumptive use, which can improve not only out-of-stream water demand estimates but could also be used for real-time consumptive use monitoring. Initial groundwork for incorporating METRIC was laid in the 2016 Forecast; the next step would be to expand this method to the WRIA scale using a case study approach.

Improving Usefulness

For future Forecasts, it is critical to better understand the extent to which we are meeting the information needs that exist in ways that inform water management and policy decisions. While working with various state agencies and other partners, some questions have arisen such as: How do we best portray surface water supply (with or without out-of-stream demands removed)? How do we quantify water supply and demand for WRIAs that cross state boundaries? Therefore, we propose using surveys and other instruments to more systematically understand these communication gaps, so we can provide more directly usable information in future Forecasts.

Evaluating Assumptions

In 2026, it will have been twenty years since the Department of Ecology's Office of Columbia River was established and the first Long-Term Forecast was completed in 2006. This poses an opportunity to learn about the validity of assumptions made by comparing forecasted water and supply values to present day values. Methodologies have changed considerably over the years, which can complicate such comparisons. For example, the 2006 Forecast completed by Golder Associates, Anchor Environmental, and WSU researchers did not consider the impacts of climate change on water supply and demand, whereas all later forecasts used integrated computational modeling to quantify these impacts. Nevertheless, as we develop the scope and methodology for the 2026 Forecast, we could explore options for improving our assumptions by examining historical trends starting with the 2006 Forecast.

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How to Read the WRIA's Results

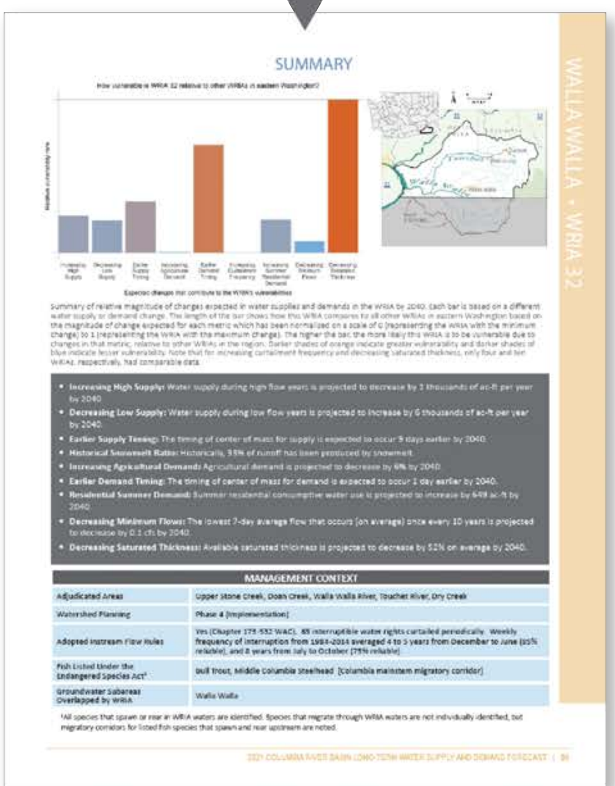
WRIA Summary Figure shows each WRIA rank compared to other WRIAs in terms of key vulnerability metrics. Higher bars indicate higher vulnerability relative to the other eastern Washington WRIAs. Some metrics are not available for all WRIAs, leading to those WRIAs not having a particular bar. The metrics reflect expected changes in water supplies and demands and are discussed in the *Water Supply & Demand Forecast for Washington's Watersheds and for Washington's Aquifers* sections.

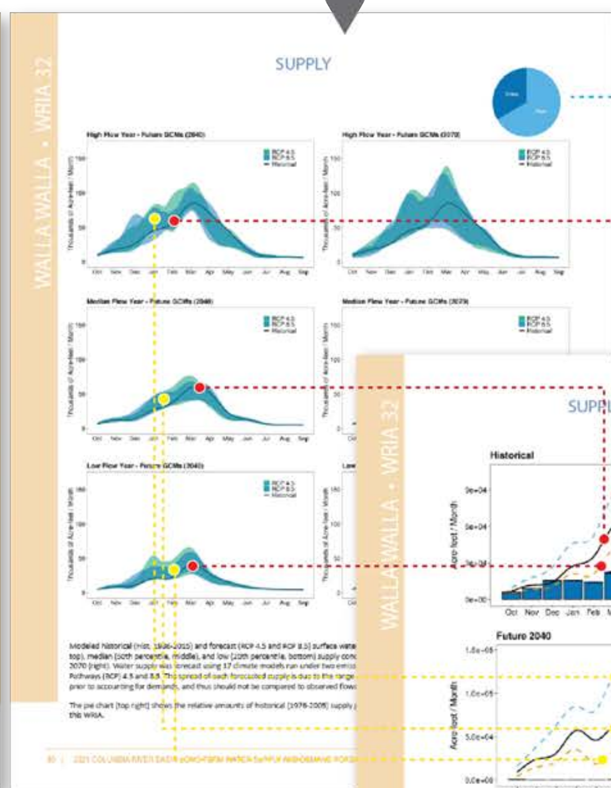
WRIA Text Box gives values for each of the key vulnerabilities shown in the WRIA Summary Figure.

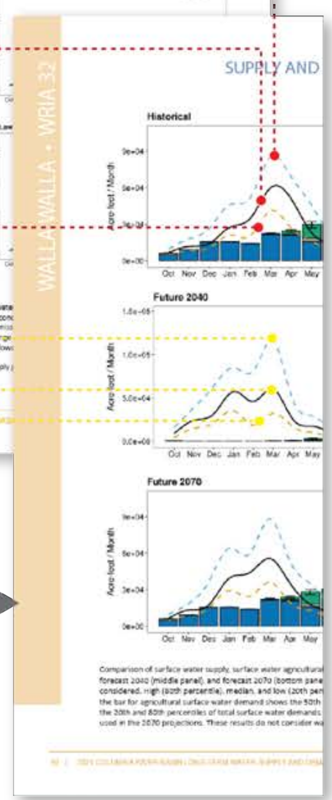
Management Context describes the regulatory and planning context of the specific WRIA.

Modeled Historical and Forecast Surface Water Supply shows how much water is available in the WRIA each month, prior to accounting for demands. Supplies are forecast through 2040 on the left, and through 2070 on the right. Both time frames are compared to the historical timeframe. The three panels for each future timeframe 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 1986-2015 climate data (black line); (2) Projected future water supply under a moderate climate change scenario (green ribbon); and (3) Projected future water supply under a more severe climate change scenario (blue ribbon). The range shown by the ribbons reflects the spread of the 17 different climate models used in the forecast.

The pie chart shows the relative amounts of supply generated from snow (dark blue) and rain (light blue) within the WRIA.

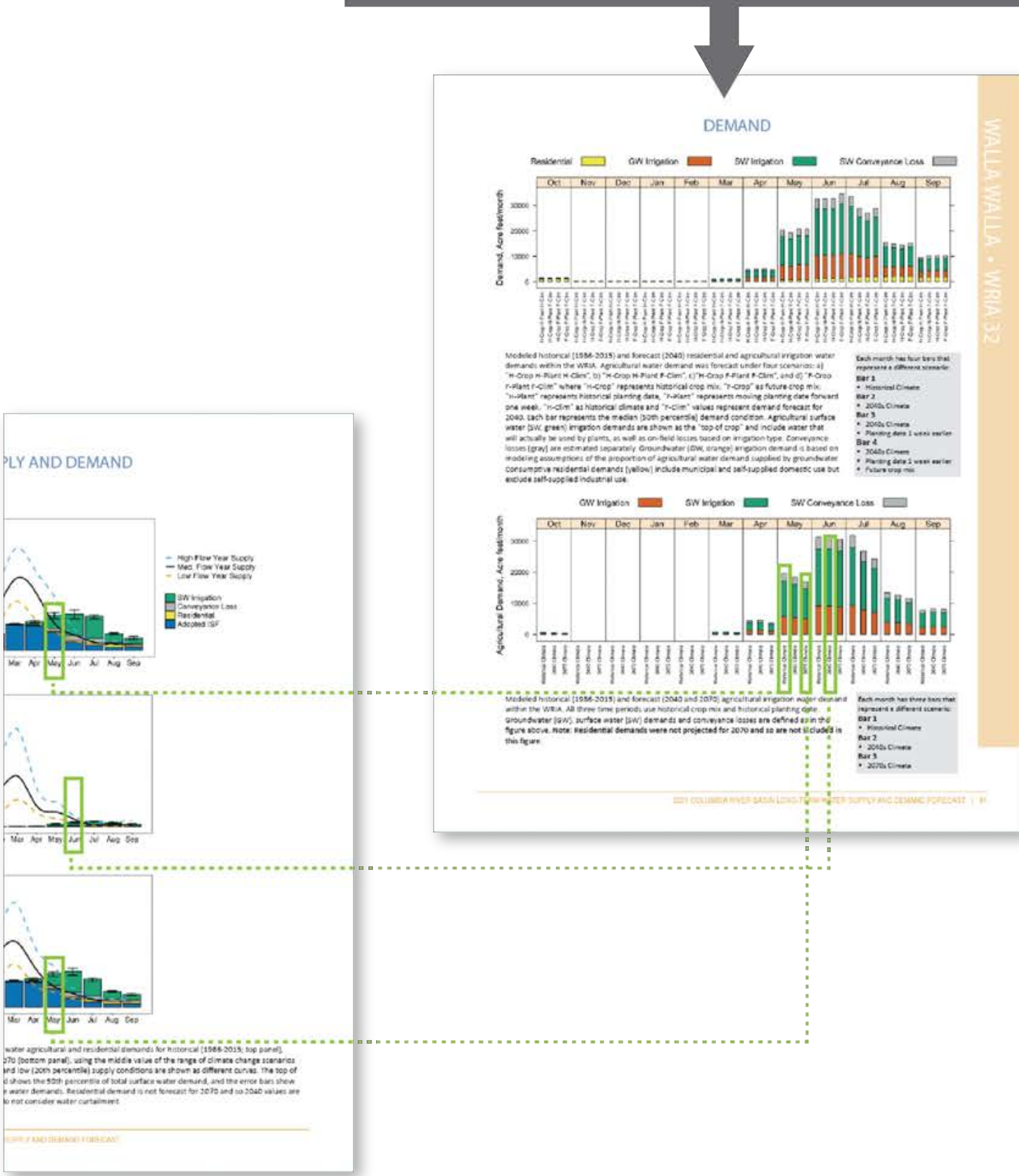






Comparison of Water Supply and Demand overlays water supply and water demand on the same graph, for the historical (1986-2015) period (top panel), for the 2040 forecast period (middle panel), and the 2070 forecast period (bottom panel). For future scenarios, the median of the full spread of 34 climate change scenarios is used to produce the curves for low, medium, and high flow years.

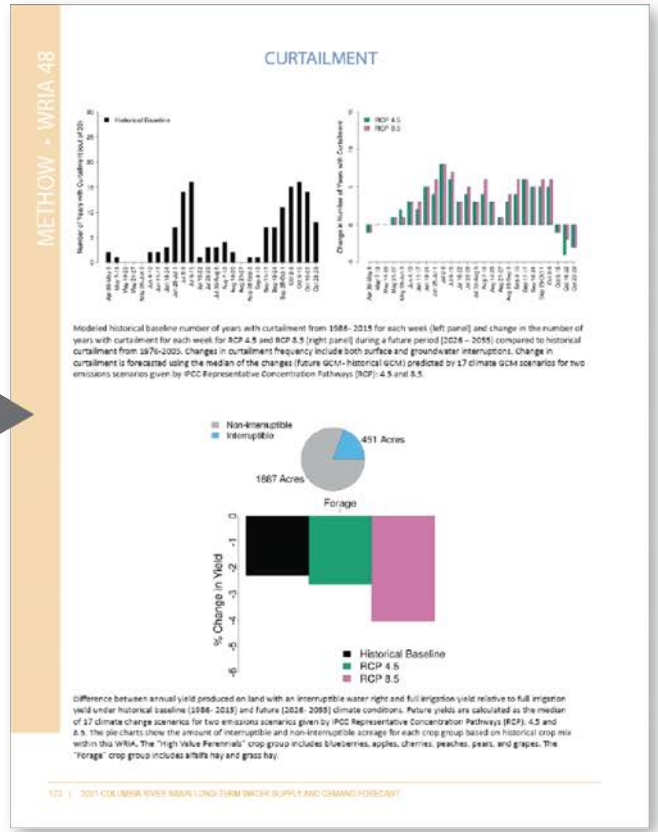
Modeled Historical and Forecast Water Demand shows how much water is needed in the WRIA each month for different uses (shown in different colors) under median demand conditions. The top chart shows four different demand scenarios: (1) Historical demand, modeled and calibrated with 1986- 2015 climate data, historical crop mix, and historical planting date; (2) projected demand in 2040 under a median climate change scenario, (3) projected demand in 2040 under a median climate change scenario and one-week earlier planting date, and (4) projected demand in 2040 under a median climate change scenario, one-week earlier planting date, and future crop mix. The bottom chart shows differences in demand solely due to changes in climate in the future: (1) projected demand under historical climate, (2) projected demand under 2040 climate, and (3) projected demand under 2070 climate. All other inputs were kept constant across these three time periods.



Curtailment Plots show historical number of years with curtailment from 1986- 2015 for each week (left panel) and change in the number of years with curtailment for each week (right panel) for a moderate climate change scenario (green bar) and a more severe climate change scenario (pink bar) during a future period (2026 – 2055) compared to historical curtailment from 1976-2005. Changes in curtailment frequency include both surface and groundwater interruptions.

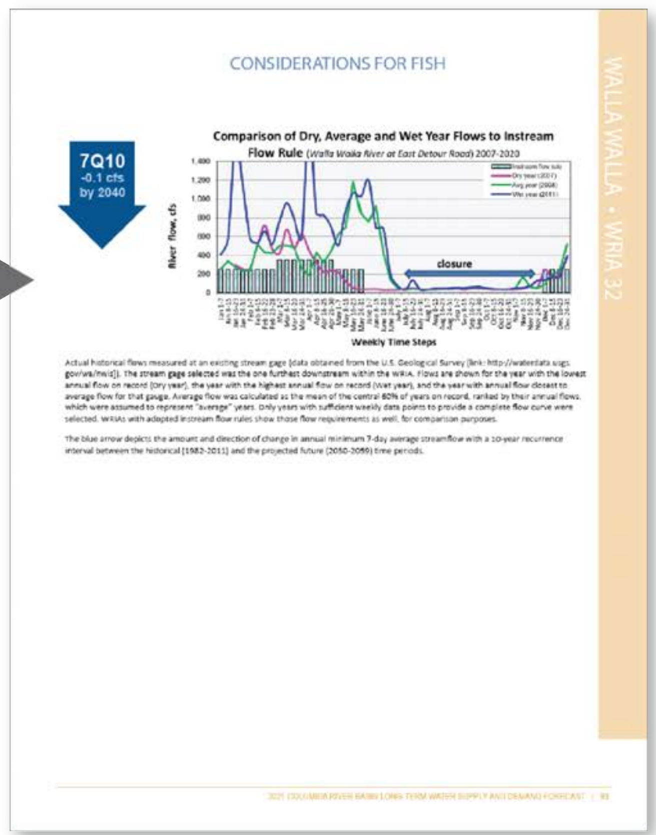
Crop Yield Plots show the difference between annual yield produced on land with an interruptible water right and full irrigation yield relative to full irrigation yield under historical baseline (1986- 2015) and future (2026 - 2055) climate conditions. Future yields are calculated as the median of 17 climate change scenarios for a moderate climate change scenario (green bar) and a more severe climate change scenario (pink bar). The pie graphs show the amount of acres for each group that are interruptible and non-interruptible.

Note that not all WRIAs have Curtailment Plots and Crop Yield Plots. Only WRIAs with adopted instream flow rules and sufficient irrigated acreage affected by curtailment were modeled.

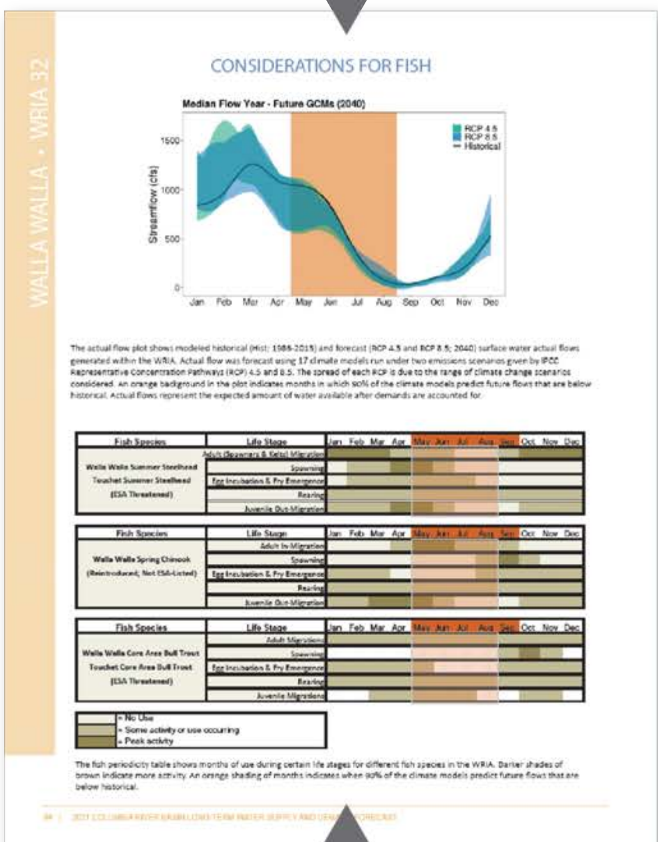


Historical Flows Data provide information on how flows have varied historically at the stream gauge located furthest downstream in this WRIA.

The 7Q10 Arrow shows whether the annual minimum 7-day average streamflow (cubic feet per second) with a 10-year recurrence interval is increasing or decreasing by 2040 compared to historical and by how much.

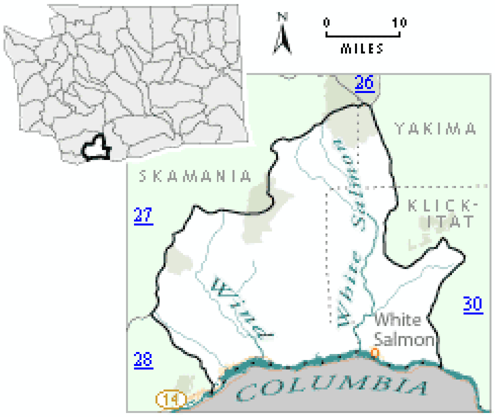


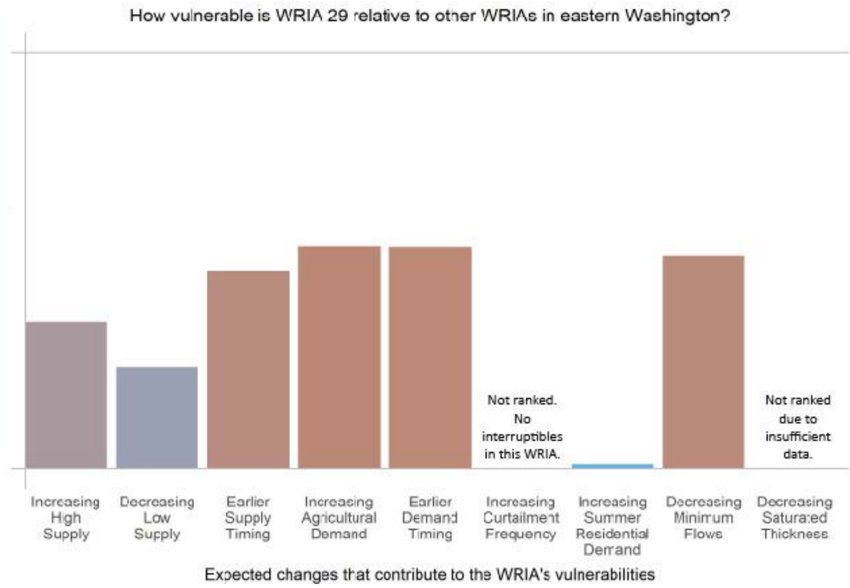
Actual Flow Data shows modeled historical (1986-2015) and forecast (2040) surface water actual flows generated within the WRIA. The three lines in each panel show: (1) Historical supply, modeled and calibrated with 1986 -2015 climate data (black line); (2) Projected future water supply under a moderate climate change scenario (green ribbon); and (3) Projected future water supply under a more severe climate change scenario (blue ribbon). The range shown by the ribbons reflects the spread of the 17 different climate models used in the forecast. An orange background in the plot indicates months in which 90% of the climate models predict future flows that are below historical.



Fish Periodicity Tables show months during which different species of fish are active in the WRIA during various life stages. The darkest shade indicates peak activity, the middle shade indicates some activity, and the lightest shade indicates a period in which there is no activity occurring. The orange boxes indicate periods in which 90% or more of future scenarios predict less flow than historical for median flow years.

SUMMARY





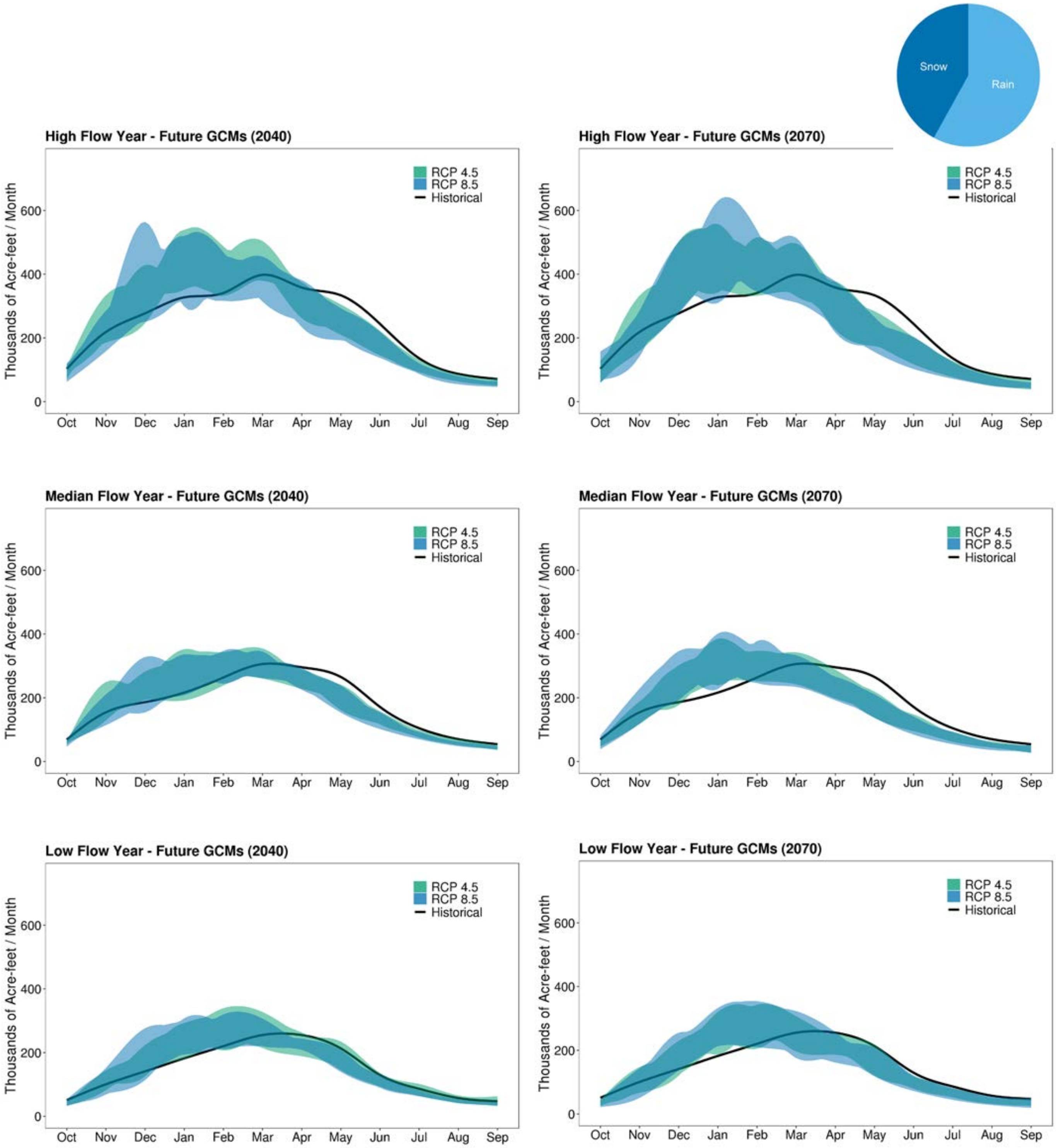
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 18 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is not projected to change by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 12 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 42% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 9% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 21 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 7.5 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	WRIA 29a: Phase 4 (Implementation), WRIA 29b: NO (planning terminated)
Adopted Instream Flow Rules	NO
Endangered Species Act-listed Stocks Known to Spawn Within WRIA Waters[1]	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 Subareas Overlapped by WRIA	NONE

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

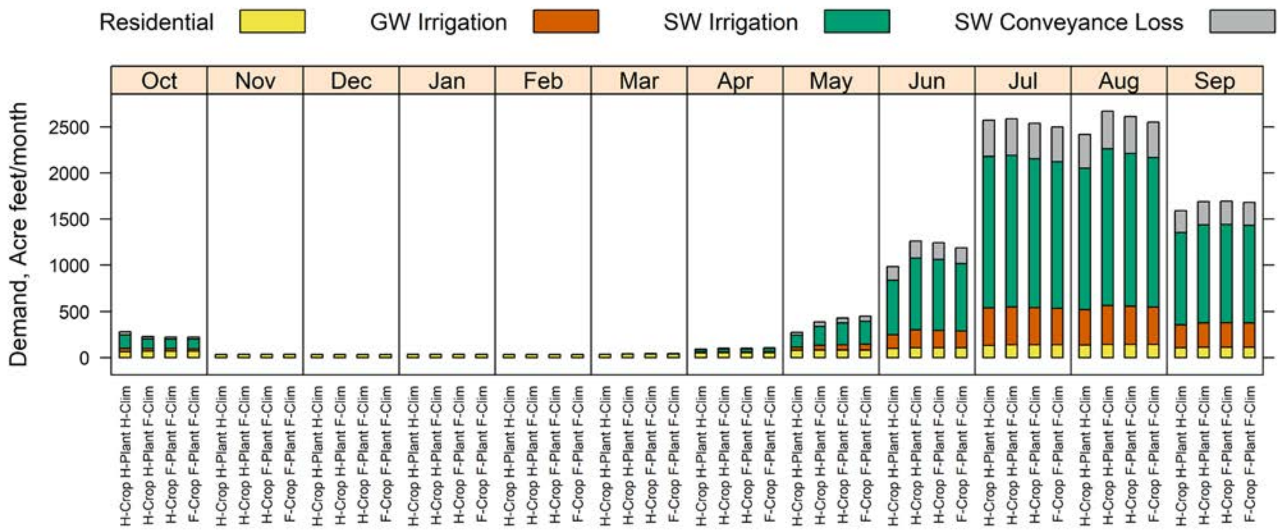
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

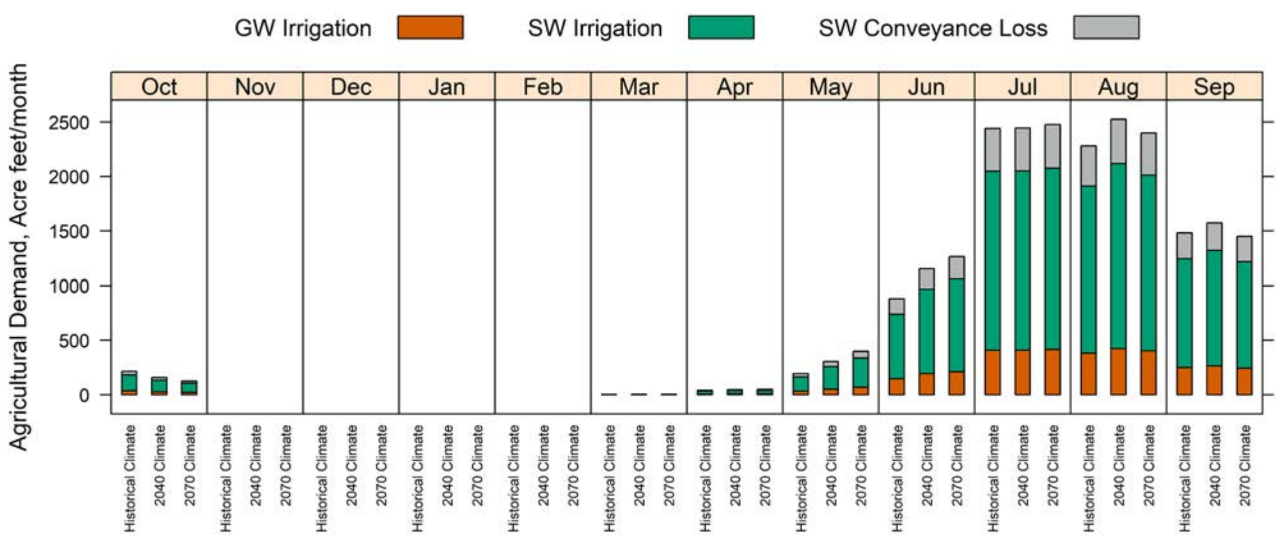
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

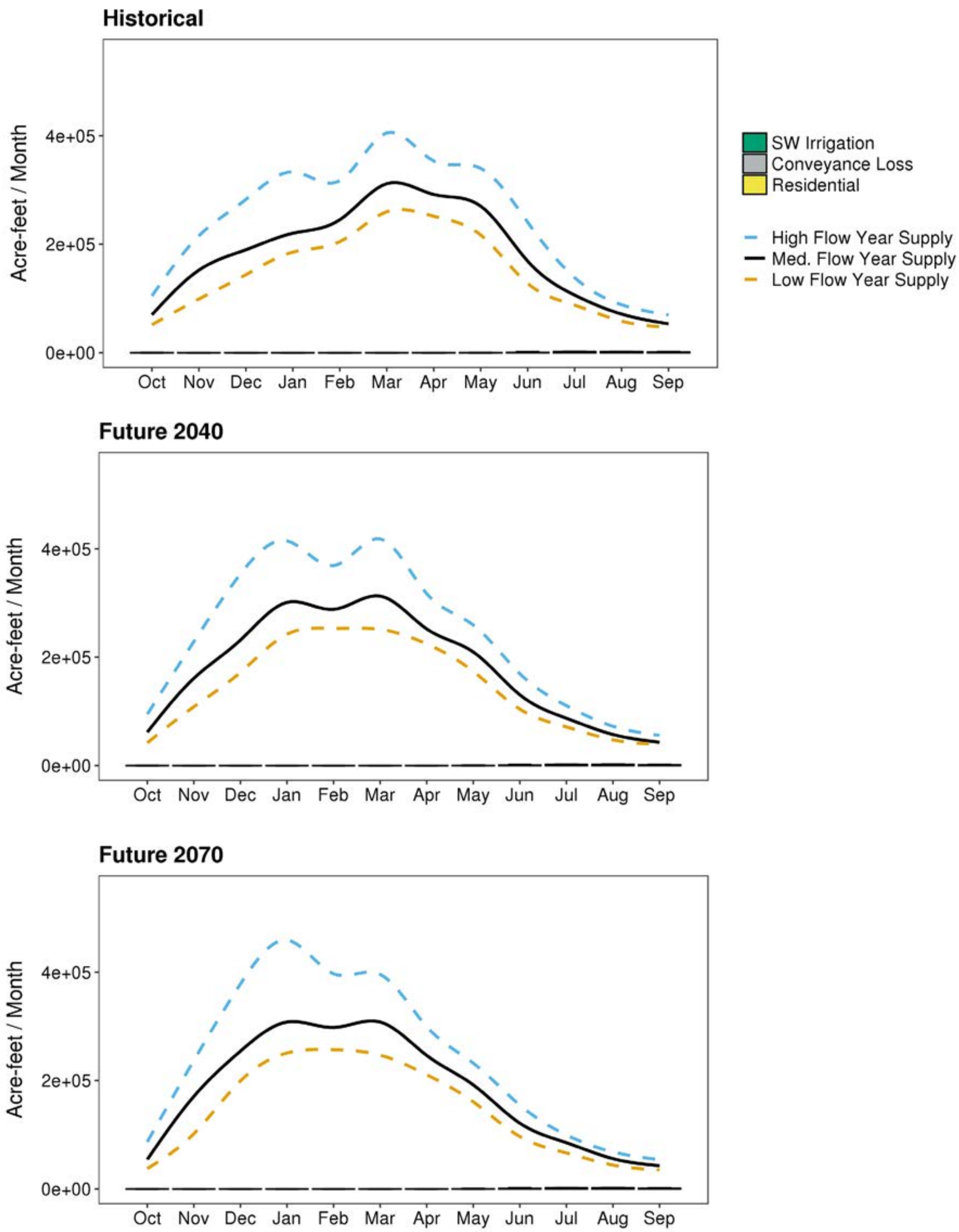
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

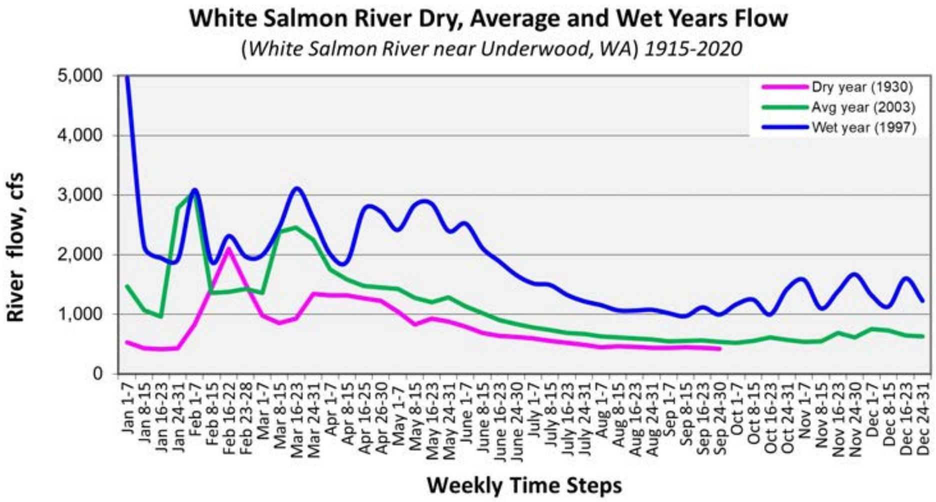
Bar 3
- 2070s Climate

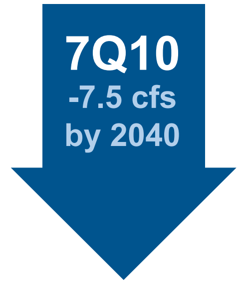
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH





Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

Wind R., Little White Salmon R. and Tributaries - WRIA 29A
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Gorge (Columbia) Fall (Tule) Chinook (ESA Threatened)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Upper Gorge (Columbia) Late Fall (Bright) Chinook (ESA Not Warranted)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Upper Gorge (Columbia) Winter Steelhead (ESA Threatened)	Adult (Spawners & Kelts) Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Wind River (Upper Gorge) Summer Steelhead (ESA Threatened)	Adult (Spawners & Kelts) Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Upper Gorge (Columbia) Coho (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
Upper Gorge (Columbia) Fall (ESA Threatened) (historically present, not observed recently in WRIA 29A rivers)	Adult In-Migration	0	0	0	0	0	0	0	0	0	0	0	0
	Spawning	0	0	0	0	0	0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0	0	0	0	0	0	0	0	0	0
	Rearing	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Out-Migration	0	0	0	0	0	0	0	0	0	0	0	0

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

White Salmon River and Tributaries - WRIA 29B
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Big White Salmon River Fall (Tule) Chinook (ESA Threatened)	Adult In-Migration	0	0	0	0	0	0	0				0	0
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing	0						0	0	0	0	0	0
	Juvenile Out-Migration	0	0							0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Big White Salmon River Spring Chinook (ESA Threatened)	Adult In-Migration	0	0							0	0	0	0
	Spawning	0	0	0	0	0	0	0				0	0
	Egg Incubation & Fry Emergence				0	0	0	0					
	Rearing												
	Juvenile Out-Migration	0							0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Big White Salmon River Late Fall (Bright) Chinook (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0	0	0				
	Spawning	0	0	0	0	0	0	0	0	0			
	Egg Incubation & Fry Emergence						0	0	0	0			
	Rearing	0	0						0	0	0	0	0
	Juvenile Out-Migration	0	0	0						0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Big White Salmon River Summer/Winter Steelhead (ESA Threatened)	Adult (Spawners & Kelts) Migration												
	Spawning							0	0	0	0	0	0
	Egg Incubation & Fry Emergence								0	0	0	0	0
	Rearing												
	Juvenile Out-Migration							0	0	0	0		

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Gorge (Columbia) Coho (ESA Threatened)	Adult In-Migration			0	0	0	0	0	0				
	Spawning			0	0	0	0	0	0	0			
	Egg Incubation & Fry Emergence						0	0	0	0			
	Rearing												
	Juvenile Out-Migration	0	0	0				0	0	0	0	0	0

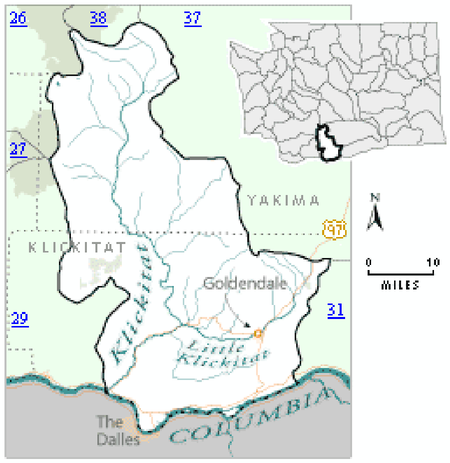
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Gorge (Columbia) Fall Chum (ESA Threatened) (spawning not yet observed)	Adult In-Migration		0	0	0	0	0	0	0	0	0		
	Spawning	0	0	0	0	0	0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0	0	0	0	0	0	0	0	0	0
	Rearing	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Out-Migration	0	0	0	0	0	0	0	0	0	0	0	0

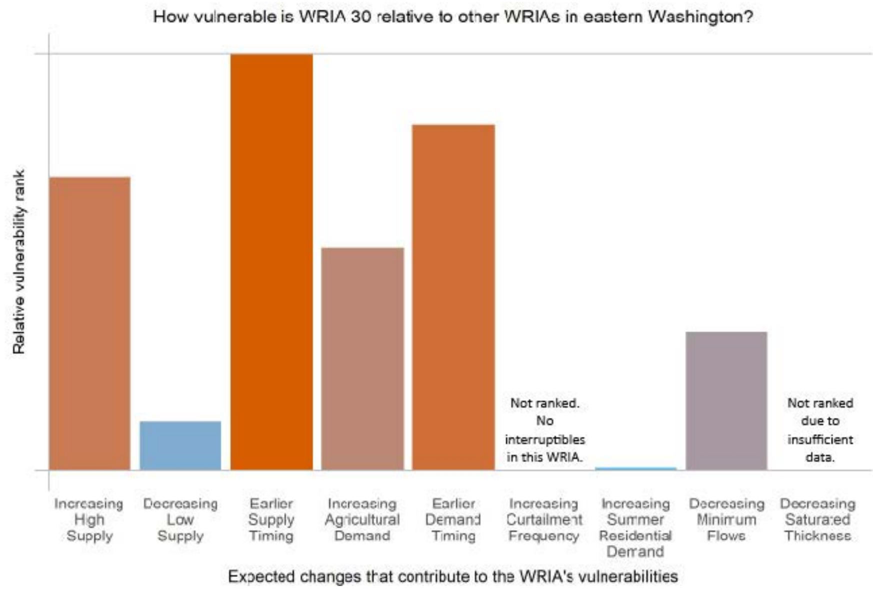
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
White Salmon River core area Bull Trout (ESA Threatened) (spawning not yet observed)	Adult Migration	0	0	0									0
	Spawning	0	0	0	0	0	0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0	0	0	0	0	0	0	0	0	0
	Rearing	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Migration or Movement	0	0	0	0	0	0	0	0	0	0	0	0

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





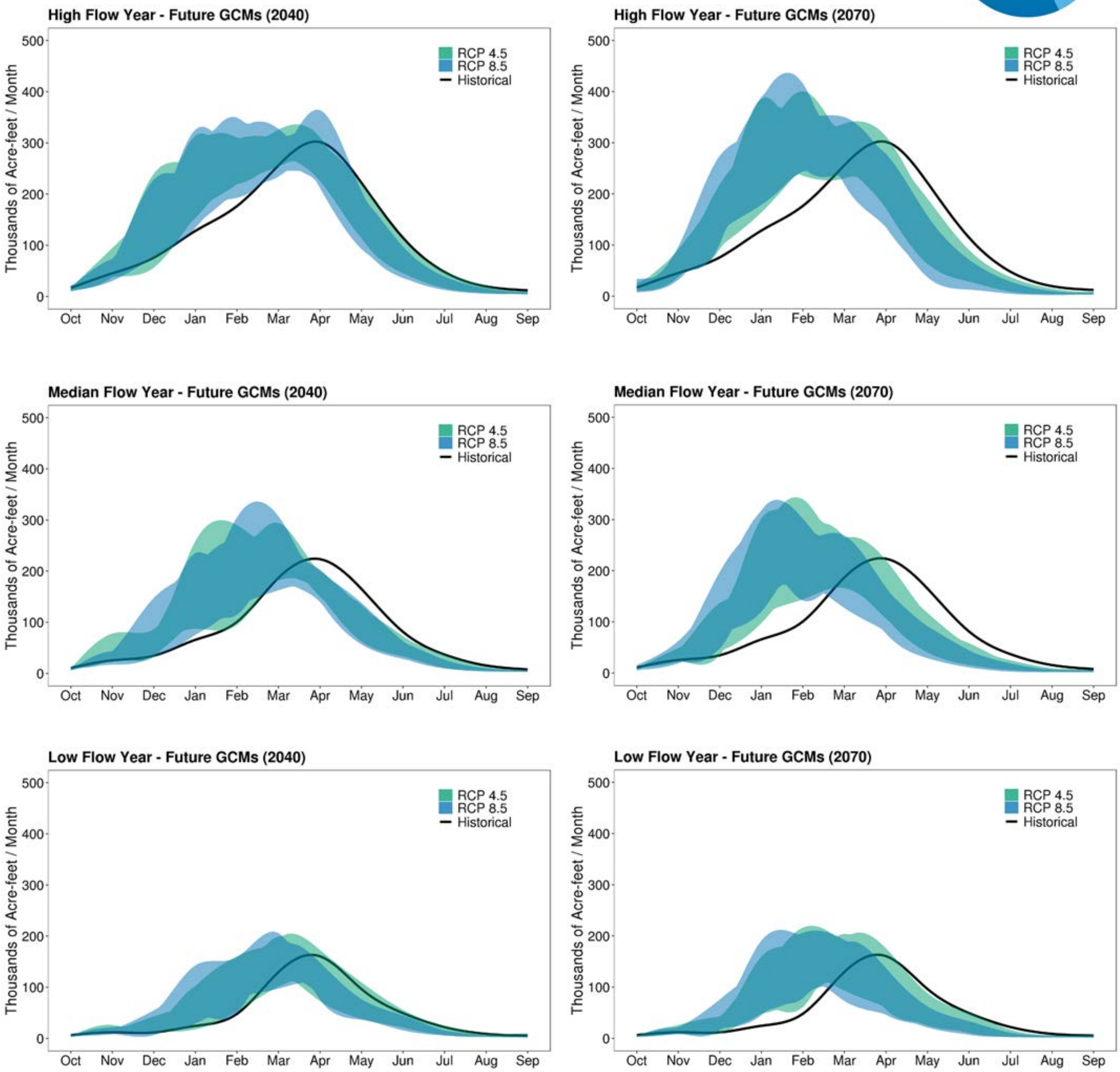
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 77 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 23 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 23 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 57% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 9% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day later by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to decrease by 11 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 4.5 cfs by 2040.

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

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

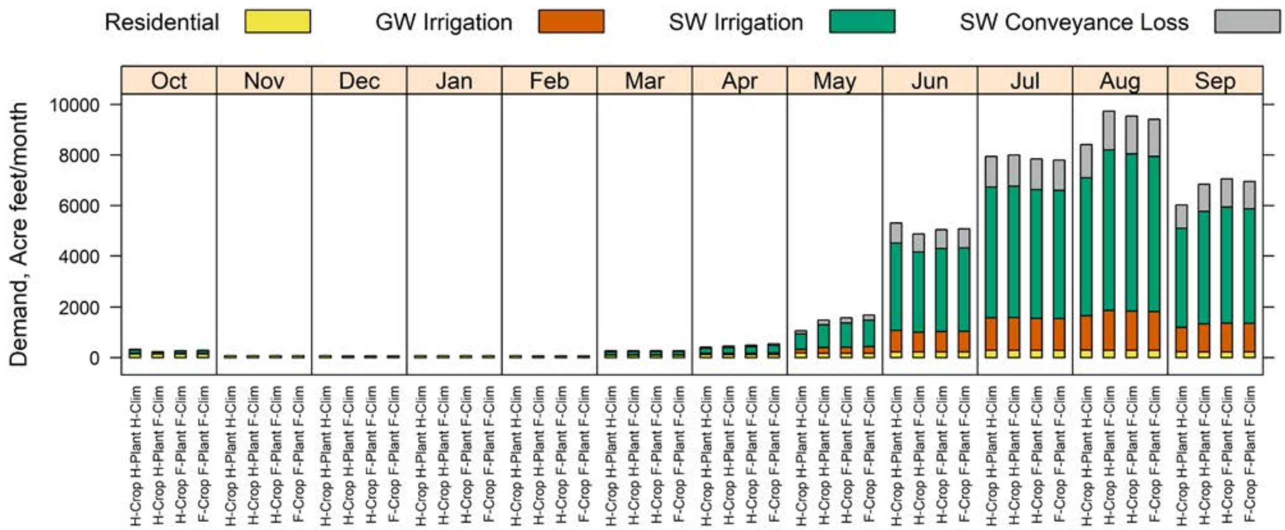
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

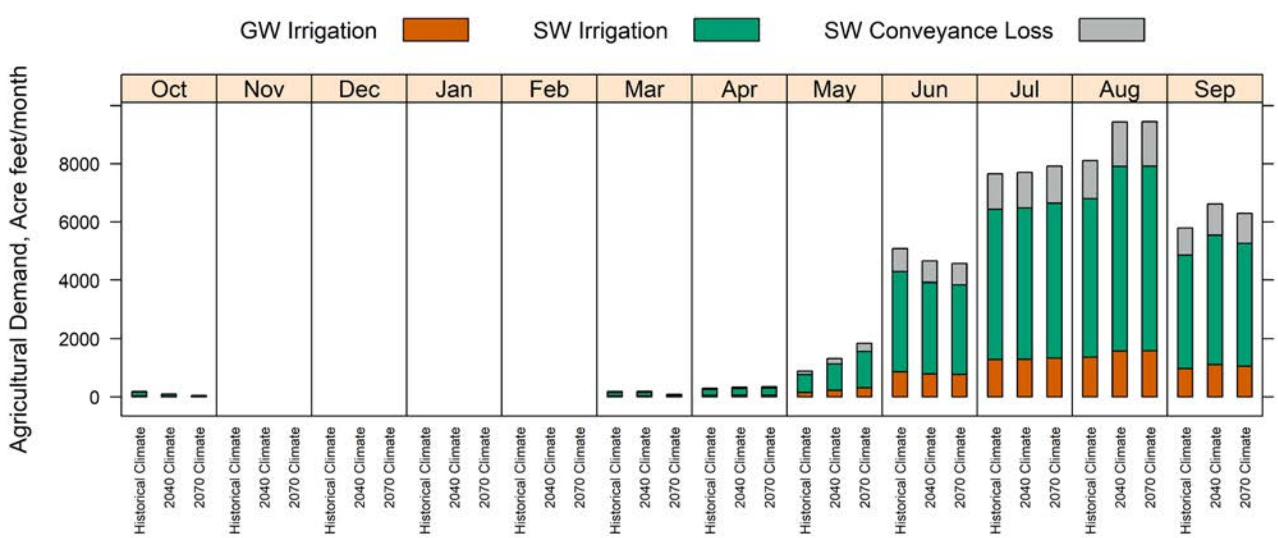
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. Note: Residential demands were not projected for 2070 and so are not included in this figure.

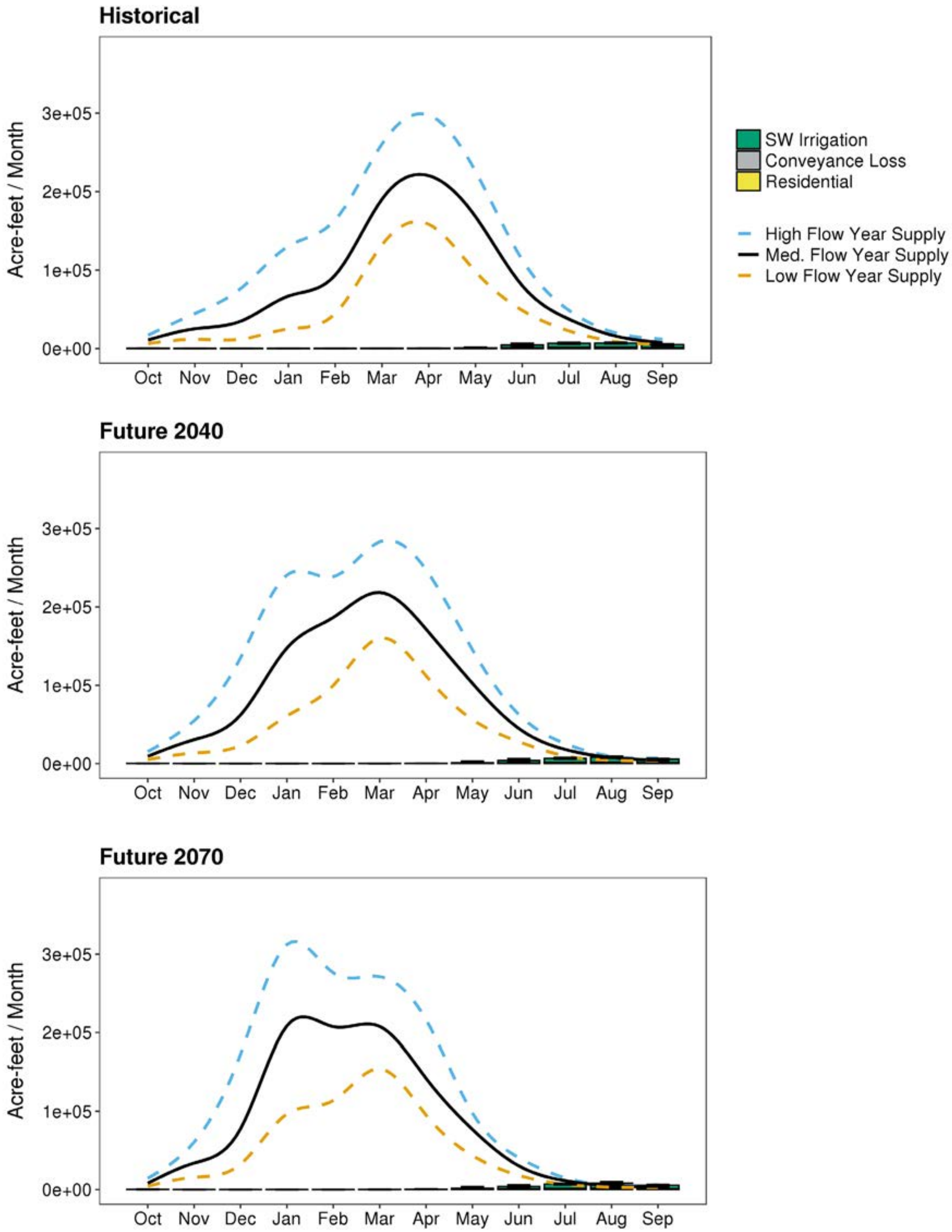
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

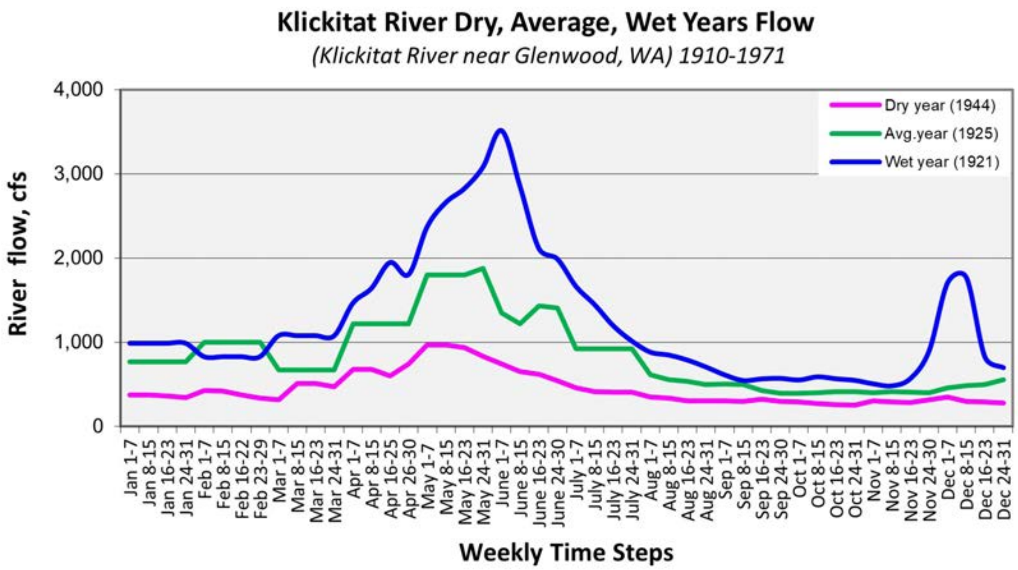
Bar 3
- 2070s Climate

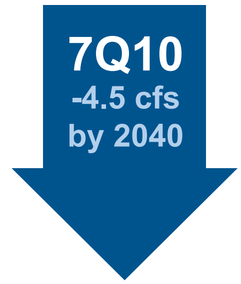
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

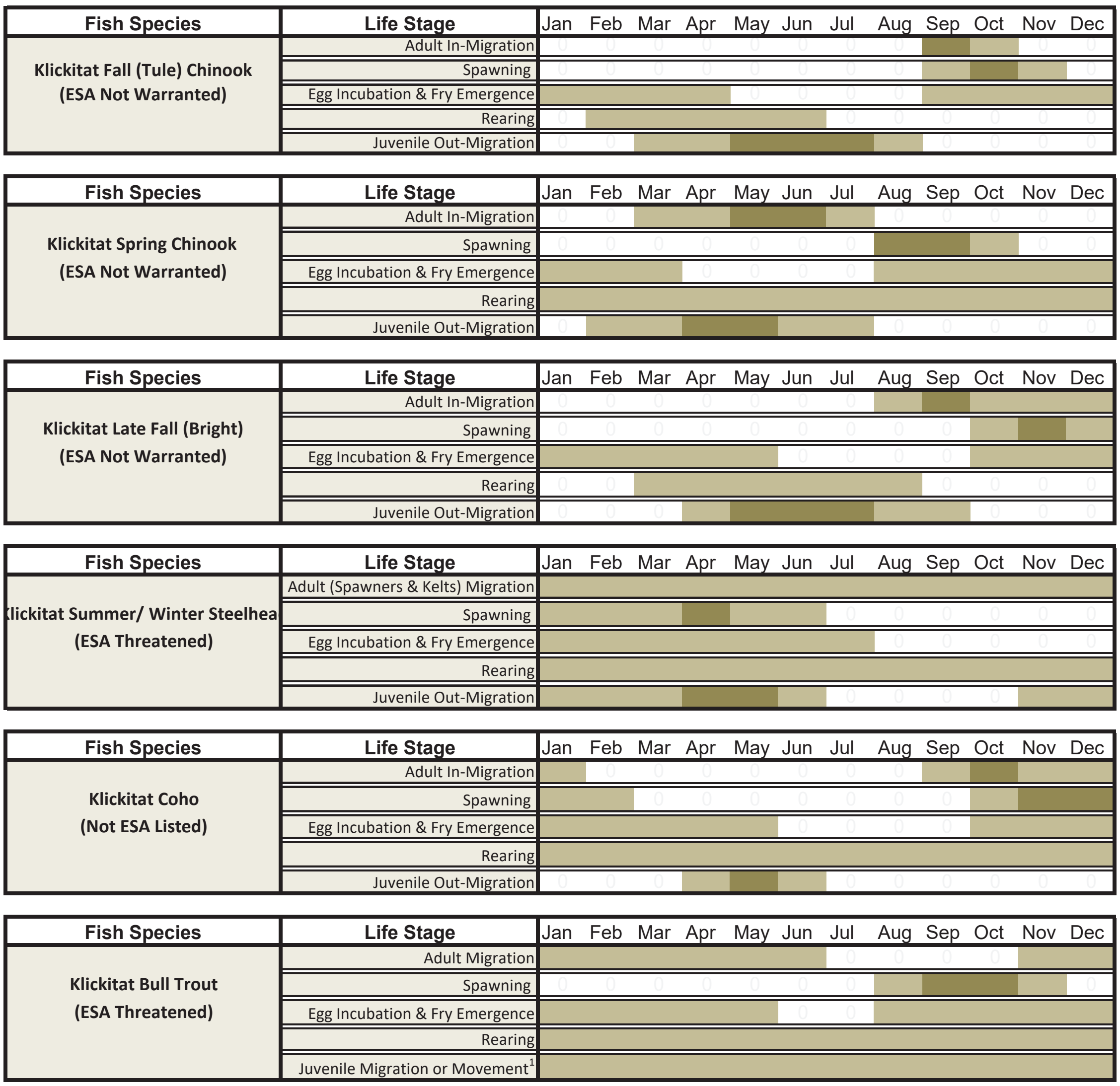




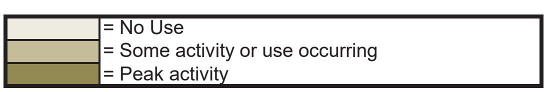
Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

Klickitat River Basin - WRIA 30
Fish Use Timing by Species

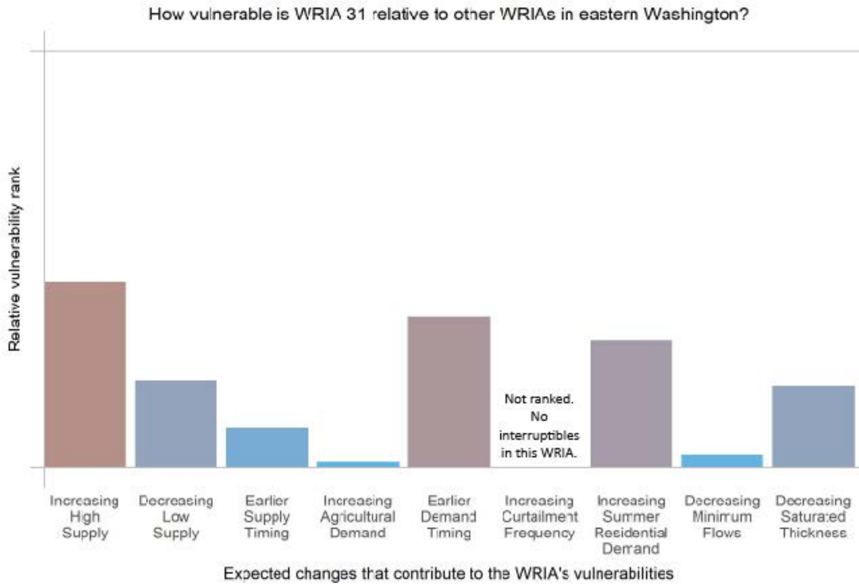


[1] Due to uncertainty about timing of juvenile (non-spawning age) bull trout movements within or among streams, all months were scored for some activity



The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY



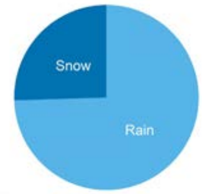
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

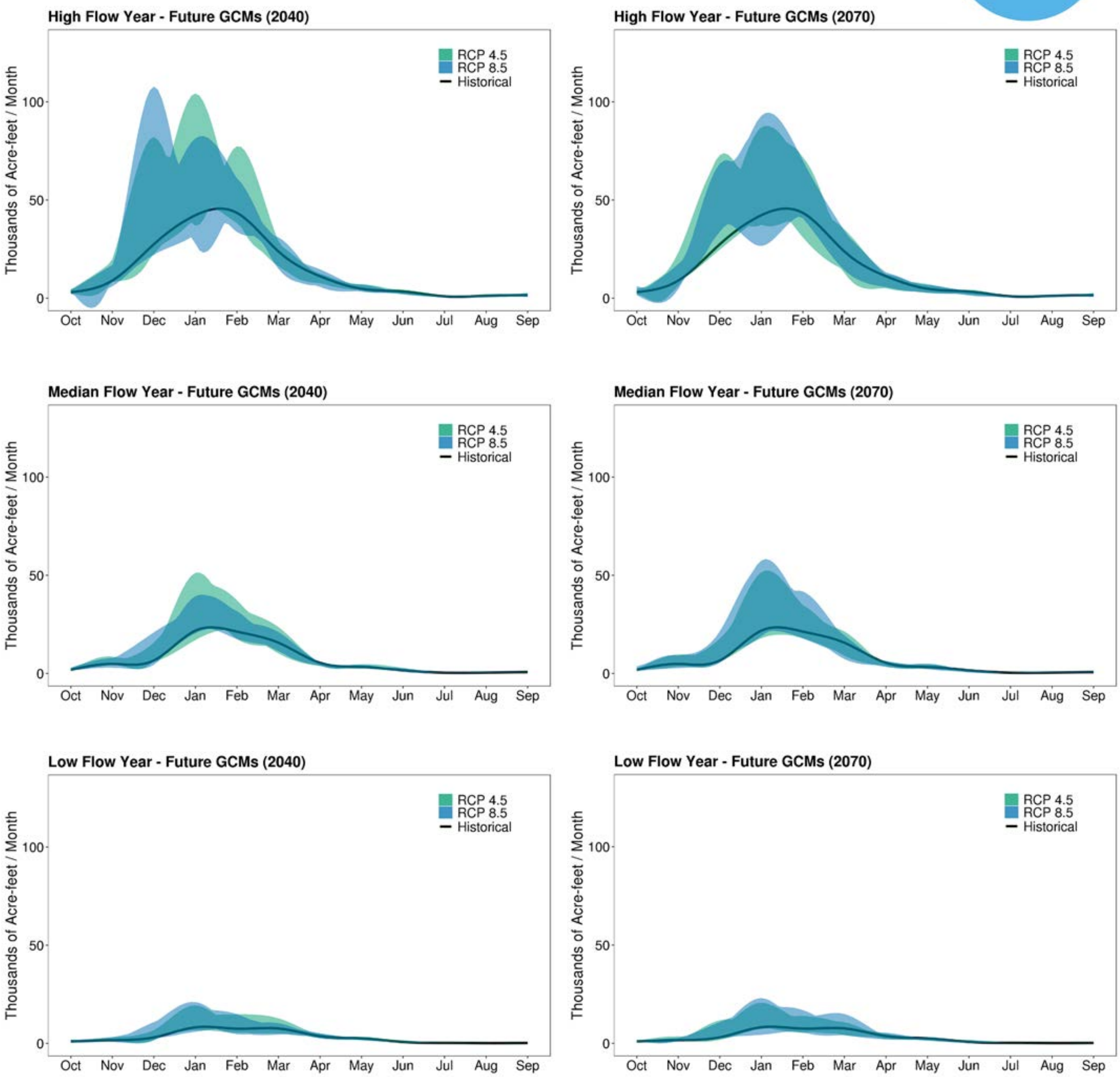
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 33 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 7 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 4 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 25% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 6% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 5 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 920 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.6 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 15% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Middle Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Rock Glade

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

SUPPLY

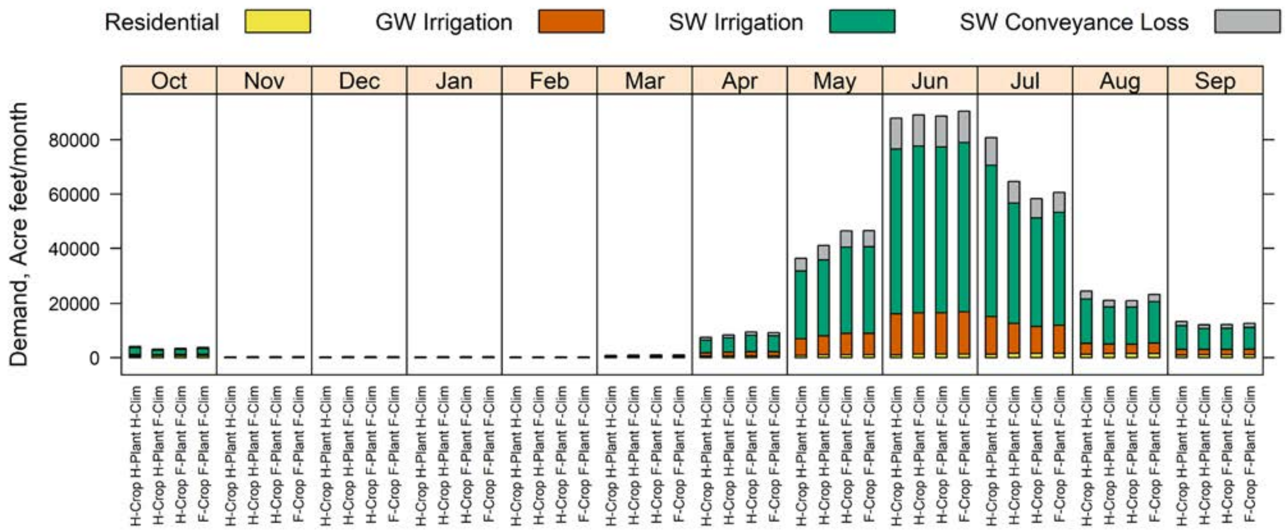




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

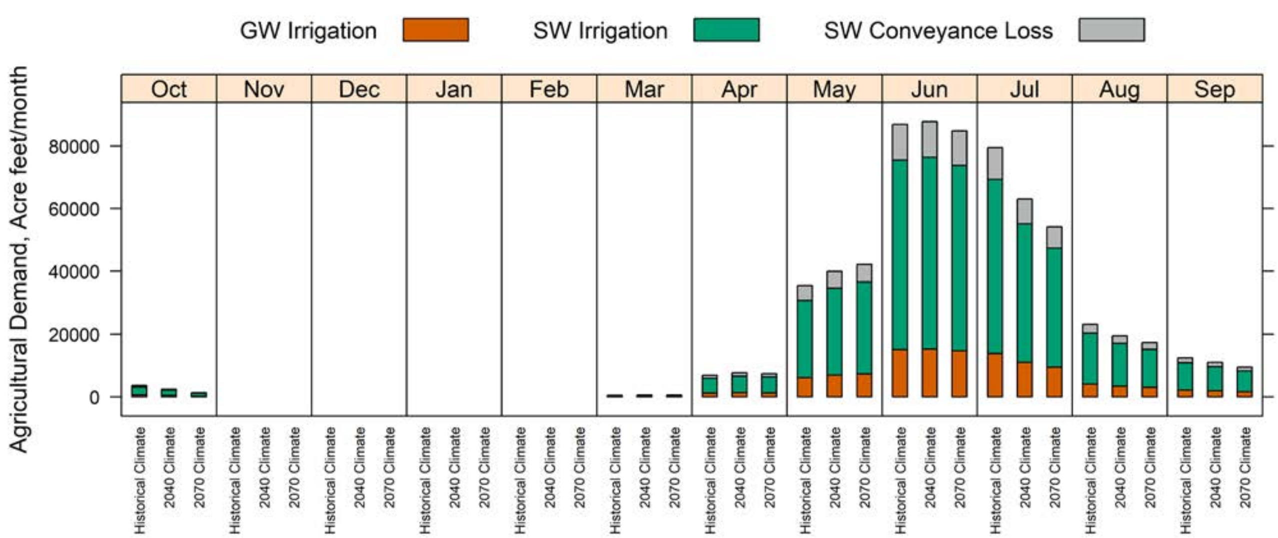
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. Note: Residential demands were not projected for 2070 and so are not included in this figure.

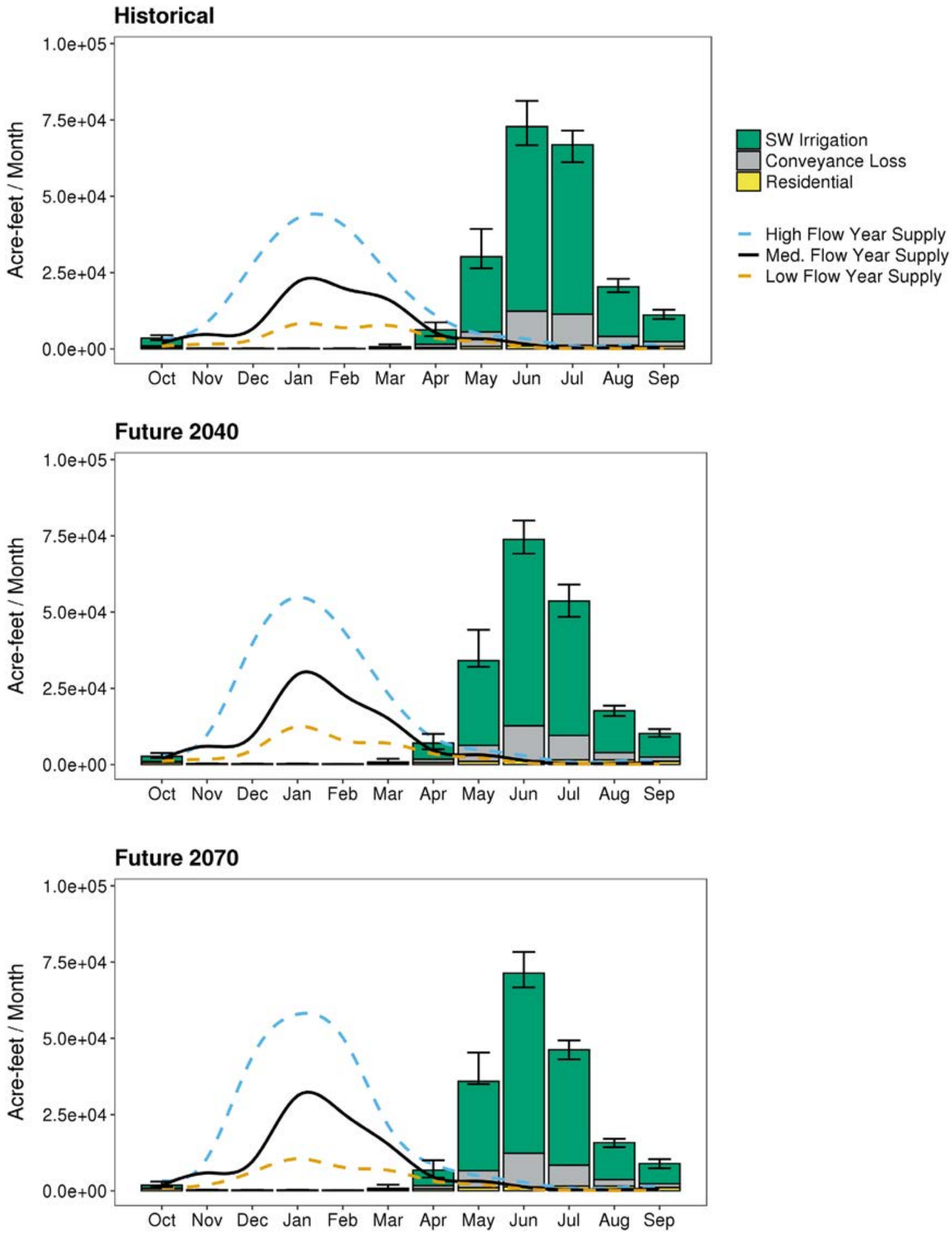
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

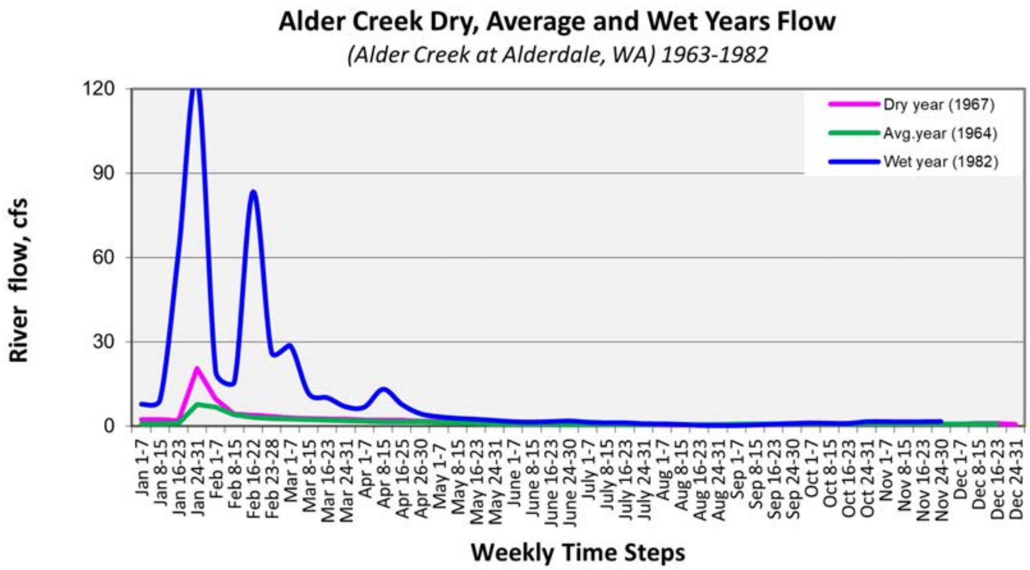
Bar 3
- 2070s Climate

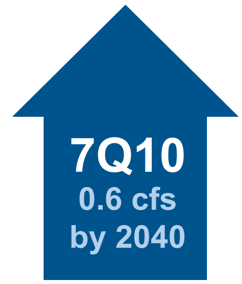
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

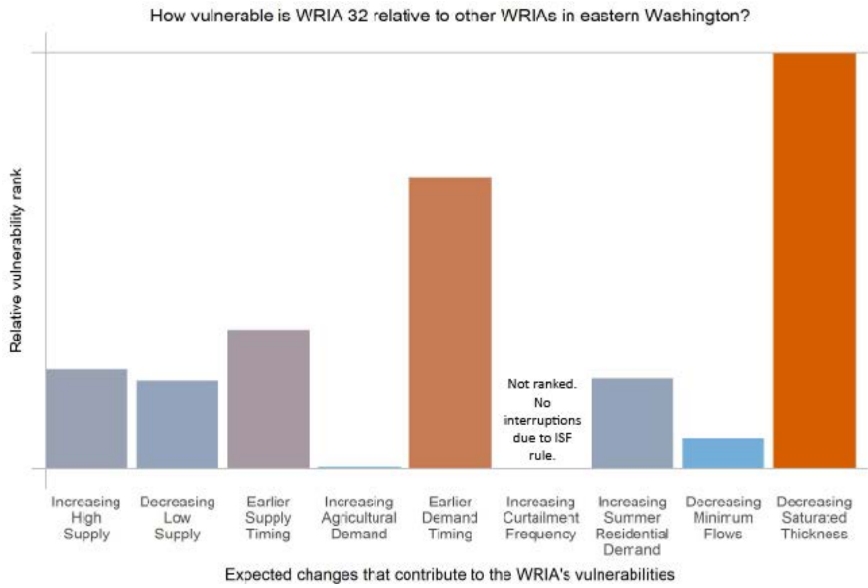


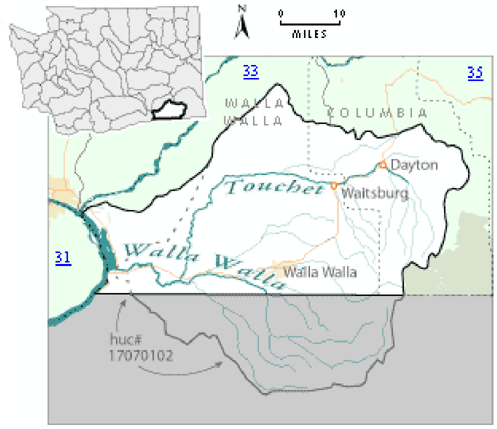


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





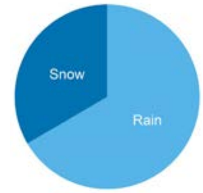
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

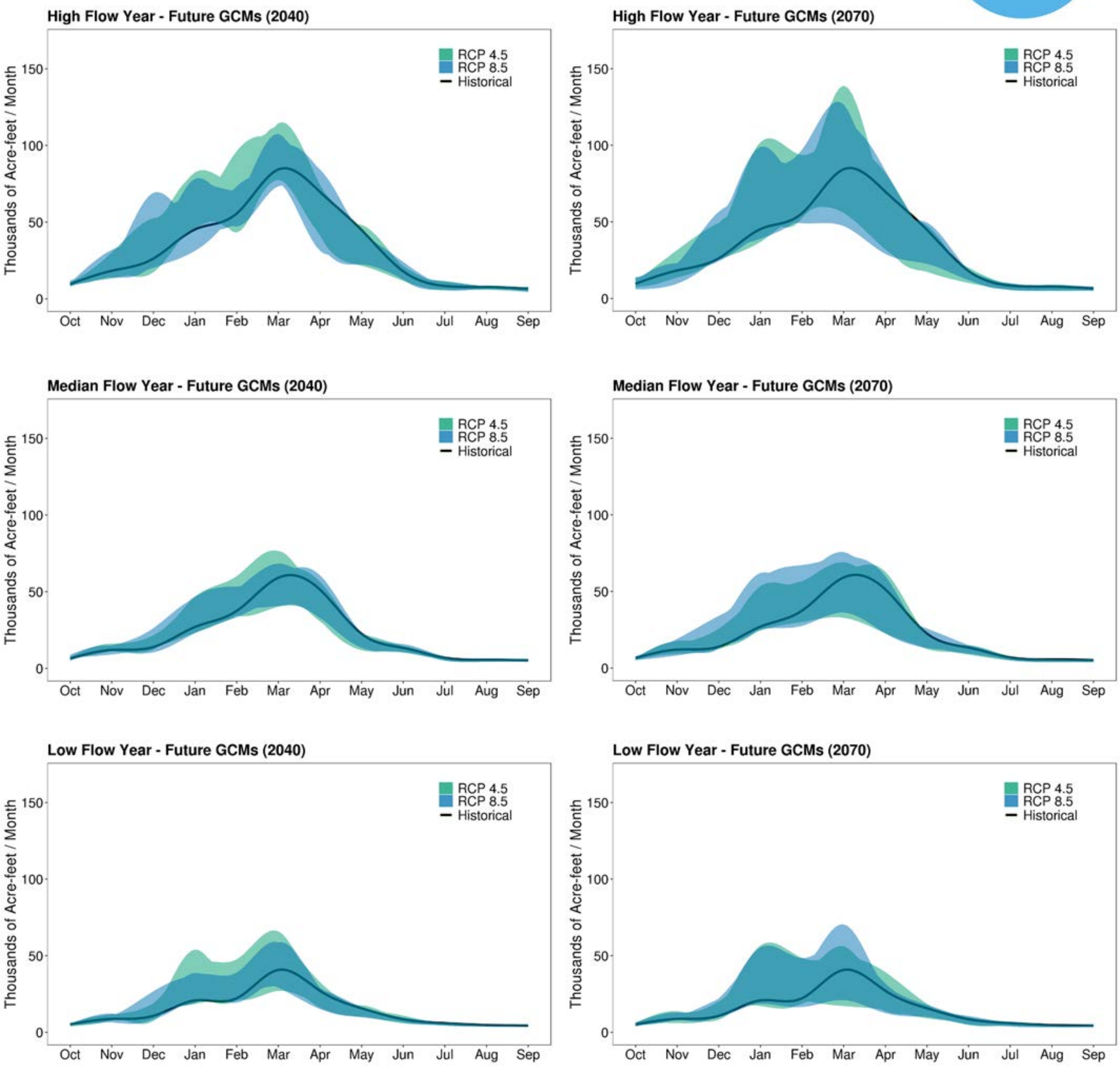
- **Increasing High Supply:** Water supply during high flow years is projected to decrease by 1 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 6 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 9 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 33% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 6% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 649 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 0.1 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 52% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Upper Stone Creek, Doan Creek, Walla Walla River, Touchet River, Dry Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-532 WAC). 65 interruptible water rights curtailed periodically, mainly due to senior to junior calls. 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[1]	Bull Trout, Middle Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Walla Walla

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

SUMMARY

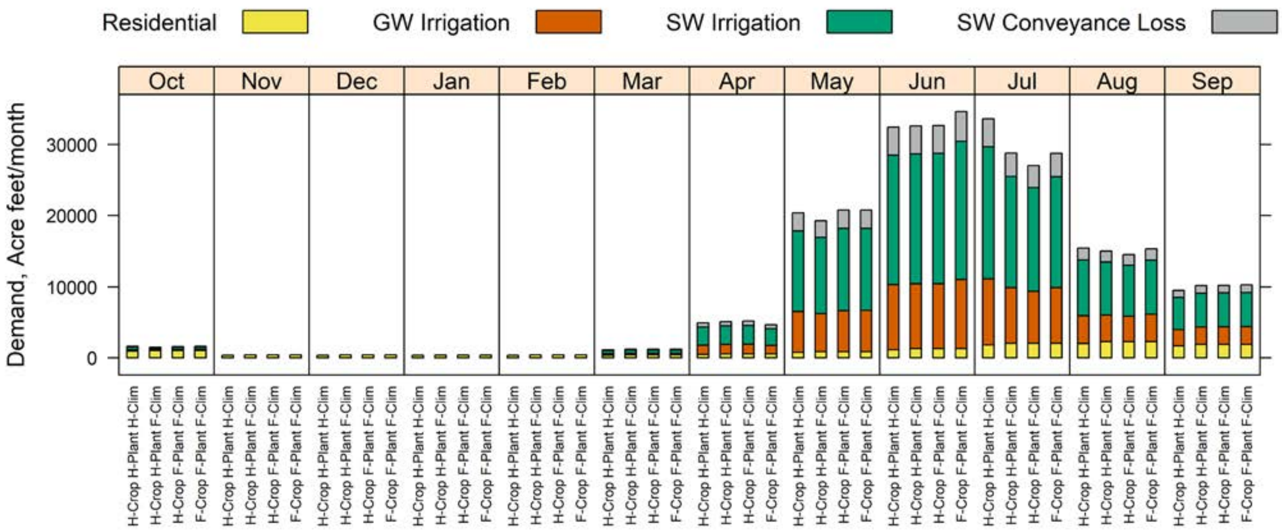




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

SUPPLY



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

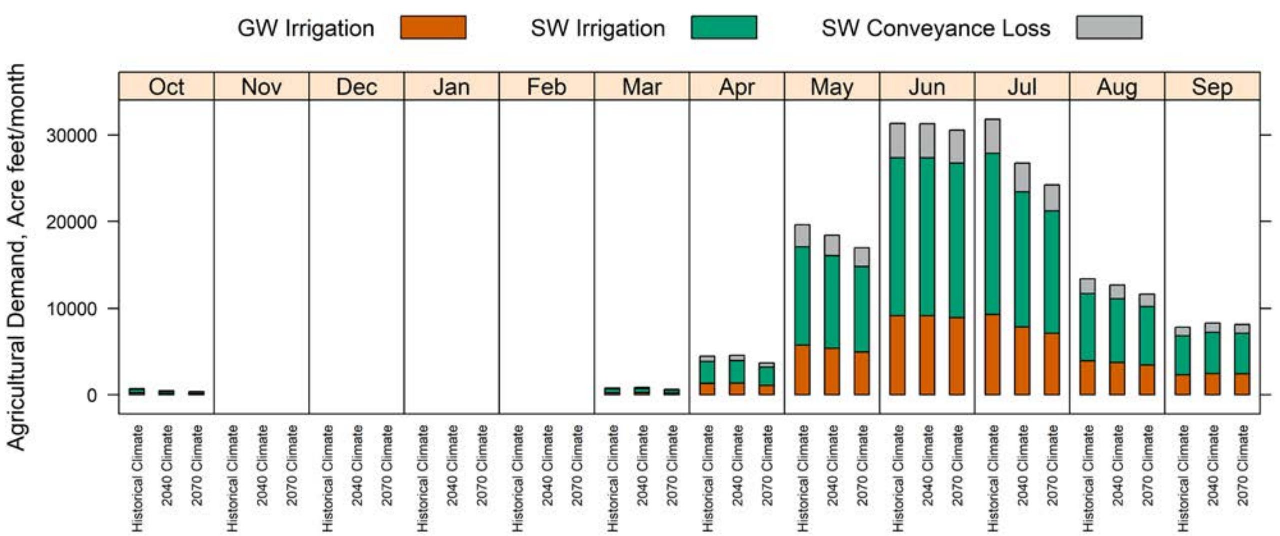
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

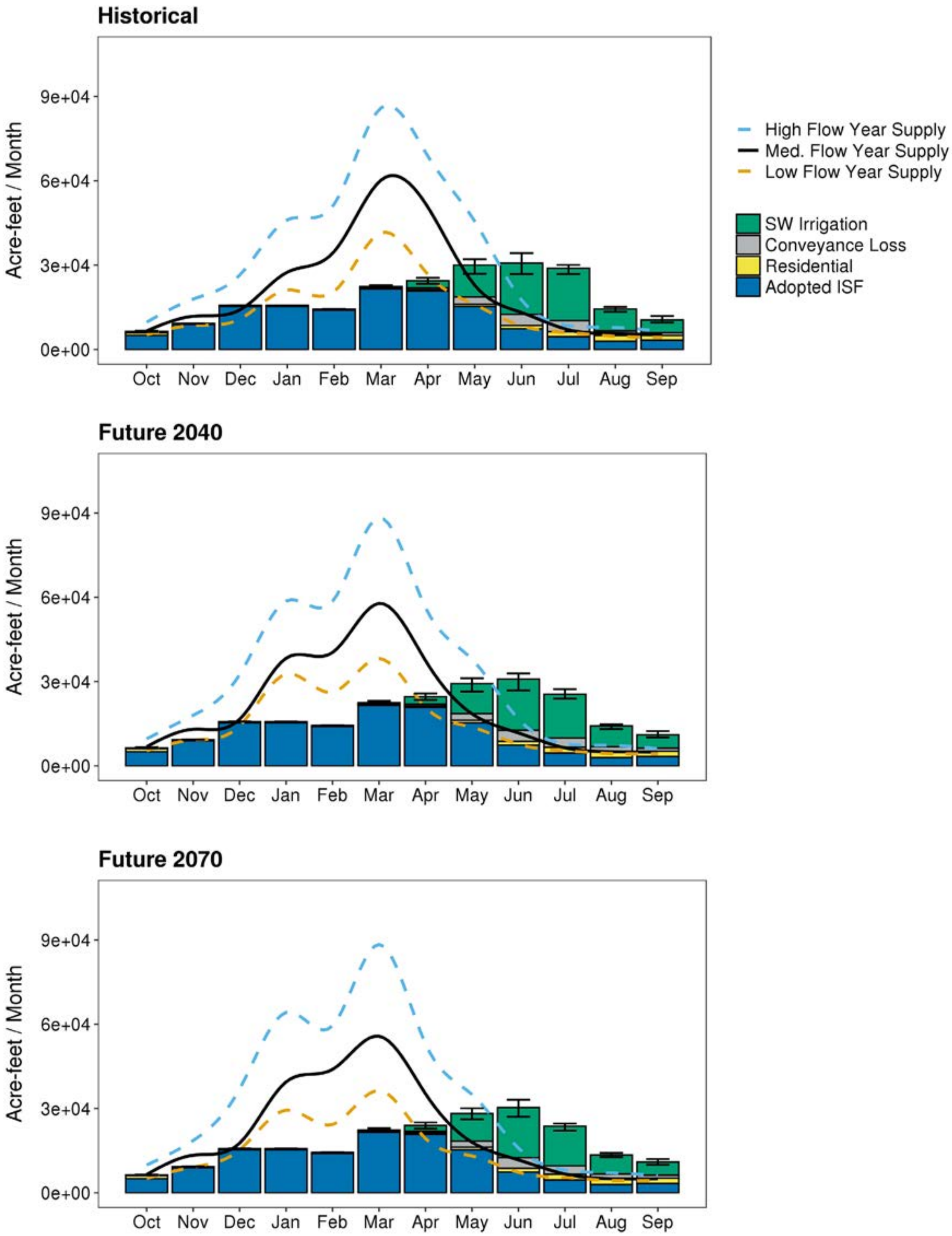
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

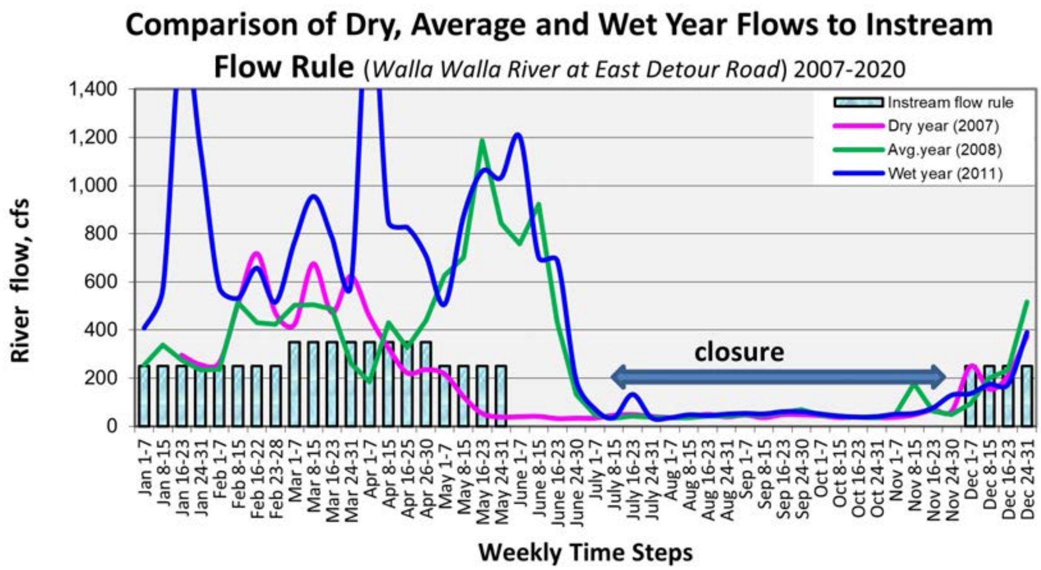
Bar 3
- 2070s Climate

SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

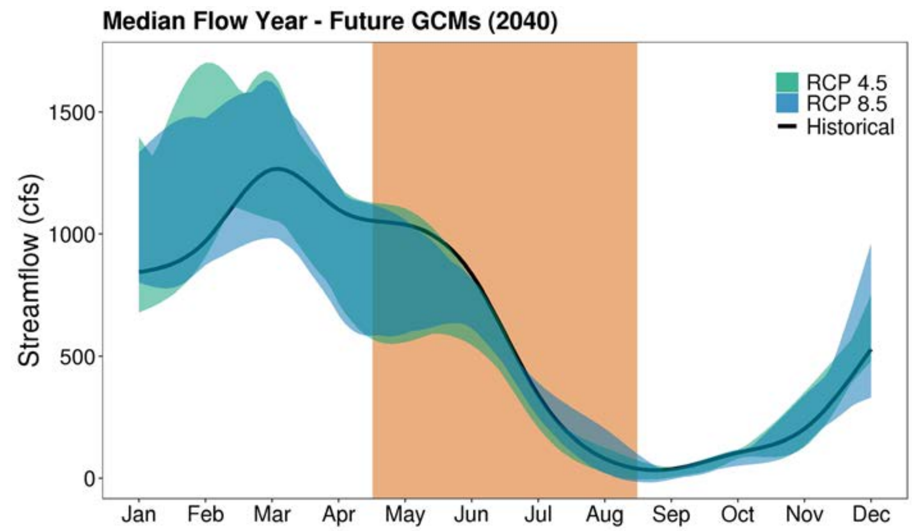
CONSIDERATIONS FOR FISH



Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

CONSIDERATIONS FOR FISH



The actual flow plot shows modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5; 2040) surface water actual flows generated within the WRIA. Actual flow was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each RCP is due to the range of climate change scenarios considered. An orange background in the plot indicates months in which 90% of the climate models predict future flows that are below historical. Actual flows represent the expected amount of water available after demands are accounted for.

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

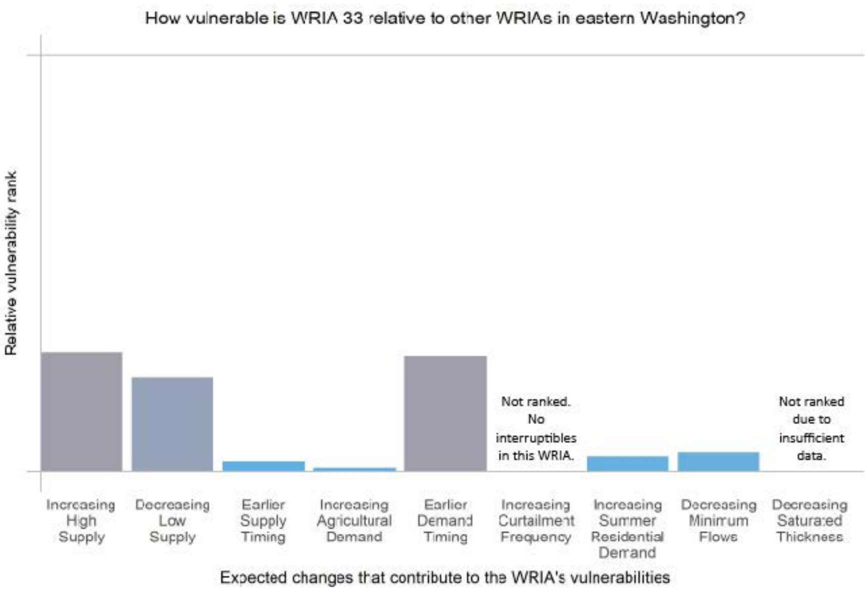
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Walla Walla Spring Chinook (Reintroduced; Not ESA-Listed)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												

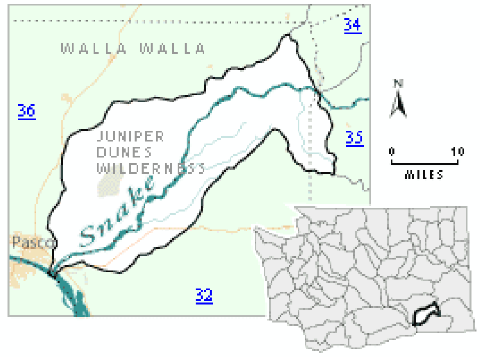
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Walla Walla Core Area Bull Trout Touchet Core Area Bull Trout (ESA Threatened)	Adult Migrations												
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence						0	0	0				
	Rearing												
	Juvenile Migrations	0	0						0	0			0

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





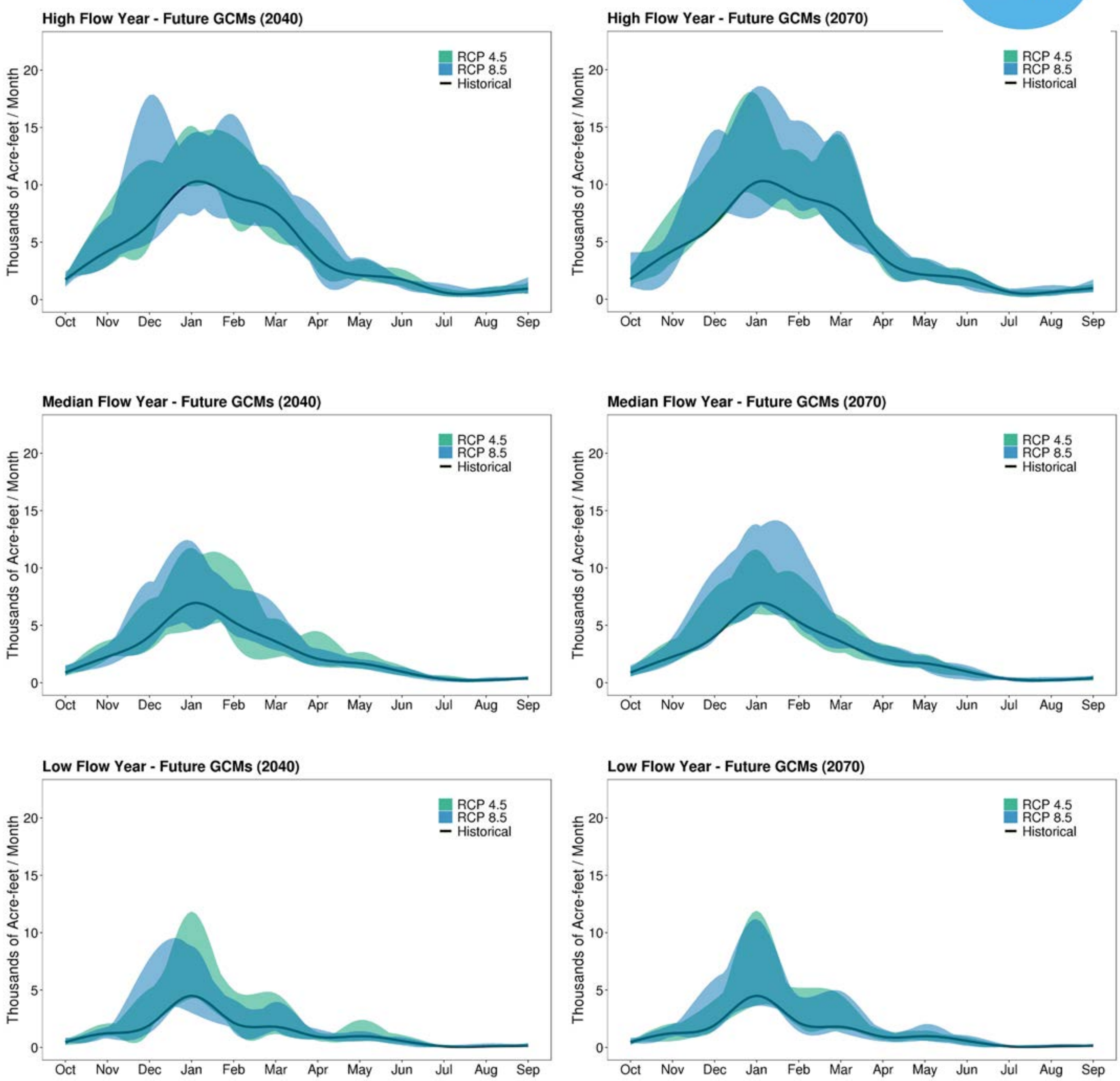
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 6 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 4 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 2 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 12% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 6% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 6 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 96 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.3 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Snake River Basin Steelhead, Snake River Fall Run Chinook, Snake River Spring and Summer Run, Chinook, [Snake mainstem migratory corridor for Snake River sockeye]
Groundwater Subareas Overlapped by WRIA	Lower Snake

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

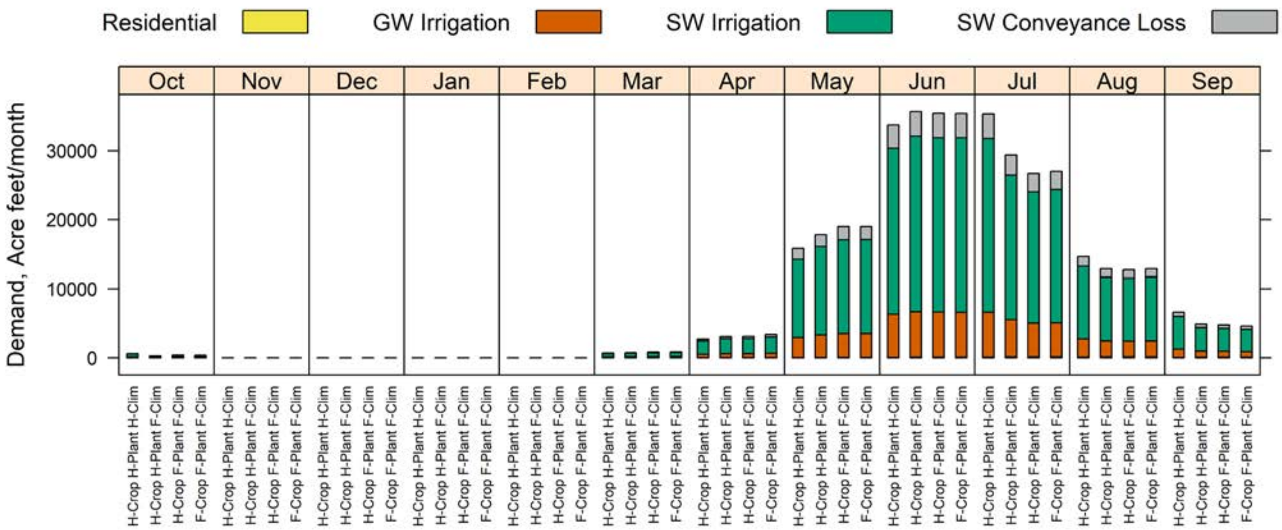
SUMMARY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

SUPPLY



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

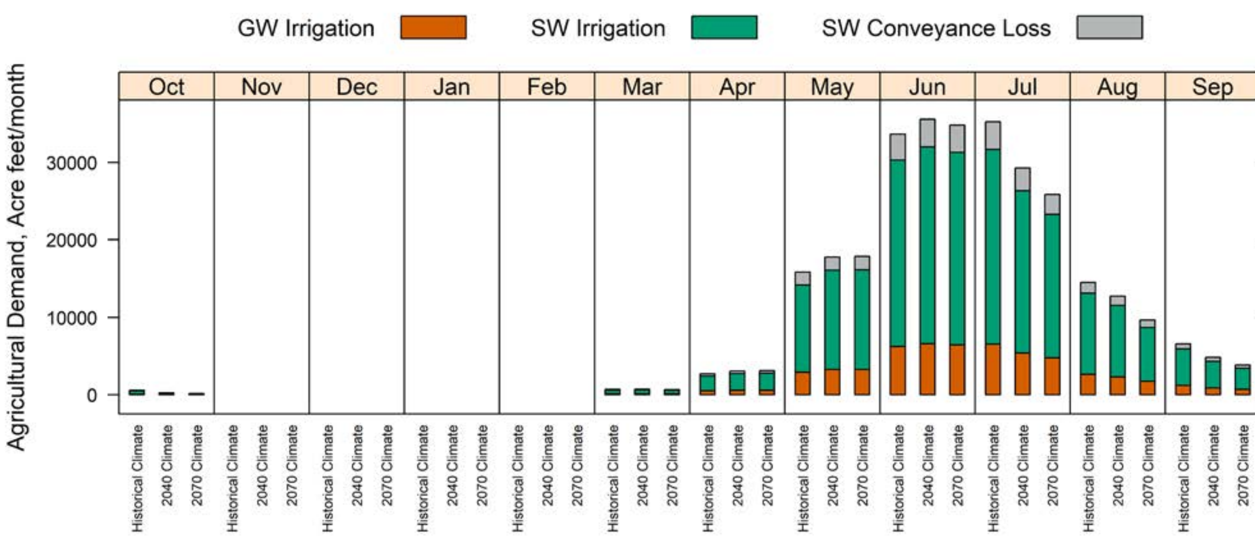
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

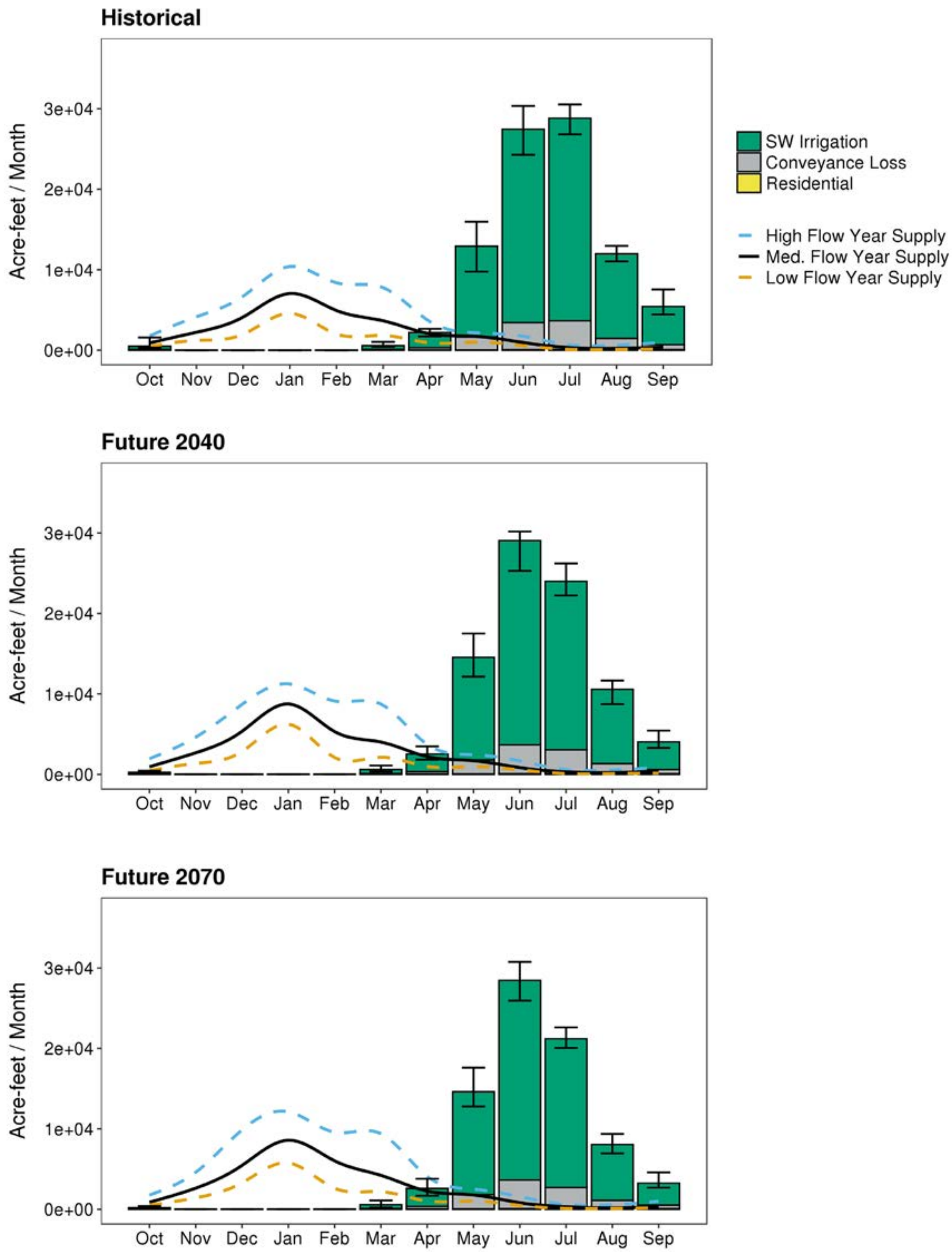
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

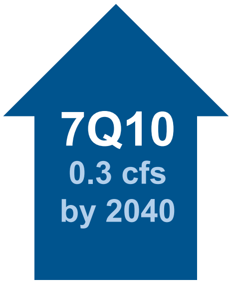
Bar 3
- 2070s Climate

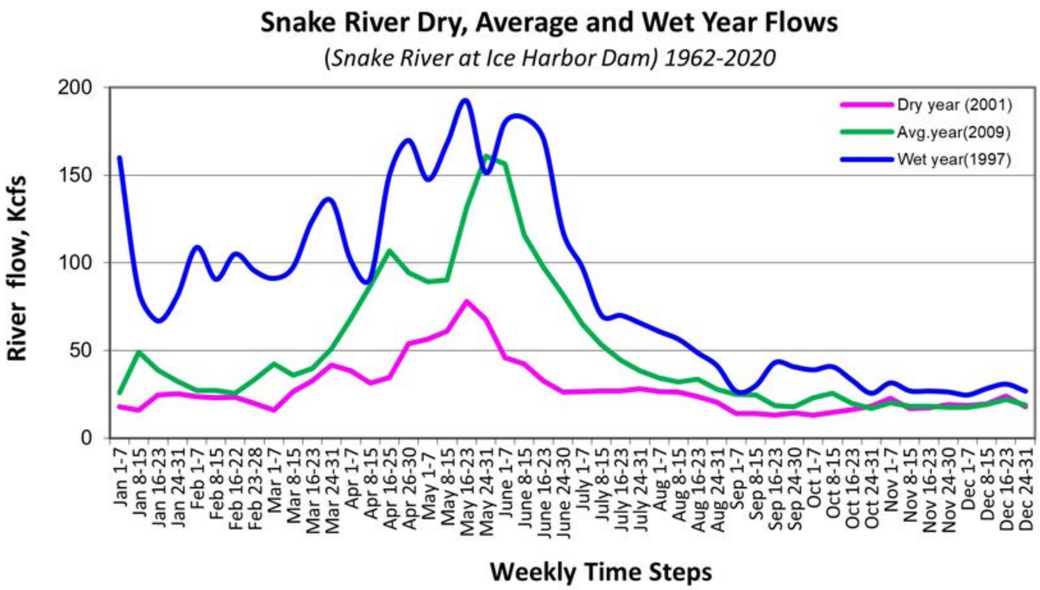
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

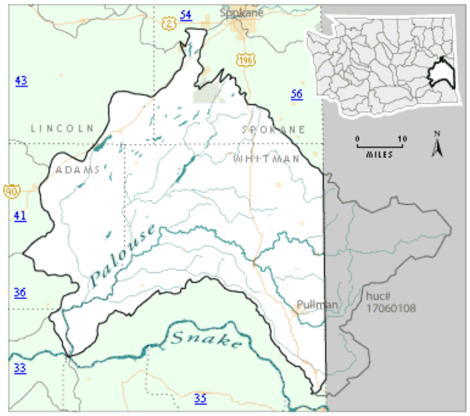


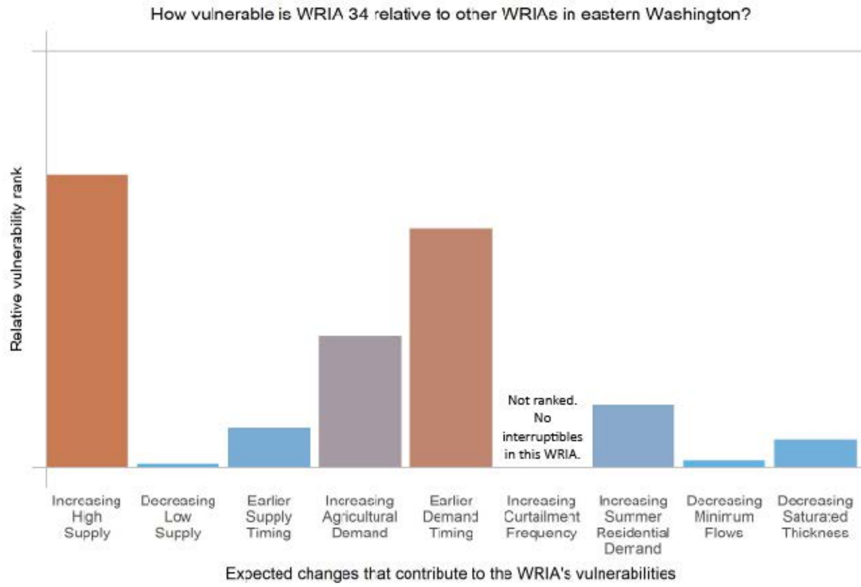


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





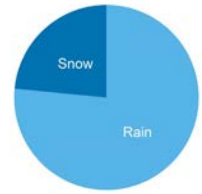
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

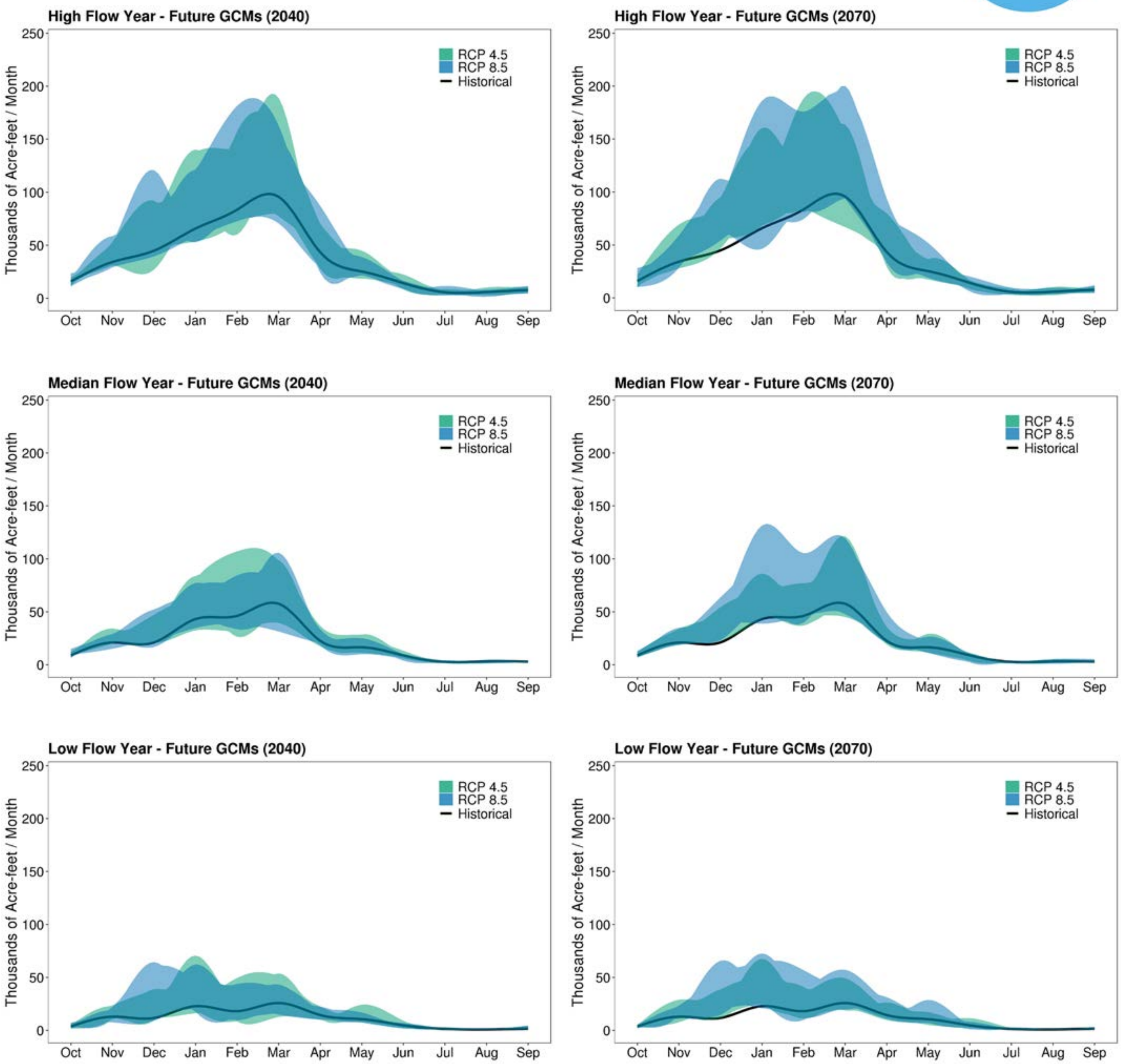
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 77 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 43 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 4 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 23% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 3% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 448 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.8 cfs by 2040.
- Decreasing Saturated Thickness: Available saturated thickness is projected to decrease by 9% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Cow Creek & Sprague Lake
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Snake mainstem migratory corridor for Snake River Basin Steelhead, Snake River Fall Run Chinook, Snake River Spring and Summer Run Chinook and Snake River sockeye]
Groundwater Subareas Overlapped by WRIA	Palouse, Odessa

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

SUPPLY

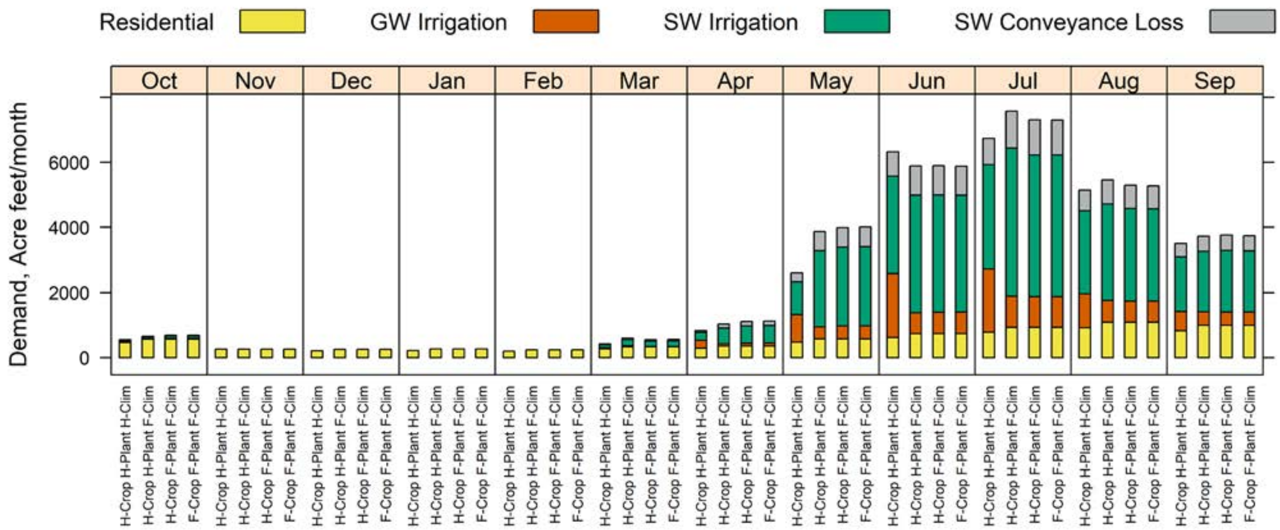




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

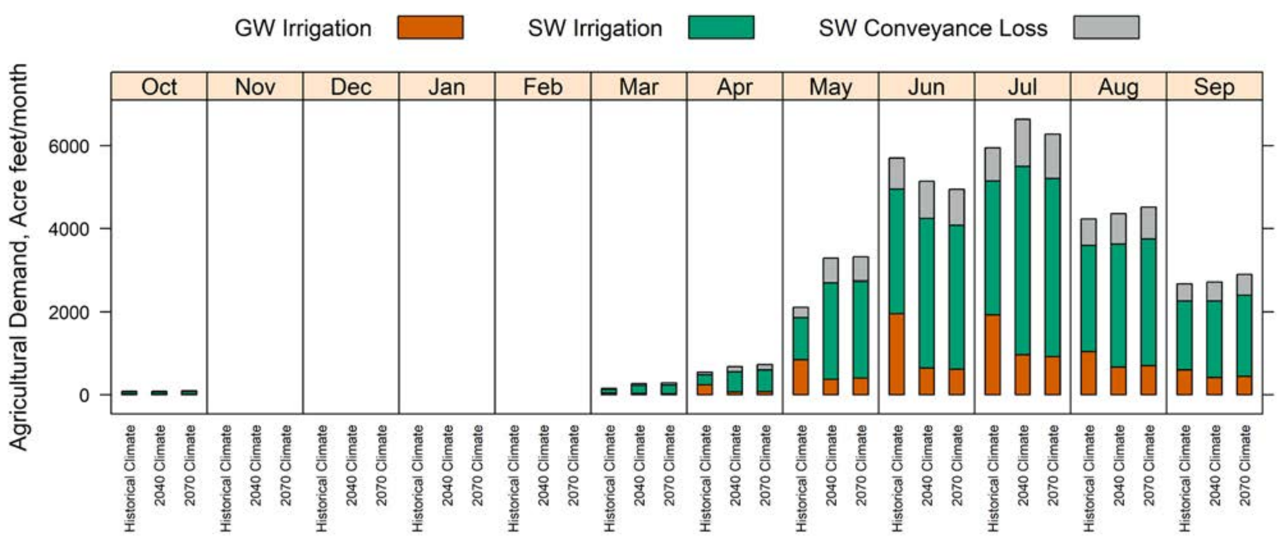
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

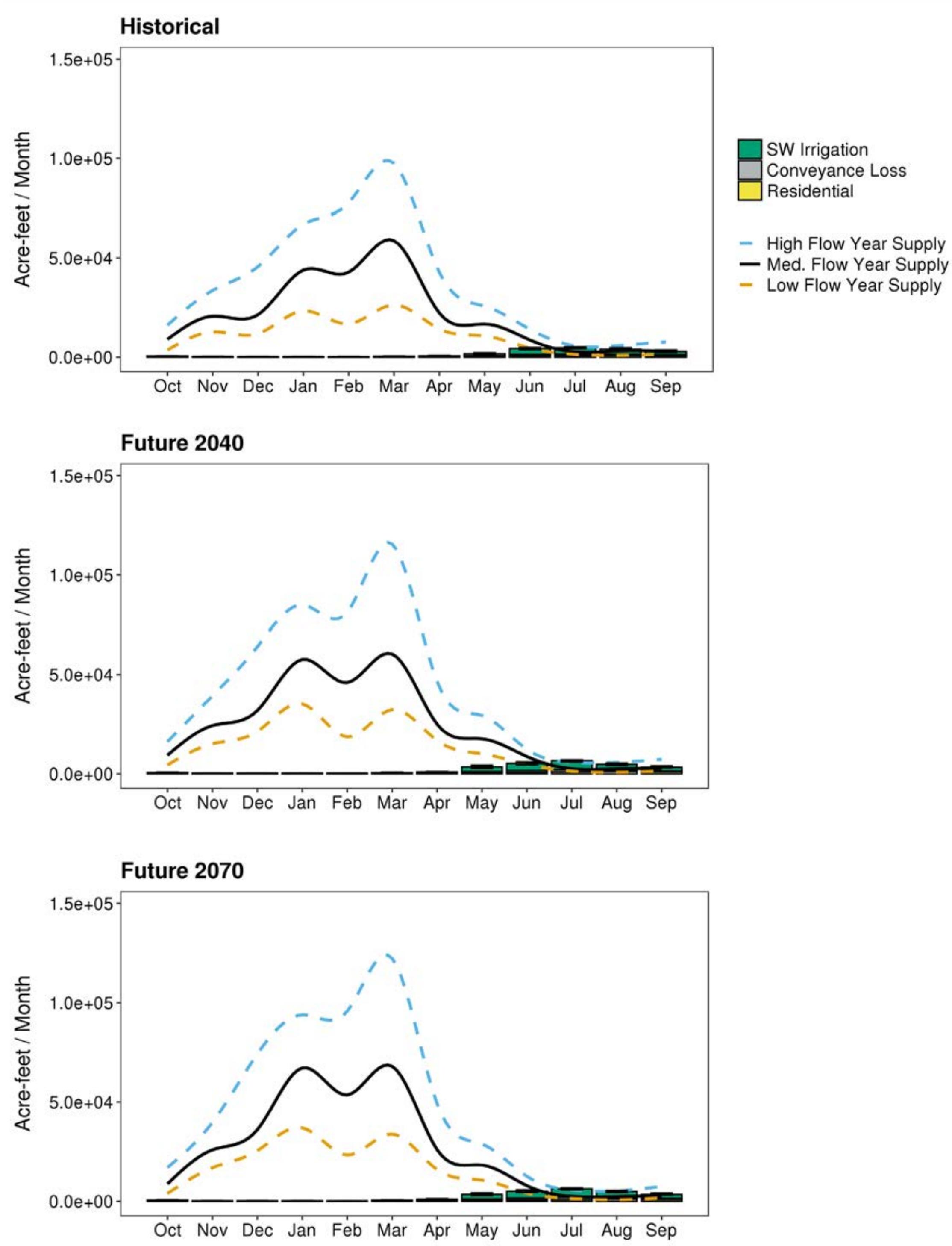
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

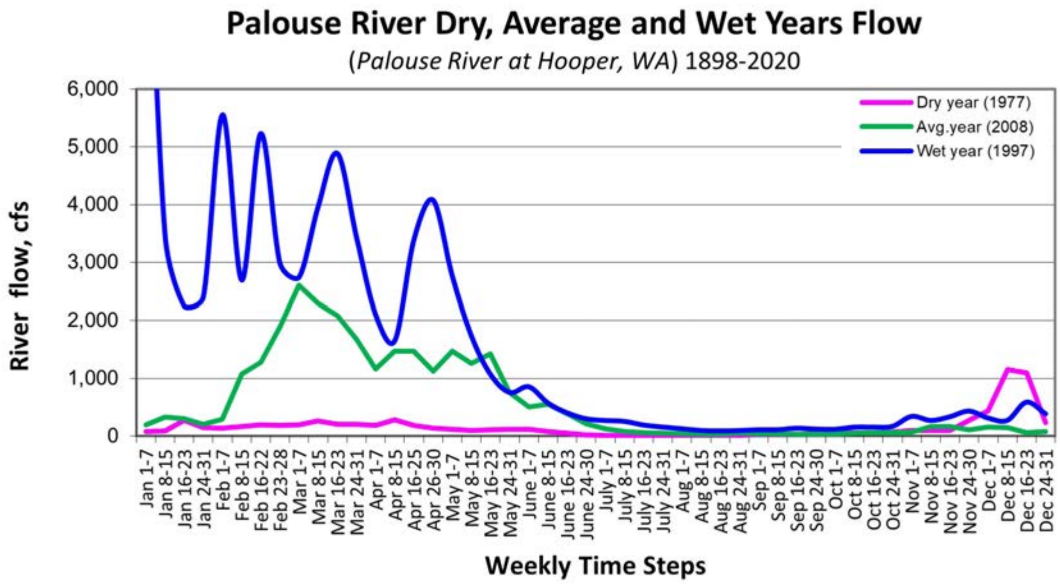
Bar 3
- 2070s Climate

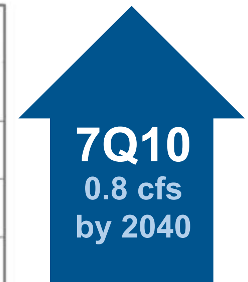
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

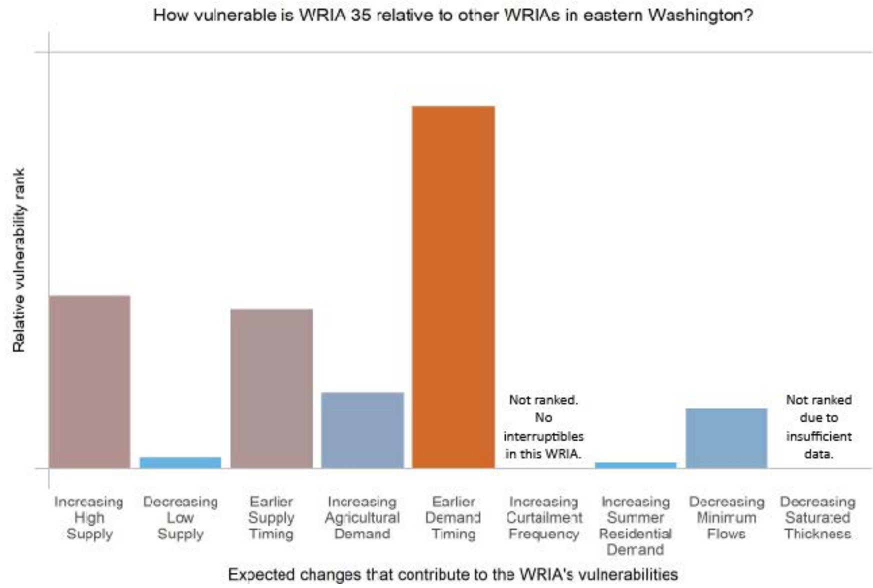


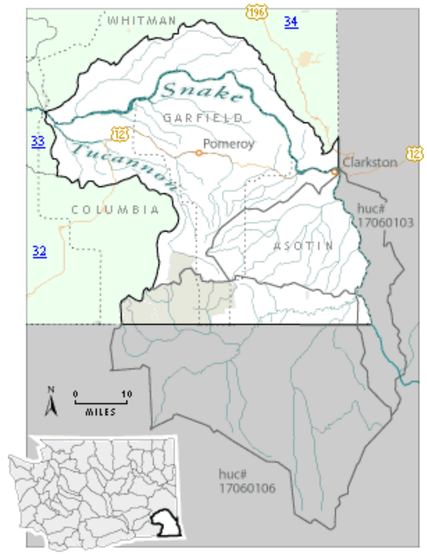


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





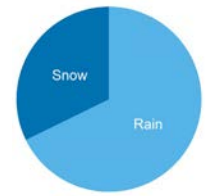
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

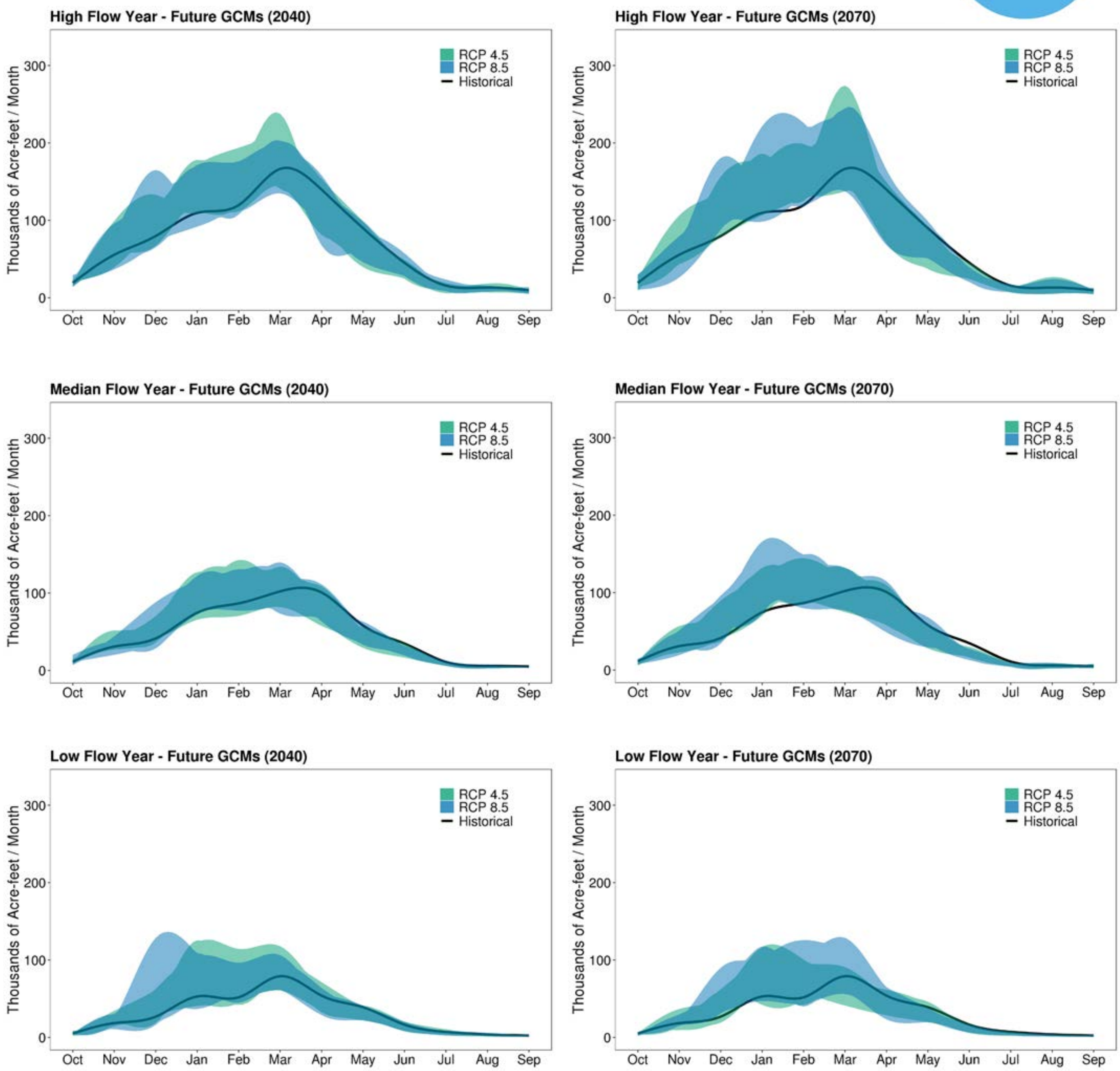
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 28 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 39 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 10 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 32% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 1% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day later by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 33 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 1.3 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Deadman Creek , Wawawai Creek, Meadow Gulch Creek, Alpowa Creek
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Snake River Basin Steelhead, Snake River Bull Trout, Snake River Fall Run Chinook, Snake River Spring and Summer Run Chinook [Snake mainstem migratory corridor for Snake River sockeye]
Groundwater Subareas Overlapped by WRIA	NONE

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

SUPPLY

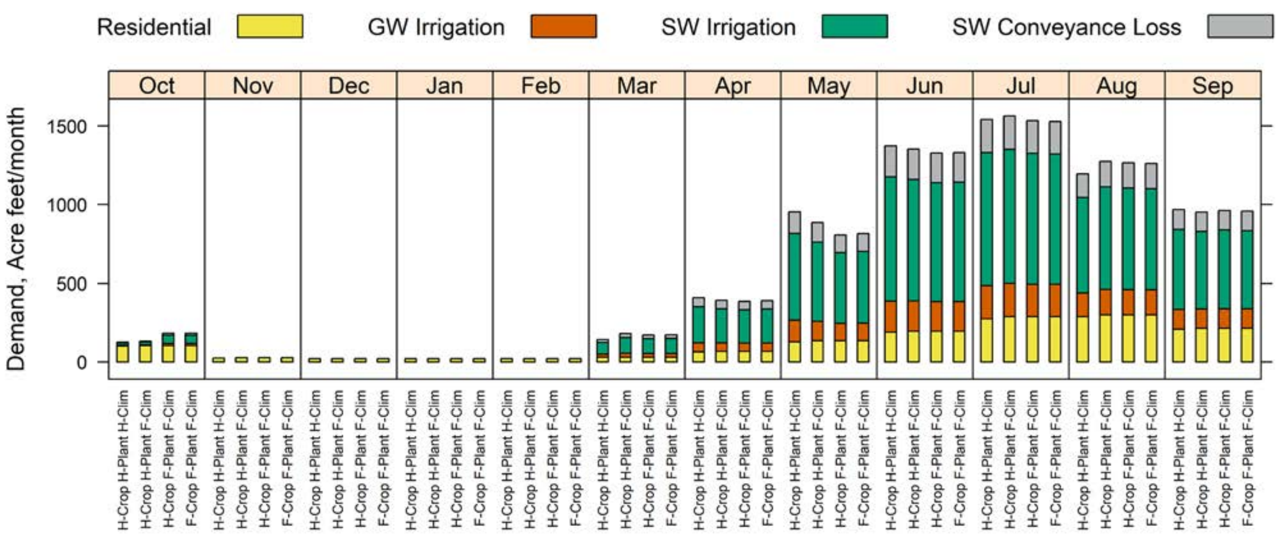




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

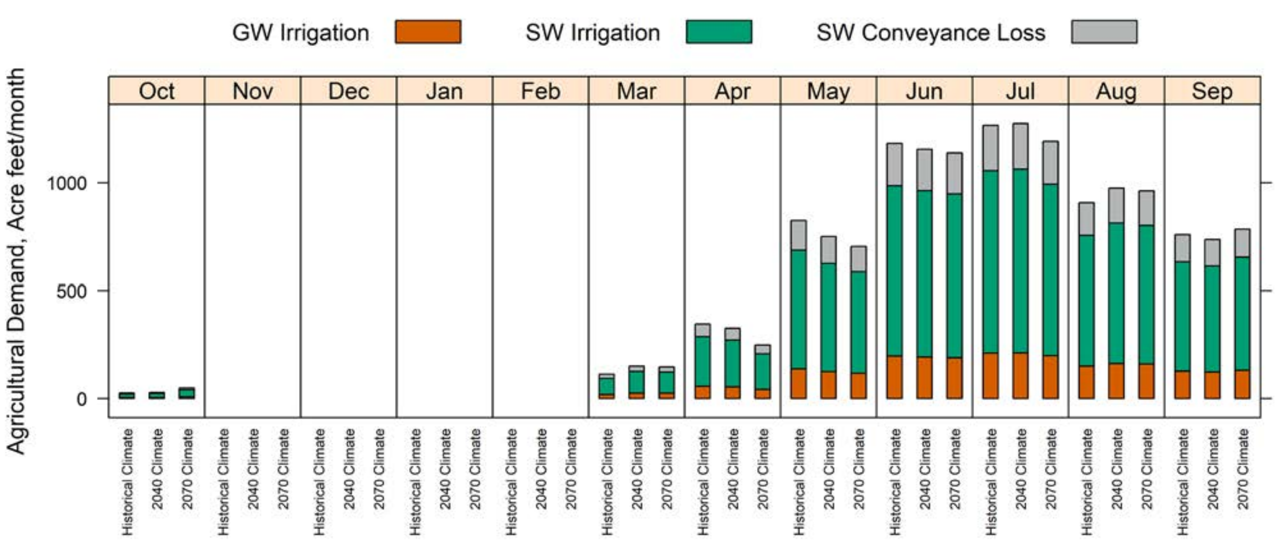
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

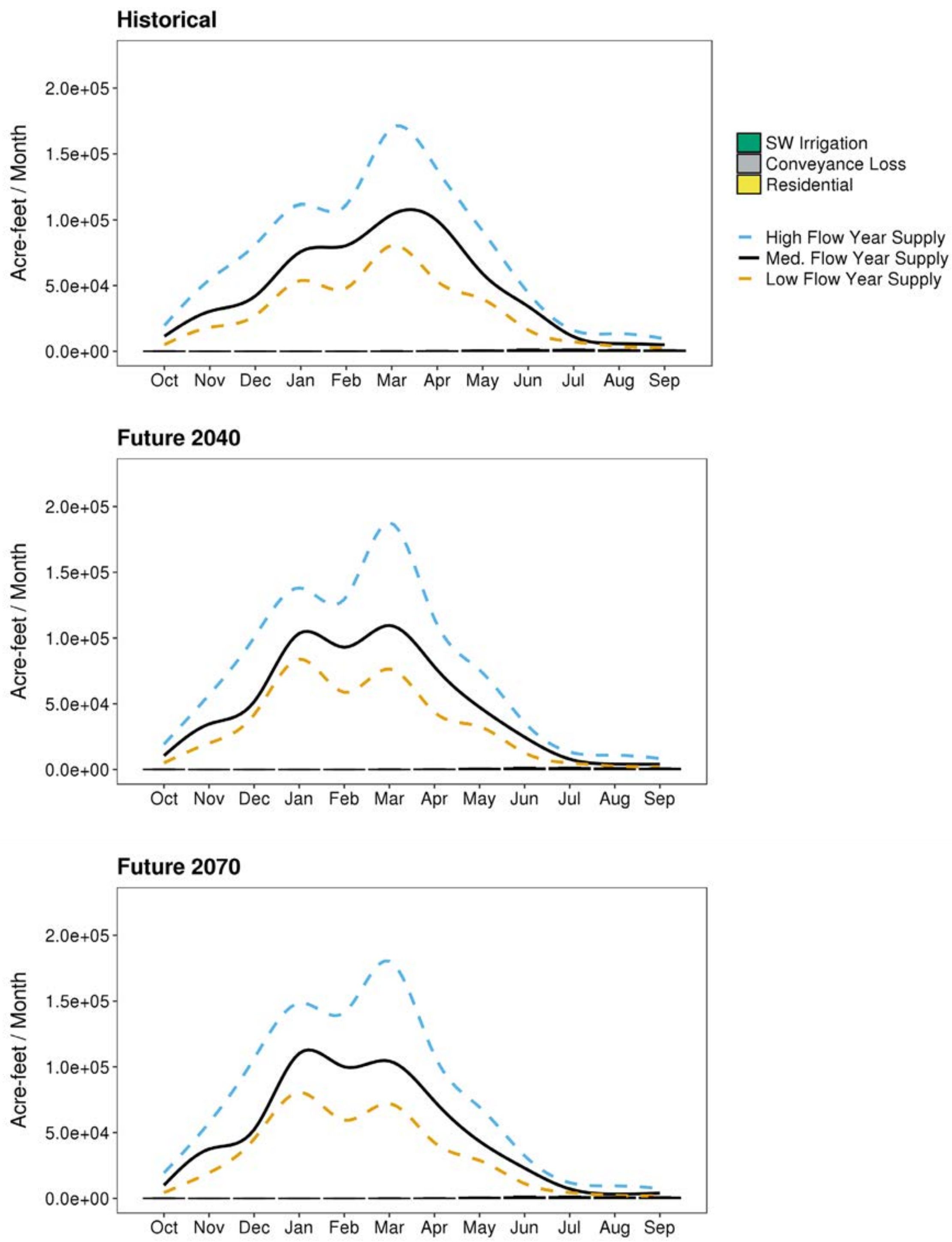
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

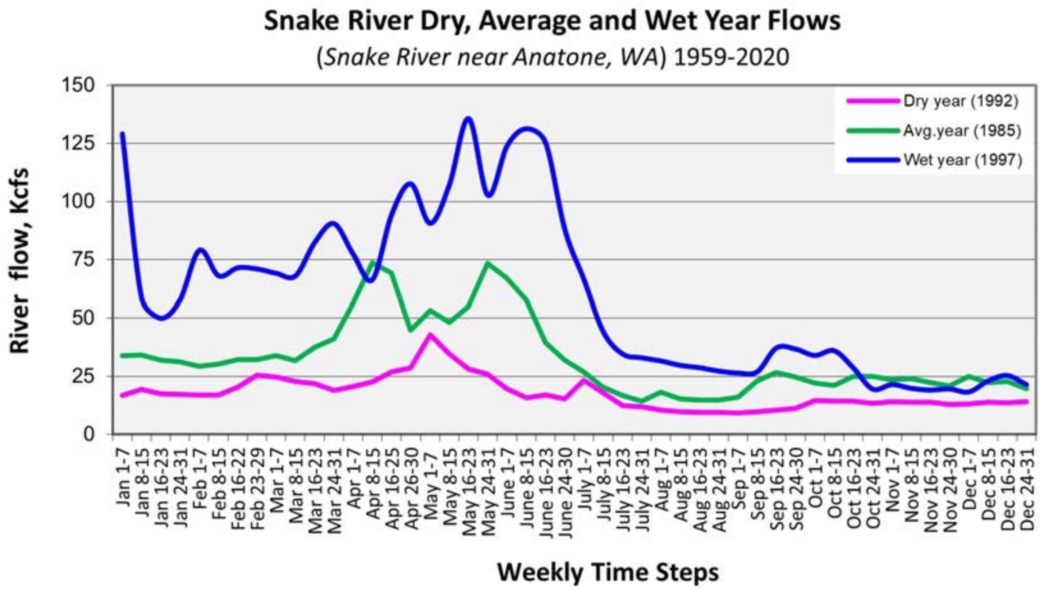
Bar 3
- 2070s Climate

SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

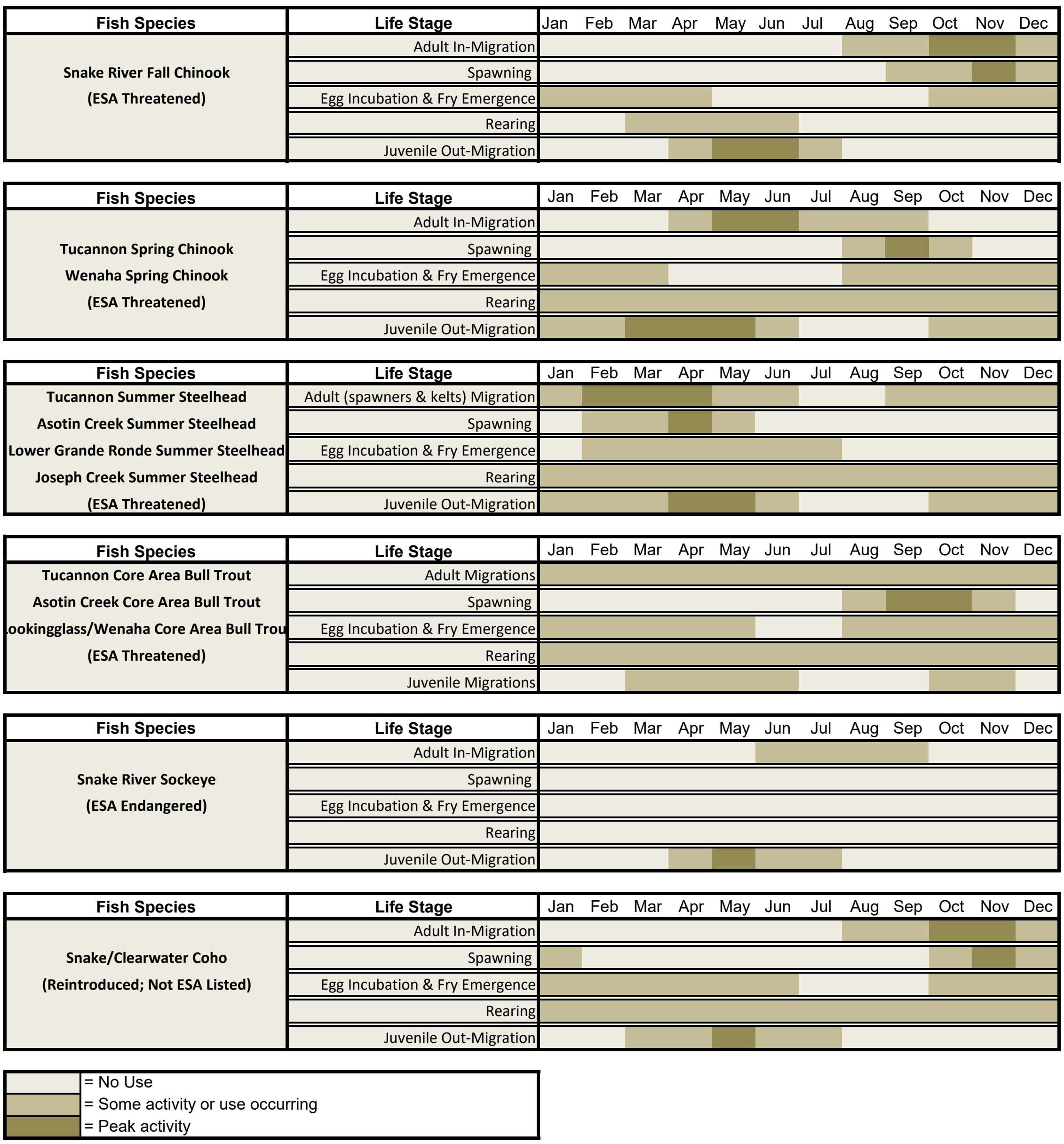


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

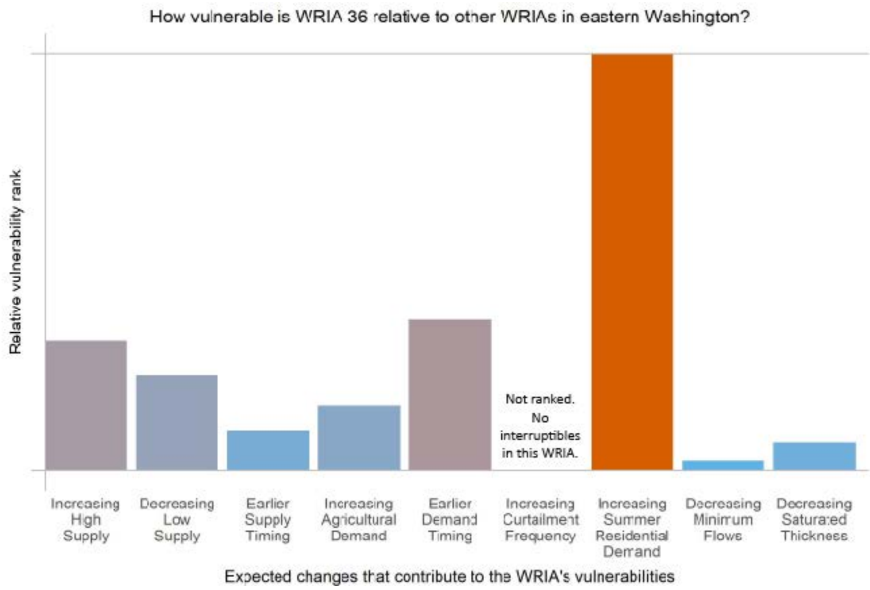
CONSIDERATIONS FOR FISH

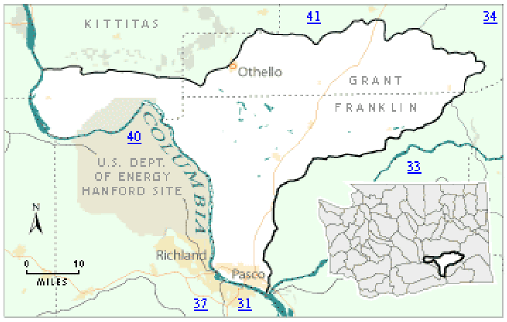
Middle Snake - WRIA 35
Fish Use Timing by Species



The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





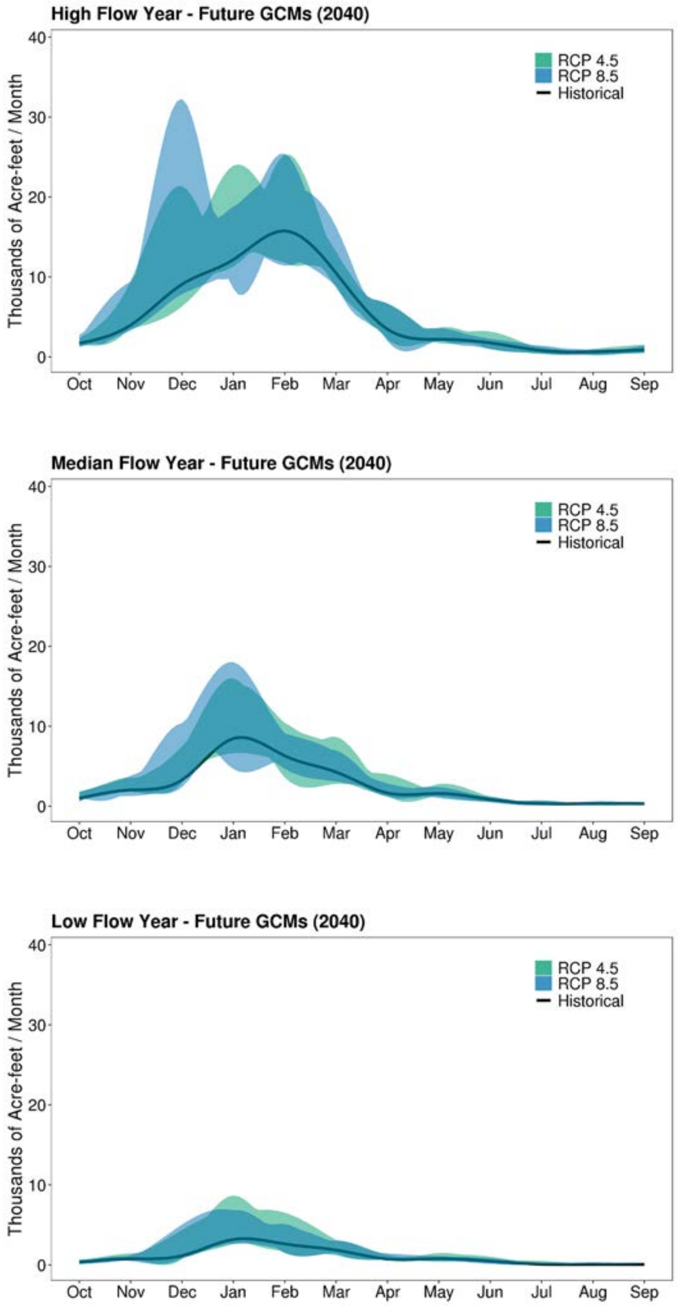
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 11 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 3 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 4 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 18% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 2% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 5 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 3,052 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.7 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 9% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Odessa

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

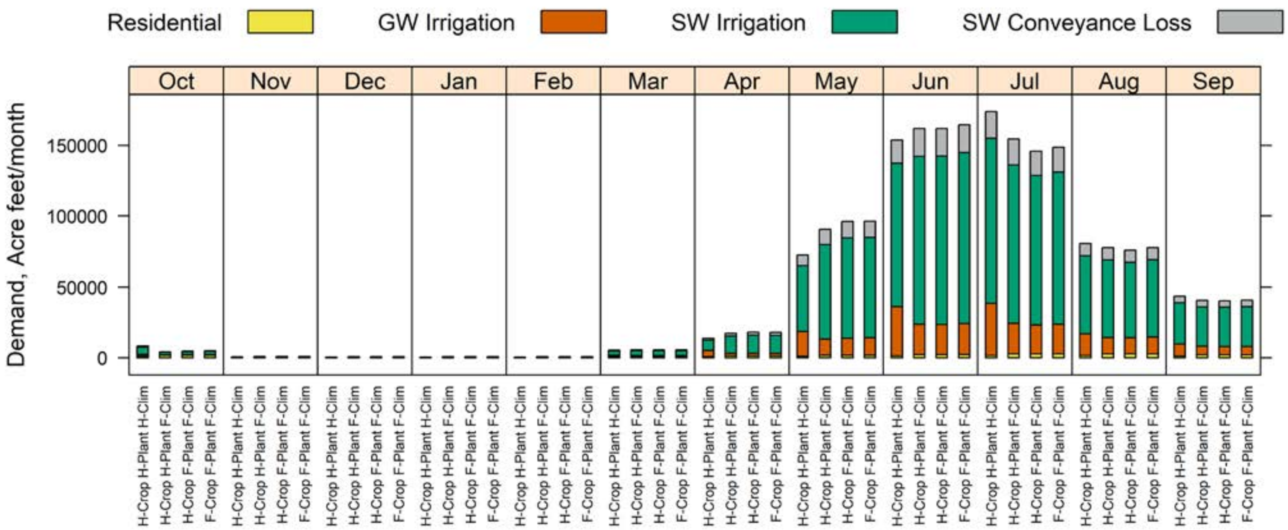
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

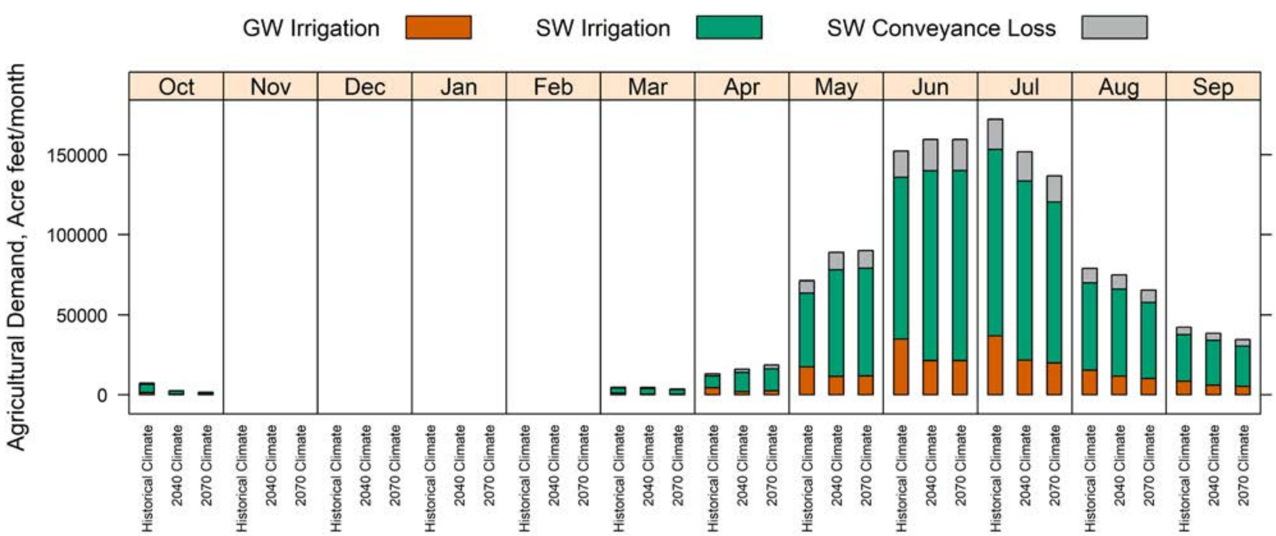
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

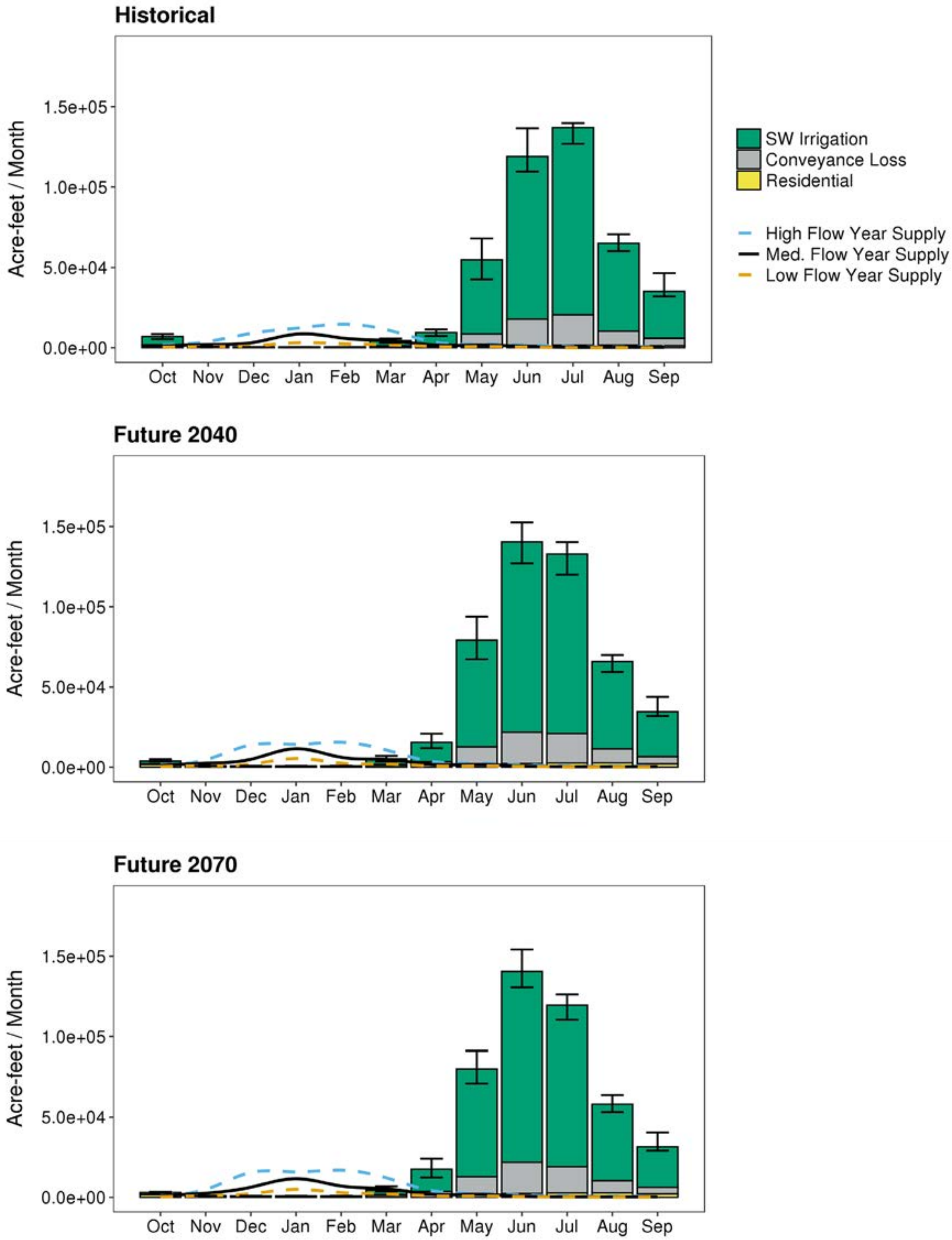
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

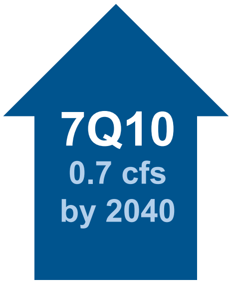
Bar 3
- 2070s Climate

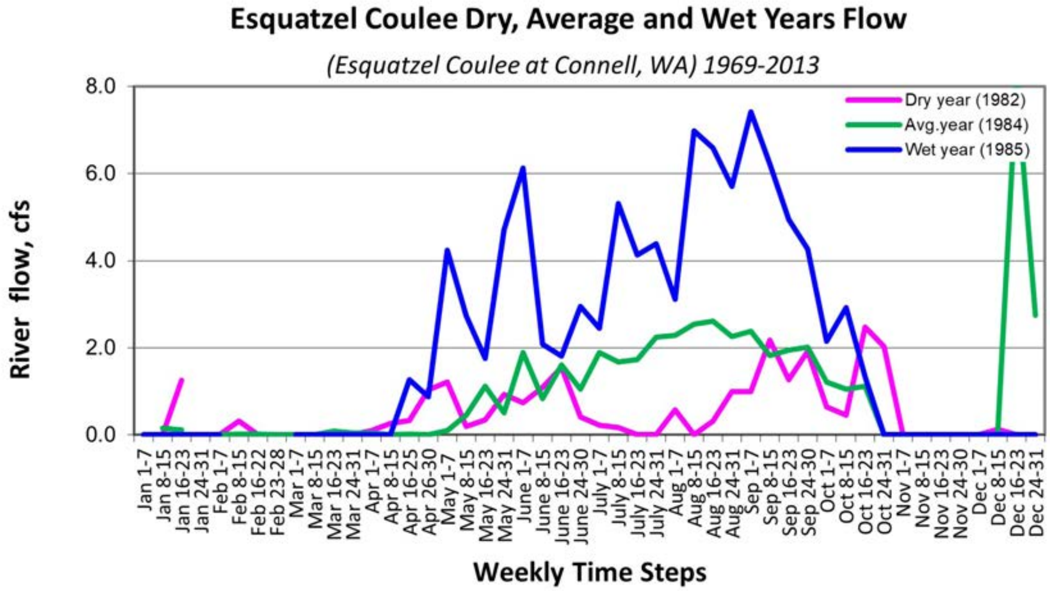
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment. For this particular WRIA, much of the irrigation water is drawn from the Columbia River which causes the supply to appear of lesser magnitude compared to demand.

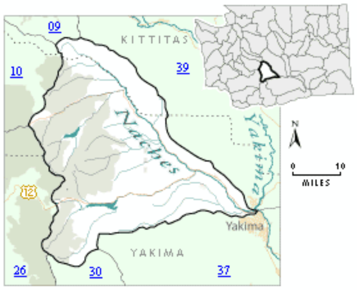
CONSIDERATIONS FOR FISH

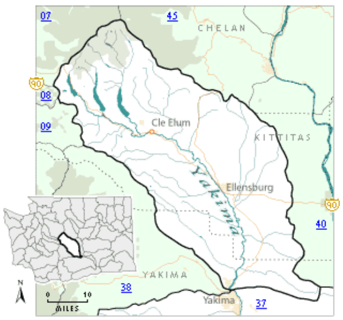


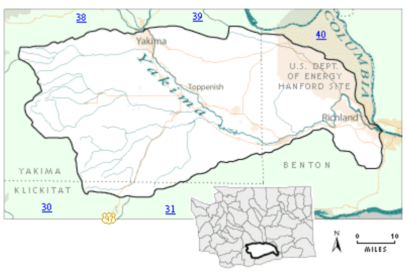


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

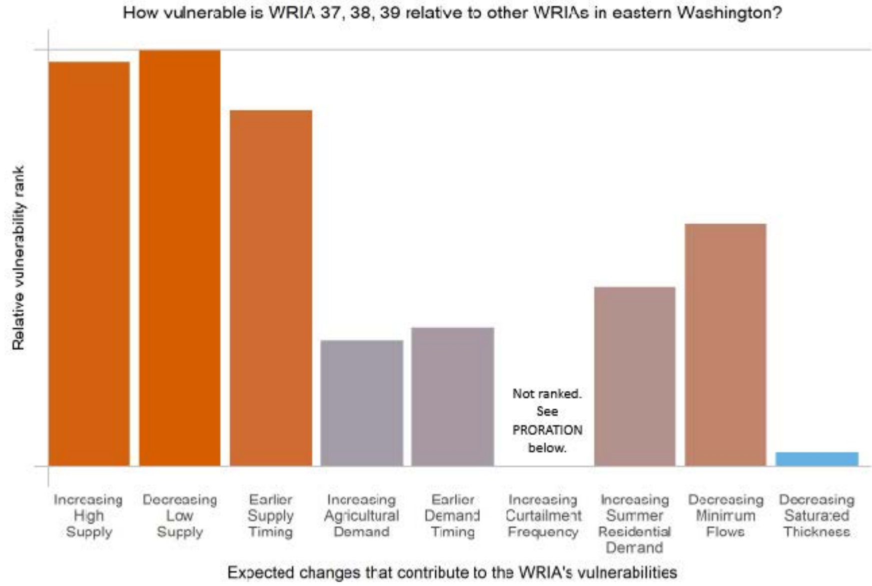
The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.







SUMMARY



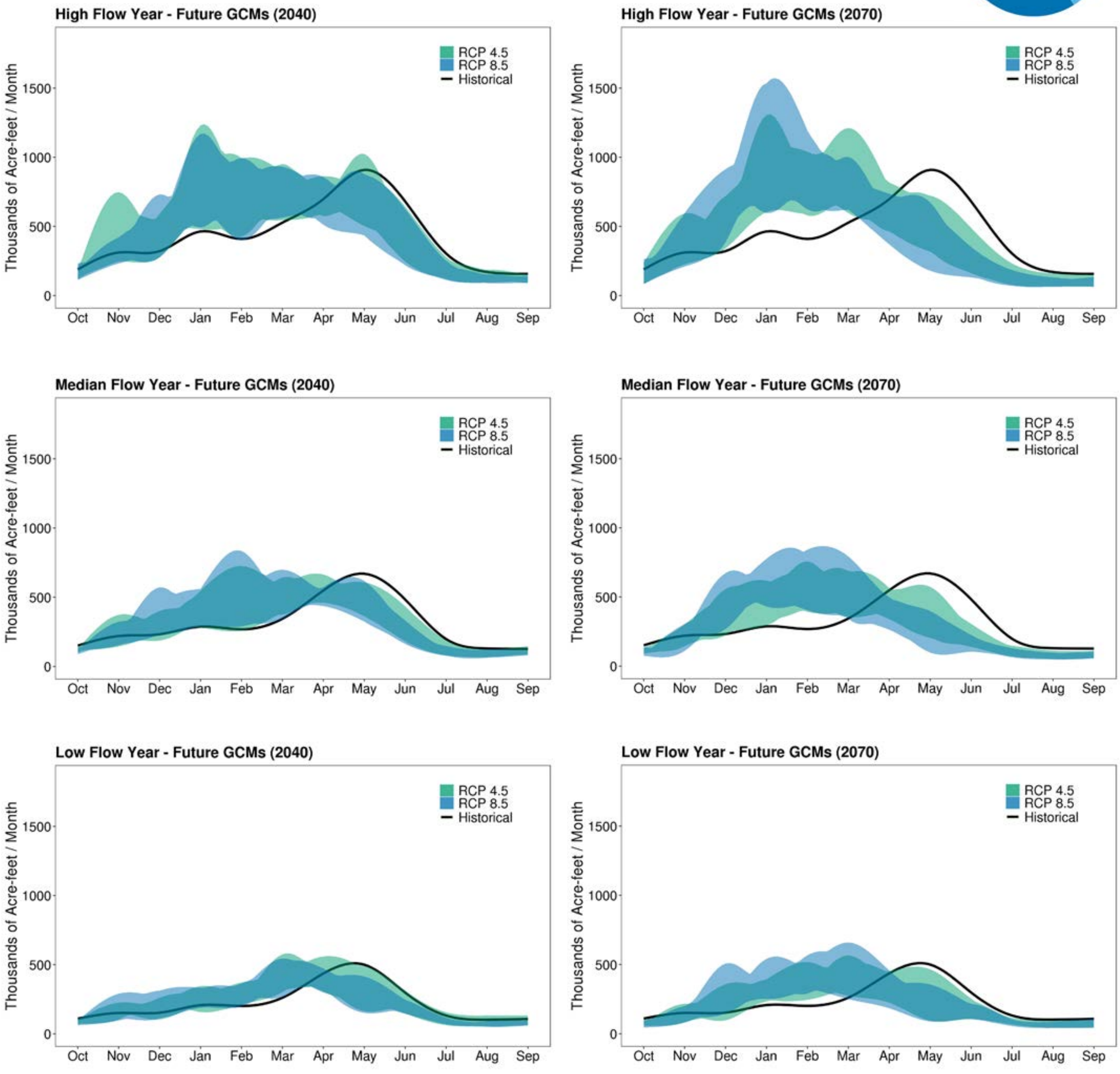
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 121 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to decrease by 134 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 20 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 59% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 2% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 5 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 3,921 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 8.7 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 6% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Ahtanum Creek, Cowiche Creek, Wenas Creek, Tenaway River, Cooke Creek, Big Creek, Yakima River Basin (Surface water only)
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[1]	Bull Trout, Middle Columbia Steelhead, [WRIA 37 is also Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Kittitas, Selah, Yakima, Extended Toppenish, Eastern Benton, Red Mountain

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

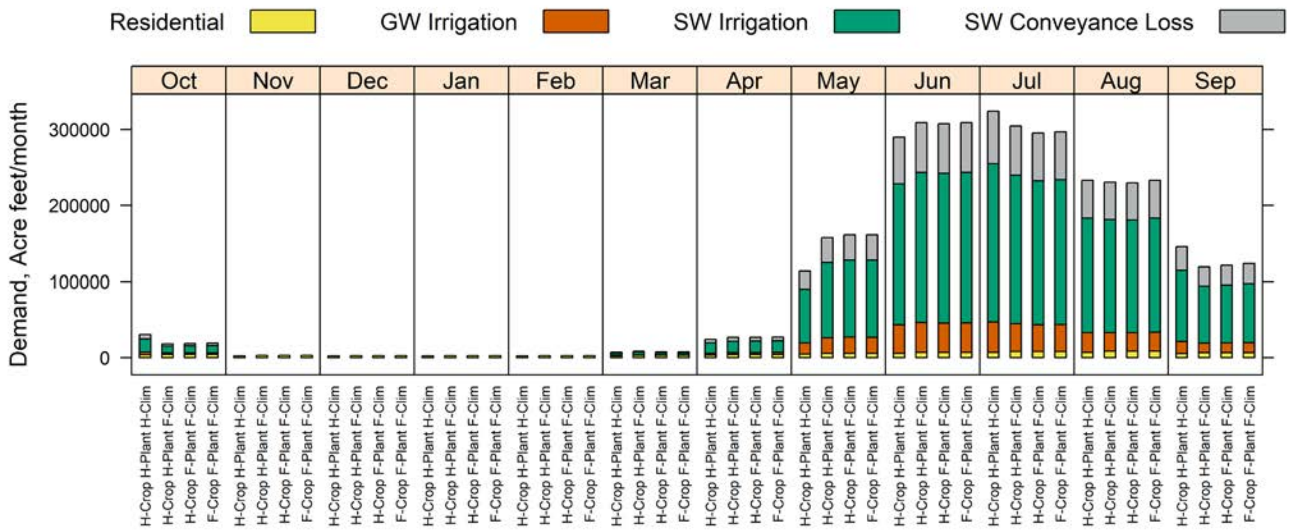
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

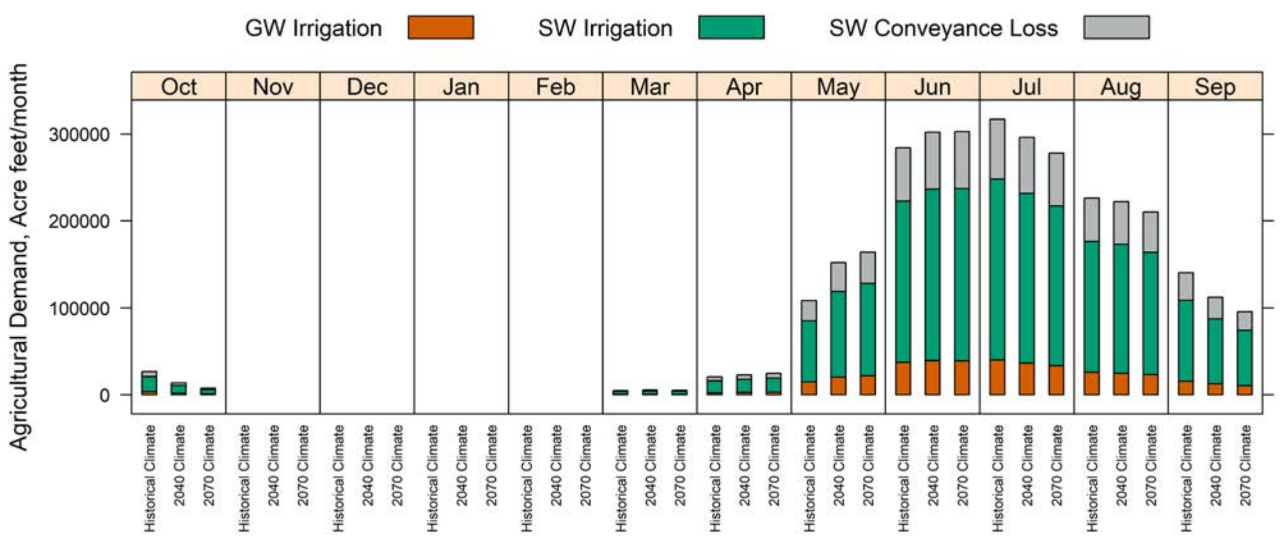
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

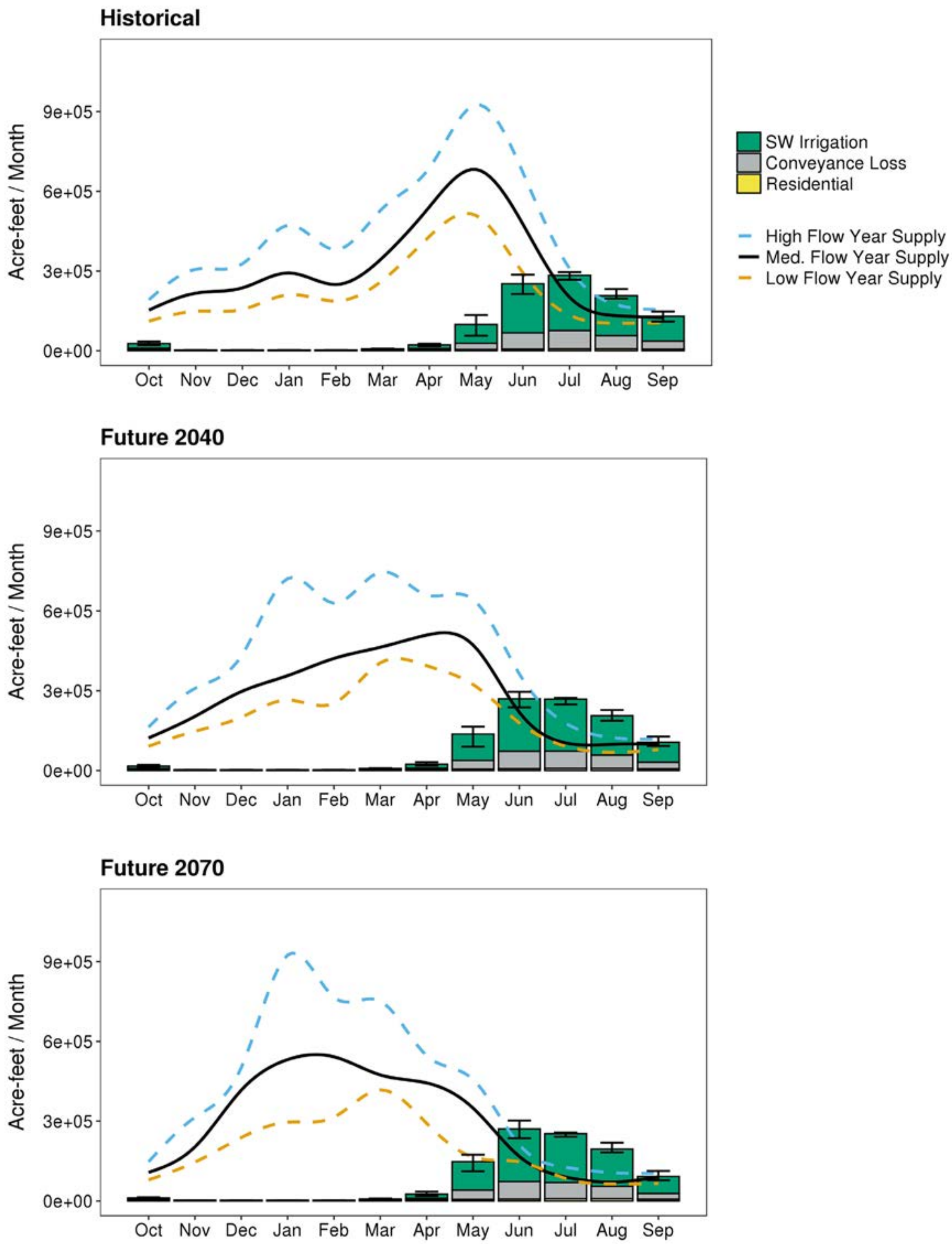
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

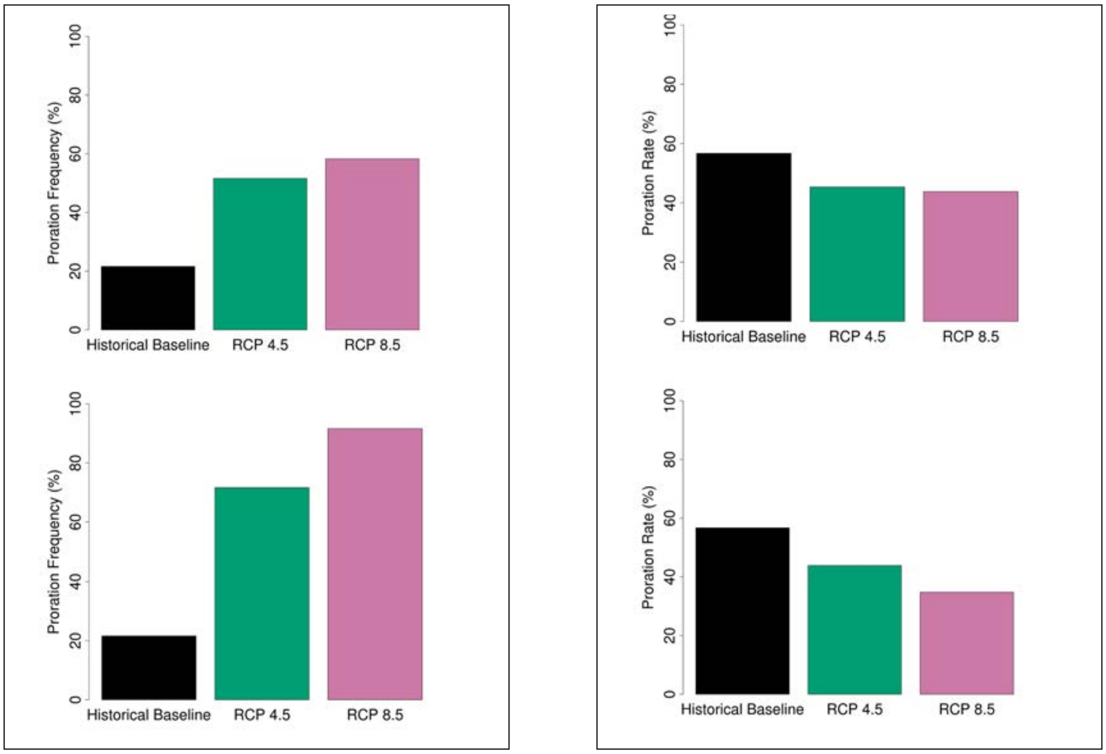
Bar 3
- 2070s Climate

SUPPLY AND DEMAND

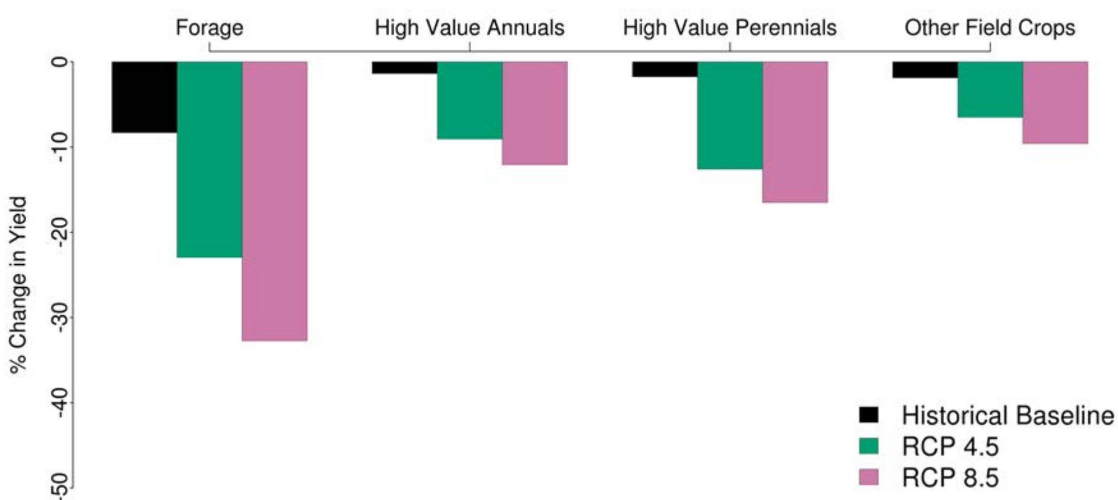


Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

PRORATION

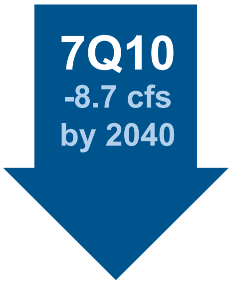


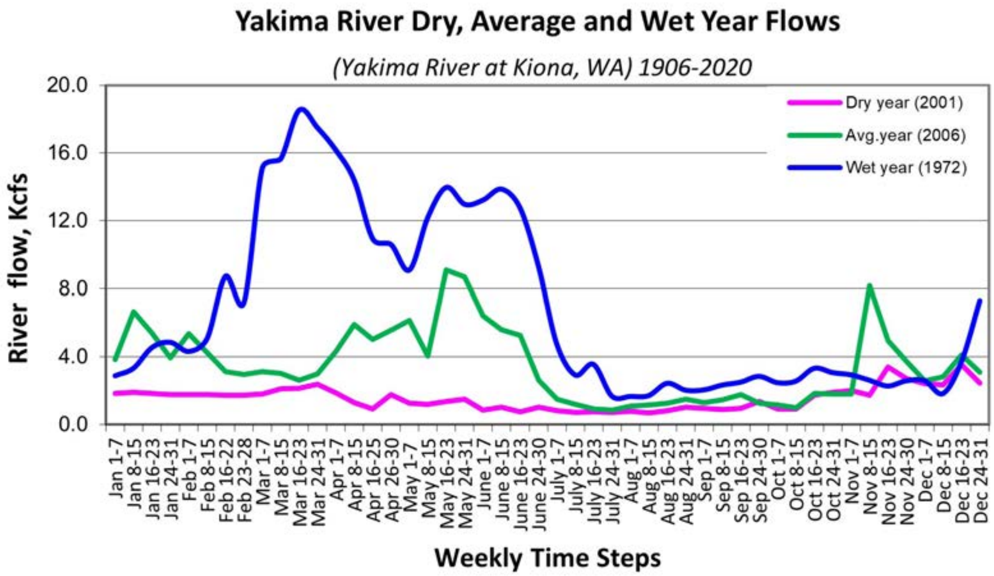
Modeled historical baseline (1986-2015) and forecast (2026-2055) proration frequency (left panel) and median annual proration rate (right panel). A proration rate of 100% corresponds to fully satisfied water entitlements. Prorationing is forecasted using the median of proration frequency and median annual proration rate predicted by 17 climate scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5. These results correspond to an annual proration rate of 70% or less. Periodic proration rates higher than 70% of entitlements do not typically have significant adverse effects on agricultural production in the Yakima region because irrigation districts have water-sharing mechanisms in place to cope with minor water restrictions.



Difference between annual yield produced on land with an interruptible water right and full irrigation yield relative to full irrigation yield under historical baseline (1986- 2015) and future (2026- 2055) climate conditions. Future yields are calculated as the median of 17 climate change scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5. The “Other Field Crops” crop group includes wheat, peas, barley, corn, and dry beans. The “High Value Annuals” crop group includes onions, potatoes, mint, sweet corn, carrots, oats, dill, grass seed, sunflower, sugar beets, pepper, canola, and yellow mustard. The “High Value Perennials” crop group includes blueberries, apples, cherries, peaches, pears, grapes, and hops. The “Forage” crop group includes alfalfa hay and grass hay. The acreage pie chart is not included for this WRIA because water rights holders in the irrigation districts share in the same prorationing rate based on what fraction of each district is interruptible.

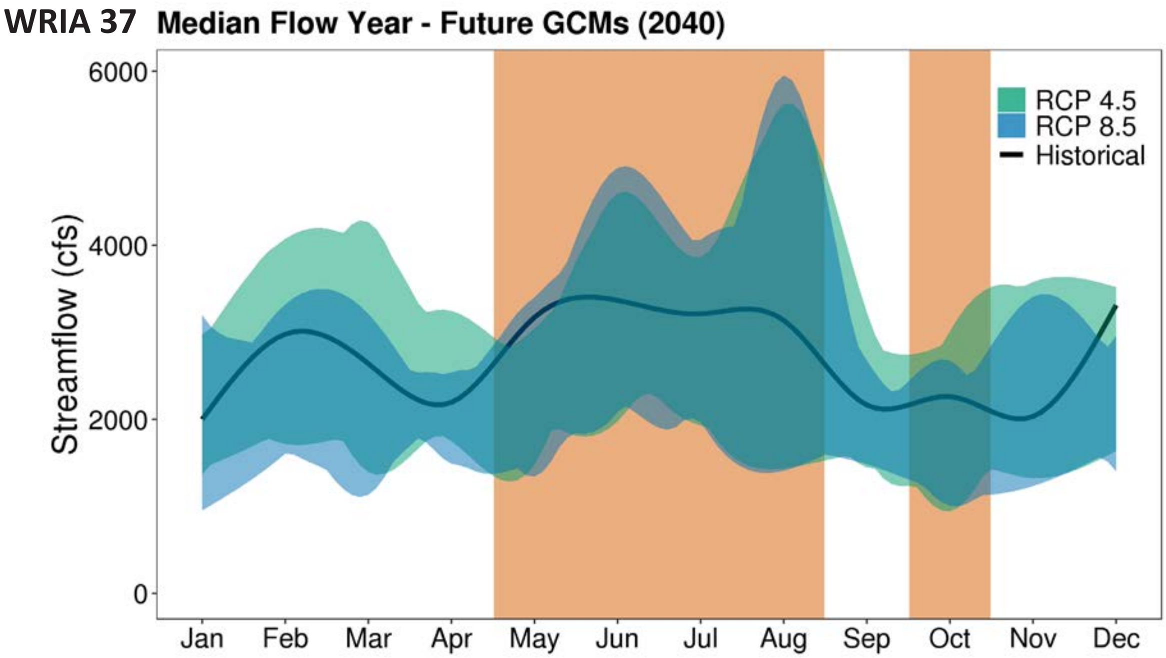
CONSIDERATIONS FOR FISH

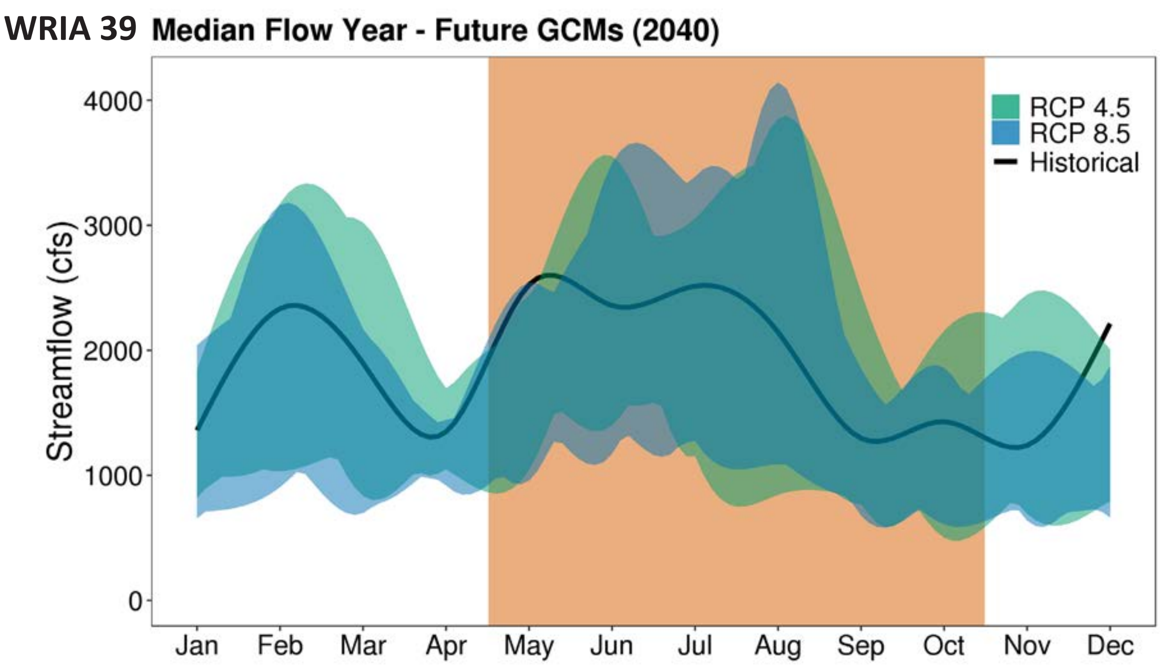




Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.





The actual flow plot shows modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5; 2040) surface water actual flows generated within the WRIA. Actual flow was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each RCP is due to the range of climate change scenarios considered. An orange background in the plot indicates months in which 90% of the climate models predict future flows that are below historical. Actual flows represent the expected amount of water available after demands are accounted for.

CONSIDERATIONS FOR FISH

Lower Yakima River - WRIA 37
Fish Use Timing by Species

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

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Yakima Summer Steelhead	Adult (spawners & kelts) Migration												
Naches Summer Steelhead	Spawning												
Toppenish Creek Summer Steelhead	Egg Incubation & Fry Emergence												
Satus Creek Summer Steelhead	Rearing												
(ESA Threatened)	Juvenile Out-Migration												

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Sockeye (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
Yakima Coho (ESA Not Warranted)	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 River Core Area Bull Trout (ESA Threatened)	Adult Migrations												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Migrations												

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical. Actual flow data is not available for WRIA 38 so there is purposefully no shading on WRIA 38's fish periodicity table.

CONSIDERATIONS FOR FISH

Naches - WRIA 38
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima River Summer/Fall Chinook (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0	0	0				0
	Spawning	0	0	0	0	0	0	0	0				
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing	0	0						0	0	0	0	0
	Juvenile Out-Migration	0	0	0					0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Yakima River Spring Chinook	Adult In-Migration	0	0	0						0	0	0	0
American River Spring Chinook	Spawning	0	0	0	0	0	0					0	0
Naches River Spring Chinook	Egg Incubation & Fry Emergence				0	0	0						
(ESA Not Warranted)	Rearing												
	Juvenile Out-Migration							0	0	0	0	0	0

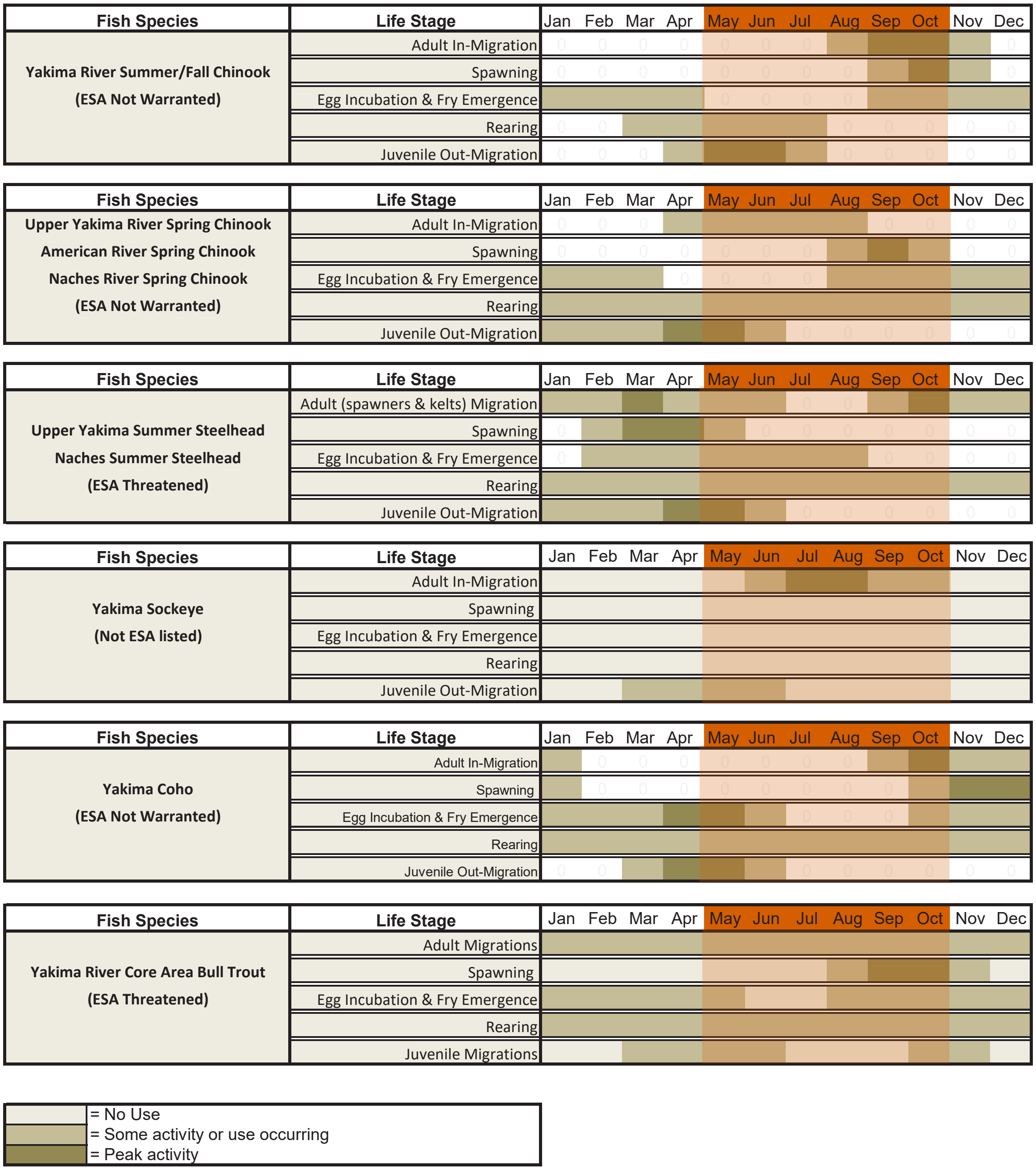
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Yakima Summer Steelhead Naches Summer Steelhead (ESA Threatened)	Adult (spawners & kelts) Migration							0	0				
	Spawning						0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence								0	0	0	0	0
	Rearing												
	Juvenile Out-Migration							0	0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima Coho (ESA Not Warranted)	Adult In-Migration		0	0	0	0	0	0	0				
	Spawning		0	0	0	0	0	0	0	0			
	Egg Incubation & Fry Emergence							0	0	0			
	Rearing												
	Juvenile Out-Migration	0	0					0	0	0	0	0	0

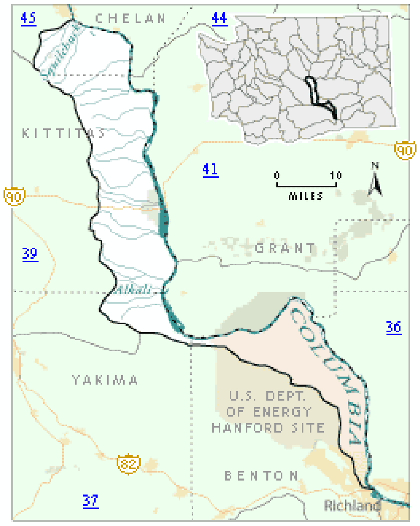
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yakima River Core Area Bull Trout (ESA Threatened)	Adult Migrations												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Migrations												

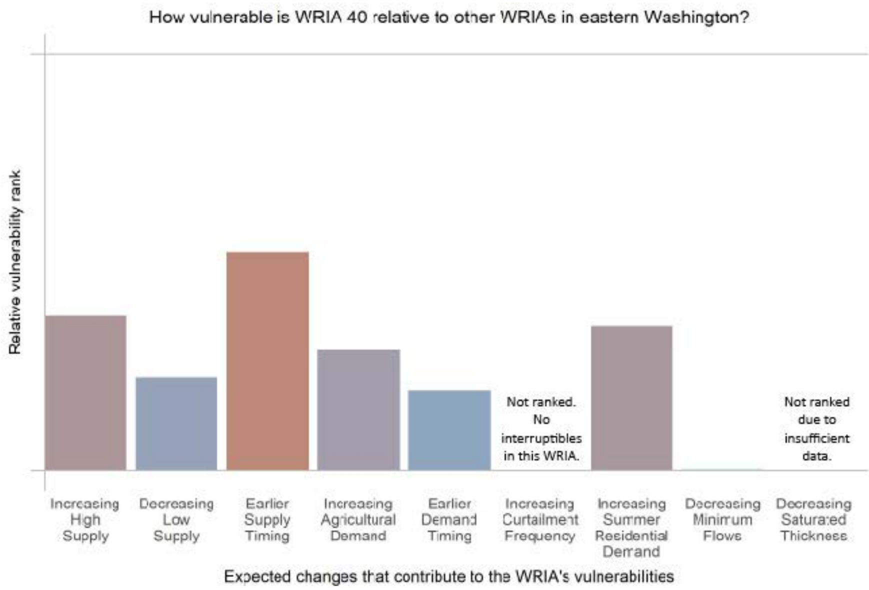
	= No Use
	= Some activity or use occurring
	= Peak activity

Upper Yakima - WRIA 39
Fish Use Timing by Species



SUMMARY





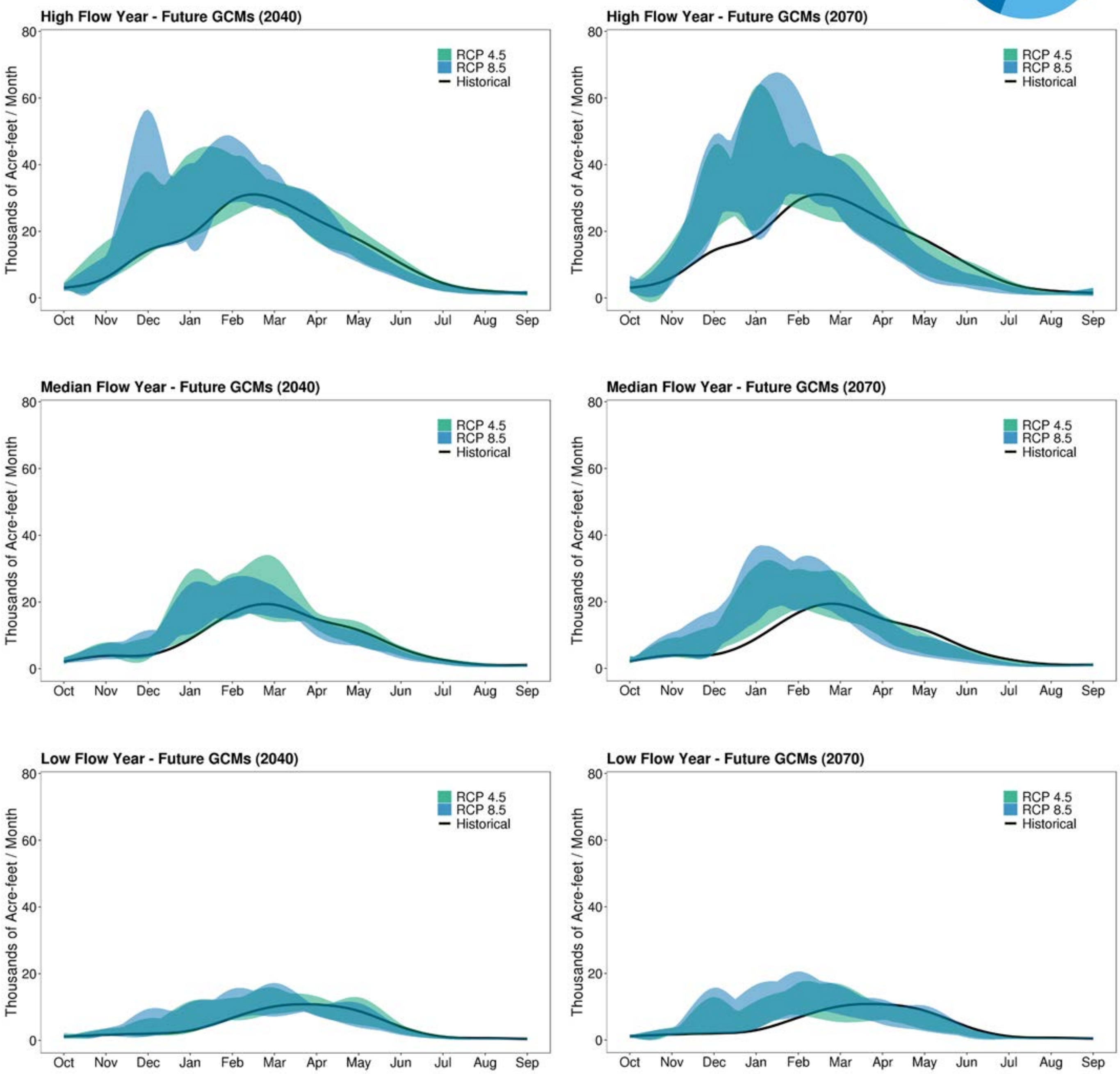
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 21 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 4 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 13 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 44% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 2% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 7 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 1,052 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 1.04 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Stemilt Creek, Squillchuck Creek, Cummings Canyon Creek
Watershed Planning	WRIA 40a: Phase 4 (Implementation), WRIA 40: NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	[Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Eastern Benton

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

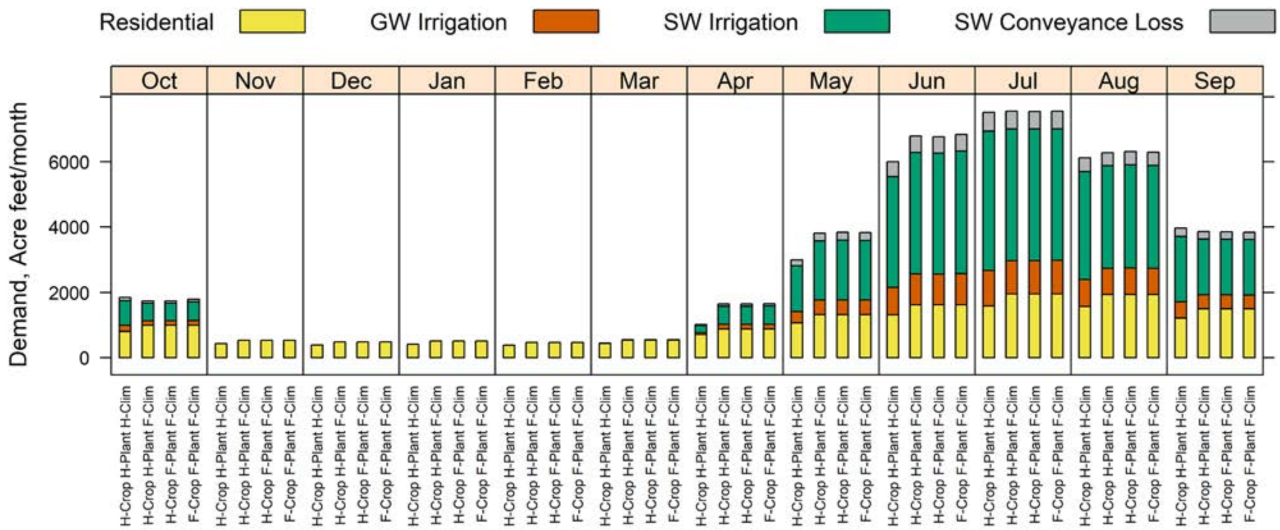
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

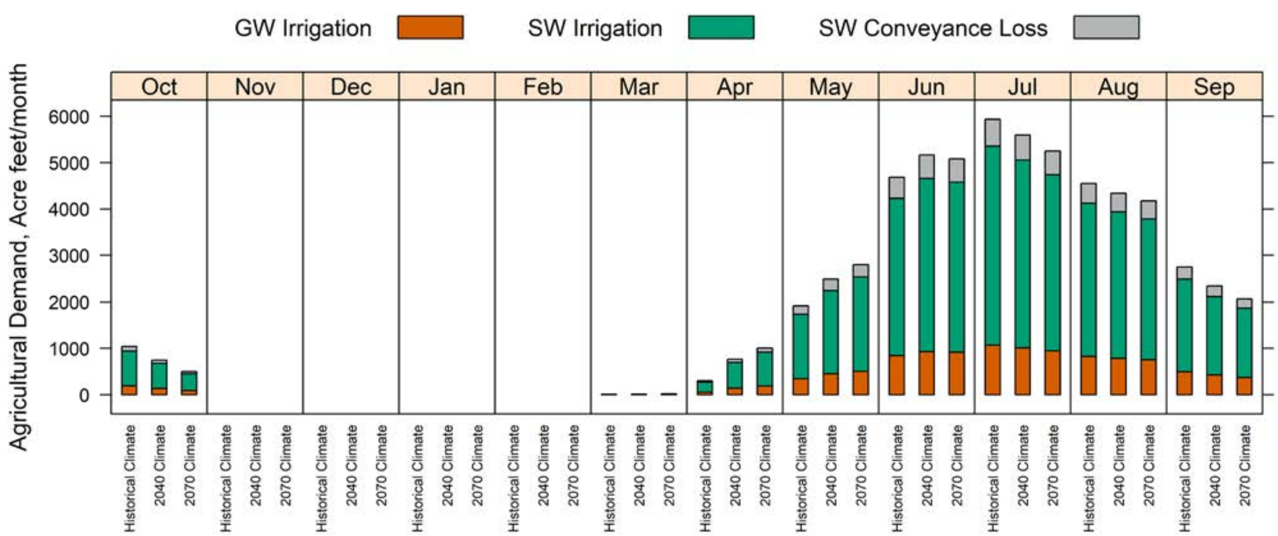
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

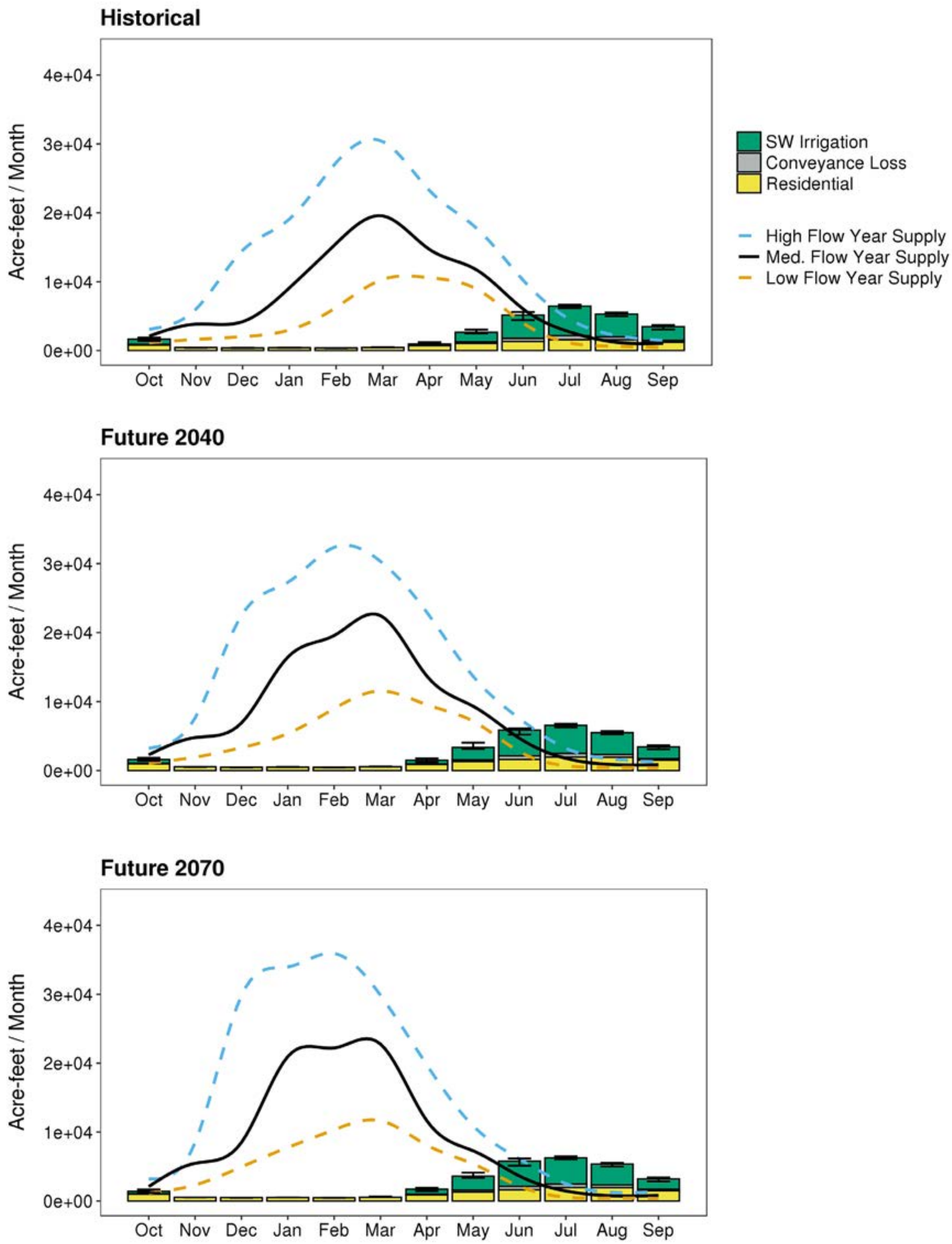
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

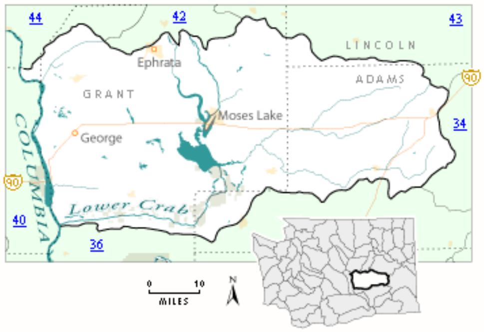
Bar 3
- 2070s Climate

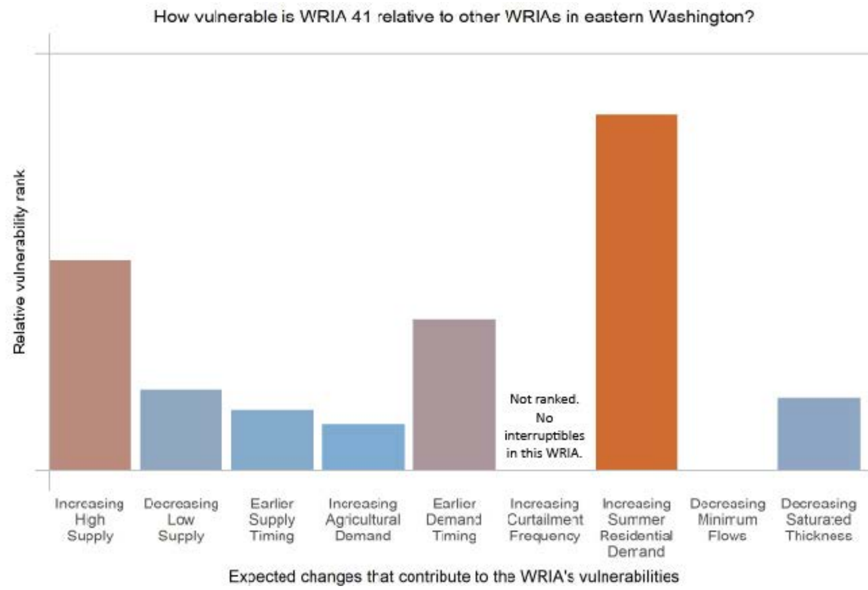
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

SUMMARY





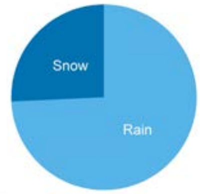
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

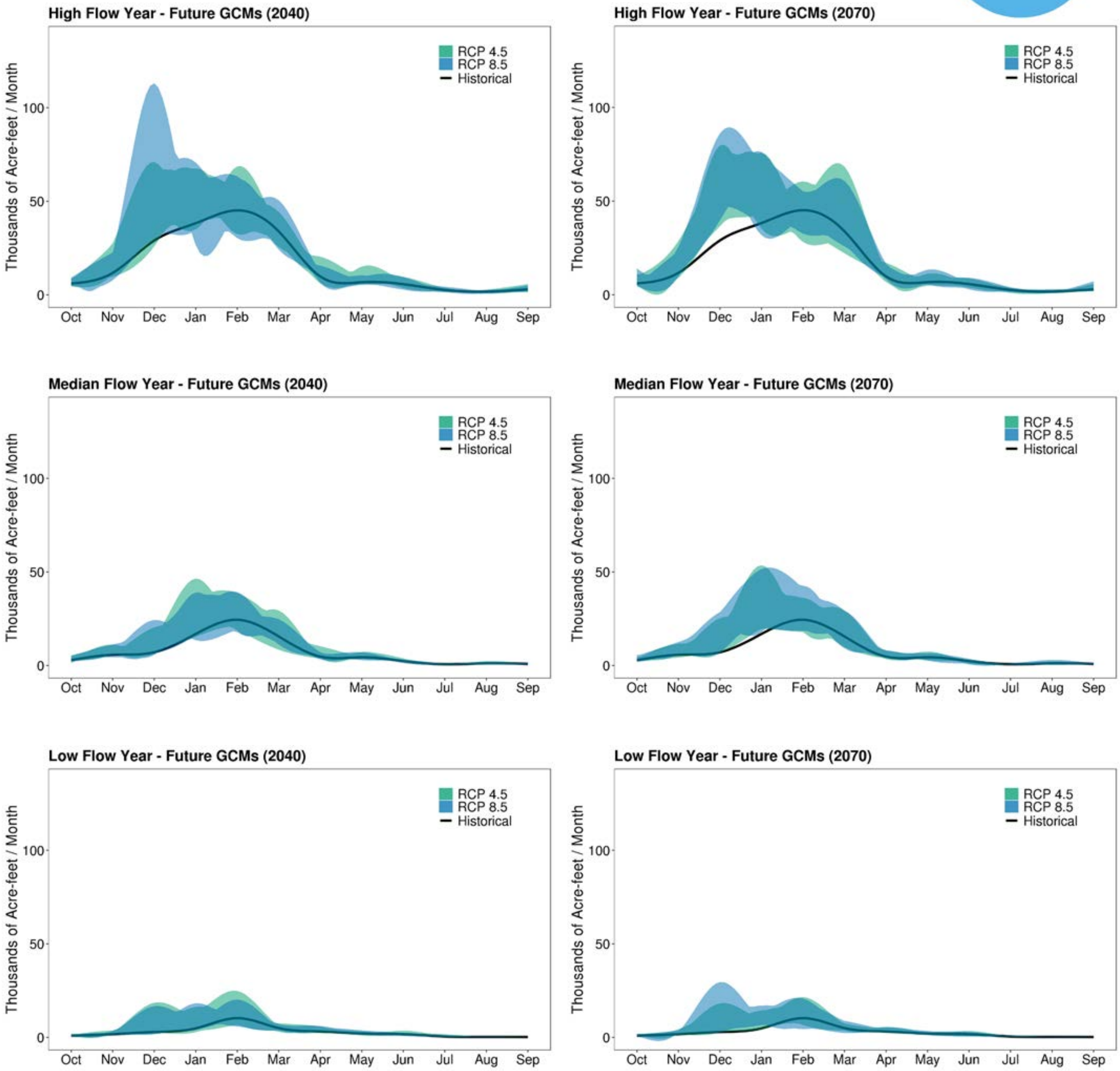
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 43 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 9 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 5 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 26% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 3% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 5 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 2,612 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 1.1 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 14% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Crab Creek & Moses Lake
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Subareas Overlapped by WRIA	Odessa, Quincy

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

SUPPLY

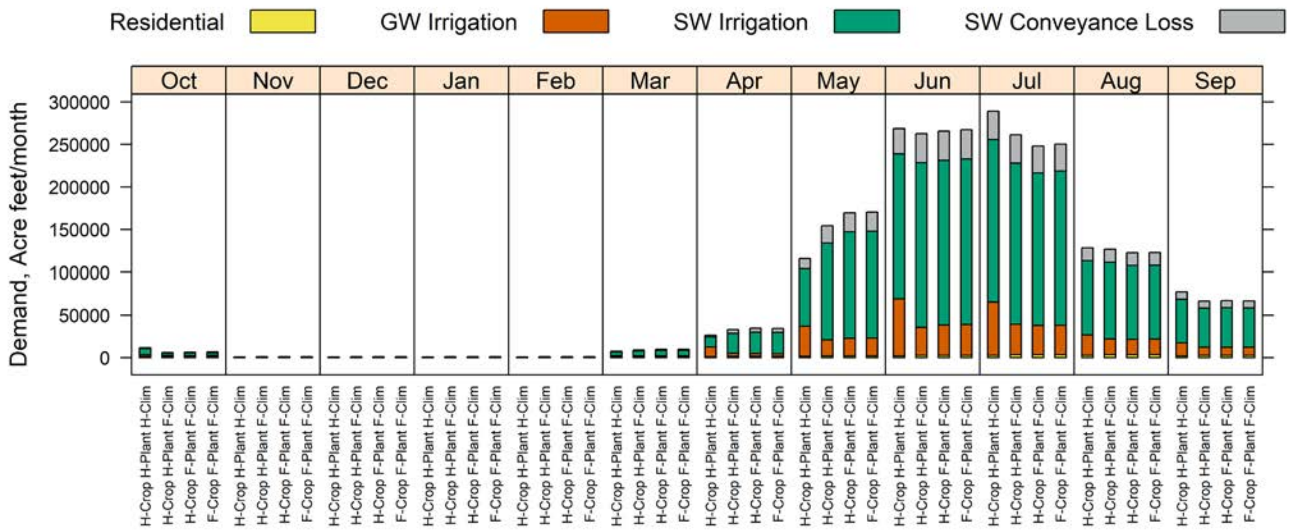




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

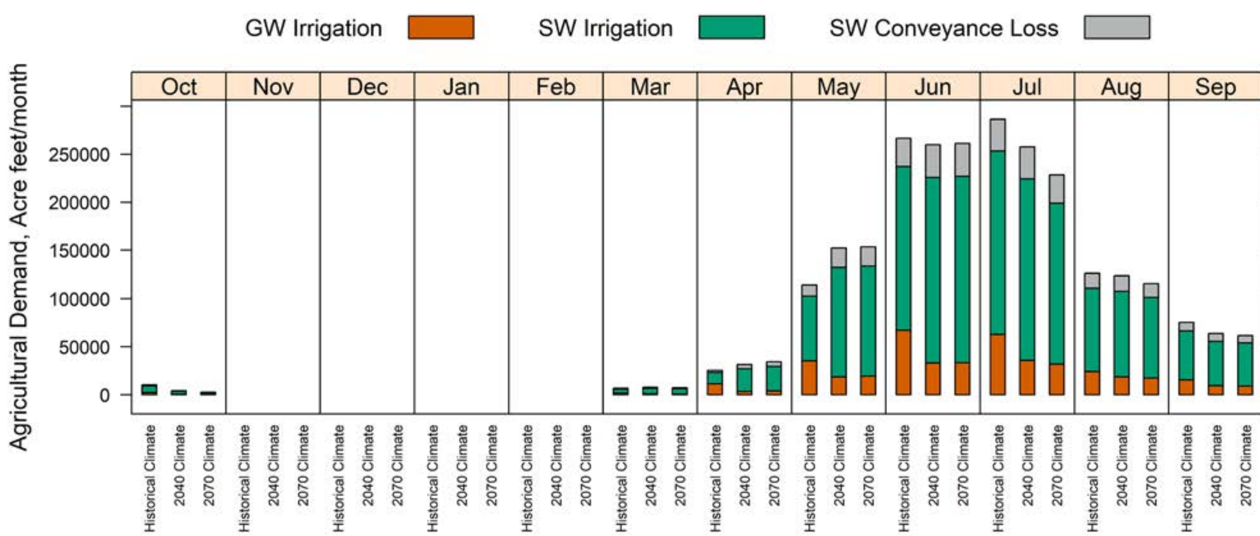
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

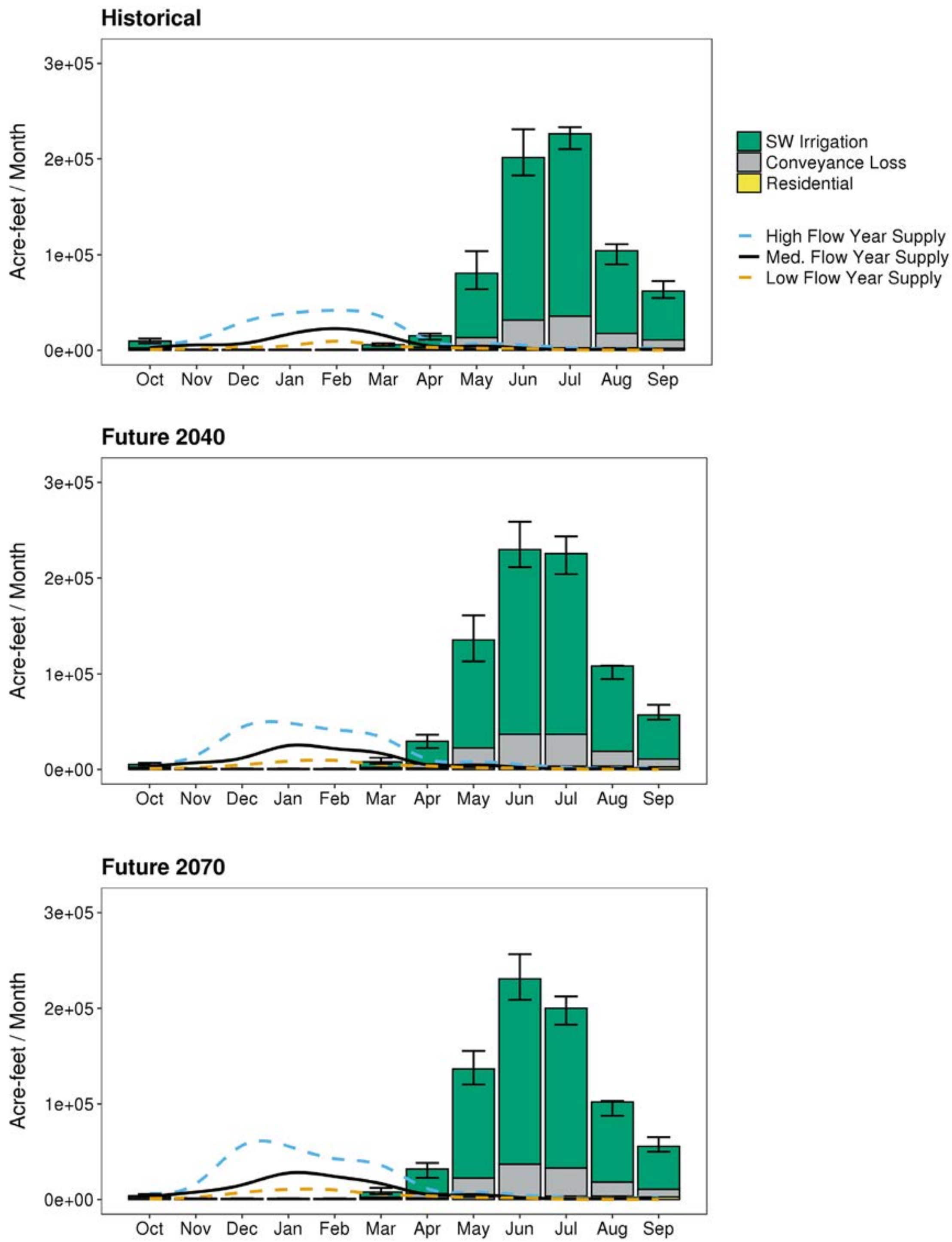
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

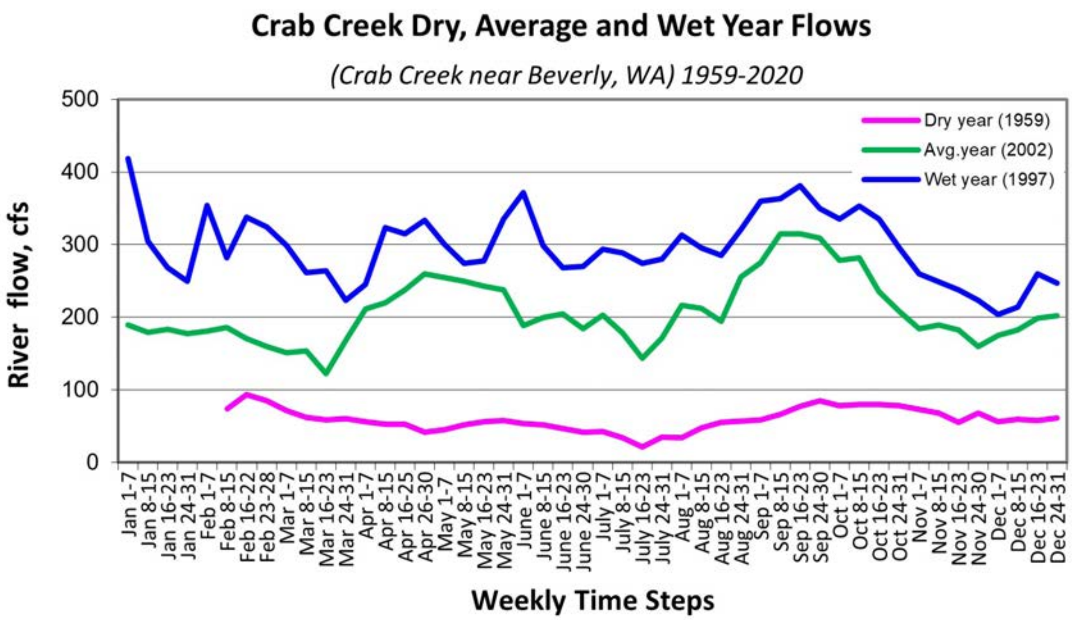
Bar 3
- 2070s Climate

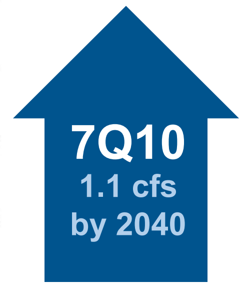
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment. For this particular WRIA, much of the irrigation water is drawn from the Columbia River which causes the supply to appear of lesser magnitude compared to demand.

CONSIDERATIONS FOR FISH

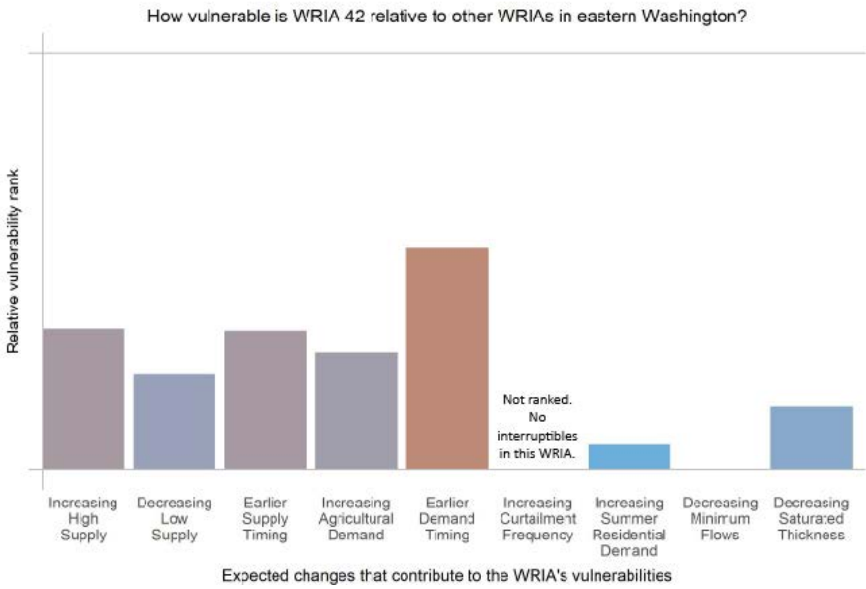


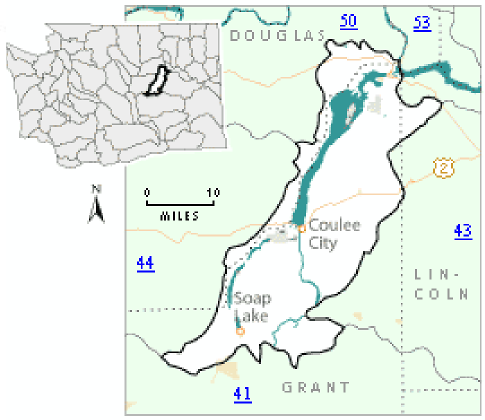


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





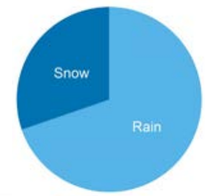
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

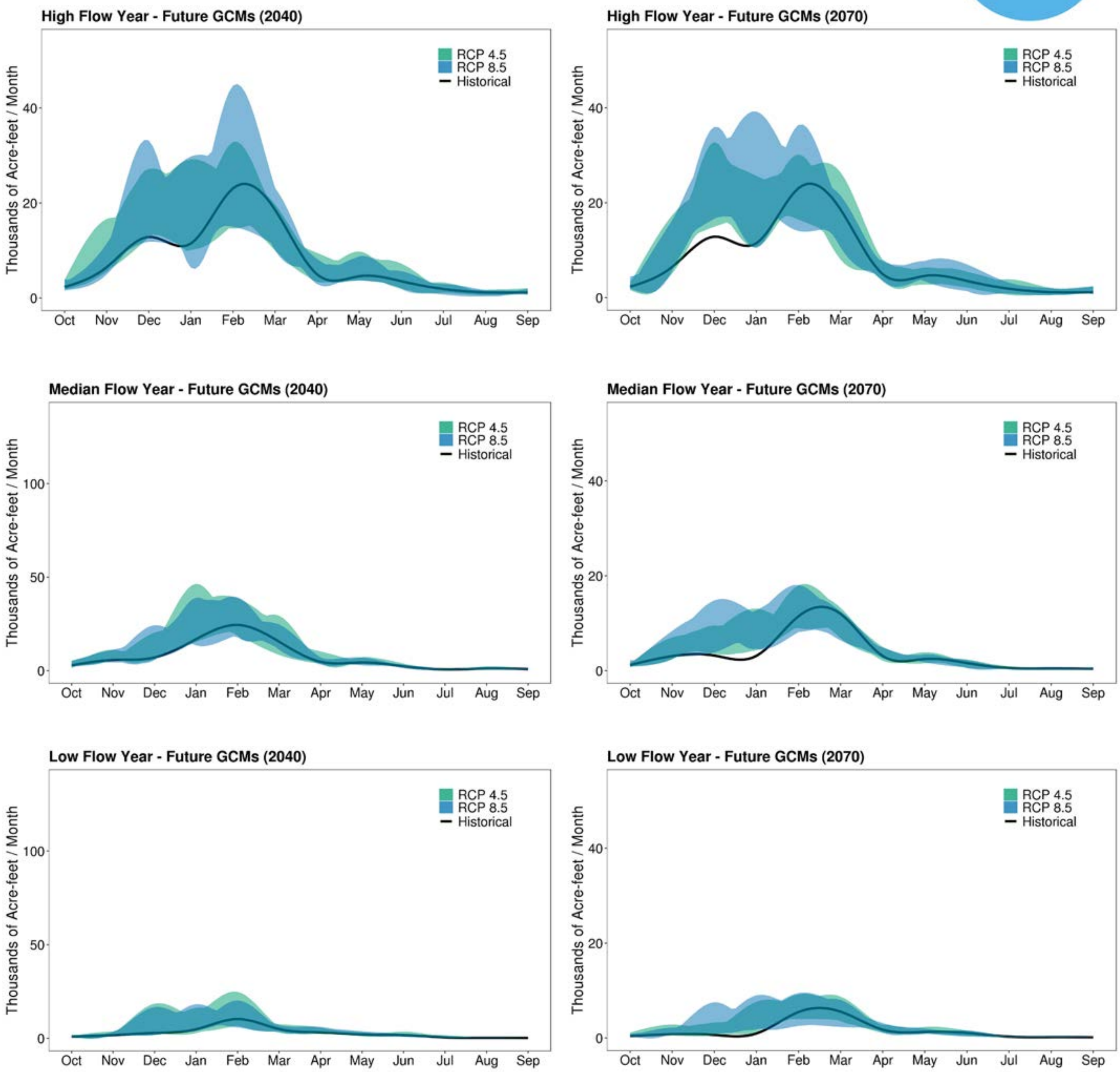
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 15 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 3 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 9 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 30% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 2% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 168 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 1.1 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 13% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Subareas Overlapped by WRIA	Odessa, Quincy, Northern CPRAS

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

SUPPLY

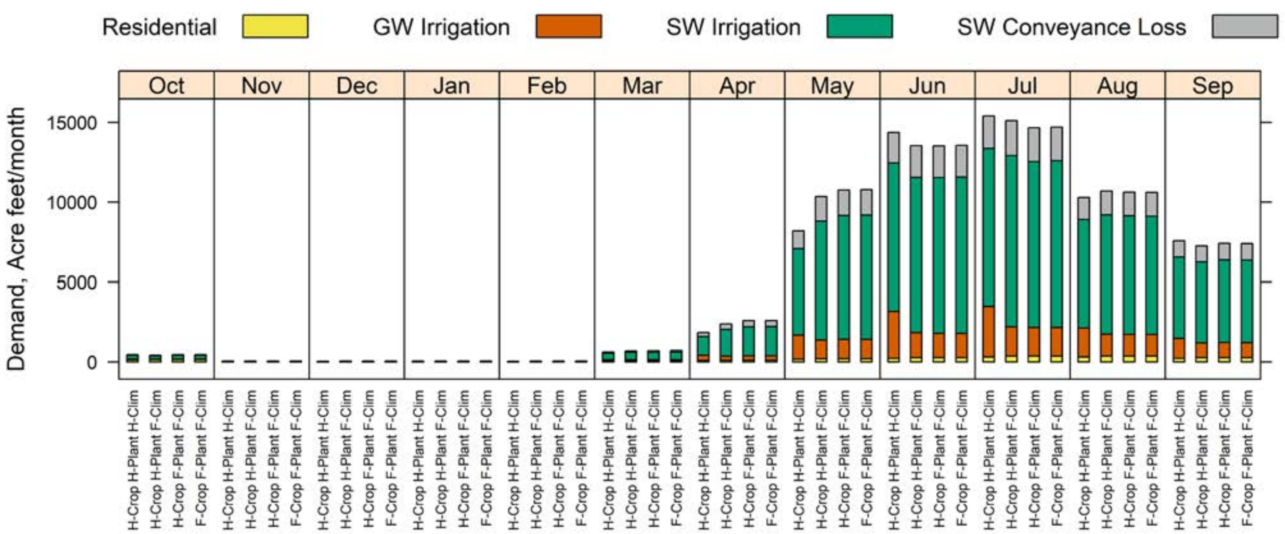




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

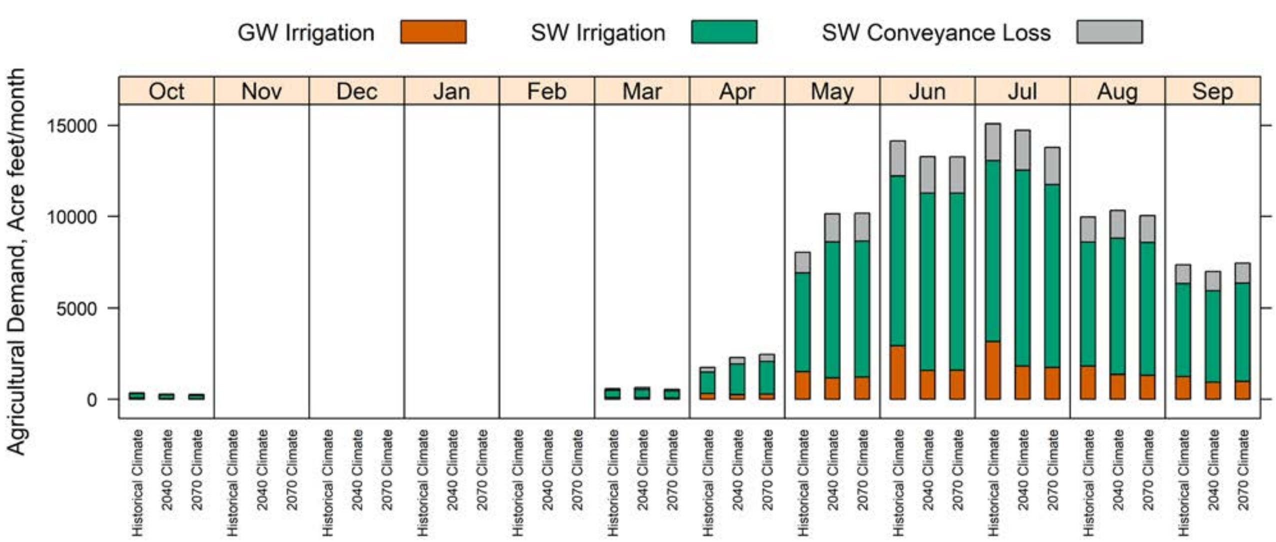
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

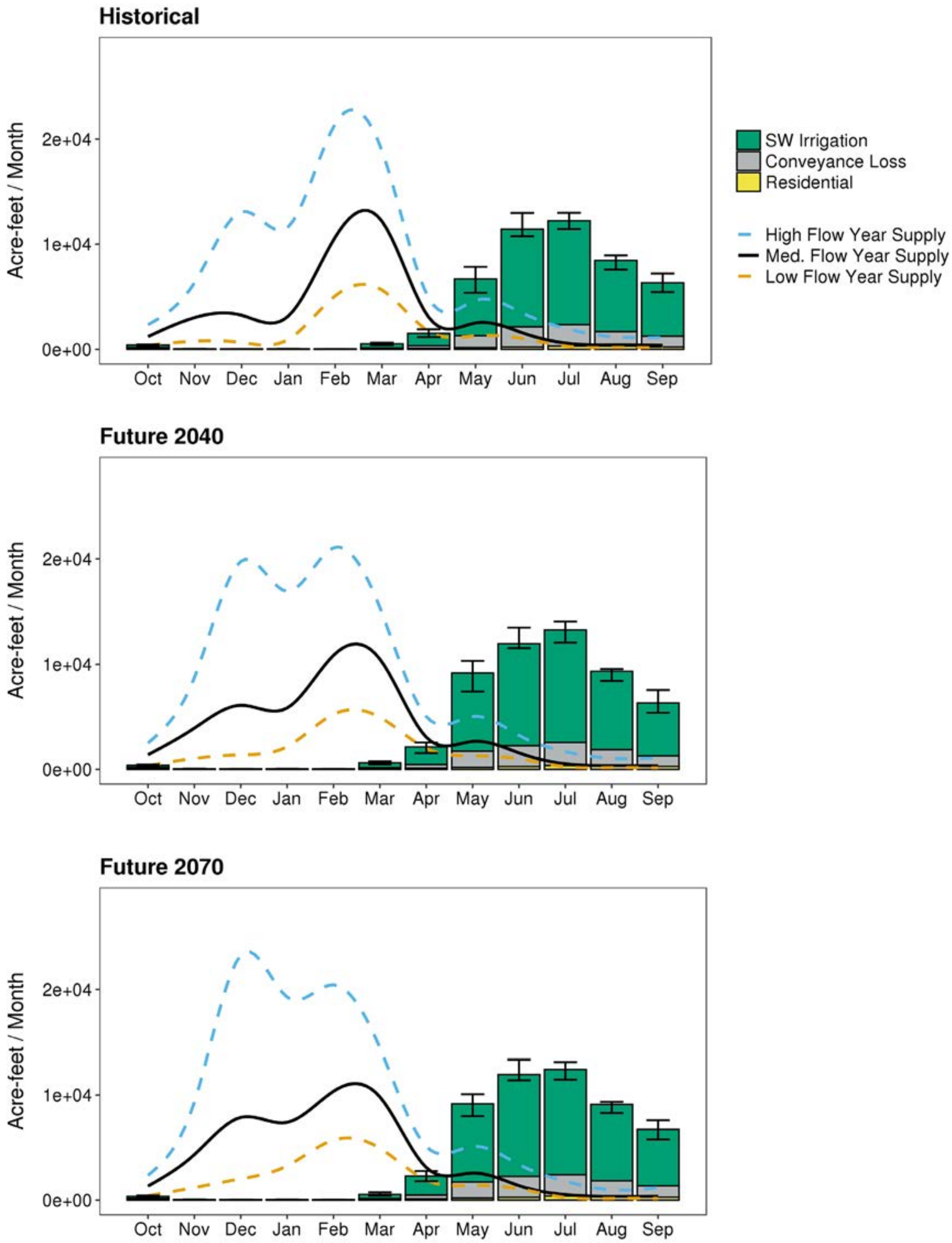
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

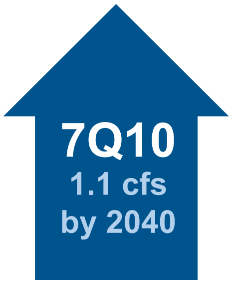
Bar 3
- 2070s Climate

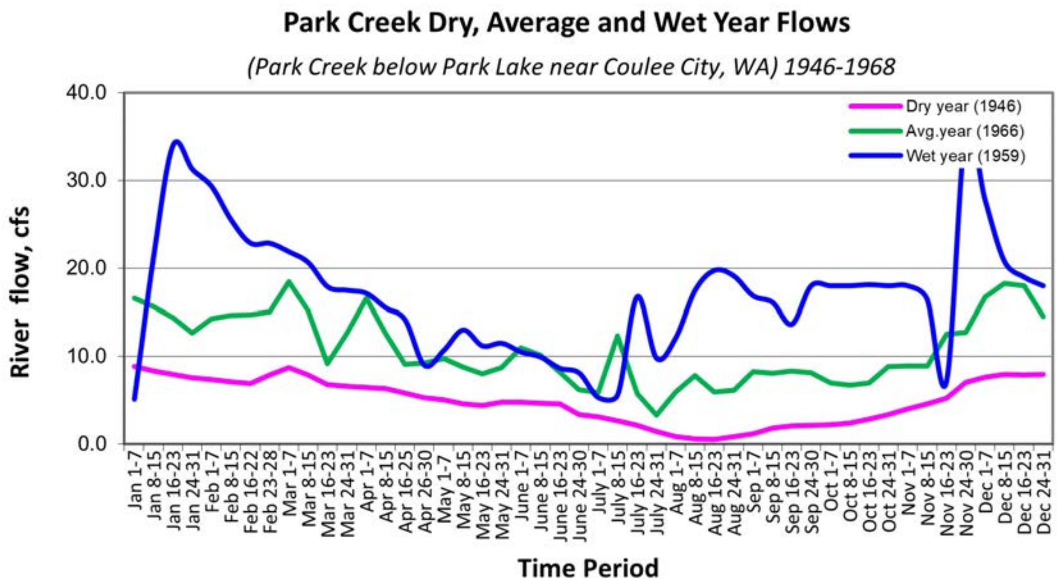
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment. For this particular WRIA, much of the irrigation water is drawn from the Columbia River which causes the supply to appear of lesser magnitude compared to demand.

CONSIDERATIONS FOR FISH

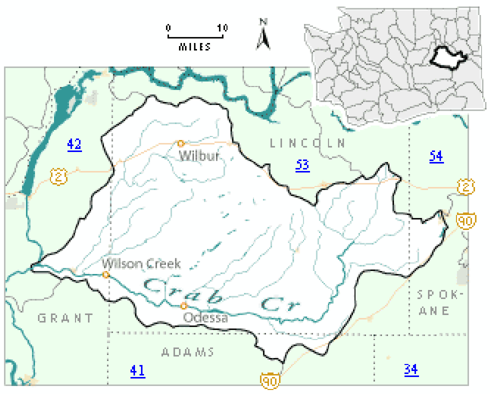


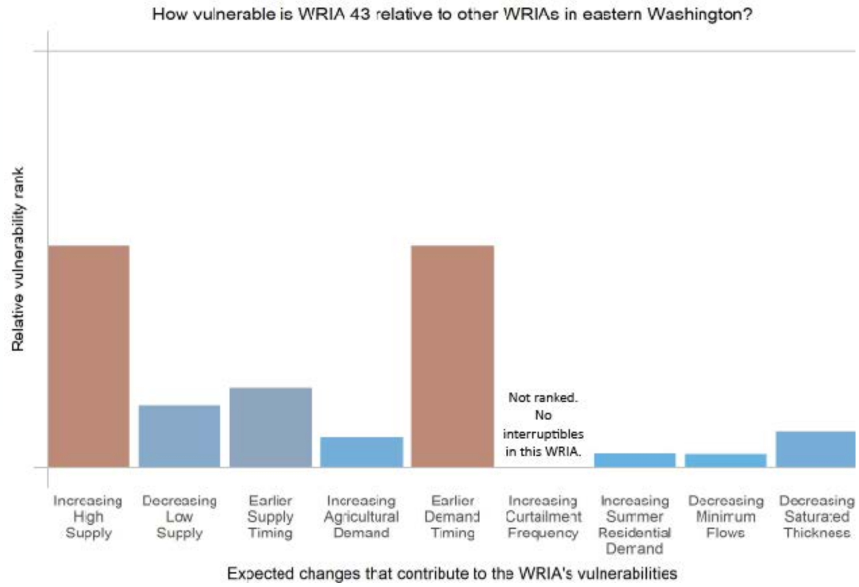


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





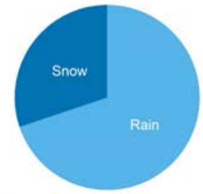
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

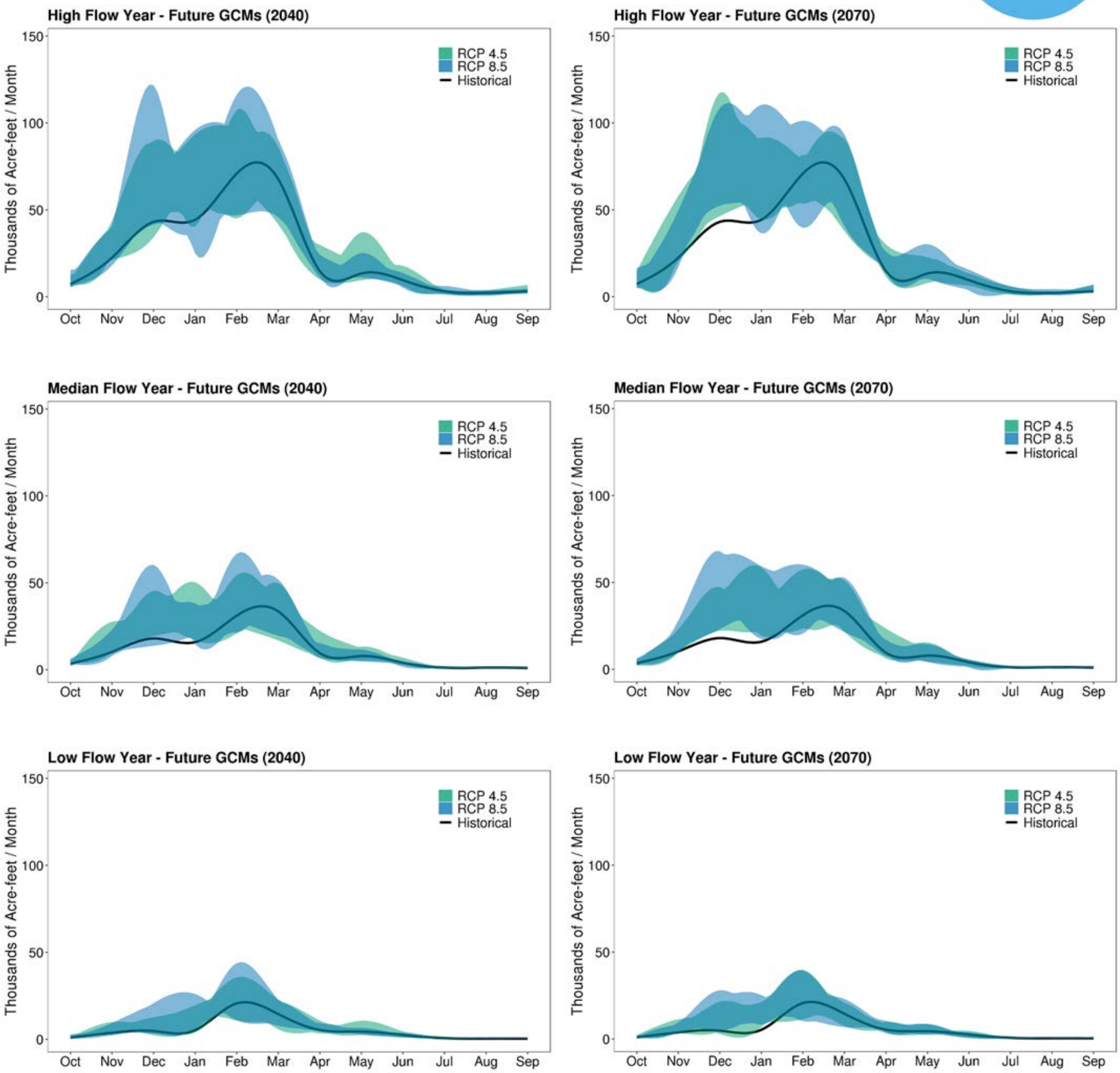
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 48 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 17 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 6 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 30% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 4% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 90 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.6 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 10% on average by 2040.

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[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Subareas Overlapped by WRIA	Odessa, Northern CPRAS

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

SUPPLY

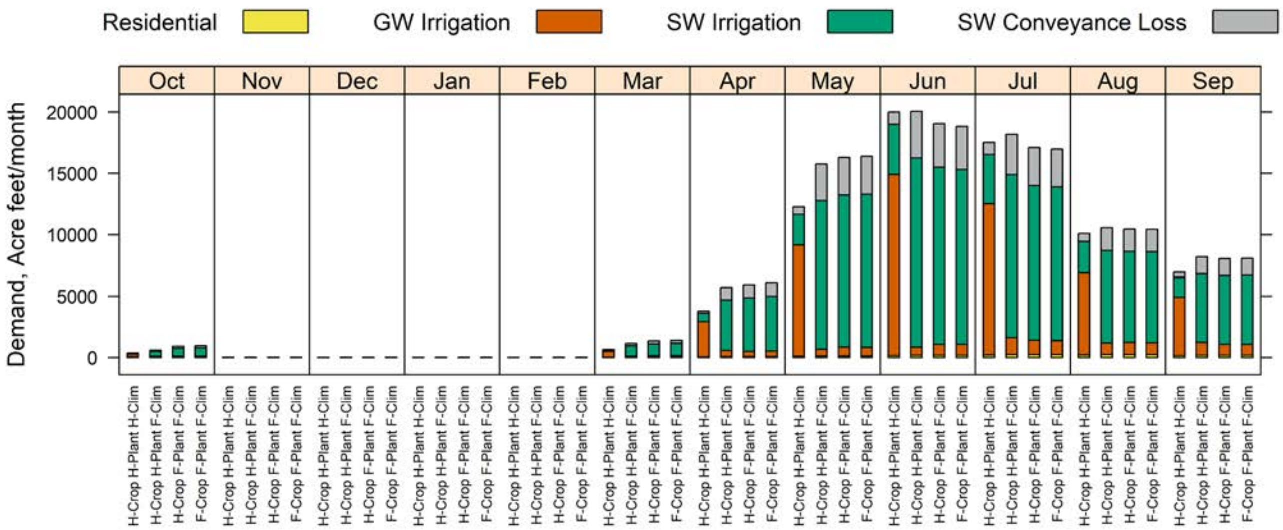




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use. We assume a large portion of groundwater rights in this WRIA will be converted to surface water rights, causing the large decrease in forecasted groundwater irrigation.

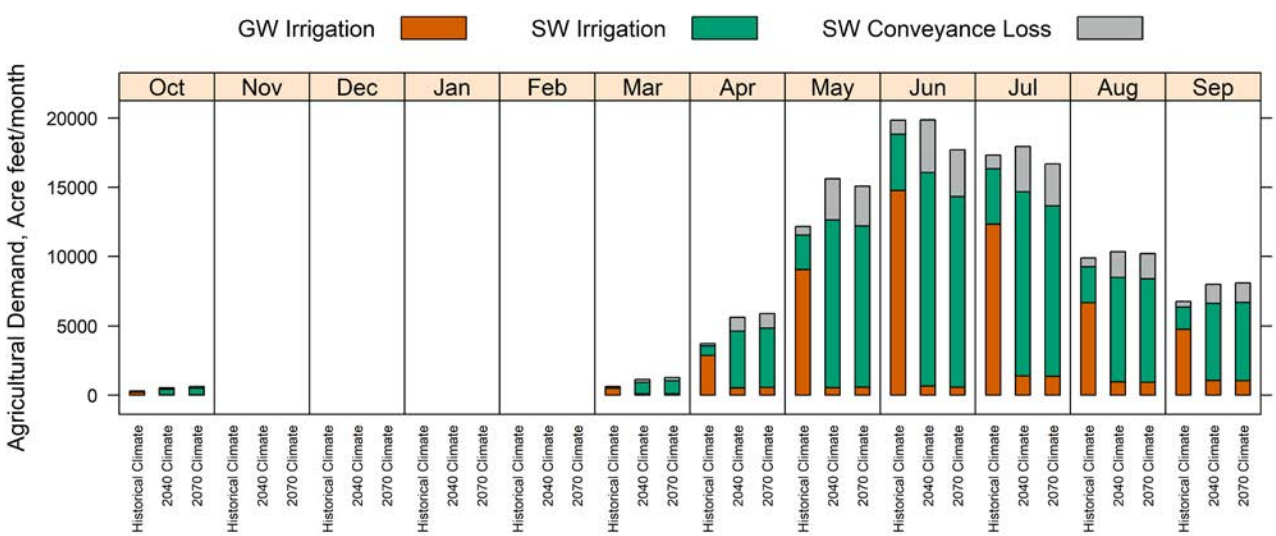
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. Note: Residential demands were not projected for 2070 and so are not included in this figure. We assume a large portion of groundwater rights in this WRIA will be converted to surface water rights, causing the large decrease in forecasted groundwater irrigation.

Each month has three bars that represent a different scenario:

Bar 1
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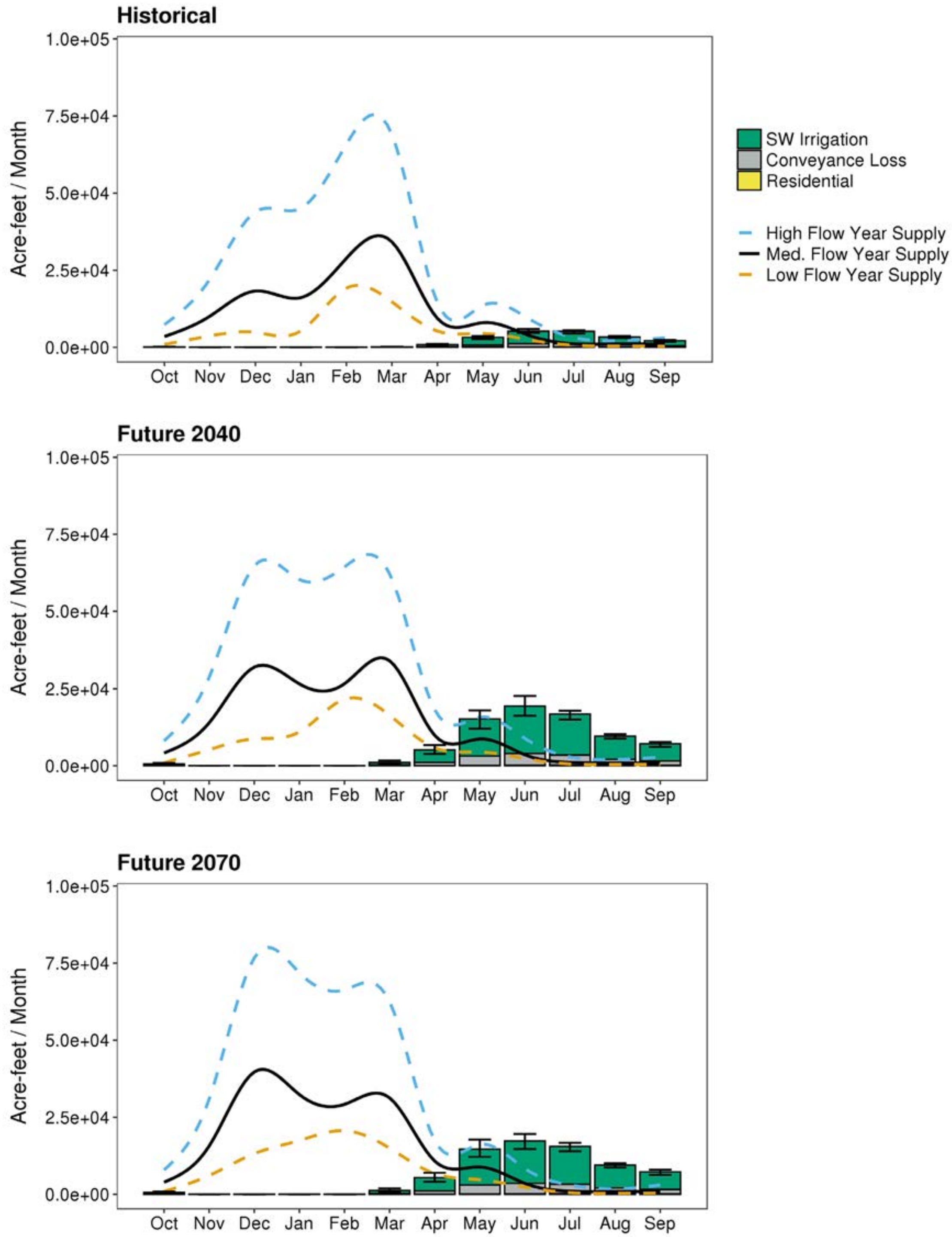
Bar 2
- 2040s Climate

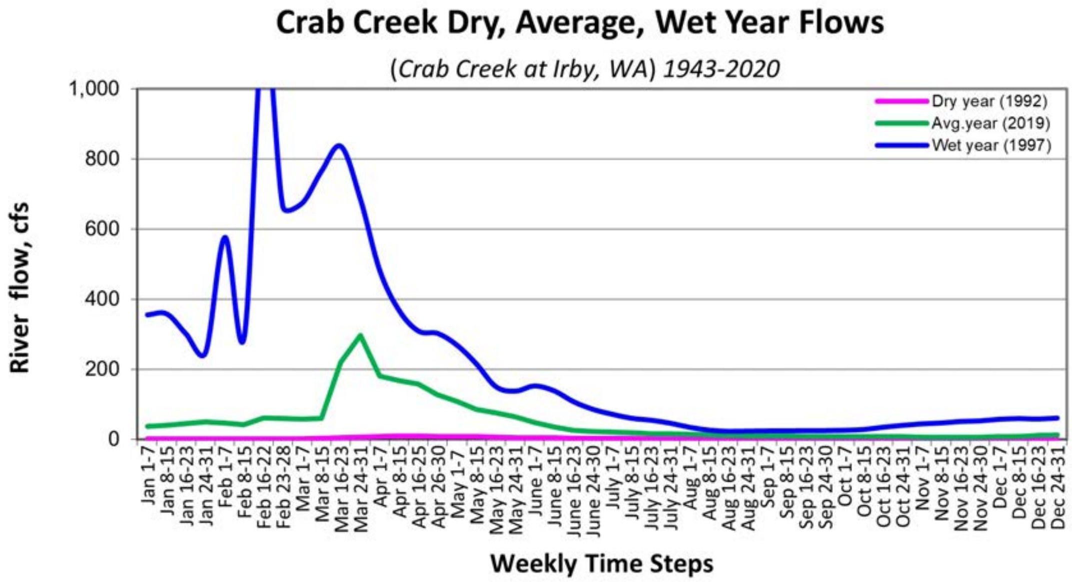
Bar 3
- 2070s Climate

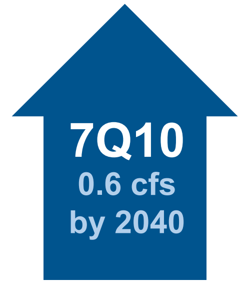
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment. We assume a large portion of groundwater rights in this WRIA will be converted to surface water rights, causing the large decrease in forecasted groundwater irrigation.

CONSIDERATIONS FOR FISH

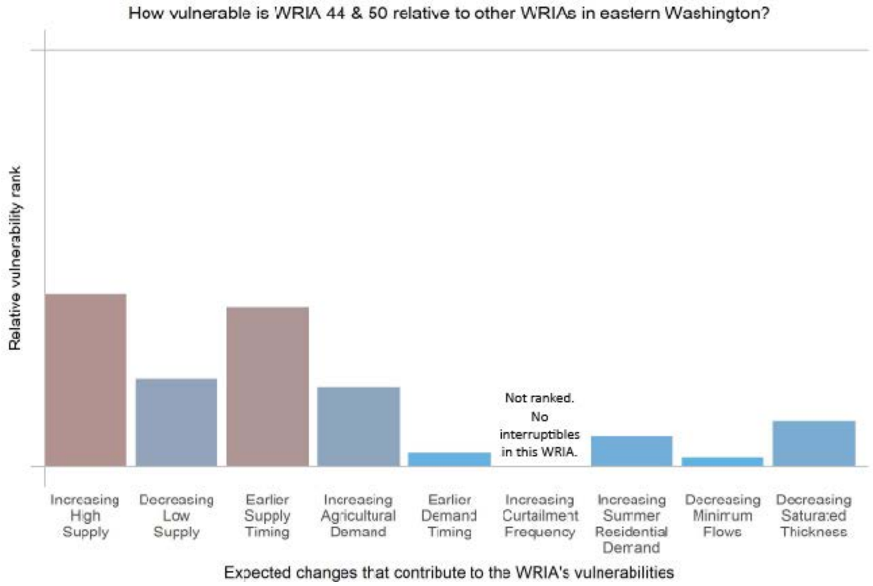


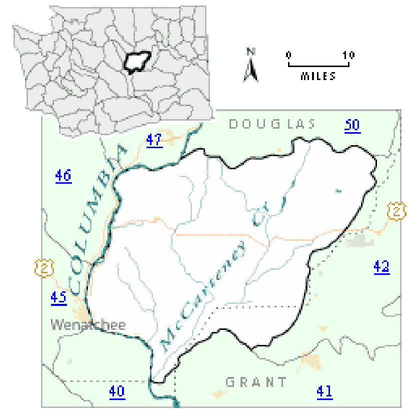


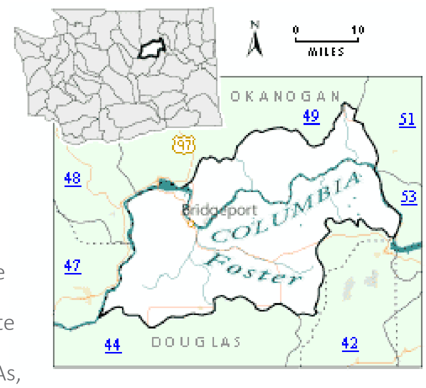
Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY







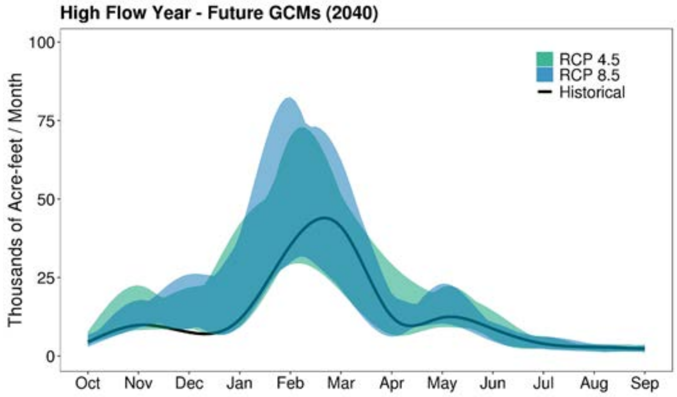
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

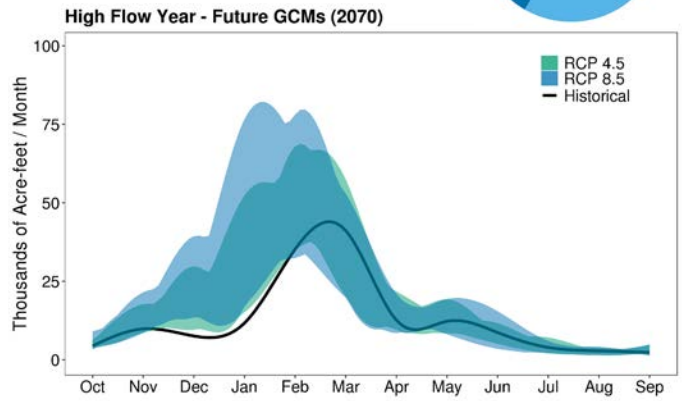
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 28 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 6 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 10 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 42% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 1% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 9 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 365 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.4 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 11% on average by 2040.

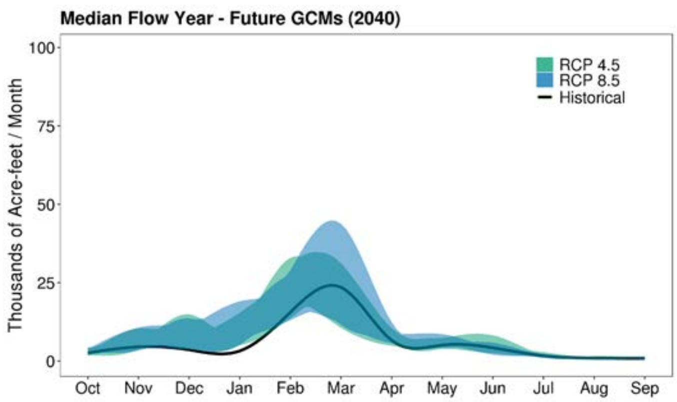
MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	WRIA 44: No ESA-listed fish spawn or rear in WRIA waters, WRIA 50: Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead, [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Northern CPRAS

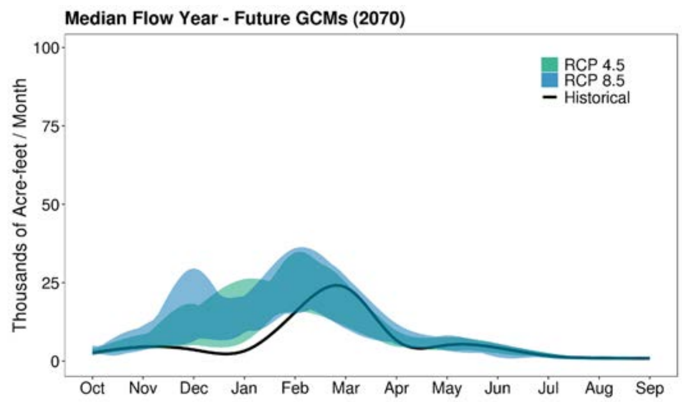
[1]All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

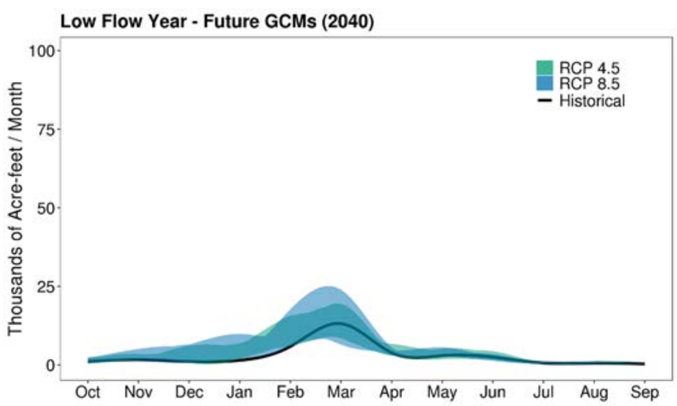
SUPPLY

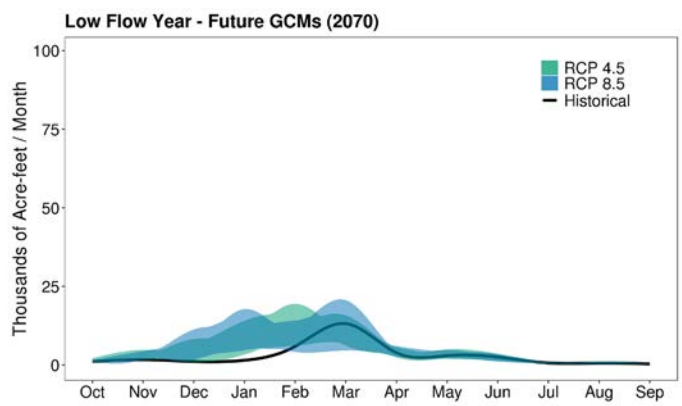








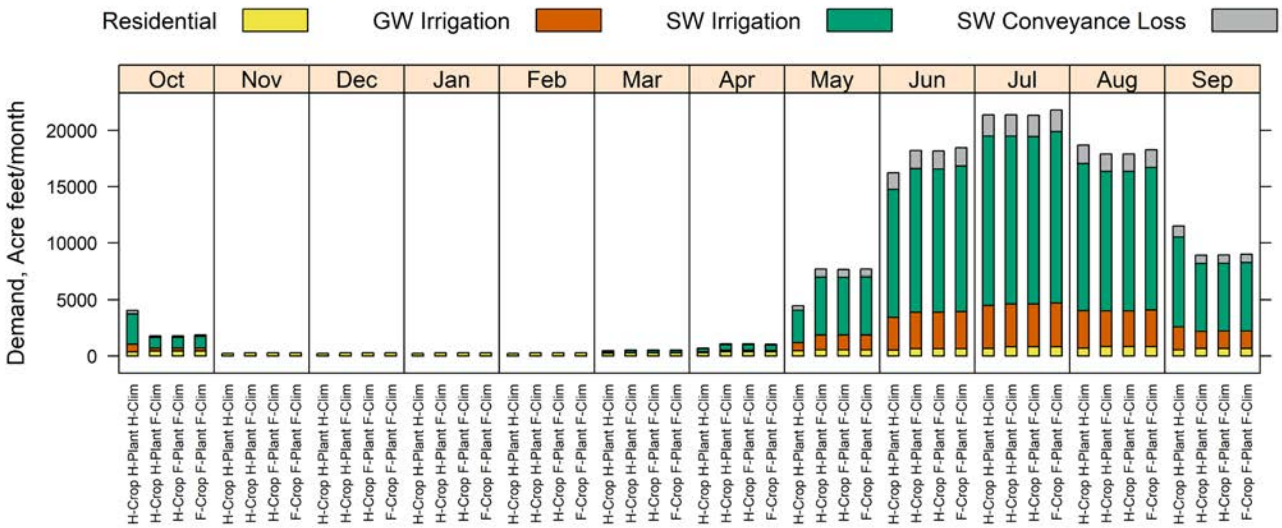




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

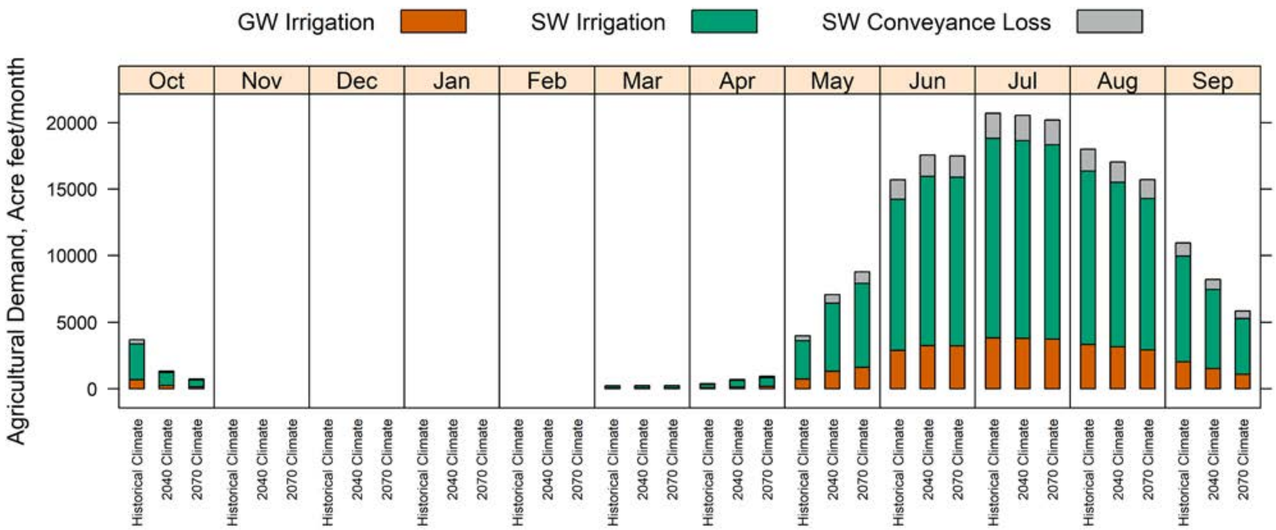
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

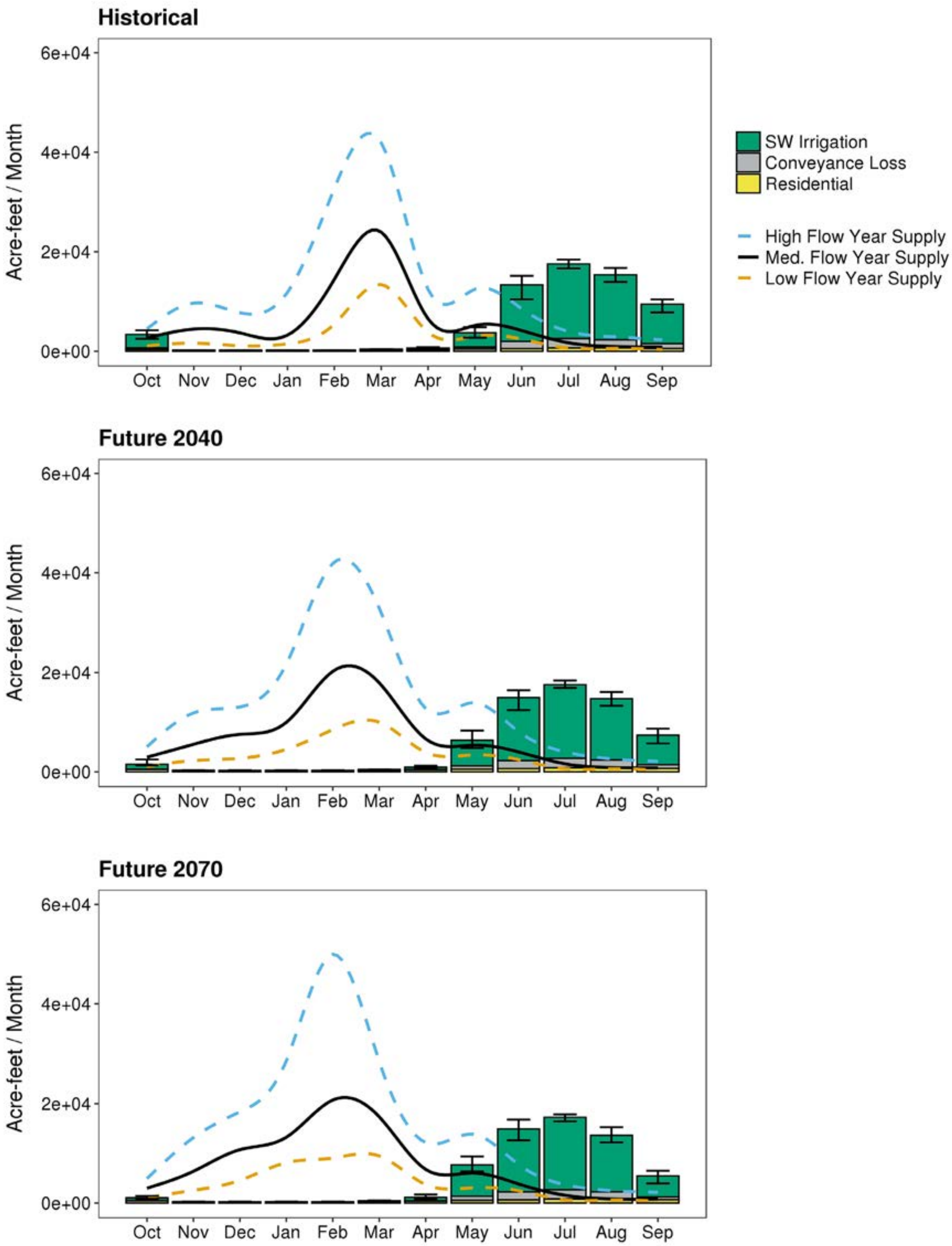
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2070s Climate

SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

Foster - WRIA 50
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
"Upper Columbia" Summer Chinook[1] (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0	0	0	0	0	0	0
	Spawning	0	0	0	0	0	0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0	0	0	0	0	0	0	0	0	0
	Rearing	0	0	0							0	0	0
	Juvenile Out-Migration	0	0	0	0						0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
"Upper Columbia" Spring Chinook[2] (ESA Endangered)	Adult In-Migration												
	Spawning	0	0	0	0	0	0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0	0	0	0	0	0	0	0	0	0
	Rearing	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Out-Migration	0	0	0	0	0	0	0	0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'Upper Columbia" Summer Steelhead[3] (ESA Threatened)	Adult (Spawners & Kelts) Migration[4]	0	0						0	0	0	0	0
	Spawning	0	0					0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0						0	0	0	0
	Rearing												
	Juvenile Out-Migration	0	0						0	0	0	0	0

[1] Foster Creek does not have a formally designated summer Chinook population; juvenile Chinook are assumed to be progeny of summer Chinook spawning in mainstem Columbia that are derived from upper Columbia sources.

[2] Foster Creek does not have a formally designated spring Chinook population; spring Chinook juveniles (from upper Columbia sources) possibly may use Foster Creek for rearing, but this has not been conclusively documented.

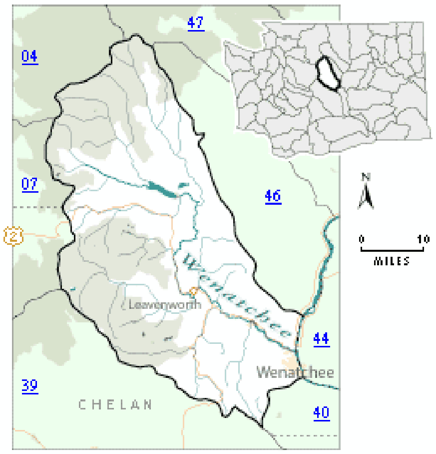
[3] Foster Creek does not have a formally designated summer steelhead population; assumed that existing steelhead are derived from upper Columbia sources.

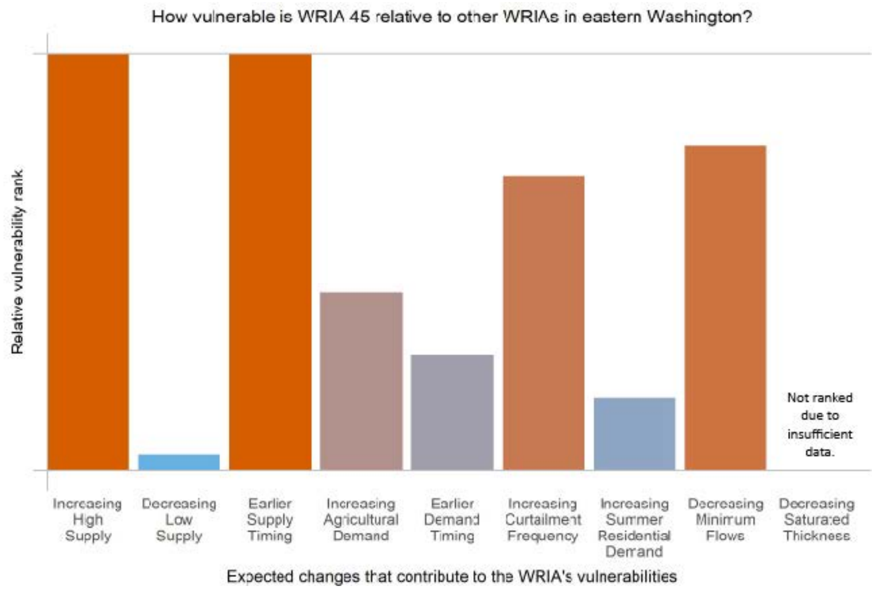
[4] This scoring indicates that steelhead adults do not enter or hold in Foster Creek during pre-spawning months, and instead overwinter in other nearby areas, such as the Columbia mainstem.

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





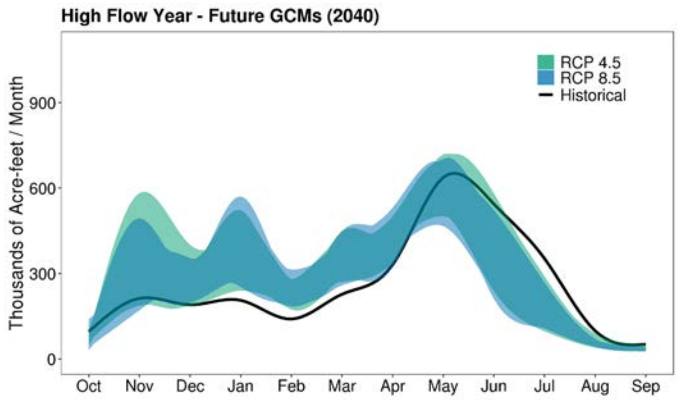
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

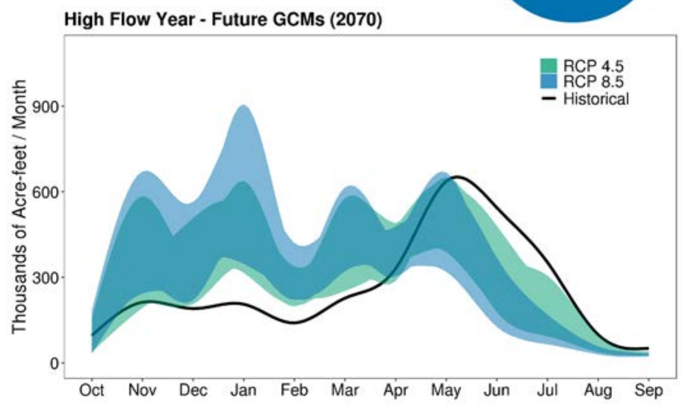
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 126 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 37 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 23 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 67% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 6% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 6 days earlier by 2040.
- **Increasing Curtailment Frequency:** The frequency of curtailment for July and August is projected to increase by 30% by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 523 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 12.0 cfs by 2040.

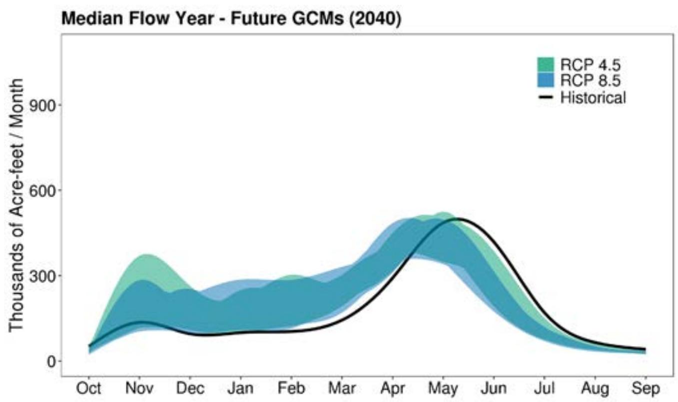
MANAGEMENT CONTEXT	
Adjudicated Areas	Icicle Creek, Joe Creek, Chumstick Creek, Nahahum Canyon
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	Yes (Chapter 173-545 WAC). 47 interruptible water rights curtailed periodically. Weekly frequency of interruption from 1984-2014 ranged 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[1]	Bull Trout, Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Wenatchee

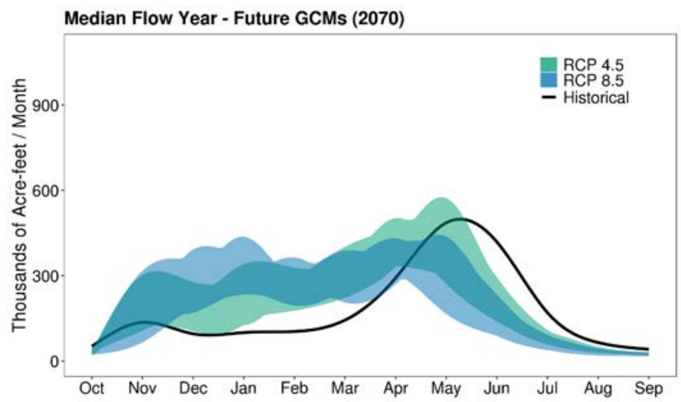
[1]All species that spawn or rear in WRIA waters are identified. Species that migrate through WRIA waters are not individually identified, but migratory corridors for listed fish species that spawn and rear upstream are noted.

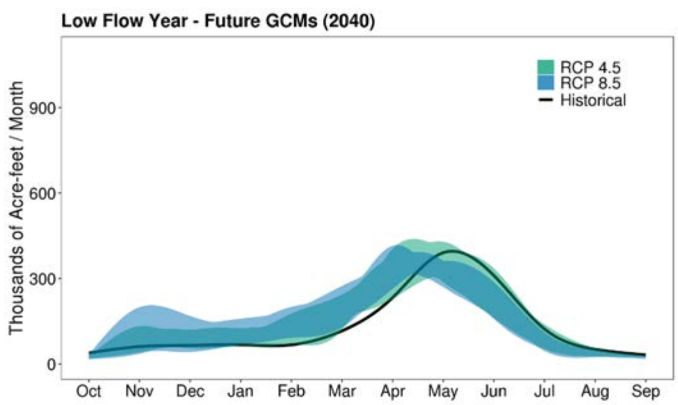
SUPPLY

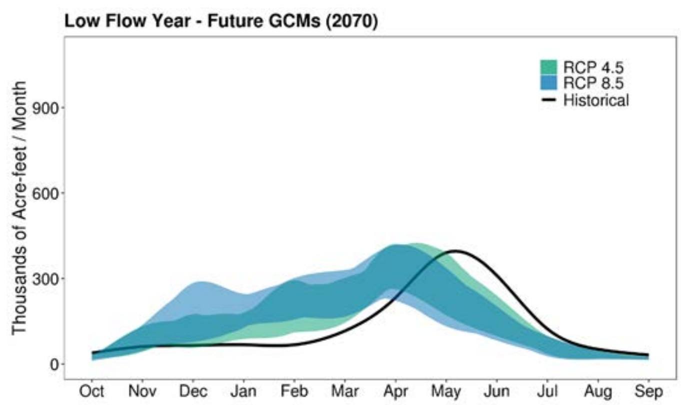








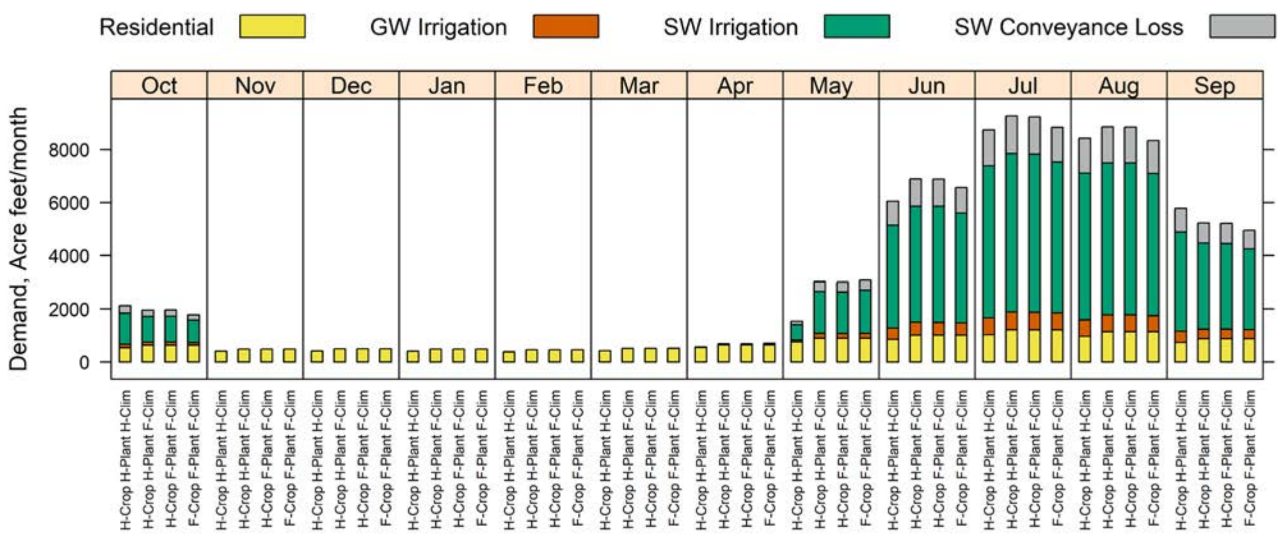




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

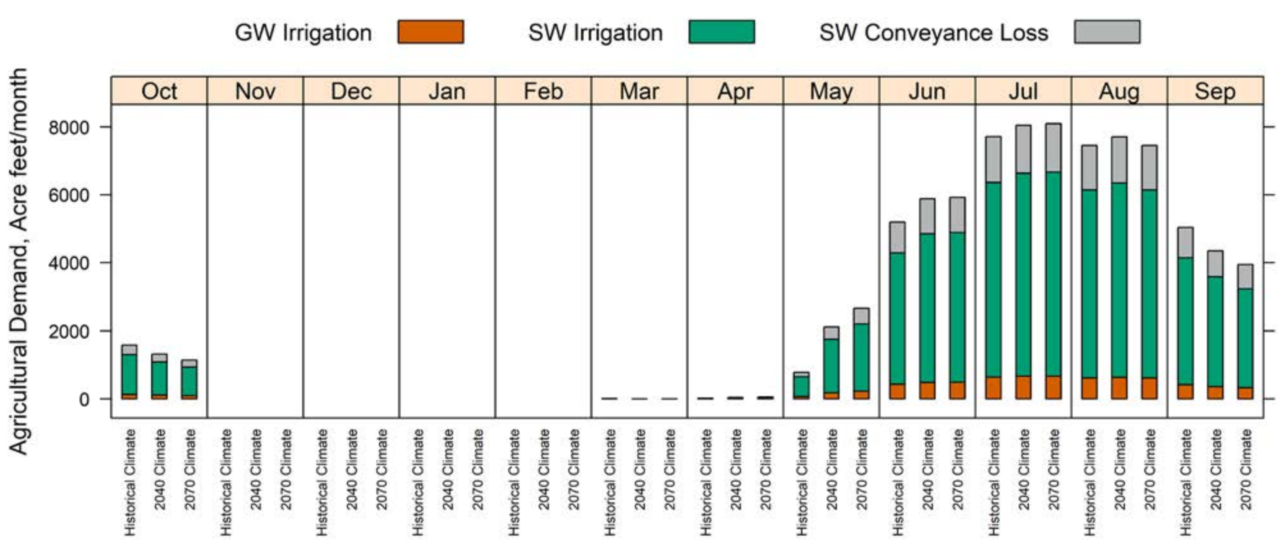
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

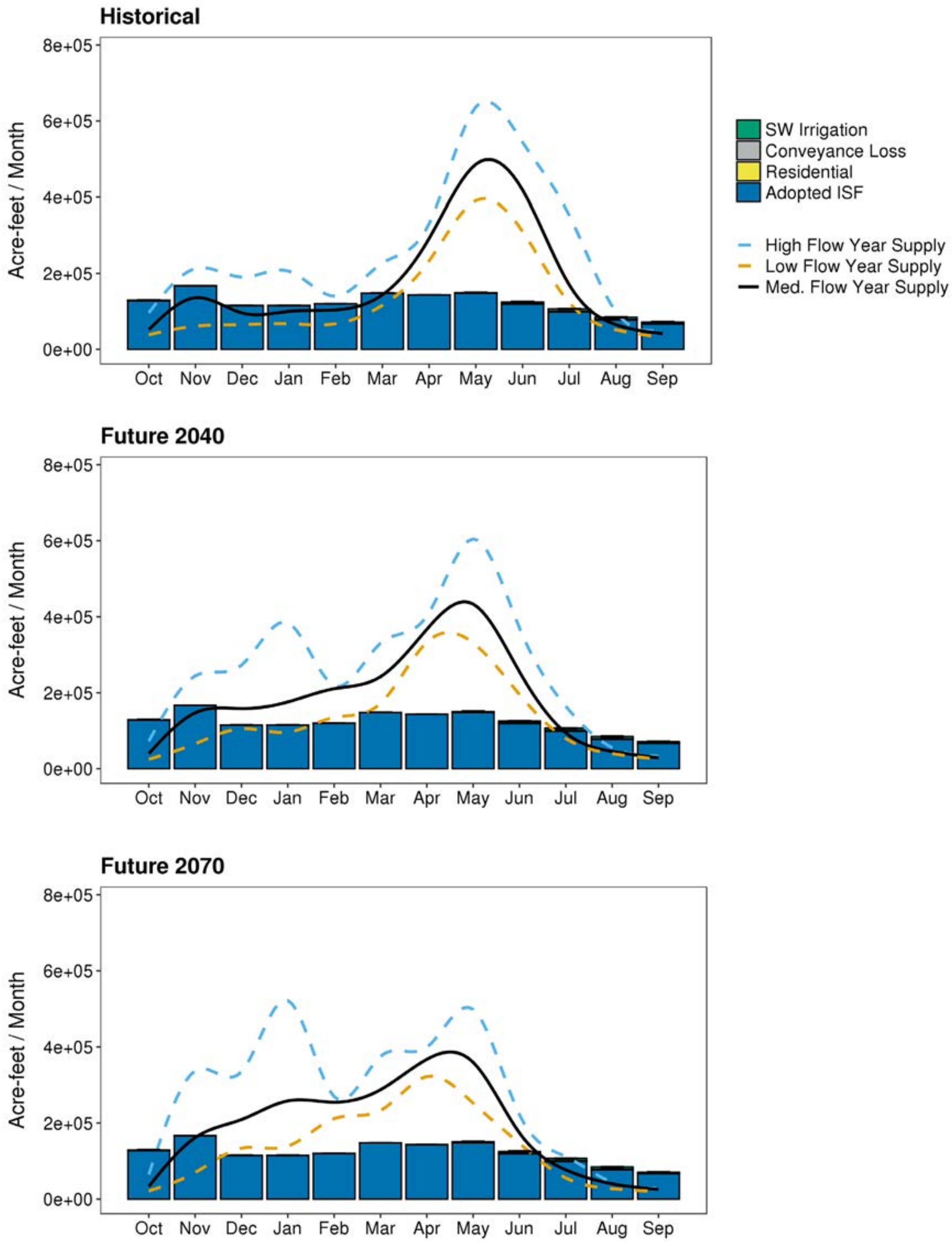
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

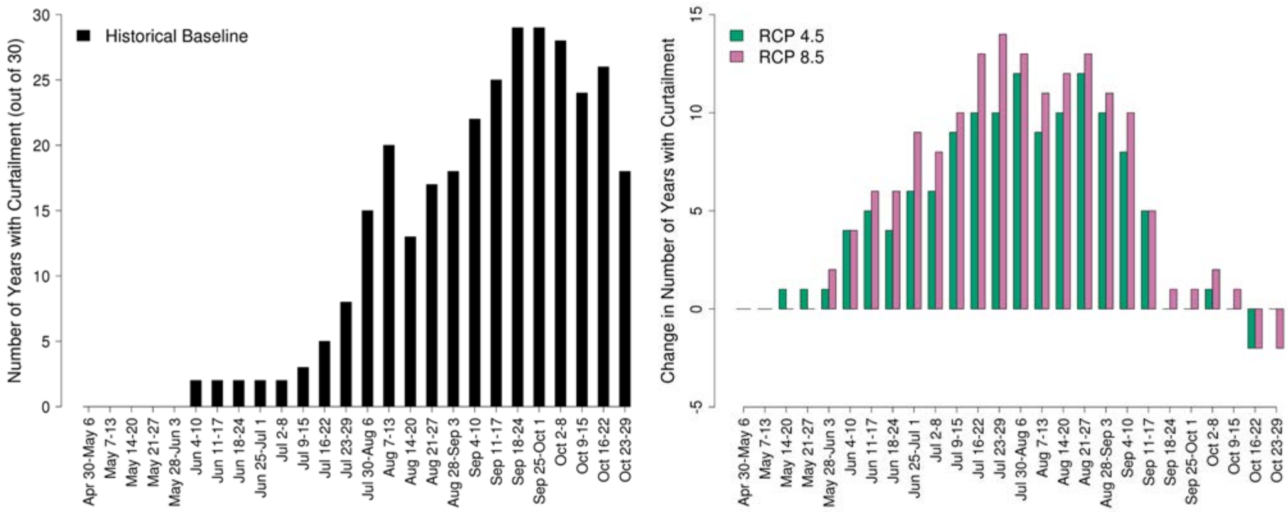
Bar 3
- 2070s Climate

SUPPLY AND DEMAND

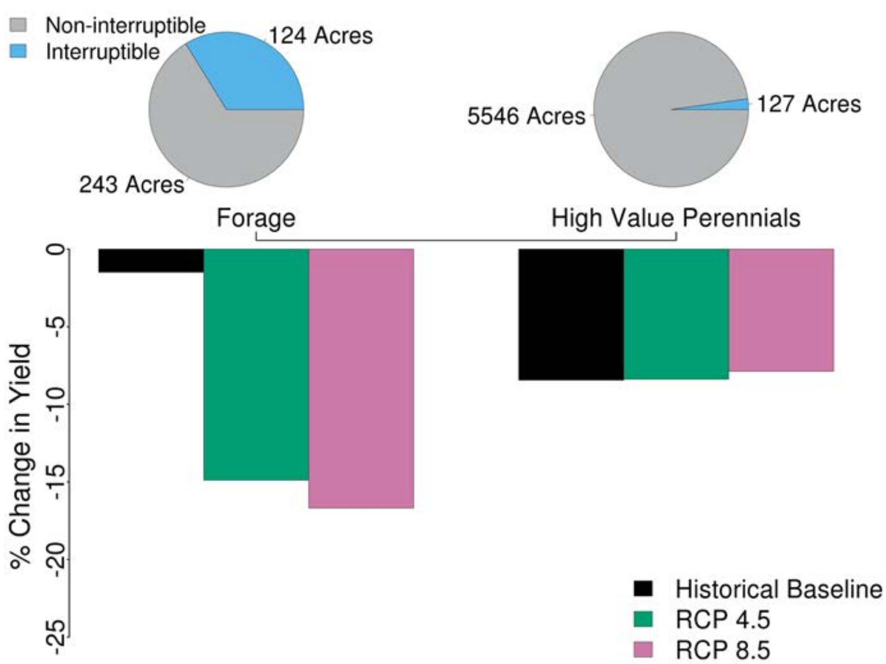


Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CURTAILMENT

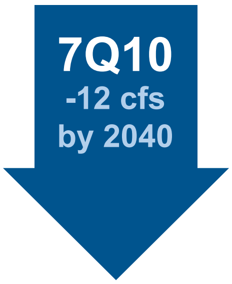


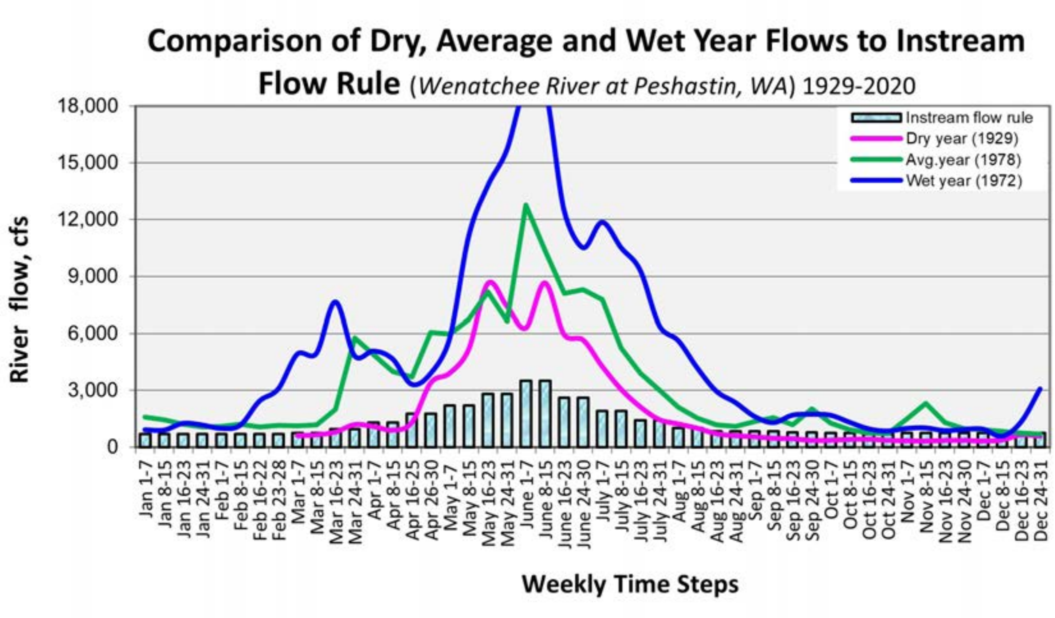
Modeled historical baseline number of years with curtailment from 1986- 2015 for each week (left panel) and change in the number of years with curtailment for each week for RCP 4.5 and RCP 8.5 (right panel) during a future period (2026 – 2055) compared to historical curtailment from 1976-2005. Changes in curtailment frequency include both surface and groundwater interruptions. Change in curtailment is forecasted using the median of the changes (future GCM- historical GCM) predicted by 17 climate GCM scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5.



Difference between annual yield produced on land with an interruptible water right and full irrigation yield relative to full irrigation yield under historical baseline (1986- 2015) and future (2026- 2055) climate conditions. Future yields are calculated as the median of 17 climate change scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5. The pie charts show the amount of interruptible and non-interruptible acreage for each crop group based on historical crop mix within this WRIA. The “High Value Perennials” crop group includes blueberries, apples, cherries, peaches, pears, and grapes. The “Forage” crop group includes alfalfa hay and grass hay.

CONSIDERATIONS FOR FISH





Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

Wenatchee River Basin - WRIA 45
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Summer Chinook (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0						0	0
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing	0								0	0	0	0
	Juvenile Out-Migration	0								0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Spring Chinook (ESA Endangered)	Adult In-Migration	0	0	0	0					0	0	0	0
	Spawning	0	0	0	0	0	0	0			0	0	0
	Egg Incubation & Fry Emergence					0	0	0					
	Rearing												
	Juvenile Out-Migration	0							0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Summer Steelhead (ESA Threatened)	Adult (Spawners & Kelts) Migration												
	Spawning	0	0					0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0							0	0	0	0
	Rearing												
	Juvenile Out-Migration	0							0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Sockeye (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0					0	0
	Spawning	0	0	0	0	0	0	0	0			0	0
	Egg Incubation & Fry Emergence				0	0	0	0	0				
	Rearing												
	Juvenile Out-Migration	0	0				0	0	0	0	0	0	0

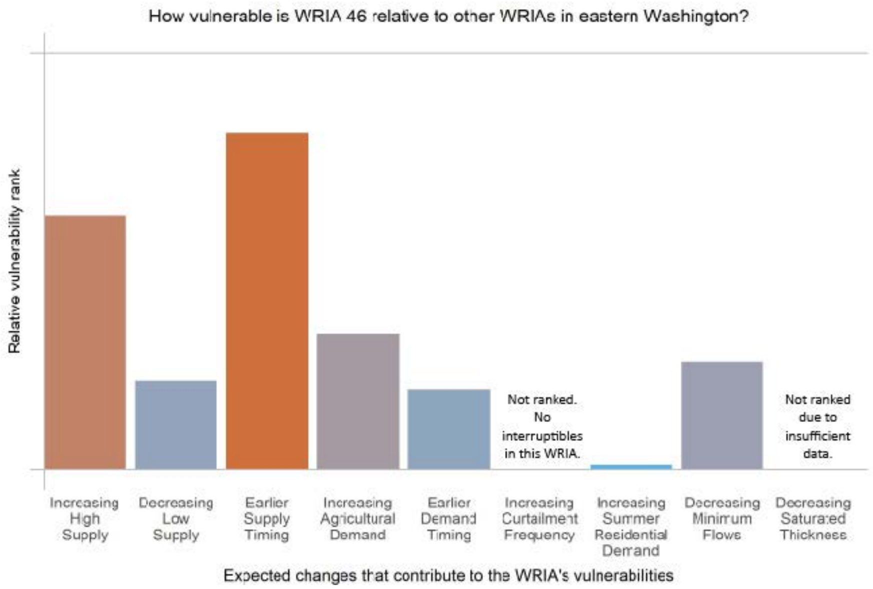
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Coho (Not ESA Listed)	Adult In-Migration	0	0	0	0	0	0	0	0				
	Spawning		0	0	0	0	0	0	0	0			
	Egg Incubation & Fry Emergence						0	0	0	0			
	Rearing												
	Juvenile Out-Migration	0	0	0				0	0	0	0	0	0

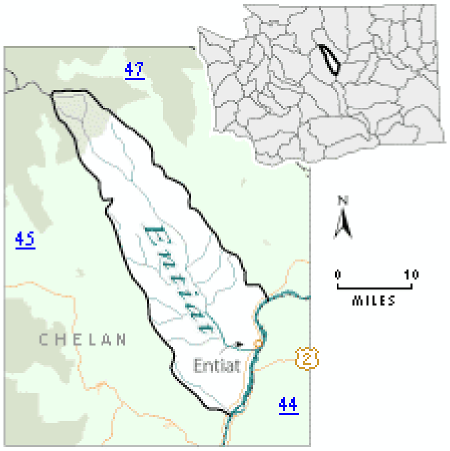
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenatchee Core Area Bull Trout (ESA Threatened)	Adult Migrations	0	0	0	0					0	0	0	0
	Spawning	0	0	0	0	0	0	0	0			0	0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing												
	Juvenile Migrations	0	0					0	0	0			0

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





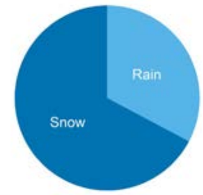
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

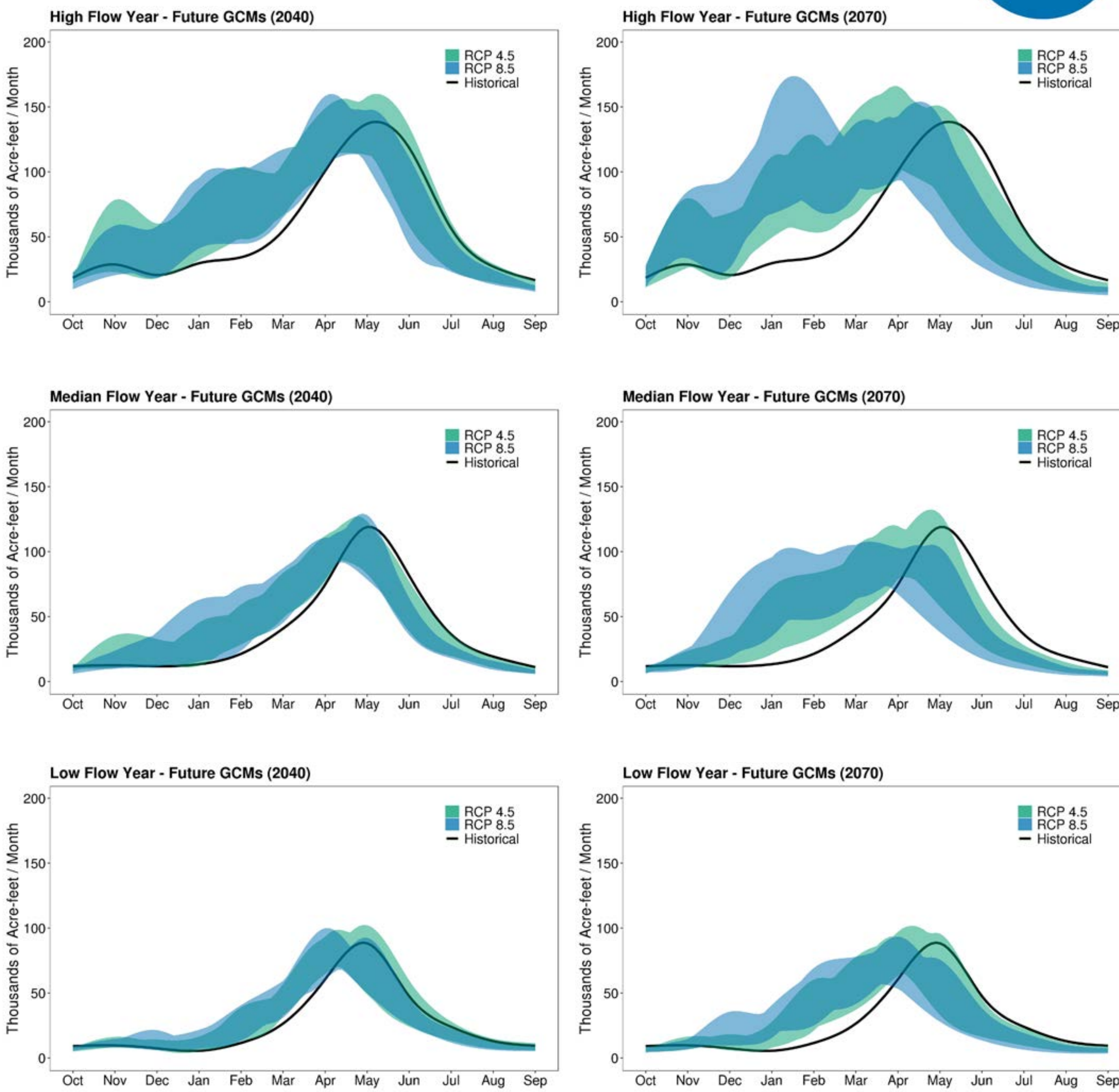
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 60 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 6 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 19 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 67% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 3% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 7 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 23 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 3.2 cfs by 2040.

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[1]	Bull Trout, Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead, [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	NONE

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

SUPPLY

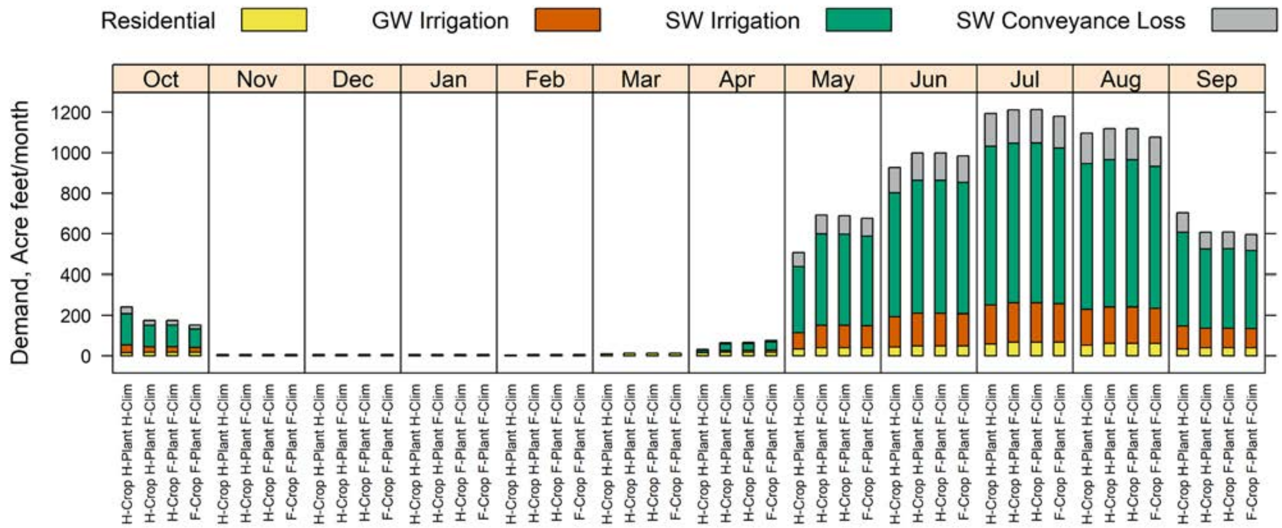




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

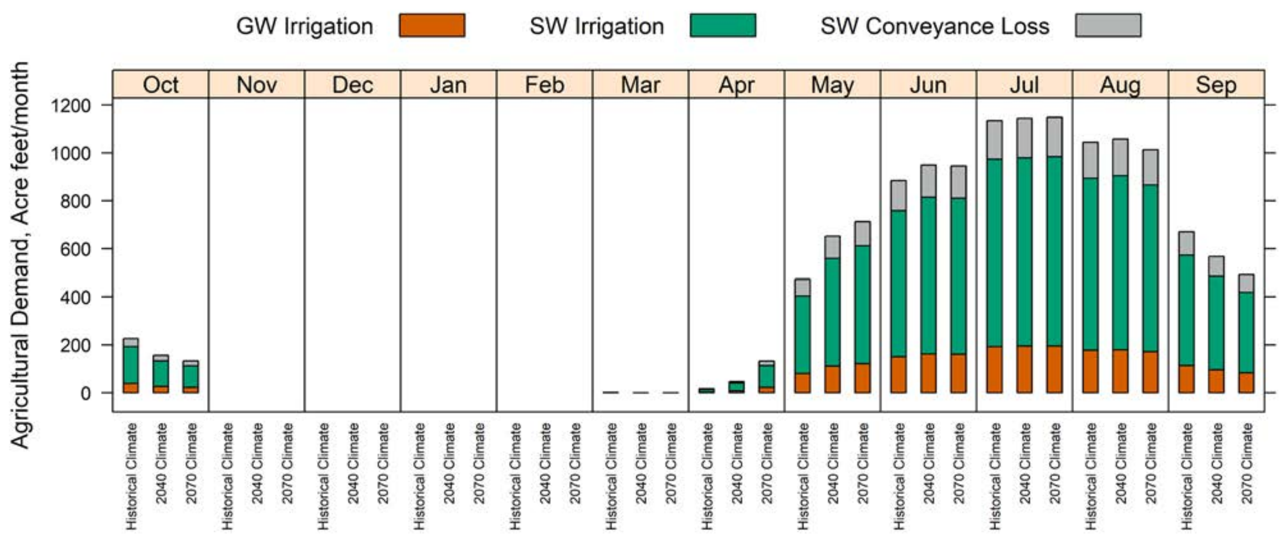
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. Note: Residential demands were not projected for 2070 and so are not included in this figure.

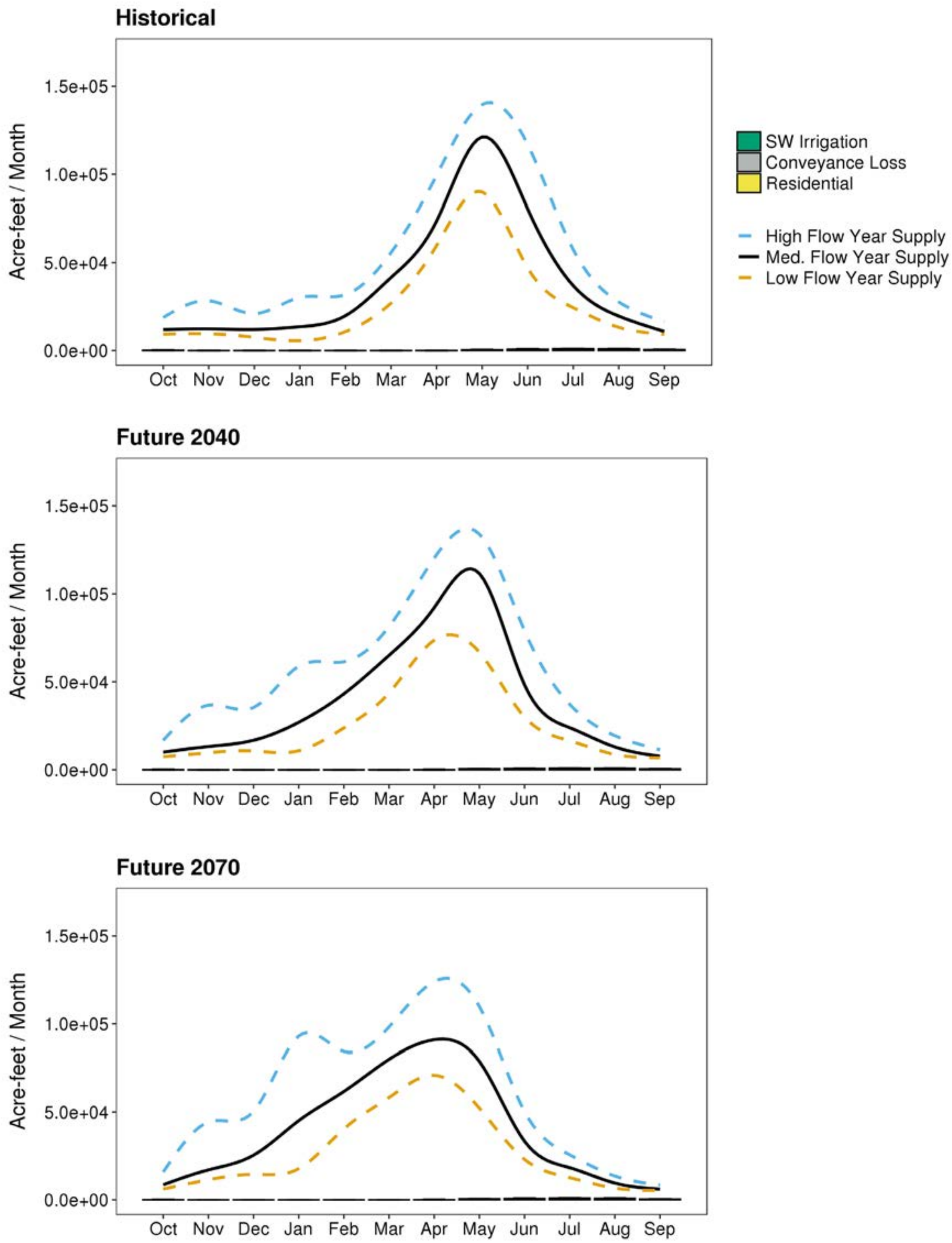
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

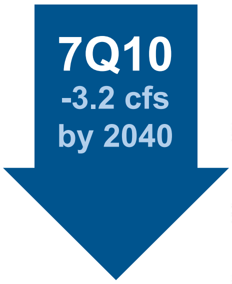
Bar 3
- 2070s Climate

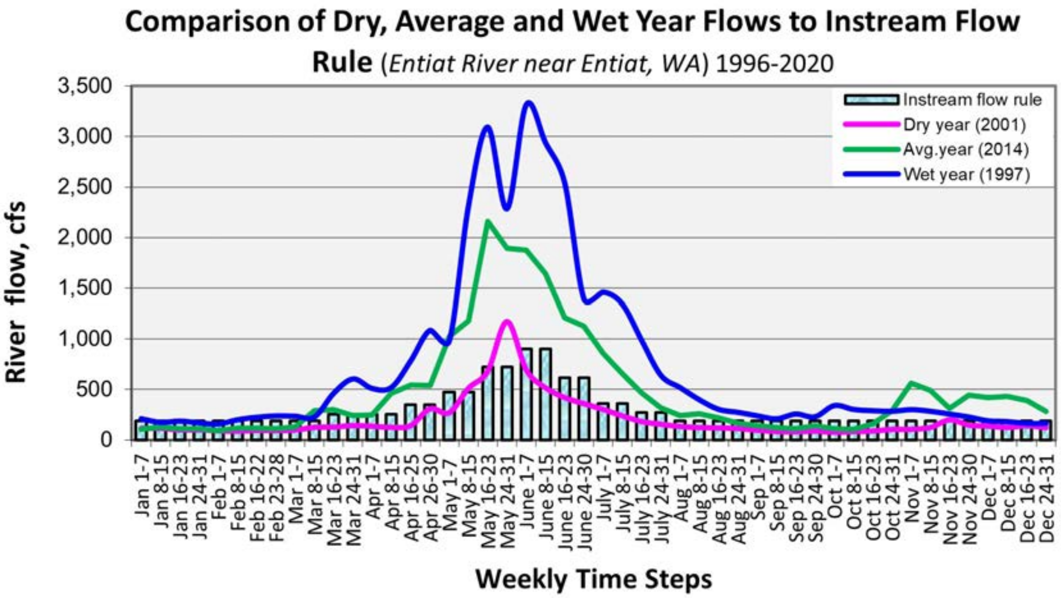
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH





Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

Entiat River Basin - WRIA 46
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
"Upper Columbia" Summer Chinook[1] (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0					0	0
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing	0								0	0	0	0
	Juvenile Out-Migration	0								0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entiat Spring Chinook (ESA Endangered)	Adult In-Migration	0	0	0	0					0	0	0	0
	Spawning	0	0	0	0	0	0	0			0	0	0
	Egg Incubation & Fry Emergence				0	0	0	0					
	Rearing												
	Juvenile Out-Migration	0								0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entiat Summer Steelhead (ESA Threatened)	Adult (Spawners & Kelts) Migration								0				
	Spawning	0	0					0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0							0	0	0	0
	Rearing												
	Juvenile Out-Migration	0	0								0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
"Upper Columbia" Sockeye[2] (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0					0	0	0
	Spawning	0	0	0	0	0	0	0	0			0	0
	Egg Incubation & Fry Emergence				0	0	0	0	0				
	Rearing												
	Juvenile Out-Migration	0	0							0	0	0	0

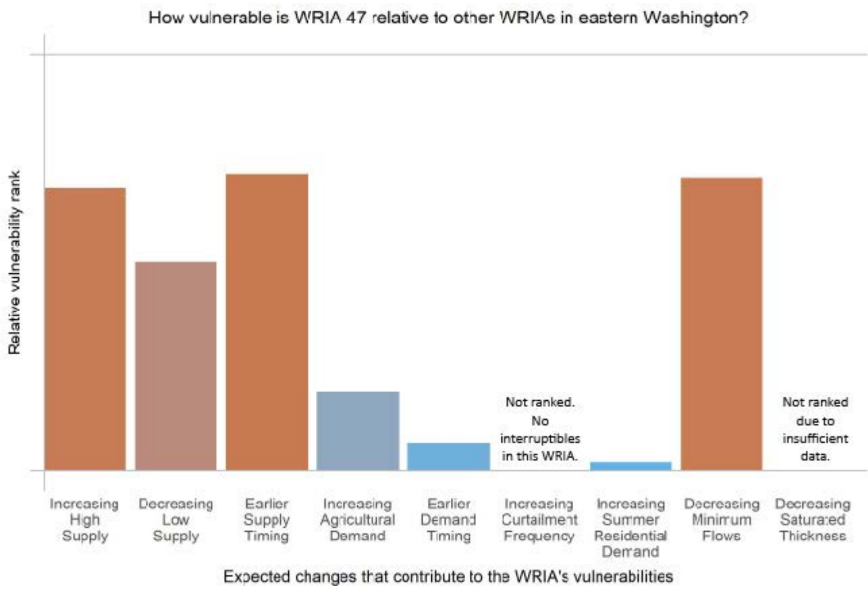
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
"Upper Columbia" Coho[3] (Not ESA Listed)	Adult In-Migration	0	0	0	0	0	0	0	0				
	Spawning		0	0	0	0	0	0	0	0			
	Egg Incubation & Fry Emergence						0	0	0	0			
	Rearing												
	Juvenile Out-Migration	0	0							0	0	0	0

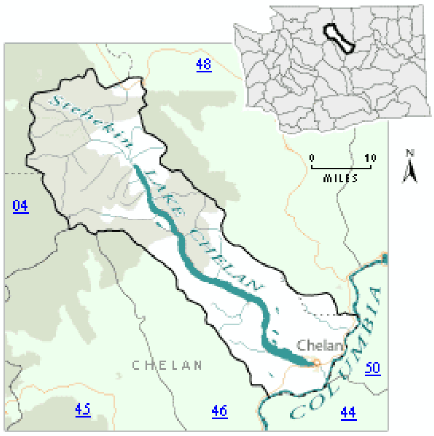
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entiat Core Area Bull Trout (ESA Threatened)	Adult Migrations	0	0	0	0								
	Spawning	0	0	0	0	0	0	0	0			0	0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing												
	Juvenile Migrations												

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





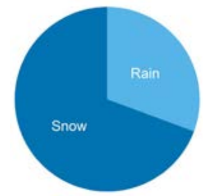
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

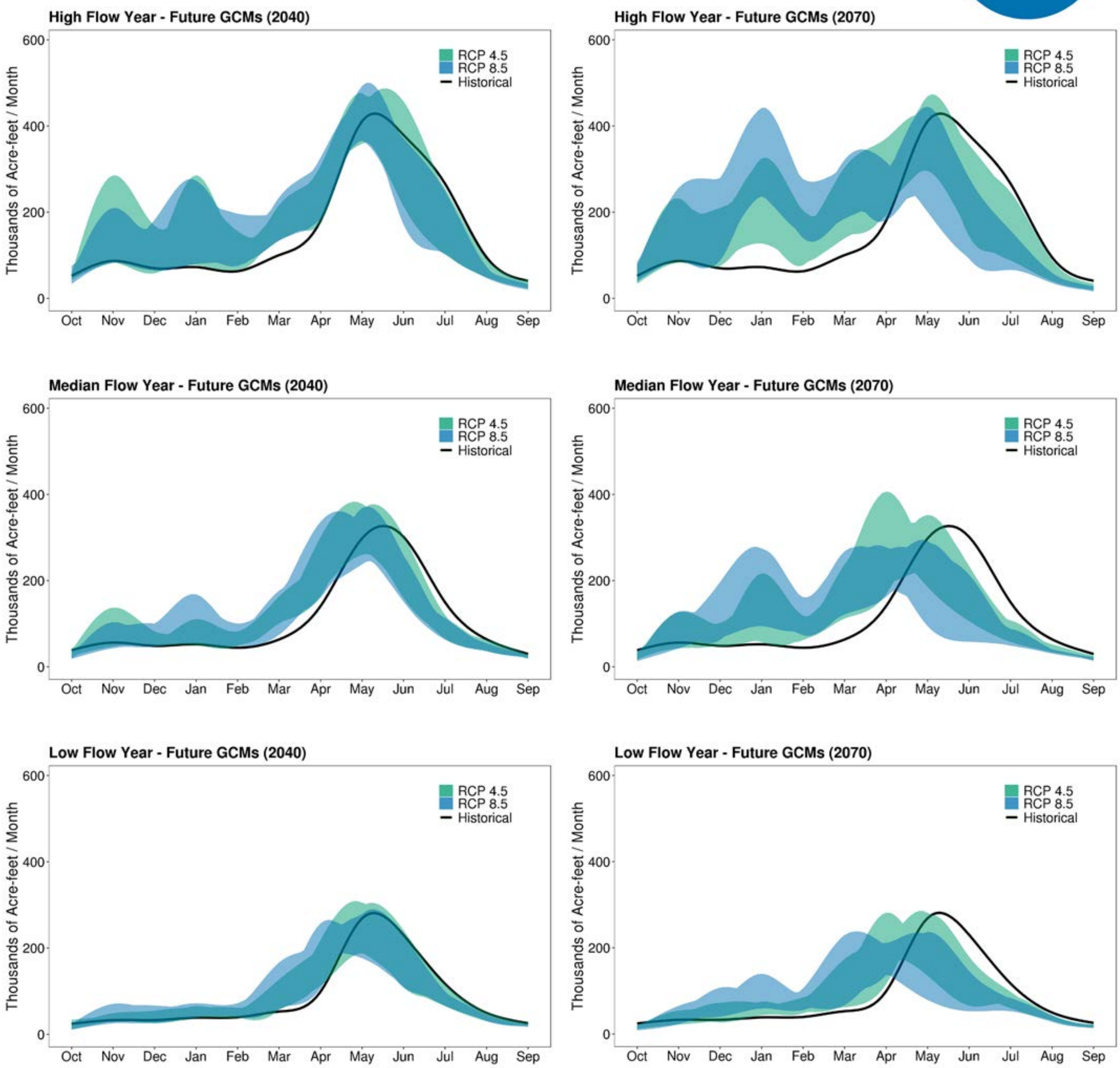
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 72 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to decrease by 46 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 17 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 69% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 1% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 9 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 49 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 10.7 cfs by 2040.

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[1]	[Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Chelan

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

SUPPLY

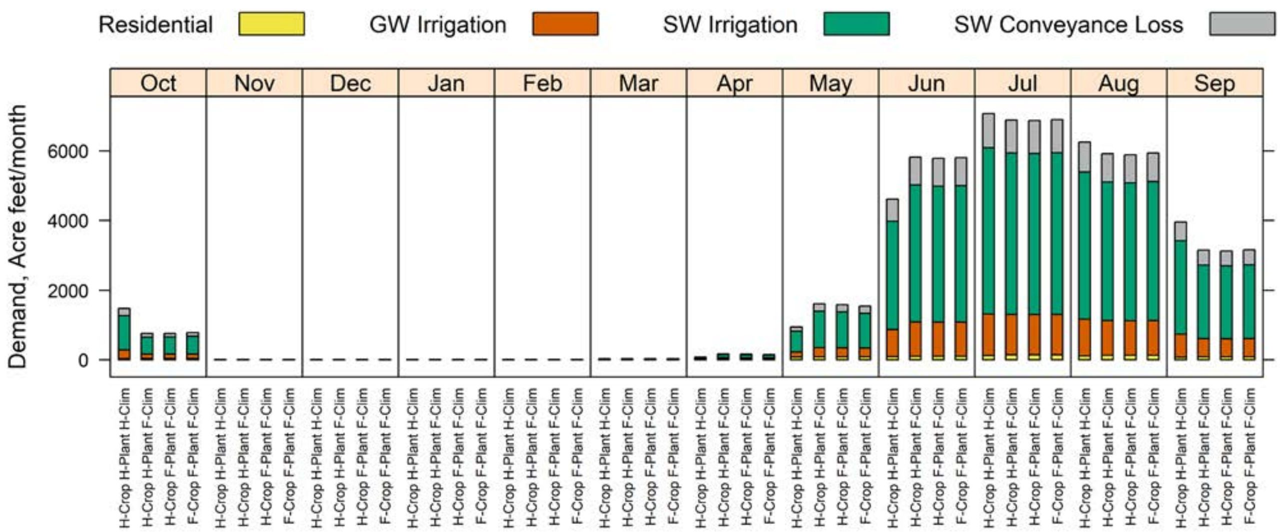




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

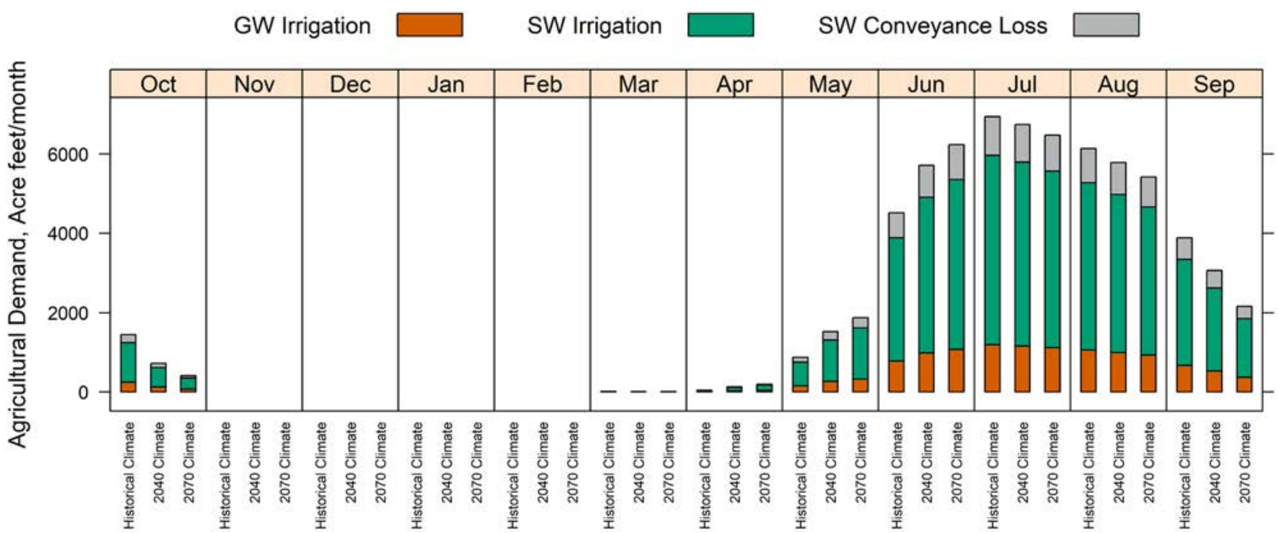
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

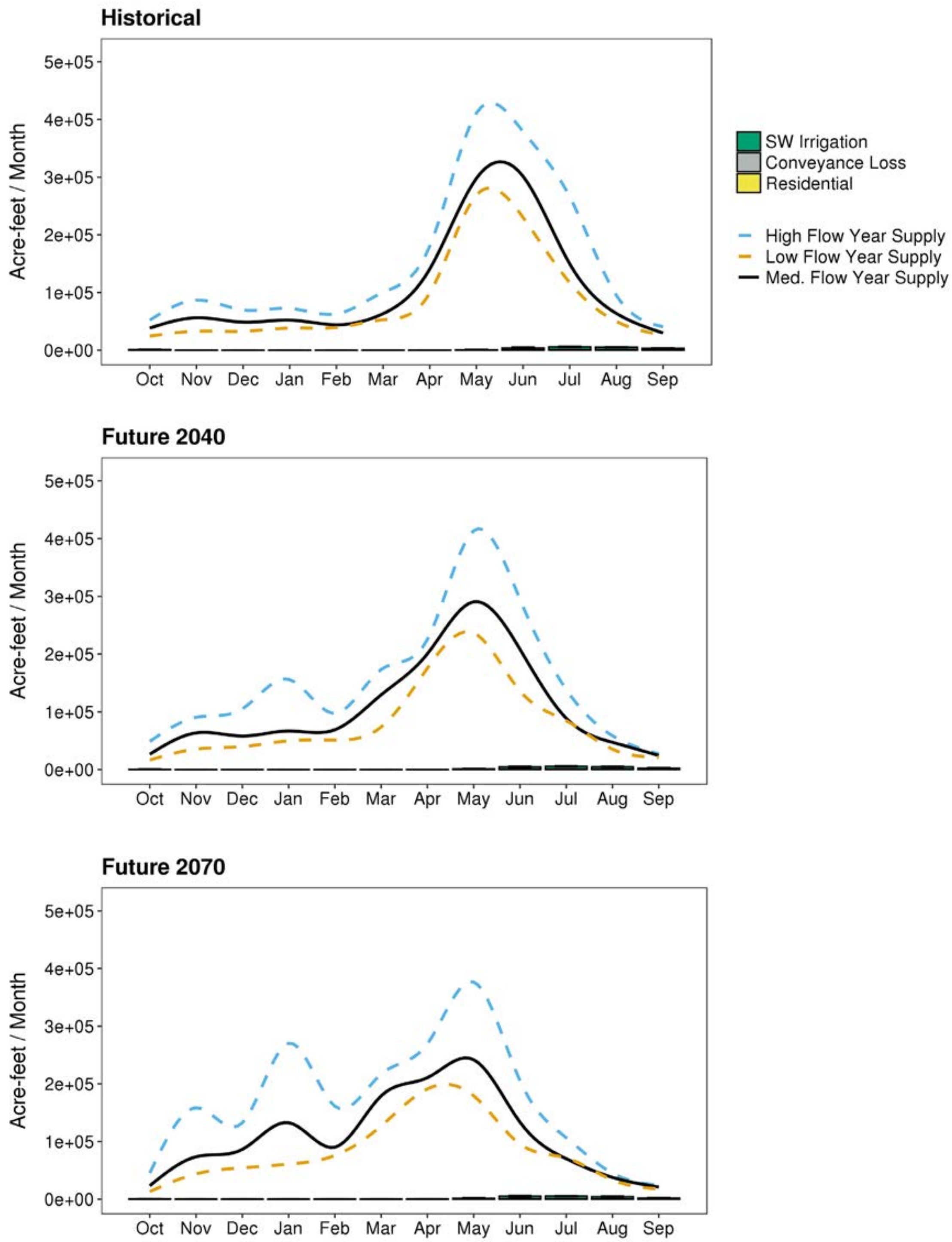
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

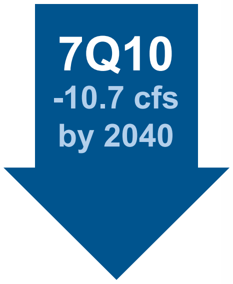
Bar 3
- 2070s Climate

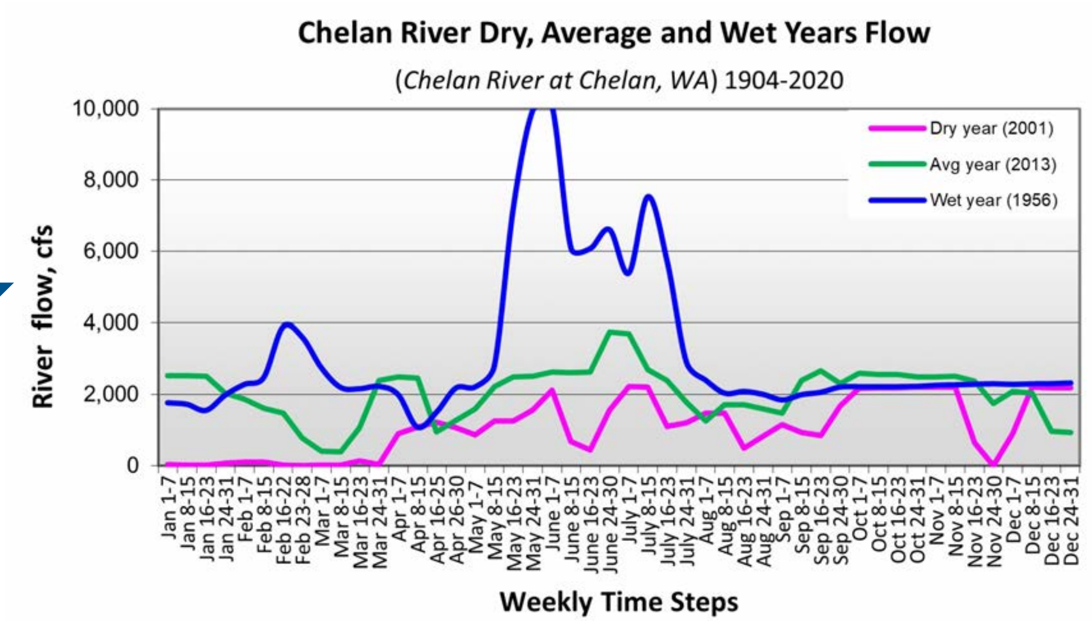
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

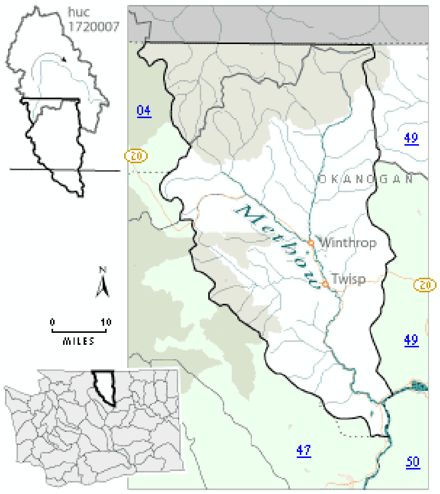


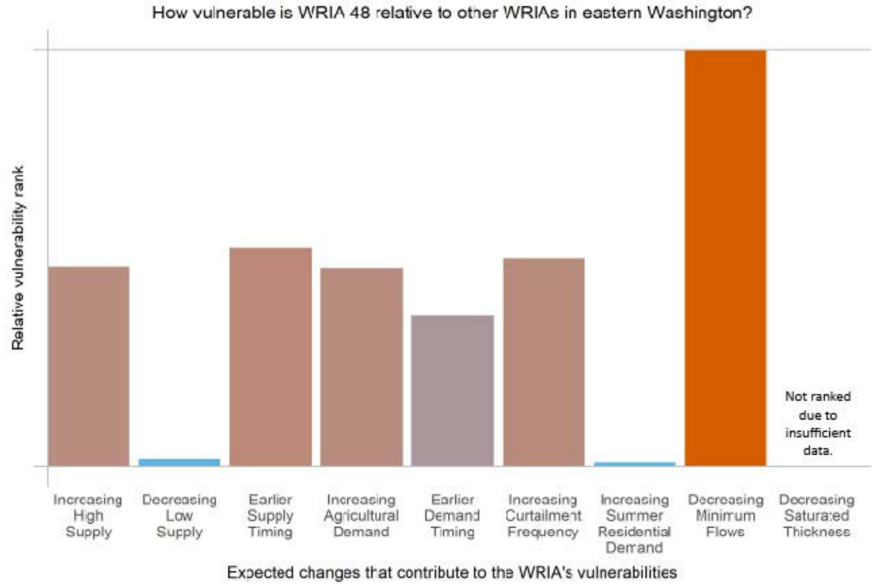


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





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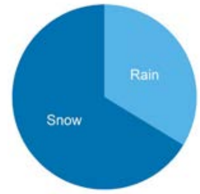
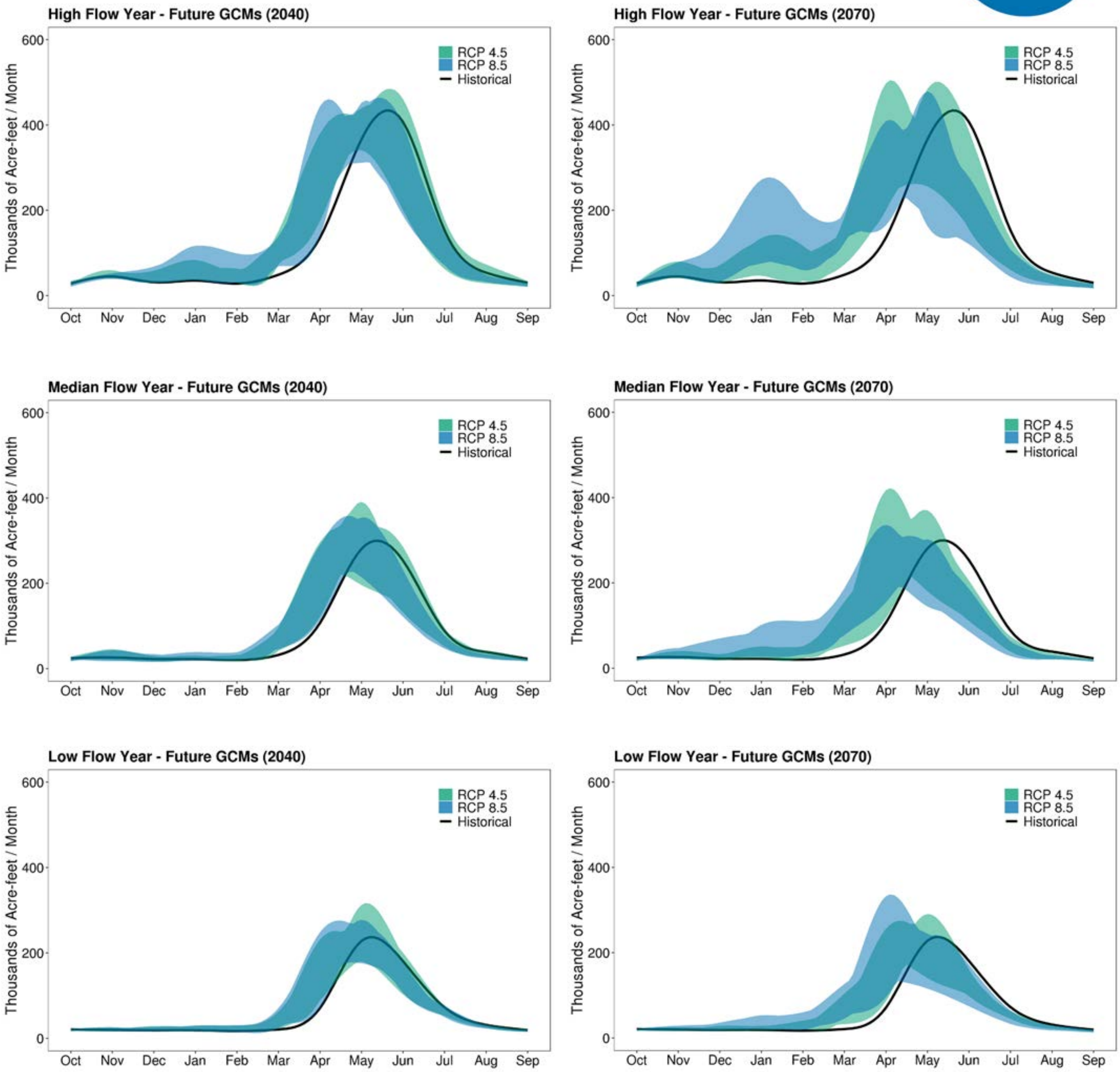
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 39 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 40 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 13 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 66% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 7% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 5 days earlier by 2040.
- **Increasing Curtailment Frequency:** The frequency of curtailment for July and August is projected to increase by 25% by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 19 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 15.6 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Wolf Creek, Bear Creek & Davis Lake, Black Canyon Creek, Gold Creek, McFarland Creek, Libby Creek, Beaver Creek
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[1]	Bull Trout, Upper Columbia River Spring Run Chinook, Upper Columbia Steelhead [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	NONE

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

SUPPLY

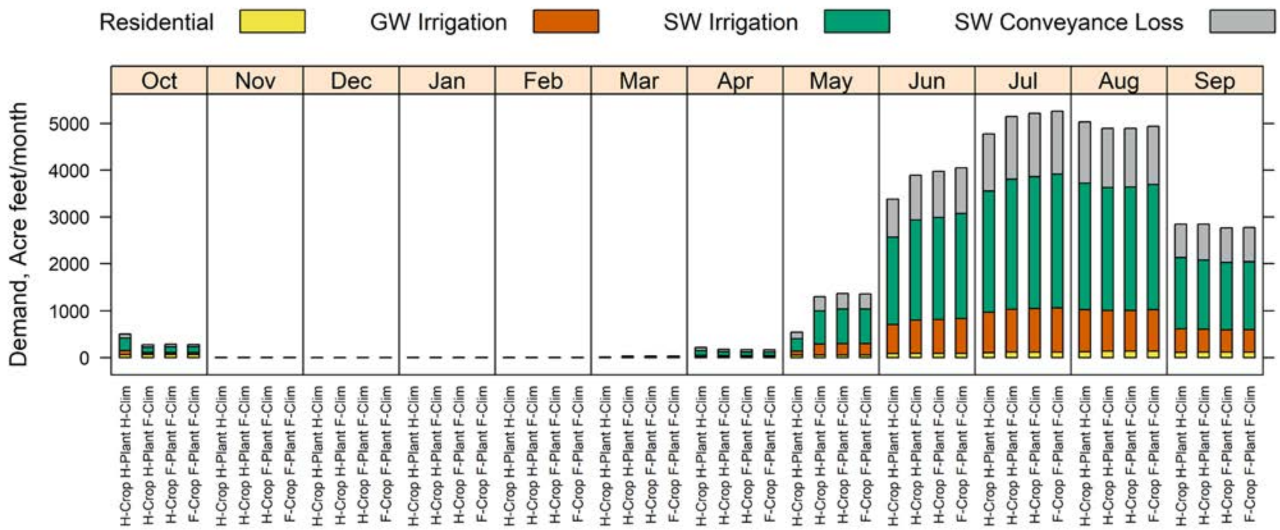




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

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Bar 1
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Bar 2
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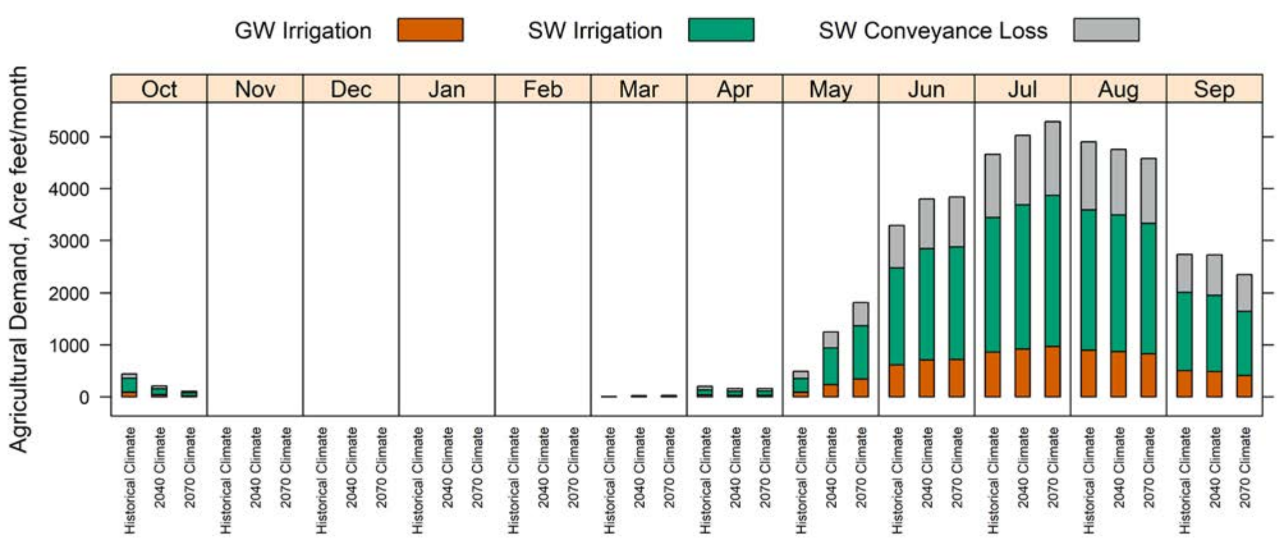
Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

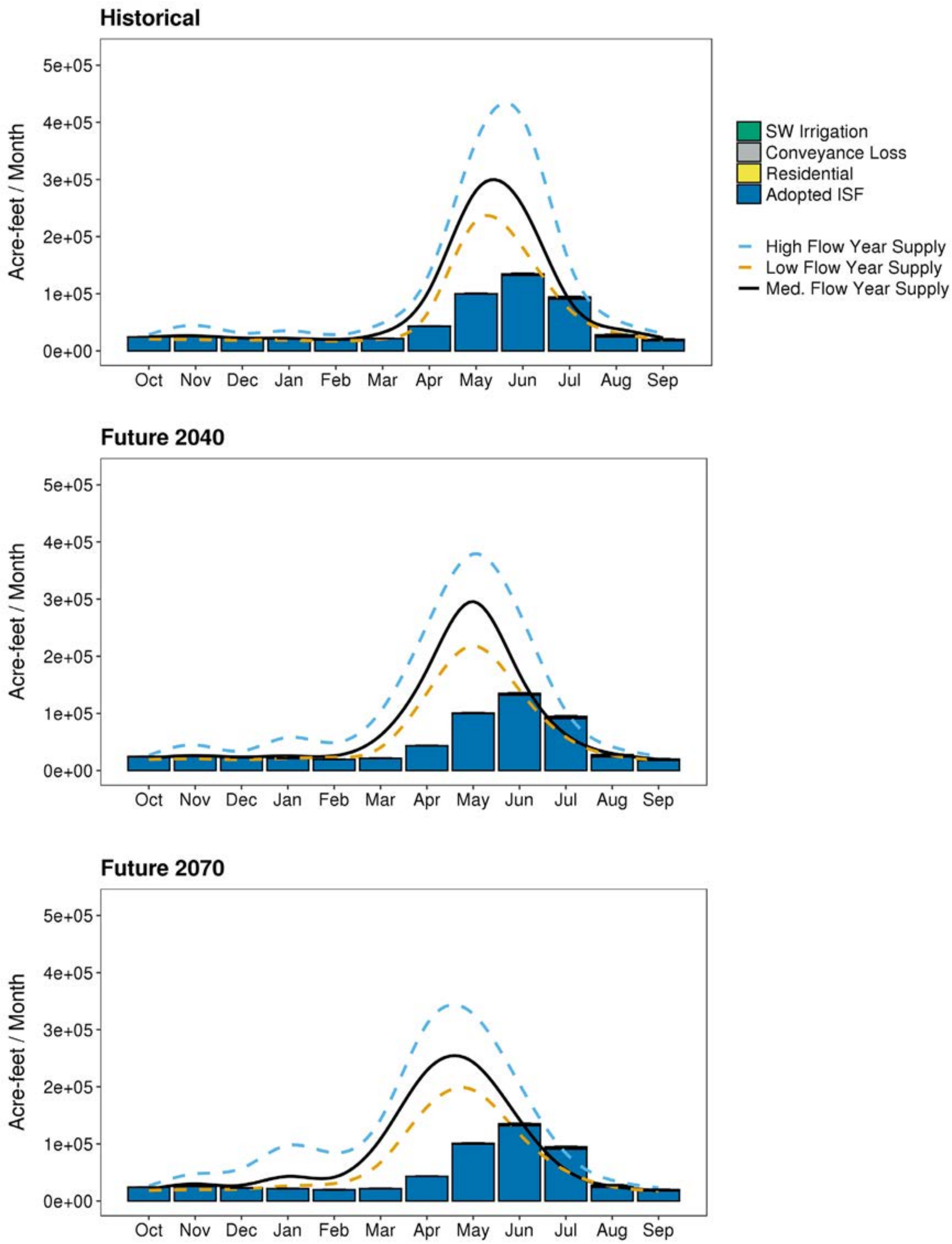
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

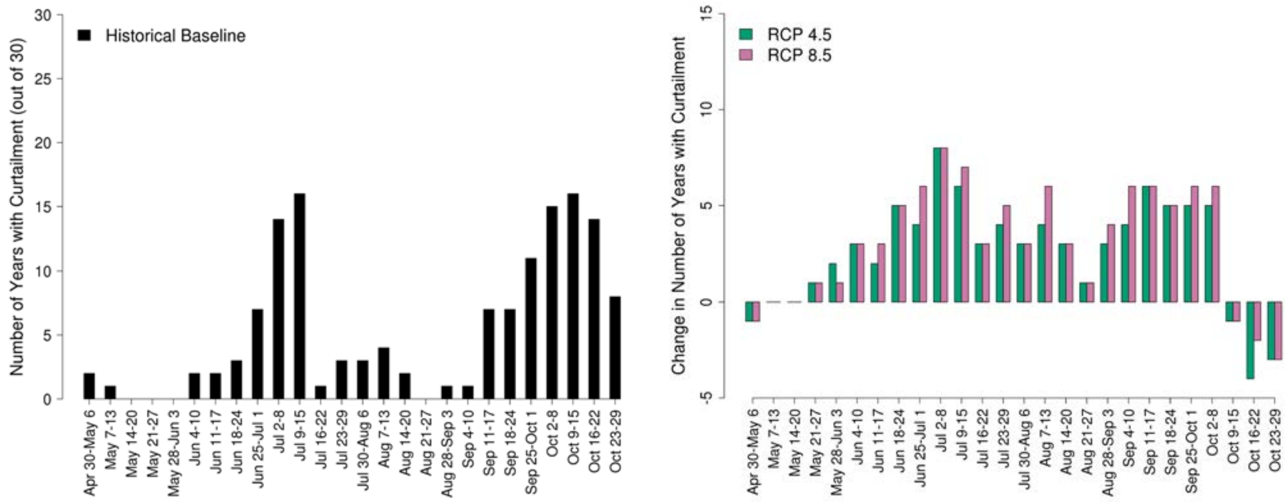
Bar 3
- 2070s Climate

SUPPLY AND DEMAND

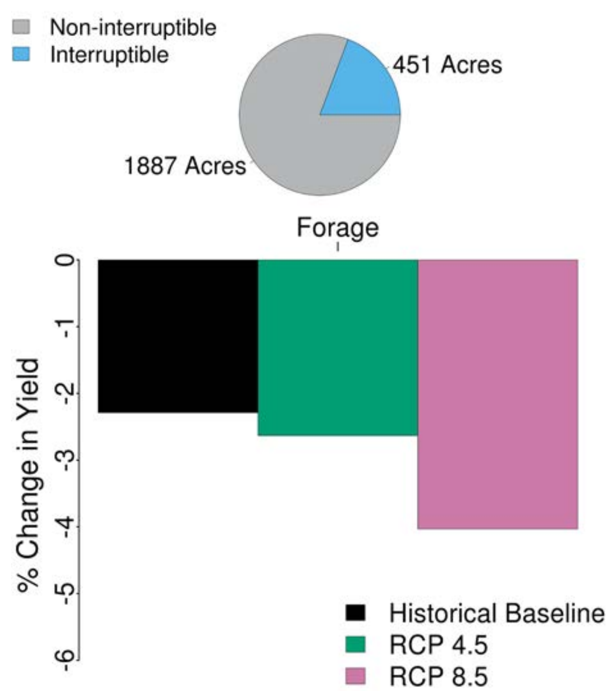


Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CURTAILMENT

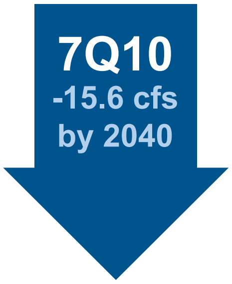


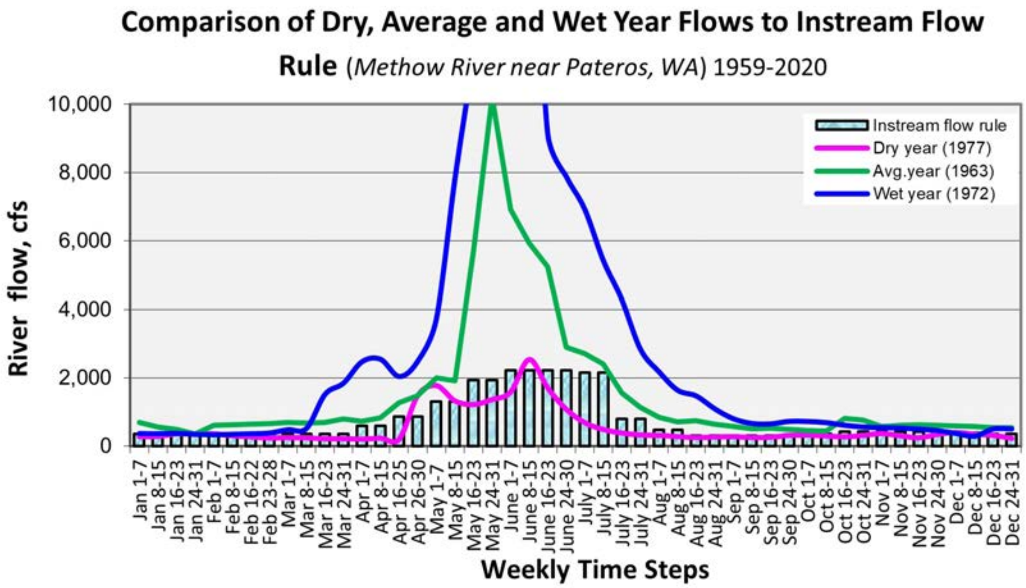
Modeled historical baseline number of years with curtailment from 1986- 2015 for each week (left panel) and change in the number of years with curtailment for each week for RCP 4.5 and RCP 8.5 (right panel) during a future period (2026 – 2055) compared to historical curtailment from 1976-2005. Changes in curtailment frequency include both surface and groundwater interruptions. Change in curtailment is forecasted using the median of the changes (future GCM- historical GCM) predicted by 17 climate GCM scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5.



Difference between annual yield produced on land with an interruptible water right and full irrigation yield relative to full irrigation yield under historical baseline (1986- 2015) and future (2026- 2055) climate conditions. Future yields are calculated as the median of 17 climate change scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5. The pie charts show the amount of interruptible and non-interruptible acreage for each crop group based on historical crop mix within this WRIA. The “High Value Perennials” crop group includes blueberries, apples, cherries, peaches, pears, and grapes. The “Forage” crop group includes alfalfa hay and grass hay.

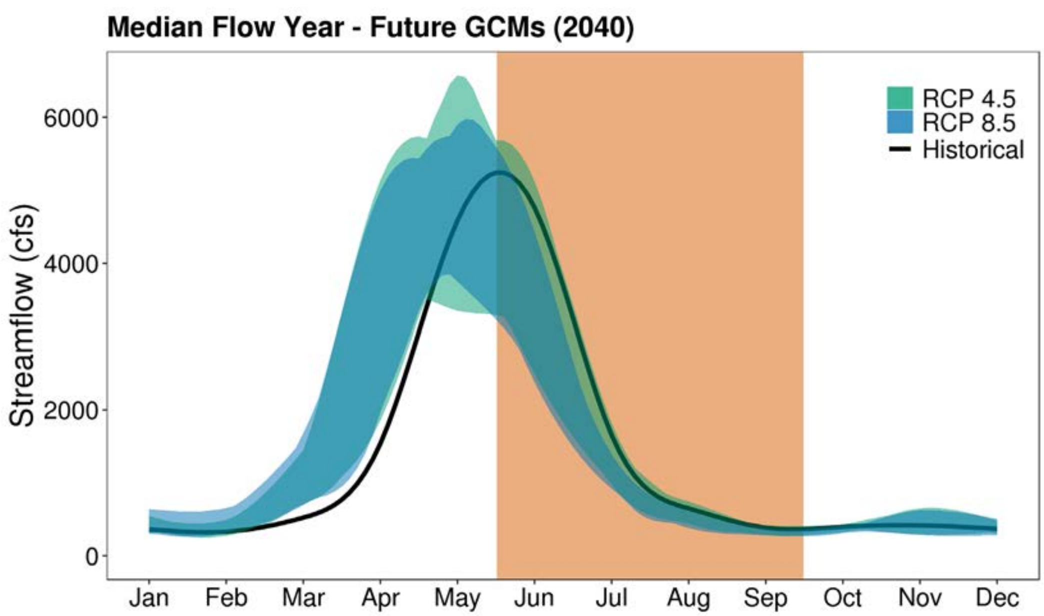
CONSIDERATIONS FOR FISH





Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.



The actual flow plot shows modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5; 2040) surface water actual flows generated within the WRIA. Actual flow was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each RCP is due to the range of climate change scenarios considered. An orange background in the plot indicates months in which 90% of the climate models predict future flows that are below historical. Actual flows represent the expected amount of water available after demands are accounted for.

Methow River Basin - WRIA 48
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Summer Chinook (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0					0	0
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing	0								0	0	0	0
	Juvenile Out-Migration	0								0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Spring Chinook (ESA Endangered)	Adult In-Migration	0	0	0	0						0	0	0
	Spawning	0	0	0	0	0	0					0	0
	Egg Incubation & Fry Emergence				0	0	0						
	Rearing												
	Juvenile Out-Migration	0	0					0	0	0	0	0	0

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Summer Steelhead (ESA Threatened)	Adult (spawners & kelts) Migration							0					
	Spawning	0	0					0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0								0	0	0
	Rearing												
	Juvenile Out-Migration	0	0						0	0	0	0	0

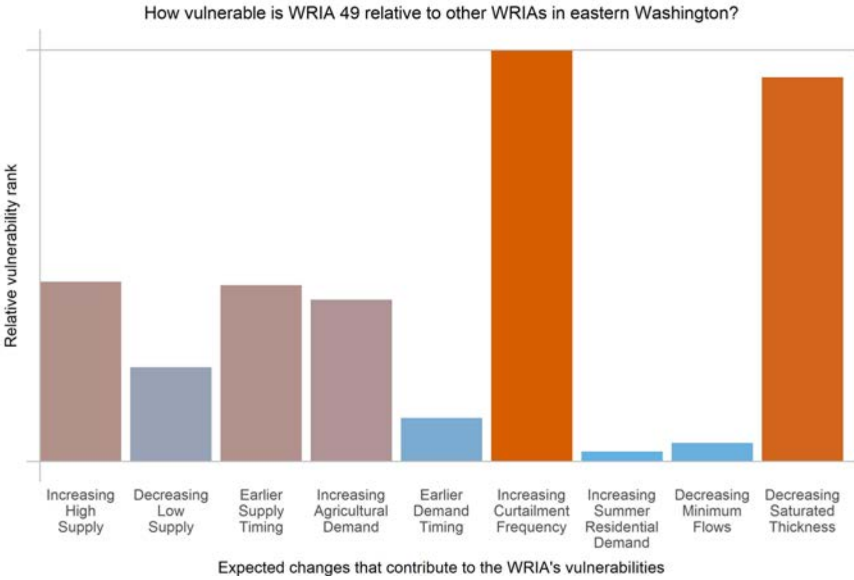
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Coho (Not ESA listed)	Adult In-Migration	0	0	0	0	0	0	0	0				
	Spawning	0	0	0	0	0	0	0	0	0			
	Egg Incubation & Fry Emergence						0	0	0	0			
	Rearing												
	Juvenile Out-Migration	0	0	0				0	0	0	0	0	0

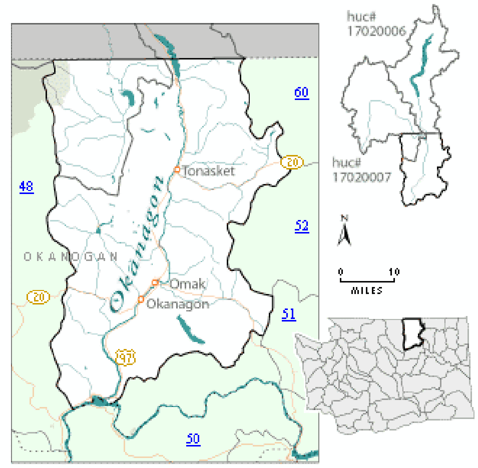
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Methow Core Area Bull Trout (ESA Threatened)	Adult Migrations	0	0	0	0								
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence						0	0	0				
	Rearing												
	Juvenile Migrations	0	0					0	0	0			0

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





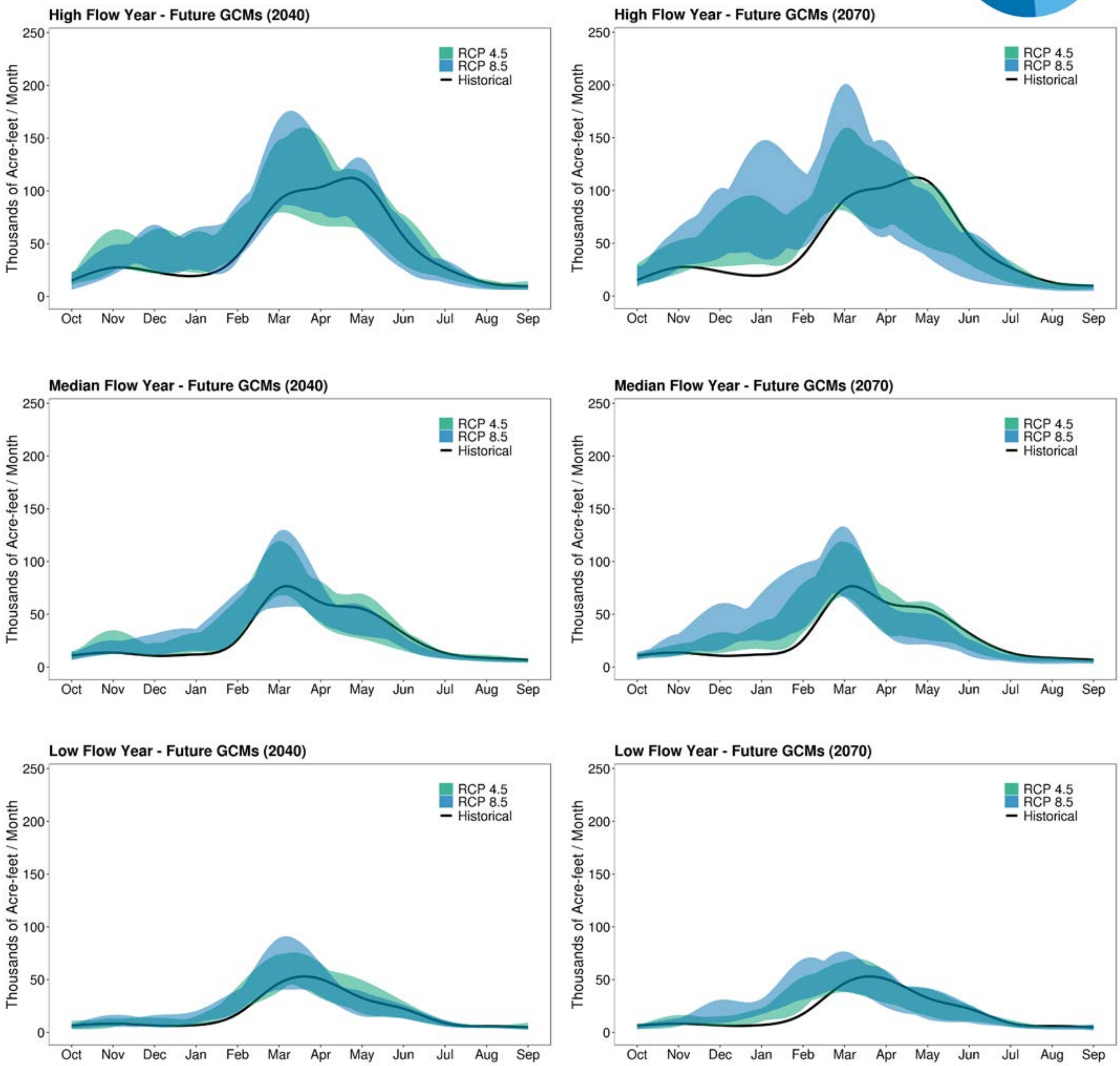
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 32 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 3 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 11 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 51% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 5% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 8 days earlier by 2040.
- **Increasing Curtailment Frequency:** The frequency of curtailment for July and August is projected to increase by 37% by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 63 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 0.3 cfs by 2040.
- **Decreasing Saturated Thickness:** Available saturated thickness is projected to decrease by 49% on average by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Simikameen River, Salmon Creek, North Fork, Johnson Creek, Lower Antoine Creek, Sinlahekin Creek, Whitestone Lake, Chiliwist Creek, Bonaparte Creek & Lake, Duck Lake Ground Water Subarea
Watershed Planning	Watershed plan addendum adopted on January 28, 2021
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[1]	Upper Columbia Steelhead, [Columbia mainstem migratory corridor]
Groundwater Subareas Overlapped by WRIA	Okanogan

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

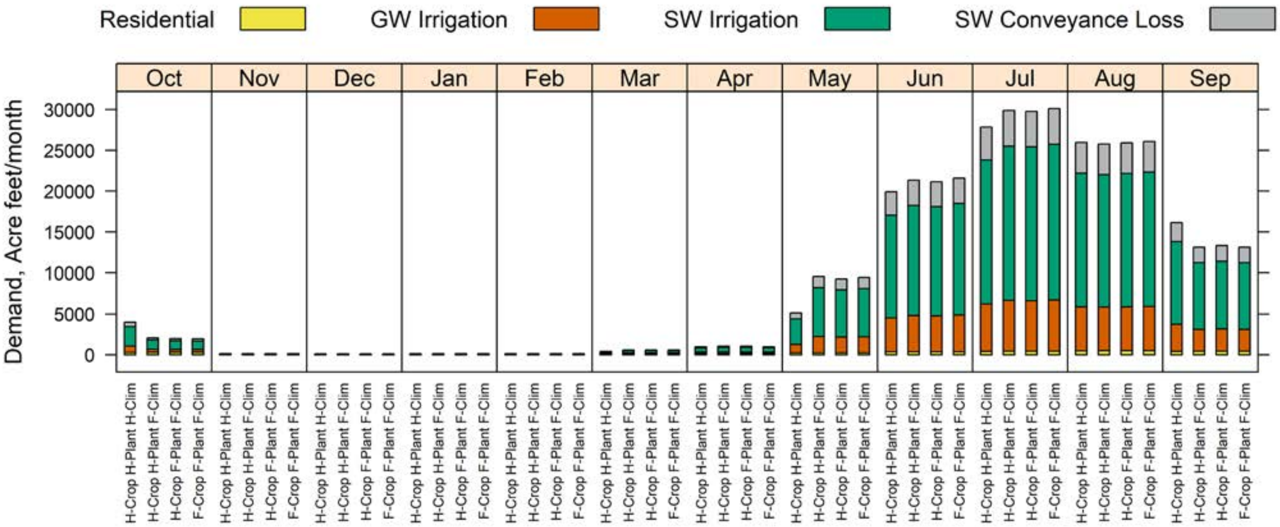
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

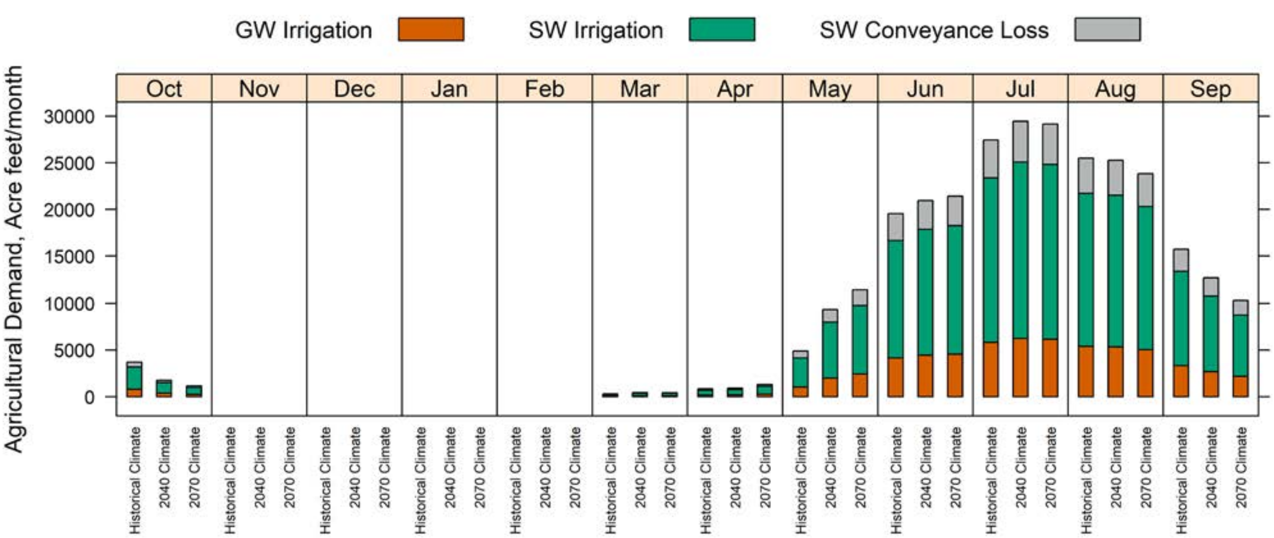
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. Note: Residential demands were not projected for 2070 and so are not included in this figure.

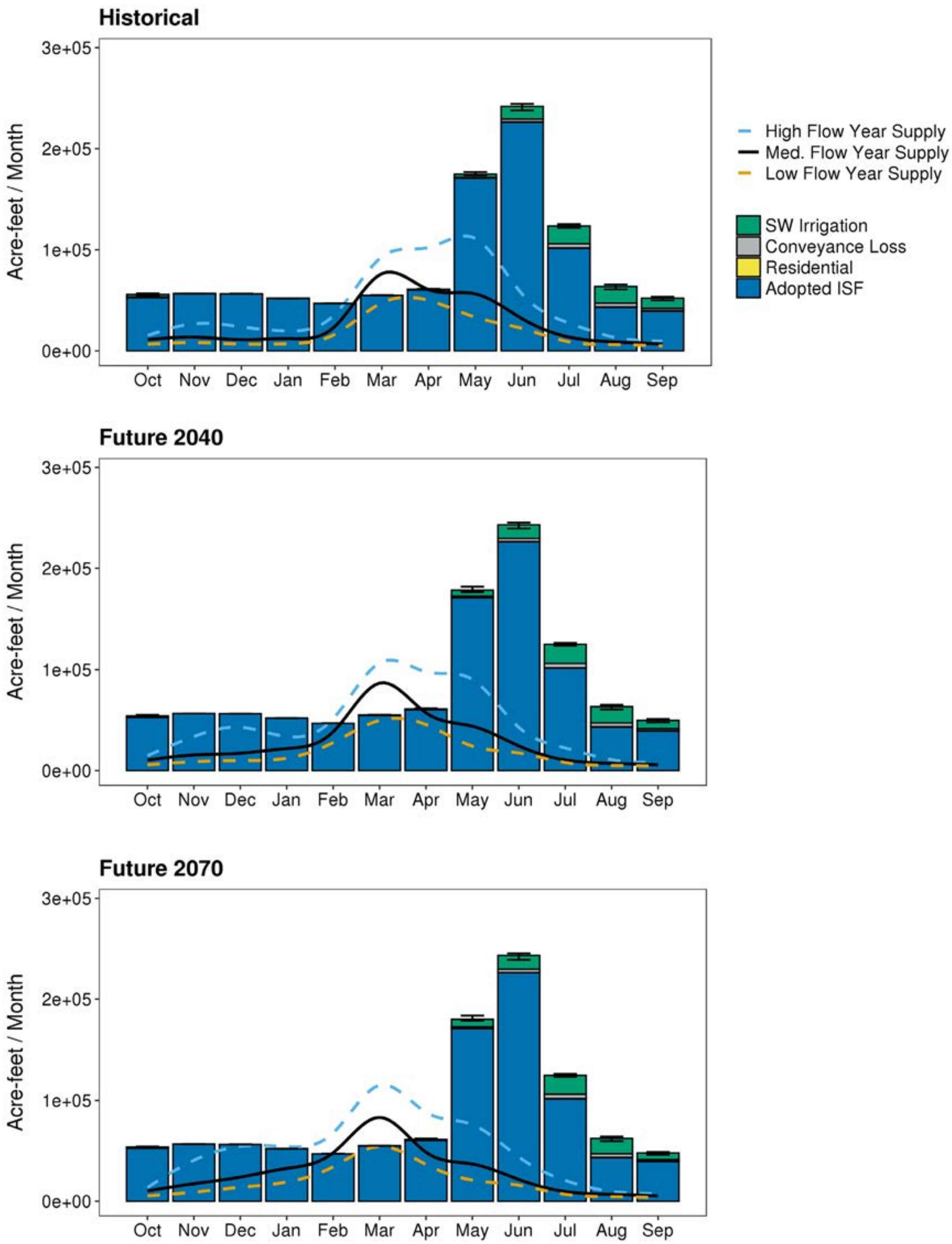
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

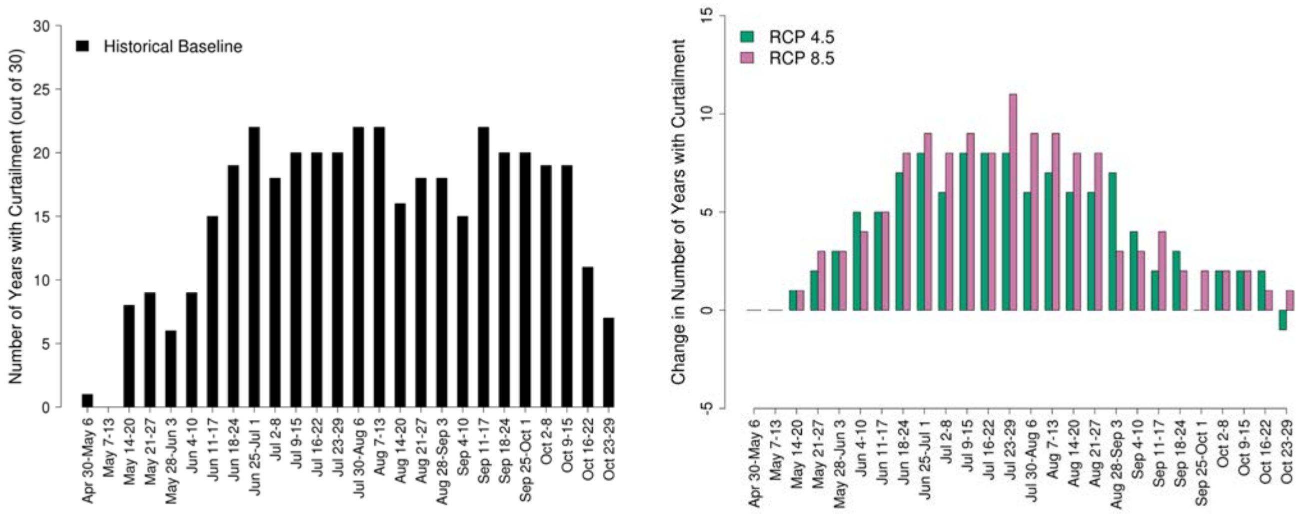
Bar 3
- 2070s Climate

SUPPLY AND DEMAND

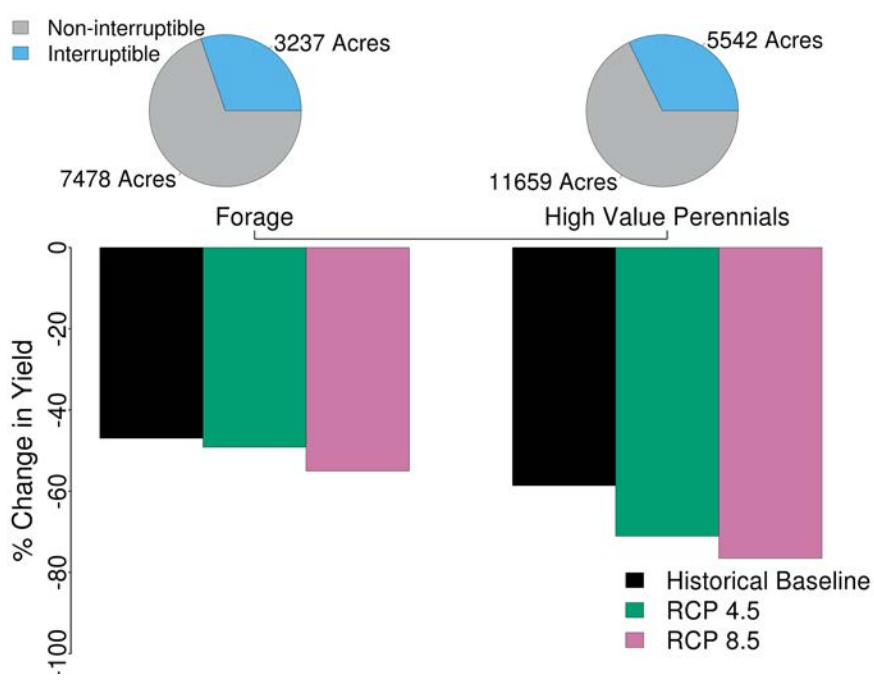


Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CURTAILMENT

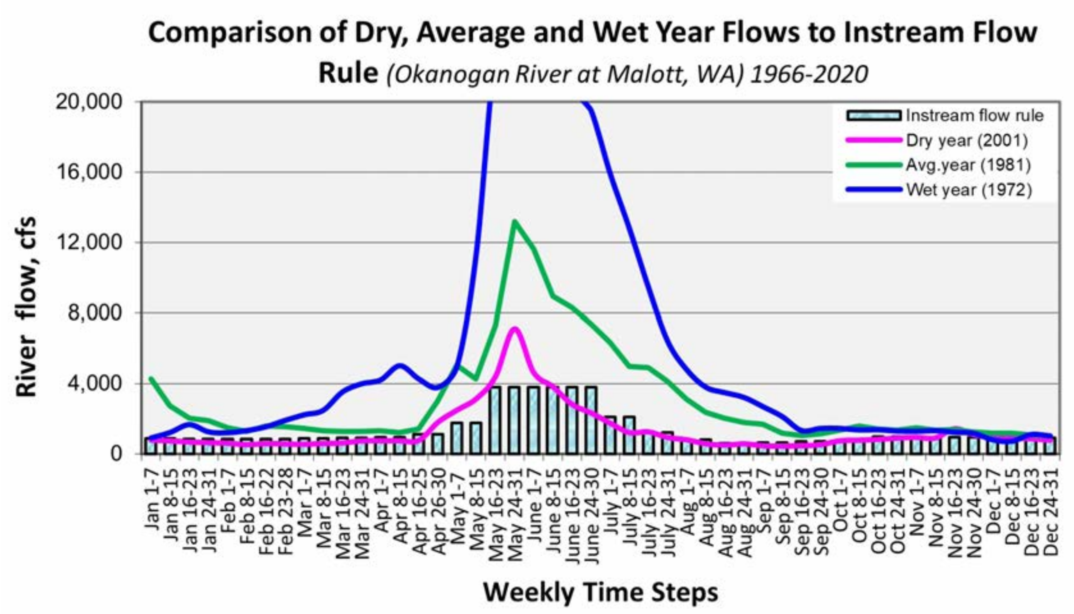


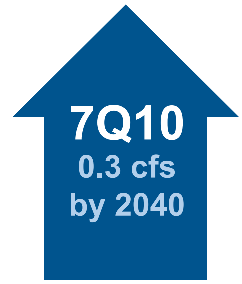
Modeled historical baseline number of years with curtailment from 1986- 2015 for each week (left panel) and change in the number of years with curtailment for each week for RCP 4.5 and RCP 8.5 (right panel) during a future period (2026 – 2055) compared to historical curtailment from 1976-2005. Changes in curtailment frequency include both surface and groundwater interruptions. Change in curtailment is forecasted using the median of the changes (future GCM- historical GCM) predicted by 17 climate GCM scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5.



Difference between annual yield produced on land with an interruptible water right and full irrigation yield relative to full irrigation yield under historical baseline (1986- 2015) and future (2026- 2055) climate conditions. Future yields are calculated as the median of 17 climate change scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5. The pie charts show the amount of interruptible and non-interruptible acreage for each crop group based on historical crop mix within this WRIA. The "High Value Perennials" crop group includes blueberries, apples, cherries, peaches, pears, and grapes. The "Forage" crop group includes alfalfa hay and grass hay.

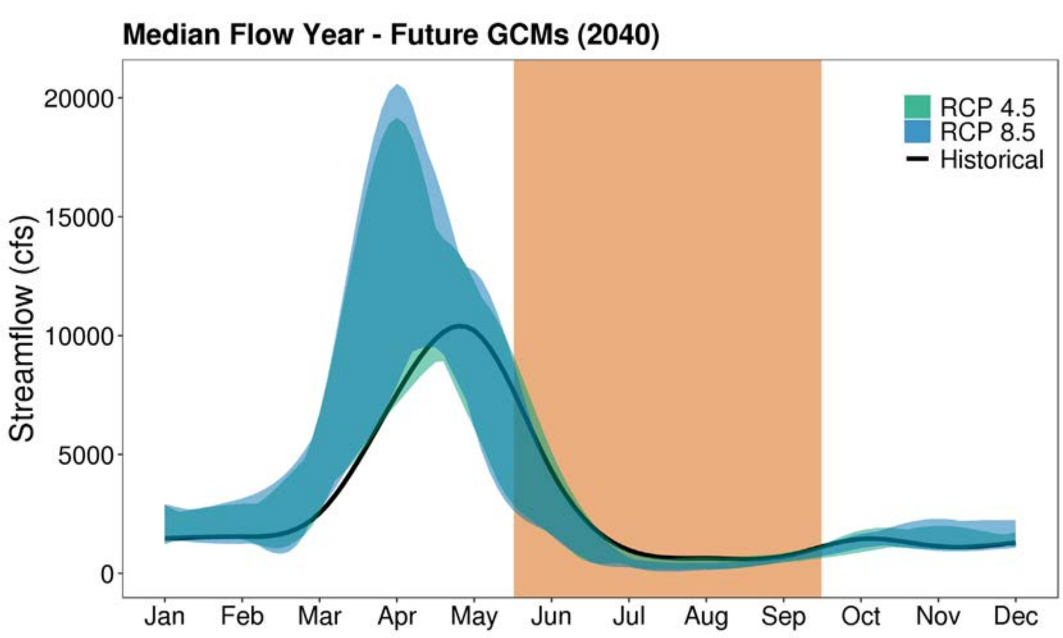
CONSIDERATIONS FOR FISH





Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.



The actual flow plot shows modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5; 2040) surface water actual flows generated within the WRIA. Actual flow was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each RCP is due to the range of climate change scenarios considered. An orange background in the plot indicates months in which 90% of the climate models predict future flows that are below historical. Actual flows represent the expected amount of water available after demands are accounted for.

Okanogan River Basin - WRIA 49
Fish Use Timing by Species

Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Okanogan Summer Chinook (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0						0
	Spawning	0	0	0	0	0	0	0	0				0
	Egg Incubation & Fry Emergence					0	0	0	0				
	Rearing	0							0	0	0	0	0
	Juvenile Out-Migration	0	0	0					0	0	0	0	0

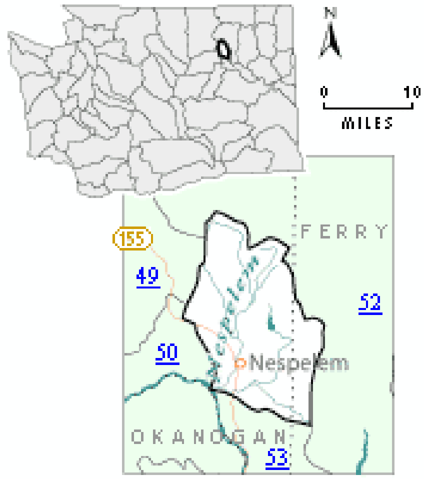
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Okanogan Summer Steelhead (ESA Threatened)	Adult (Spawners & Kelts) Migration	0						0	0	0			0
	Spawning	0	0					0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0								0	0	0
	Rearing												
	Juvenile Out-Migration							0	0				

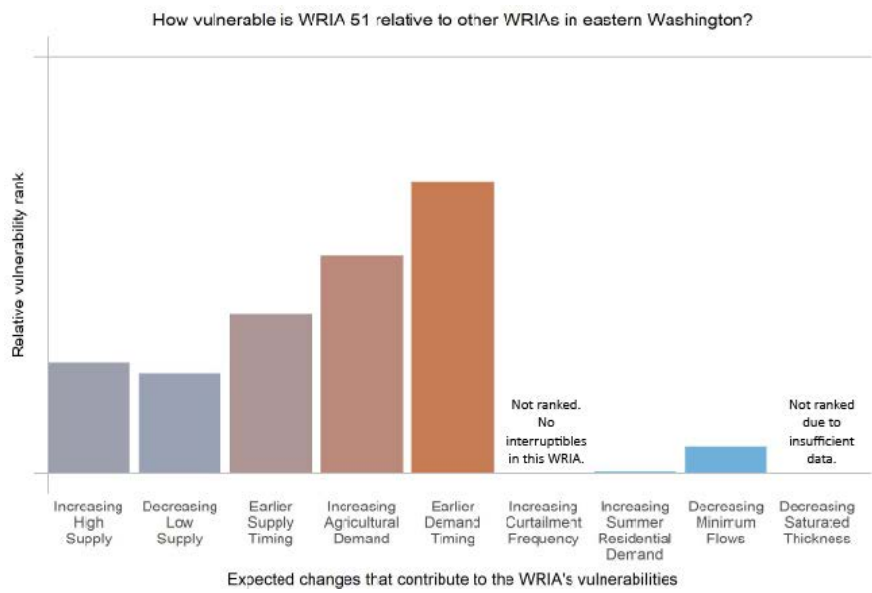
Fish Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Okanogan Sockeye (ESA Not Warranted)	Adult In-Migration	0	0	0	0	0	0					0	0
	Spawning	0	0	0	0	0	0	0	0	0	0	0	0
	Egg Incubation & Fry Emergence	0	0	0	0	0	0	0	0	0	0	0	0
	Rearing	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Out-Migration	0	0	0				0	0	0	0	0	0

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

The fish periodicity table shows months of use during certain life stages for different fish species in the WRIA. Darker shades of brown indicate more activity. An orange shading of months indicates when 90% of the climate models predict future flows that are below historical.

SUMMARY





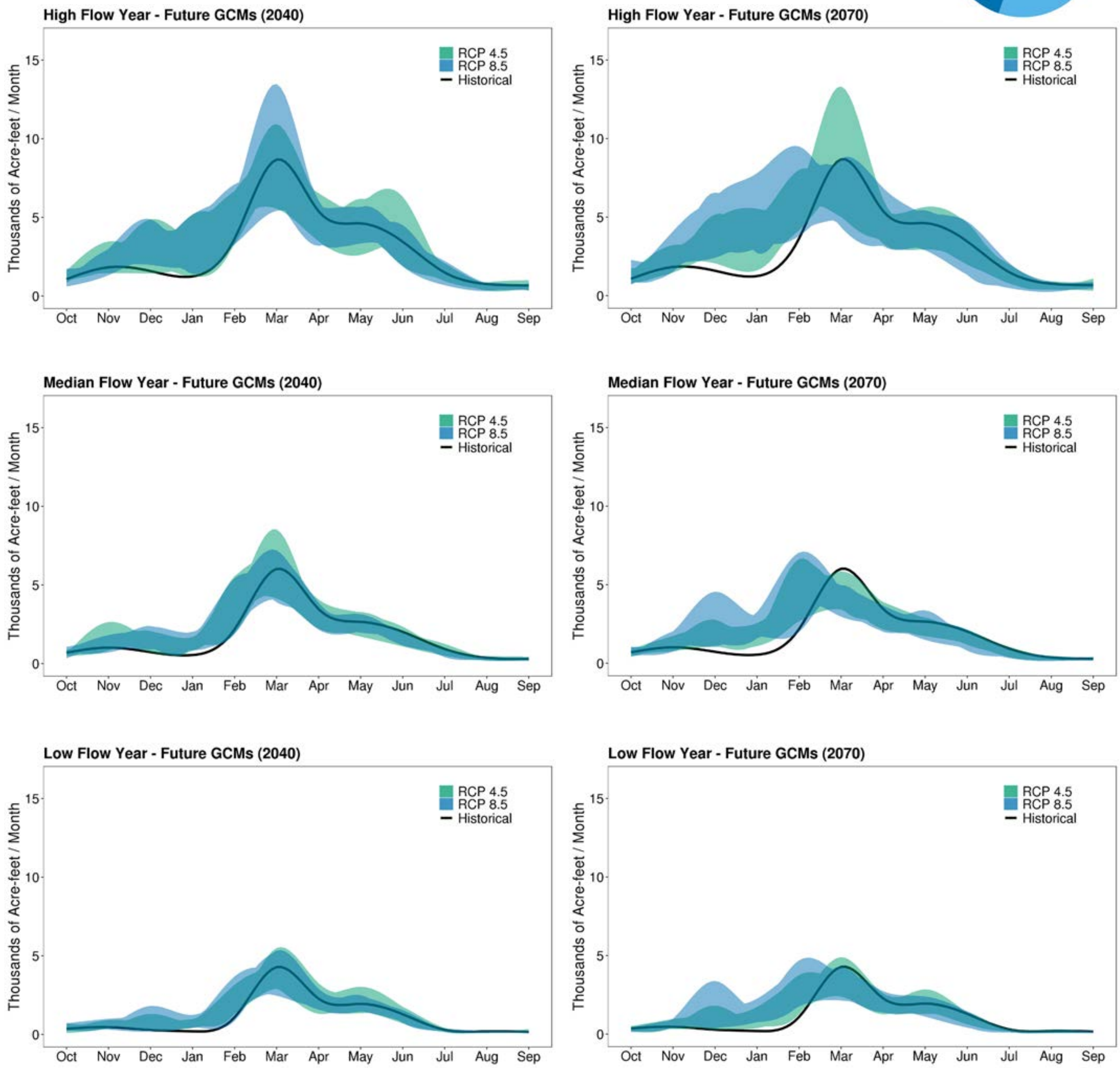
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 3 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 1 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 10 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 45% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 8% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 2 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.1 cfs 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	NONE

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

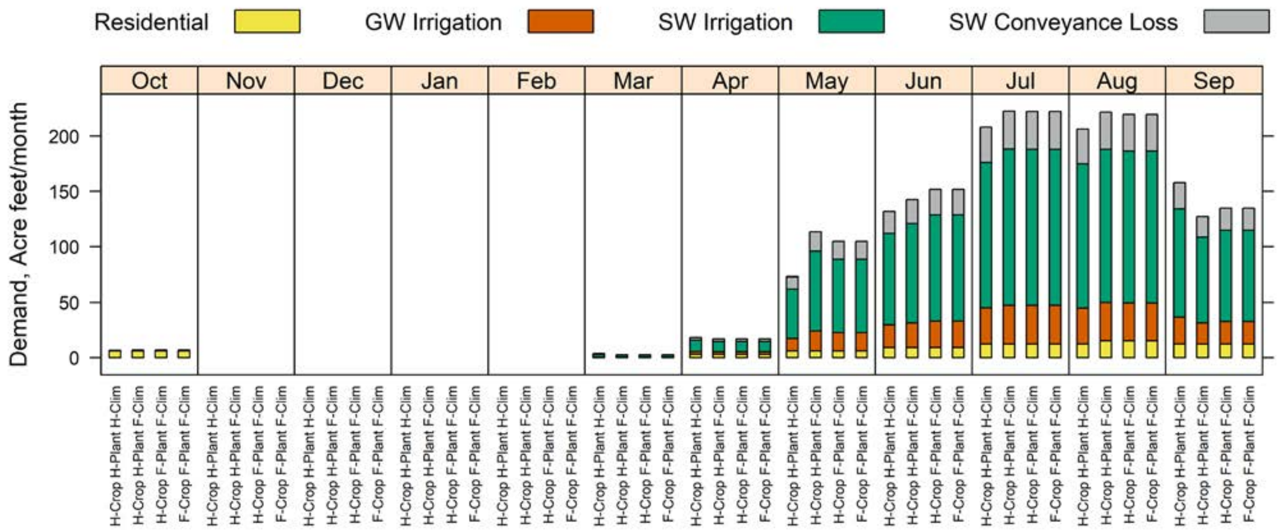
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

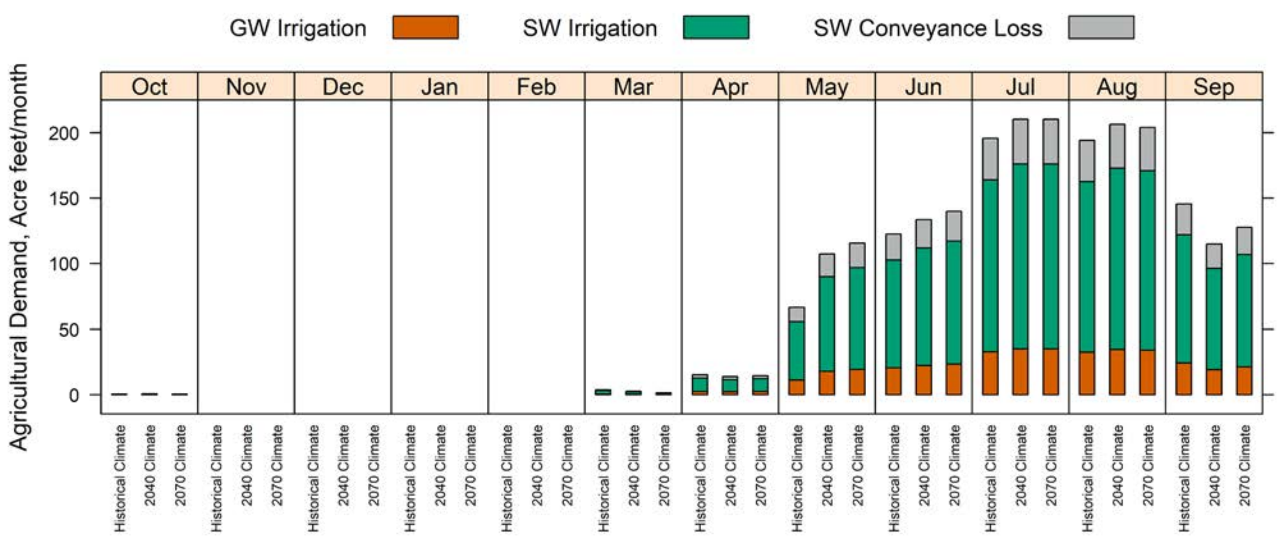
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

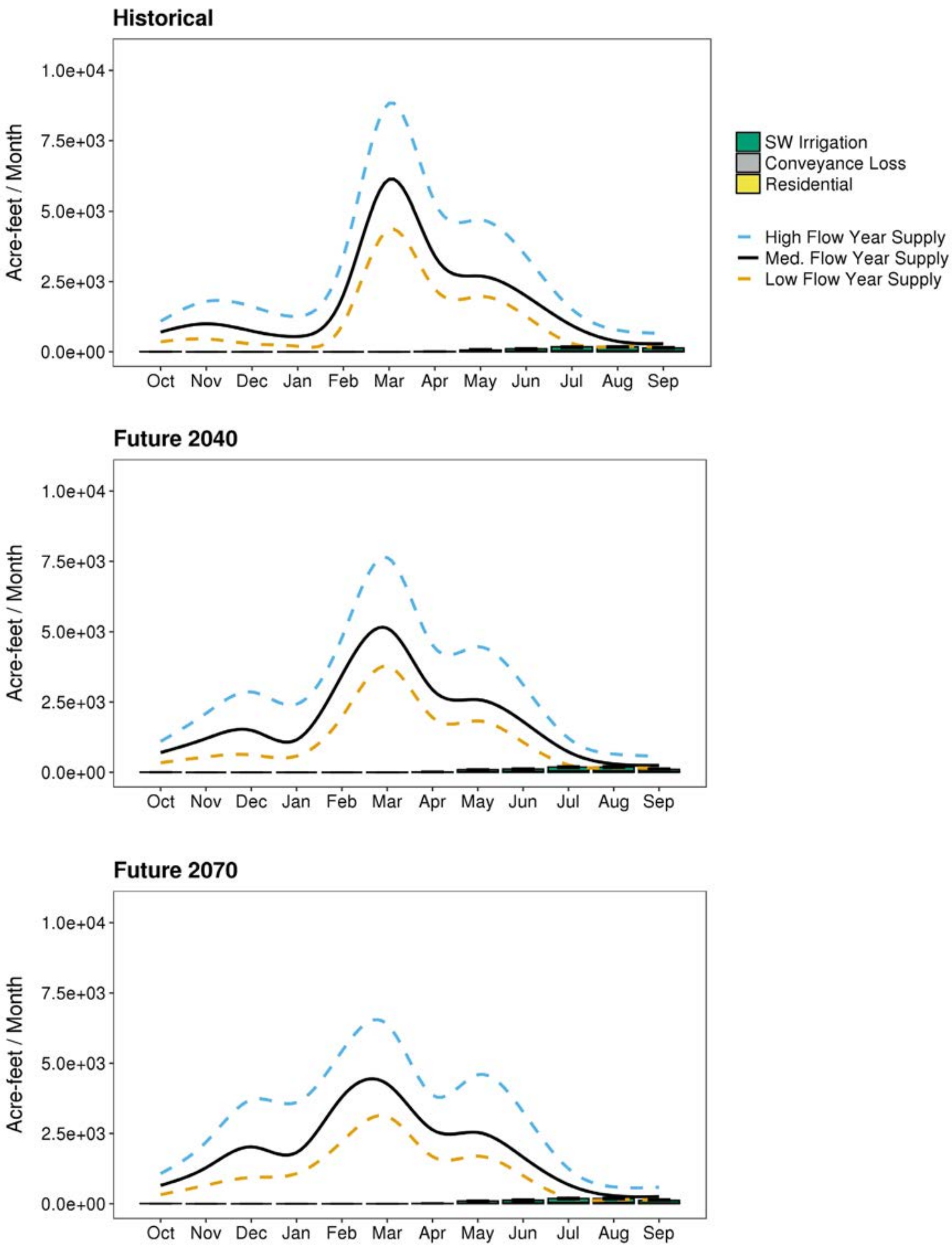
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

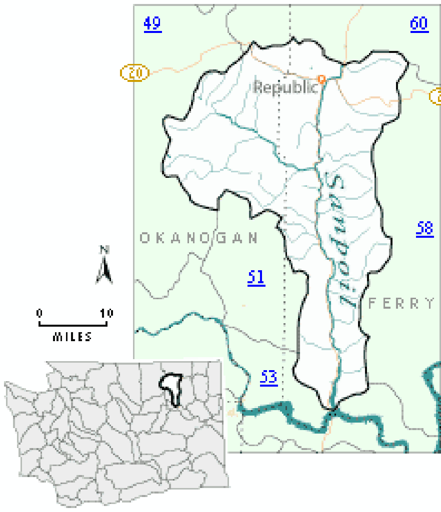
Bar 3
- 2070s Climate

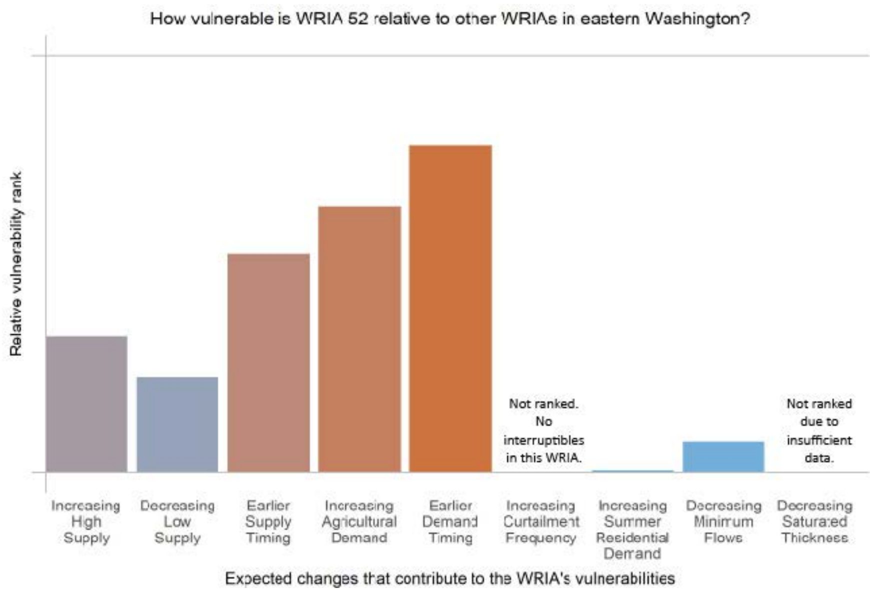
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

SUMMARY





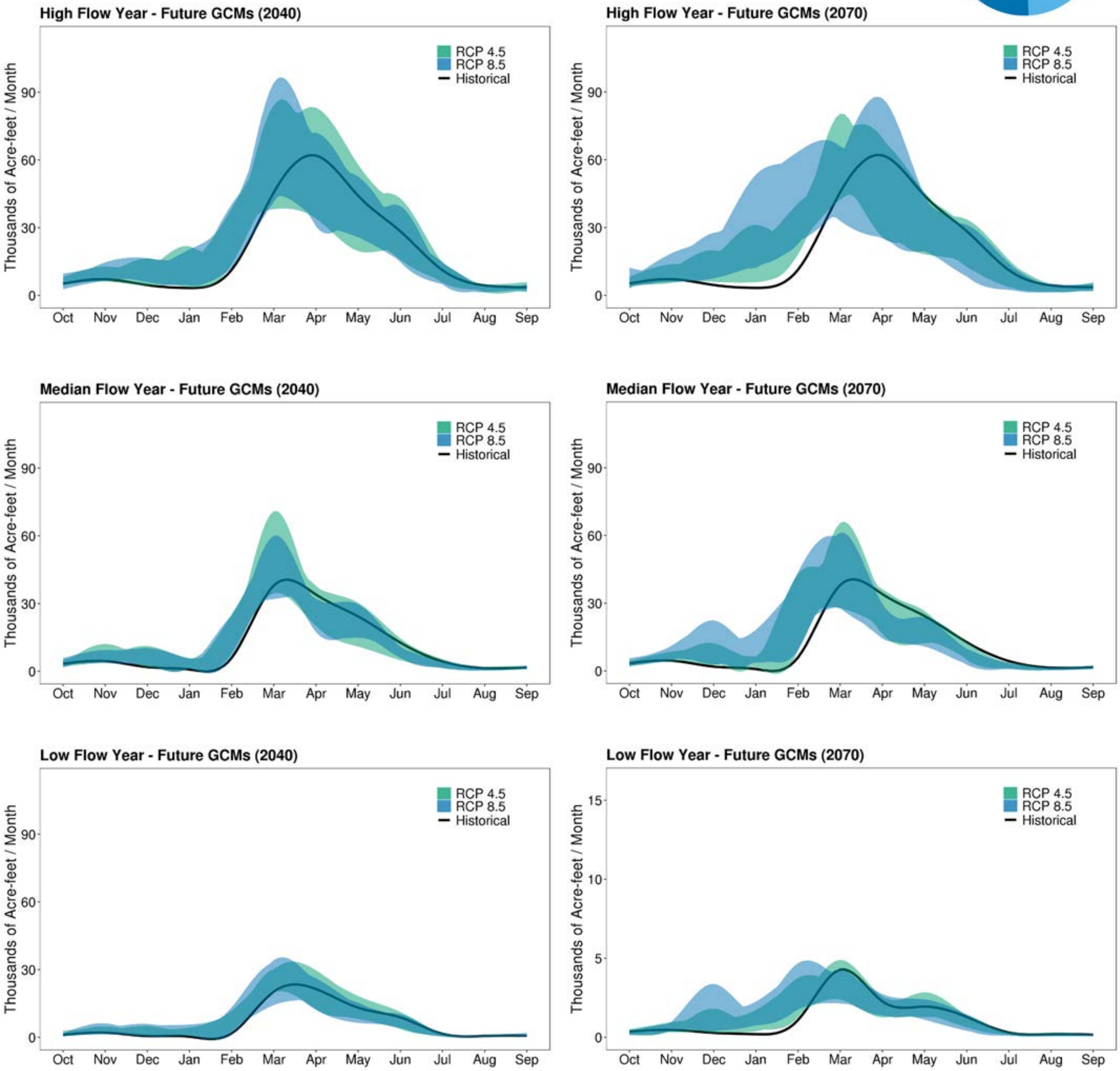
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 13 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 3 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 13 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 51% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 12% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is not expected to change by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 3.9 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 0.2 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	NONE

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

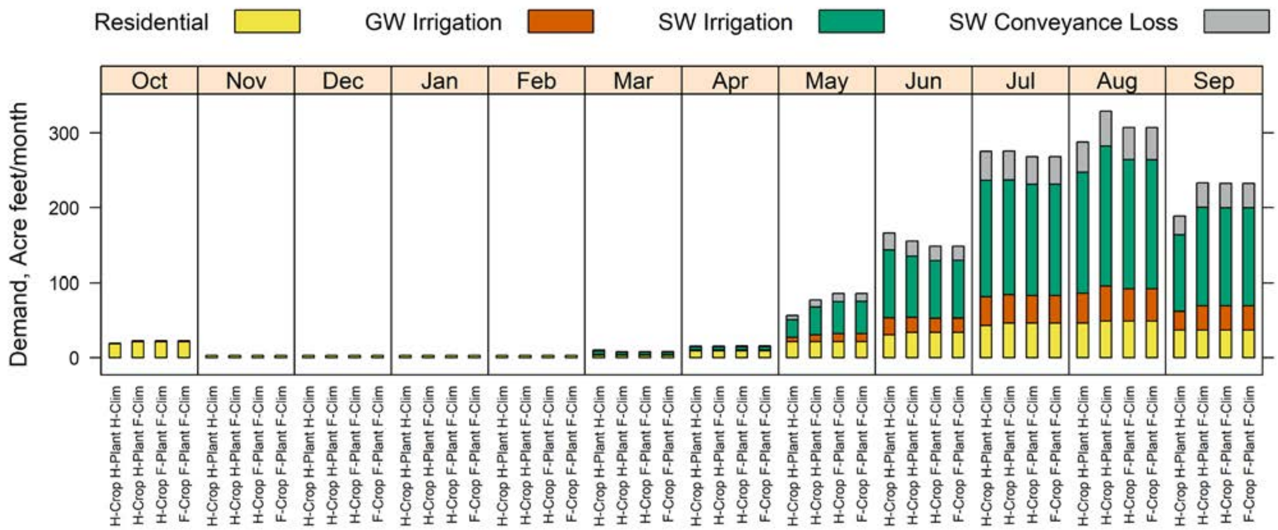
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

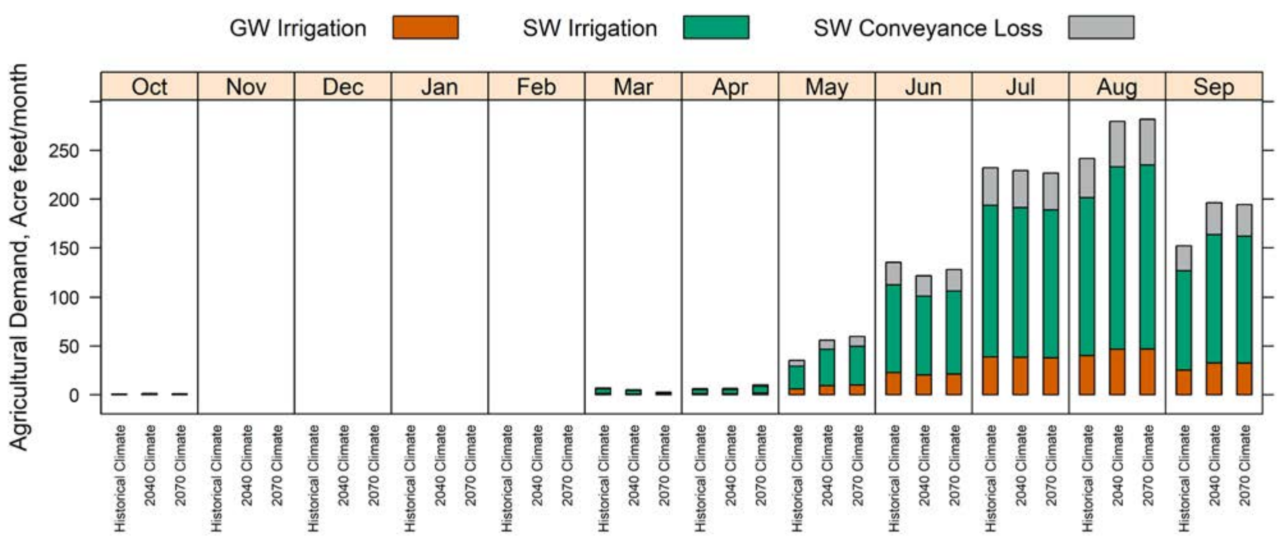
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

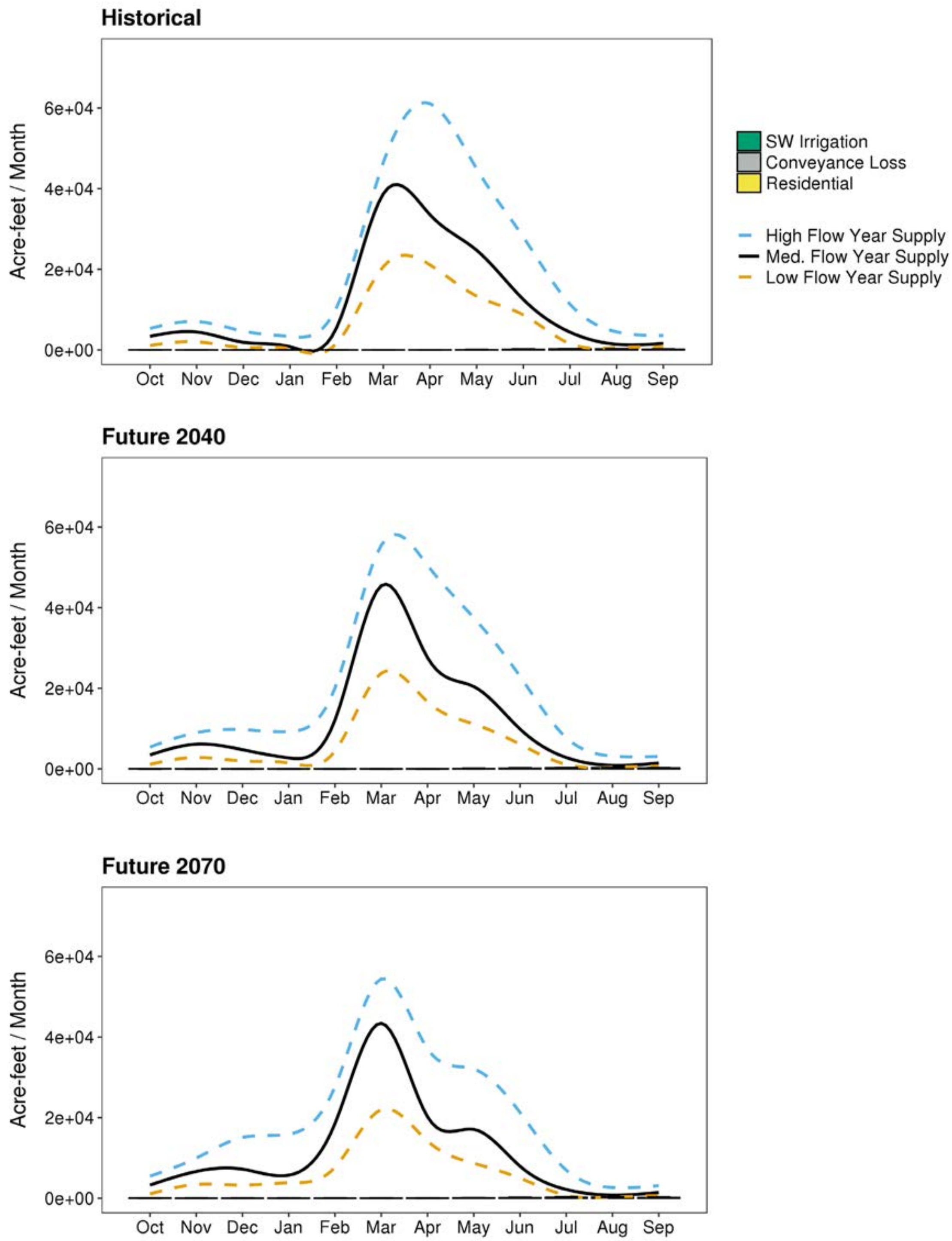
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

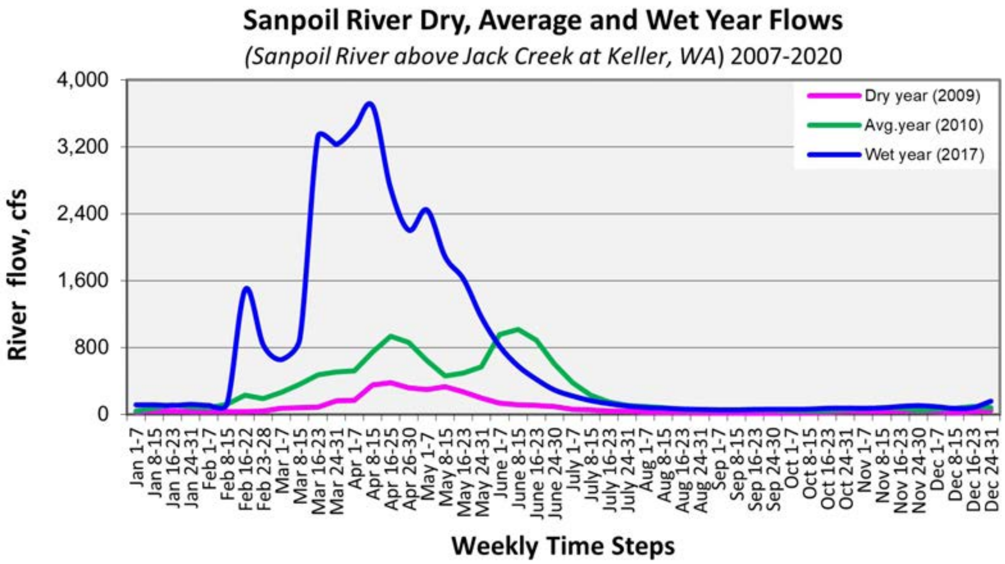
Bar 3
- 2070s Climate

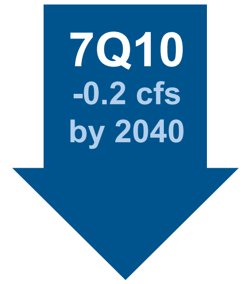
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

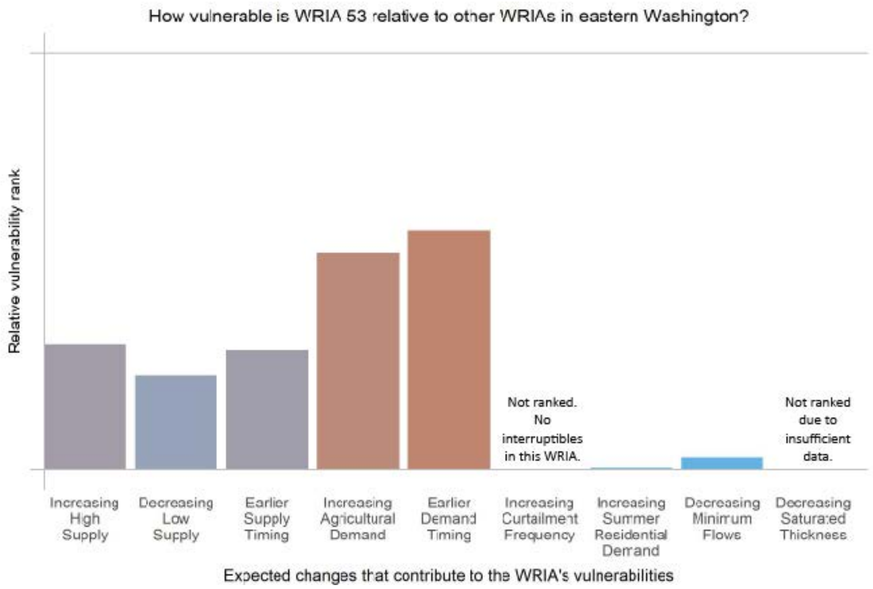


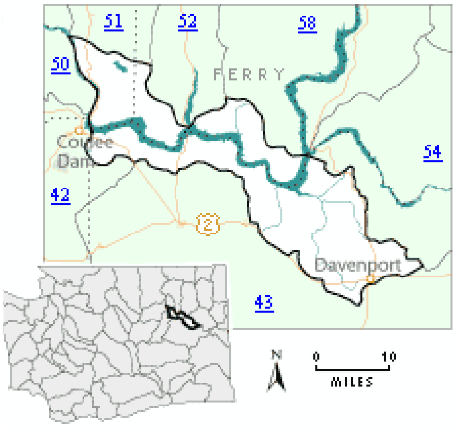


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





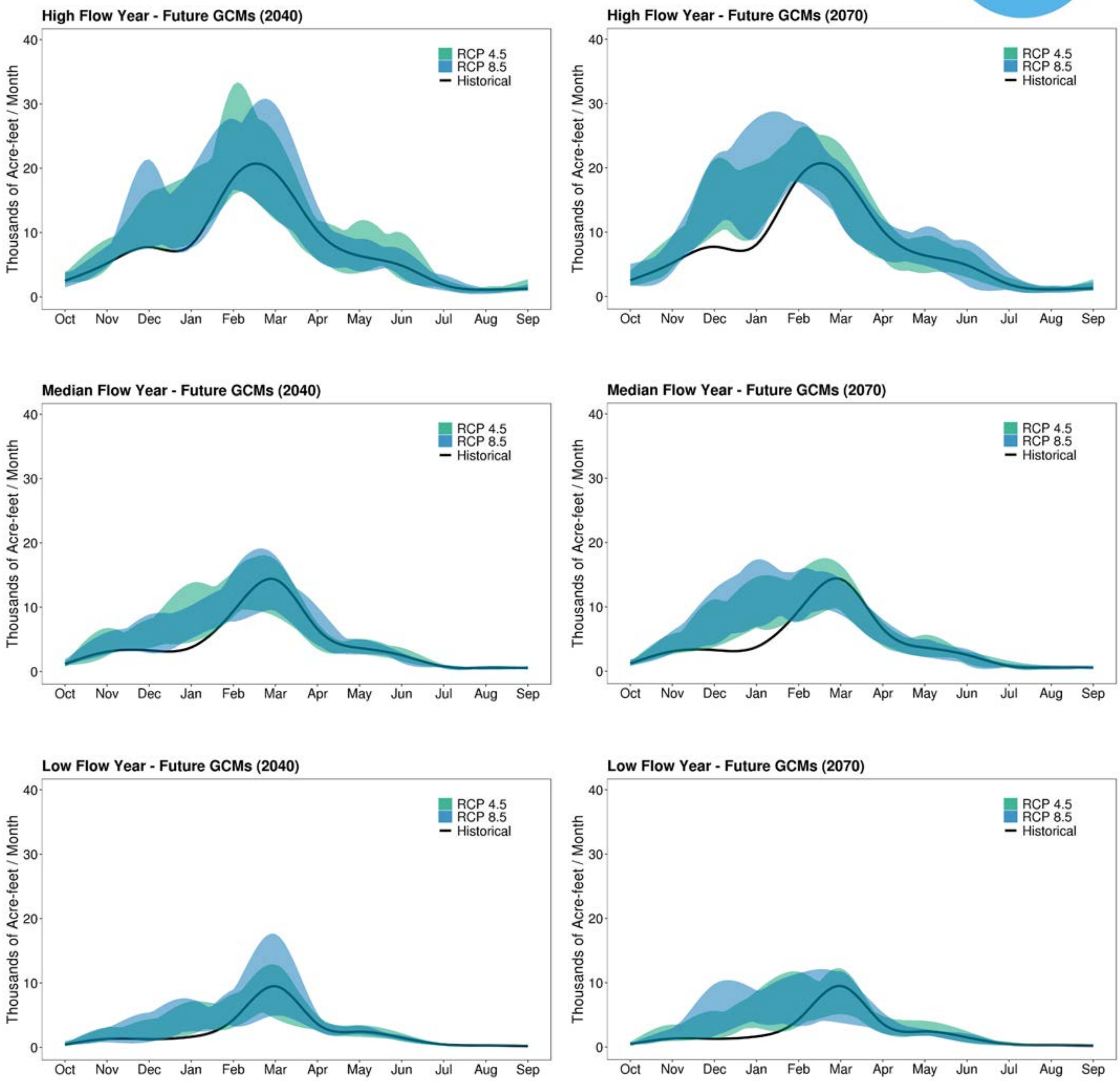
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 9 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 4 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 8 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 36% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 8% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 1.7 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.6 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	Phase 2 (Assessment)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout
Groundwater Subareas Overlapped by WRIA	NONE

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

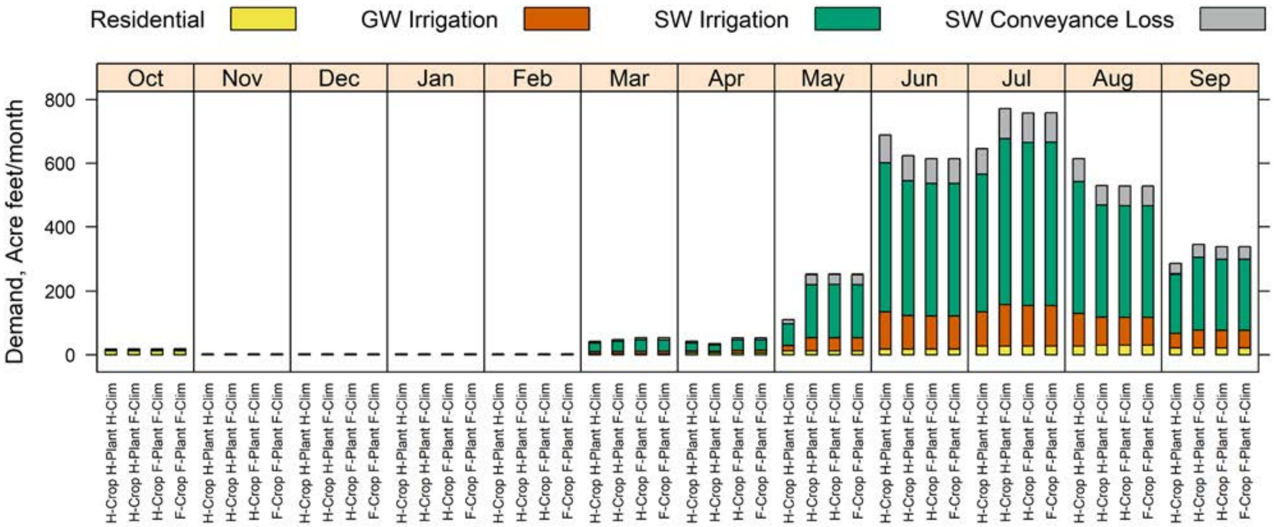
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

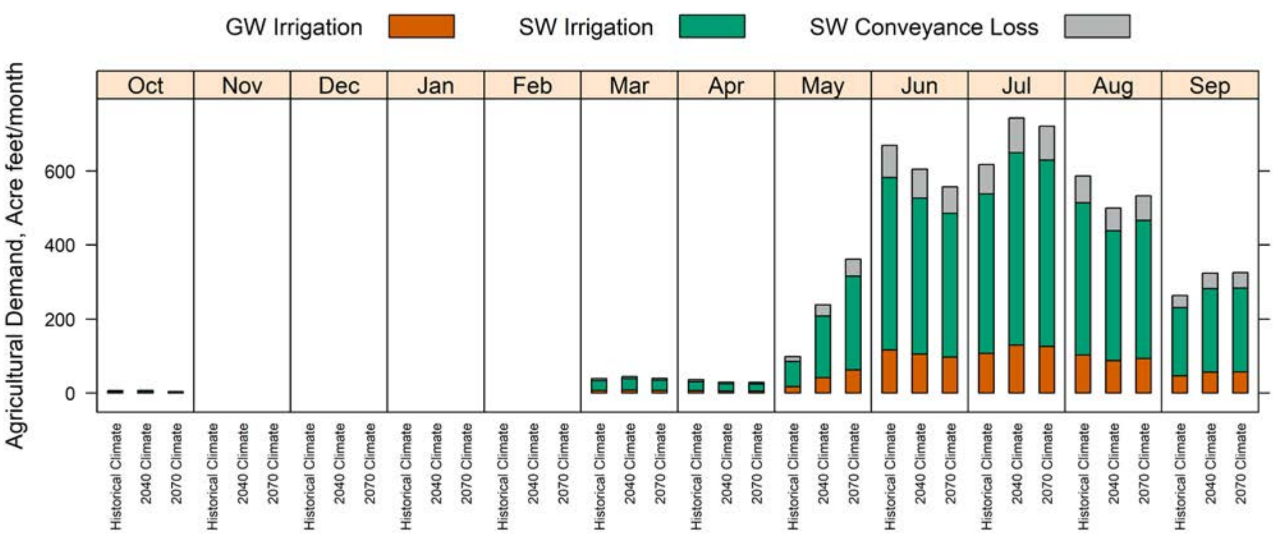
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

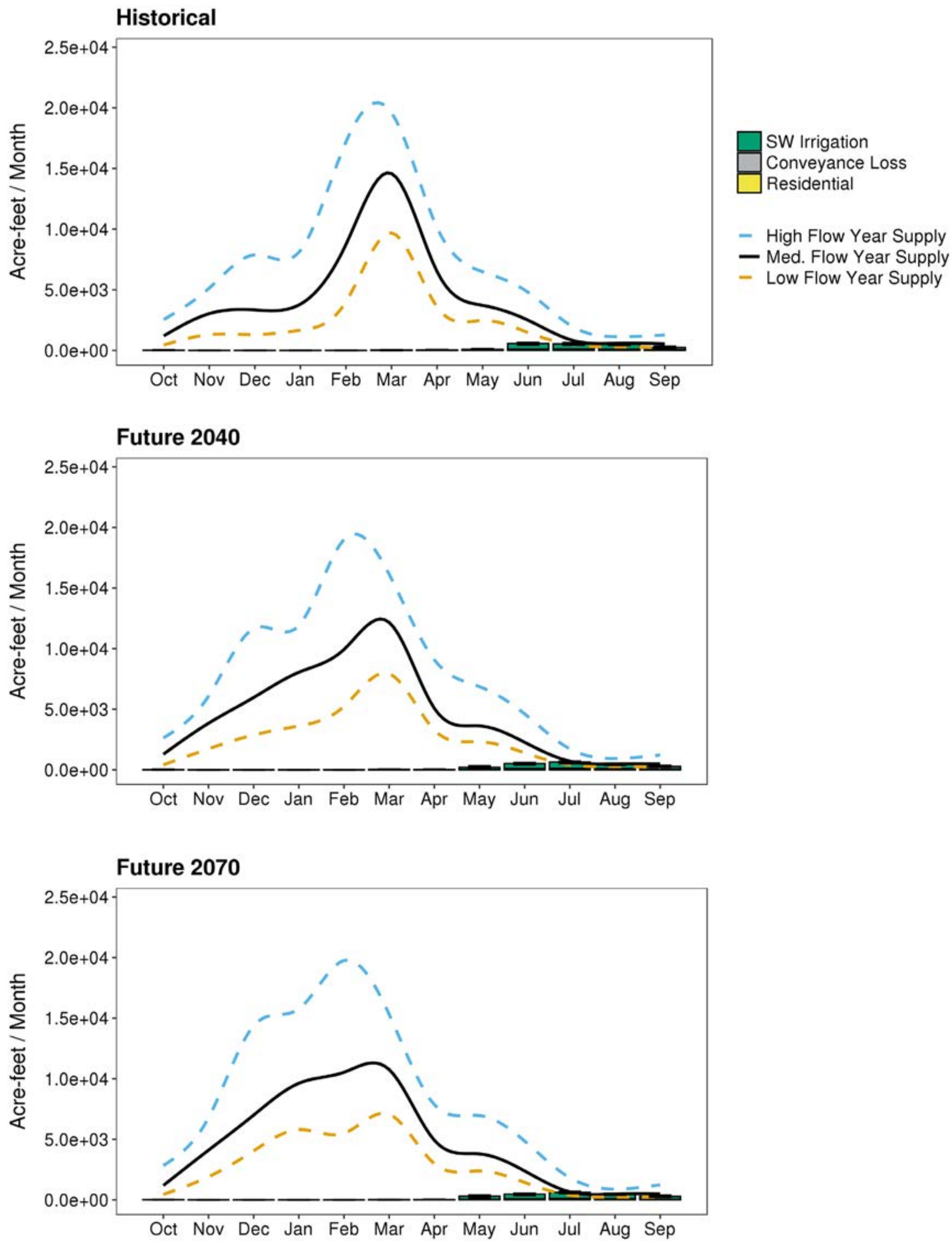
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

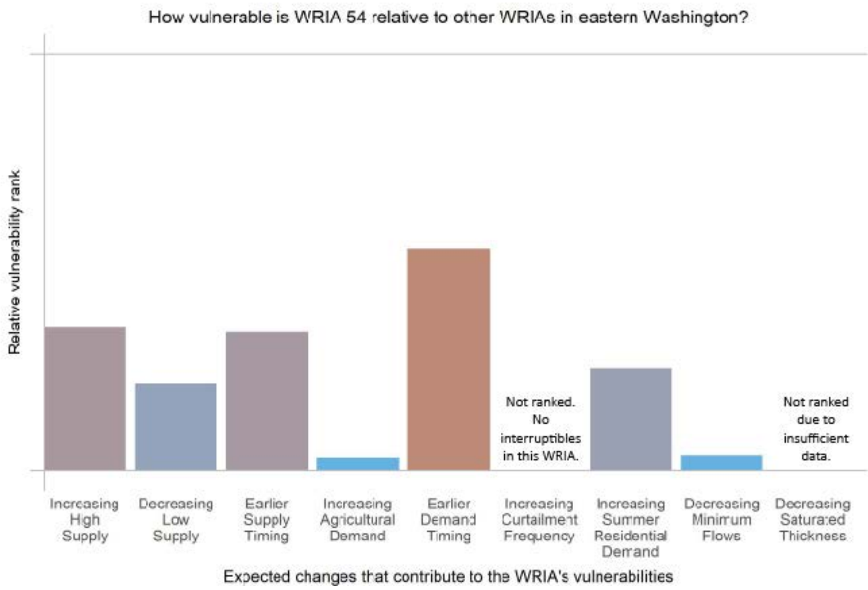
Bar 3
- 2070s Climate

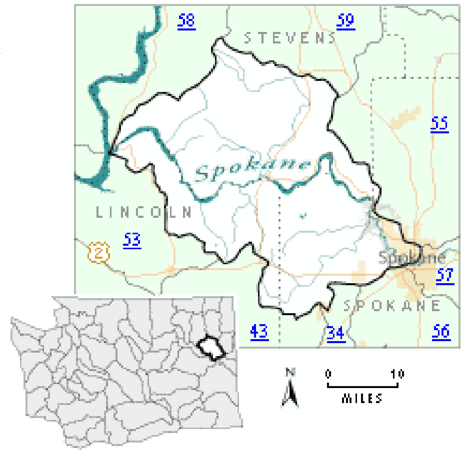
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

SUMMARY





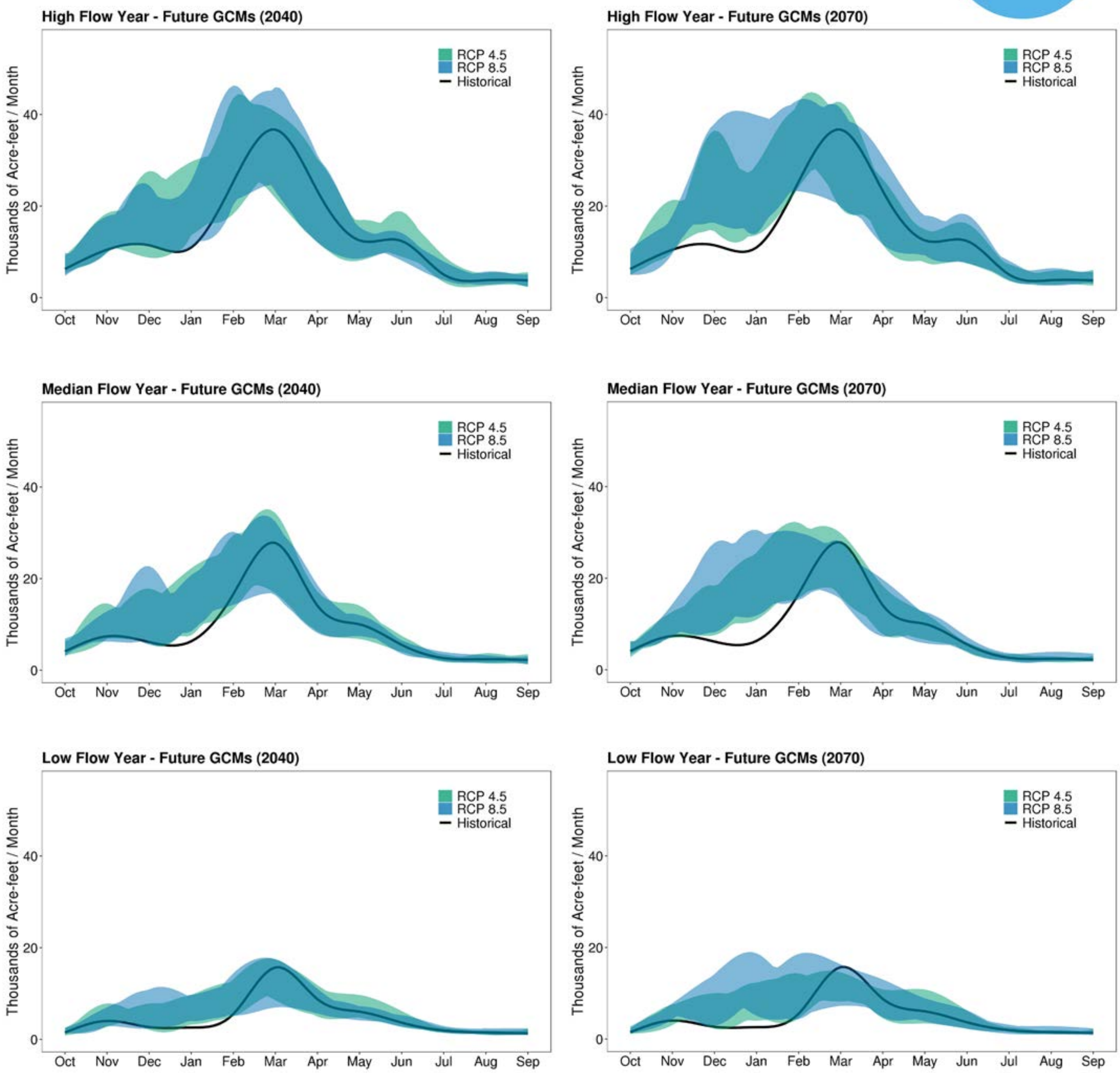
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 16 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 7 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 9 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 37% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to decrease by 5% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 744 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.5 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	YES (Chapter 173-557 WAC)
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	Spokane

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

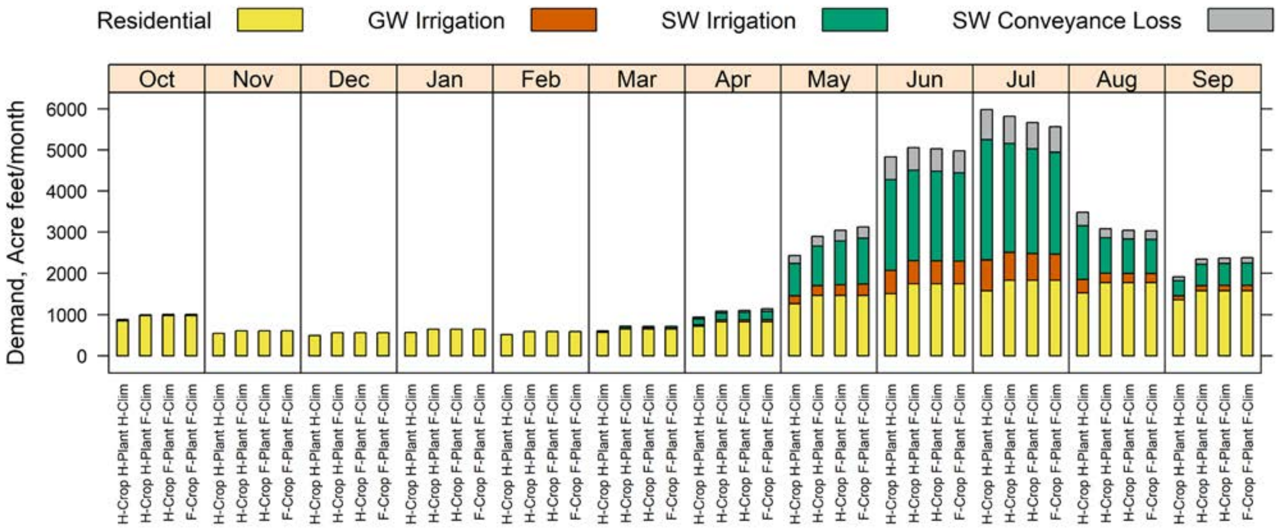
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

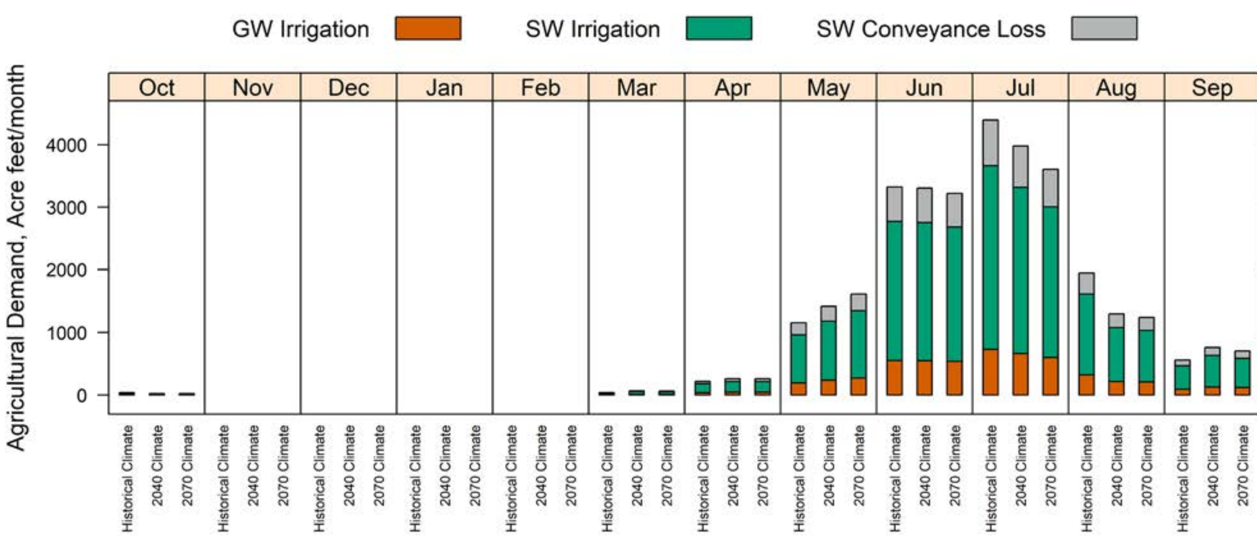
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

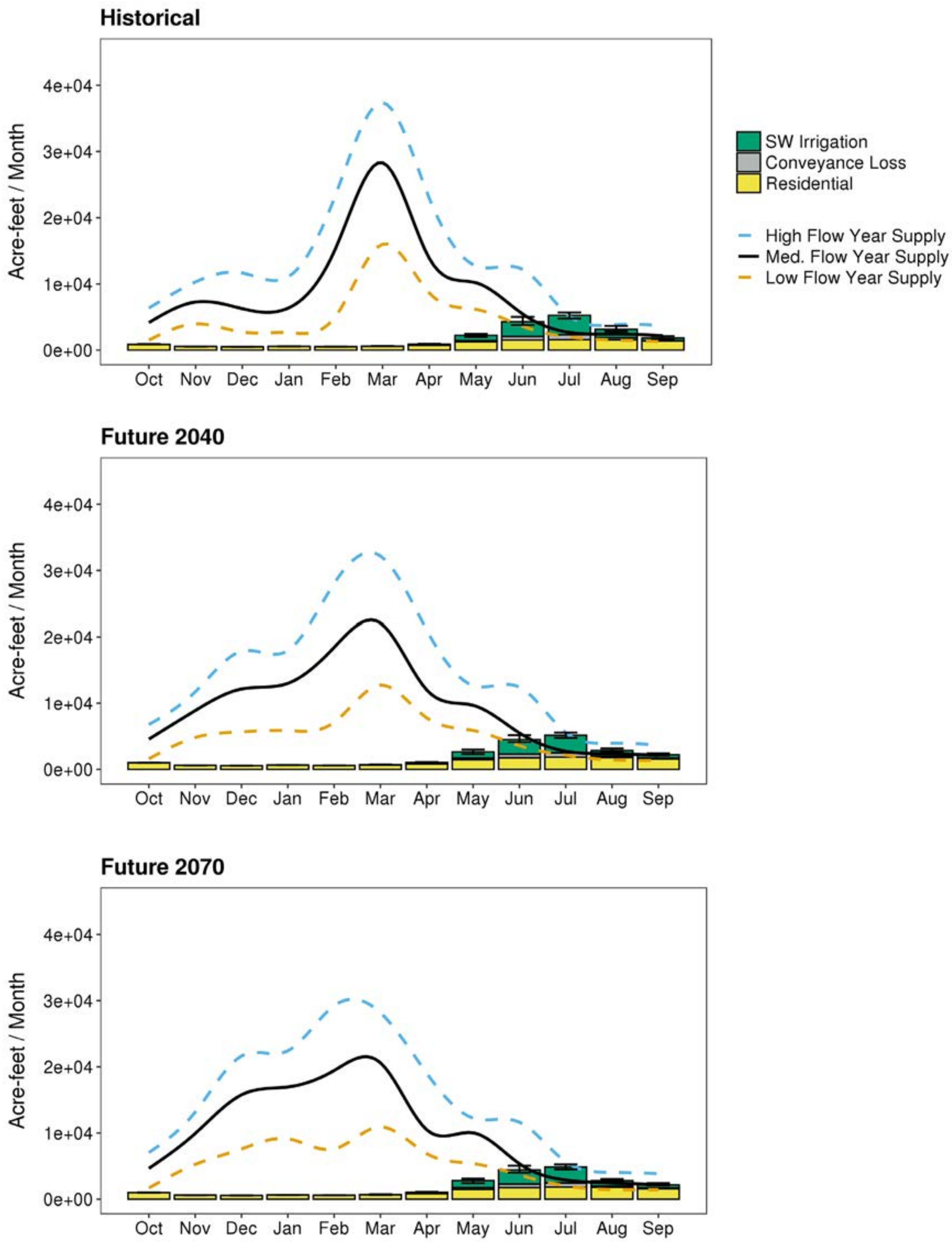
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

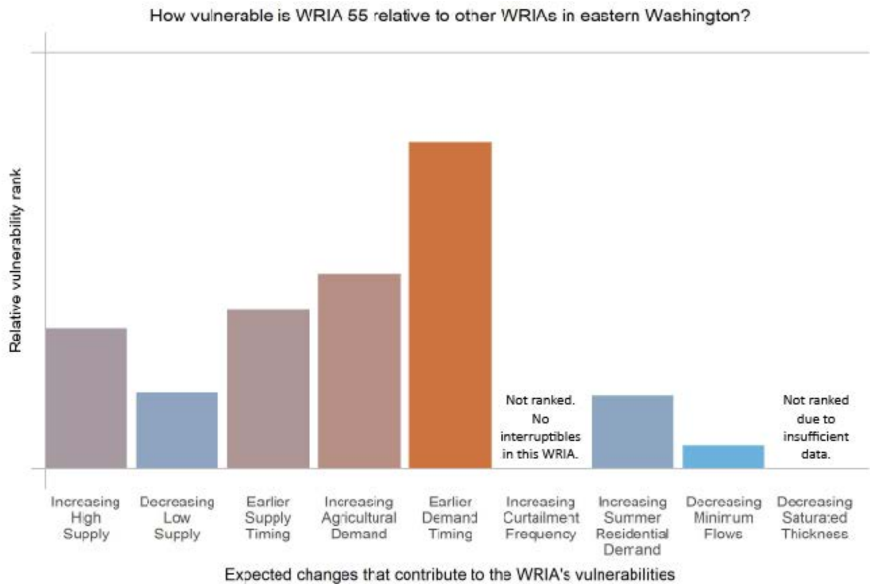
Bar 3
- 2070s Climate

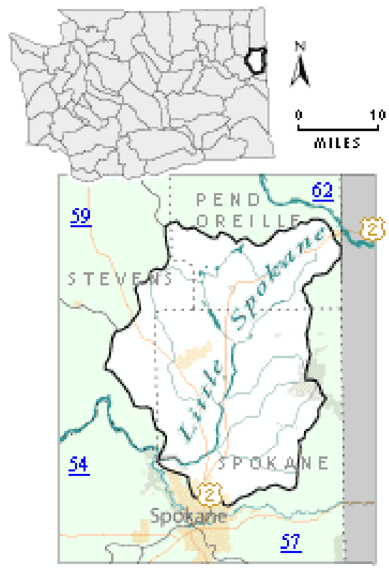
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

SUMMARY





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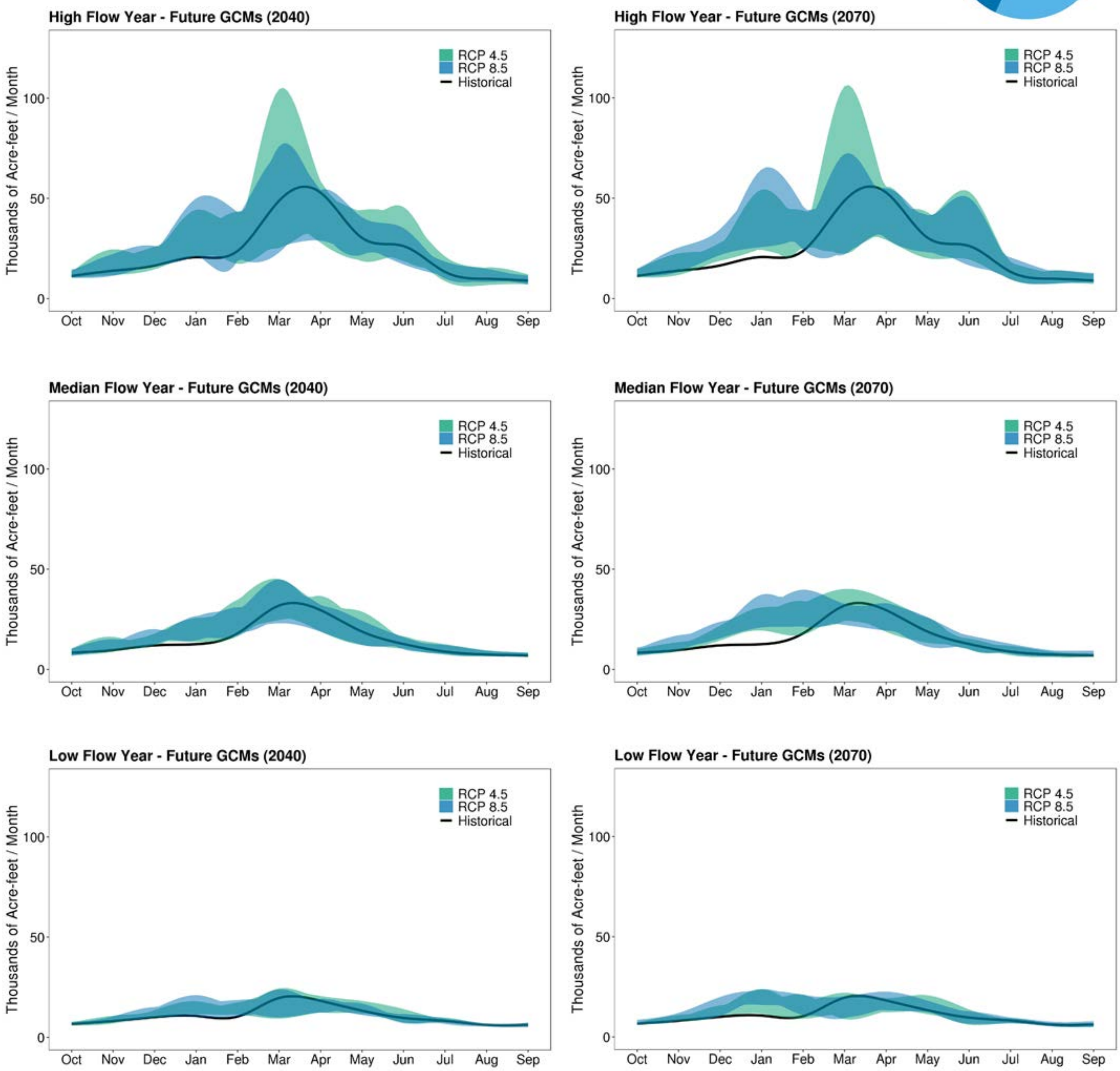
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 15 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 11 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 10 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 43% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 7% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is not expected to change by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 527 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.2 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Deadman Creek, Bigelow Gulch Creek
Watershed Planning	Watershed plan addendum adopted on January 28, 2021
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[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	Spokane, Little Spokane

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

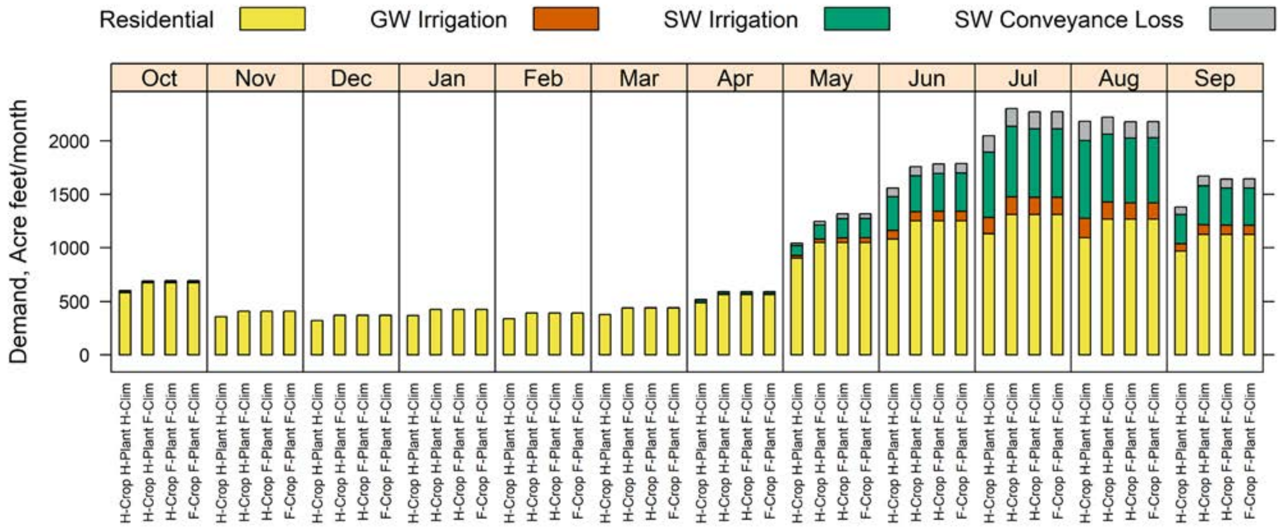
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) “H-Crop H-Plant H-Clim”, b) ”H-Crop H-Plant F-Clim”, c)“H-Crop F-Plant F-Clim”, and d) ”F-Crop F-Plant F-Clim” where “H-Crop” represents historical crop mix; “F-Crop” as future crop mix; “H-Plant” represents historical planting date, “F-Plant” represents moving planting date forward one week; ”H-Clim” as historical climate and “F-Clim” values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

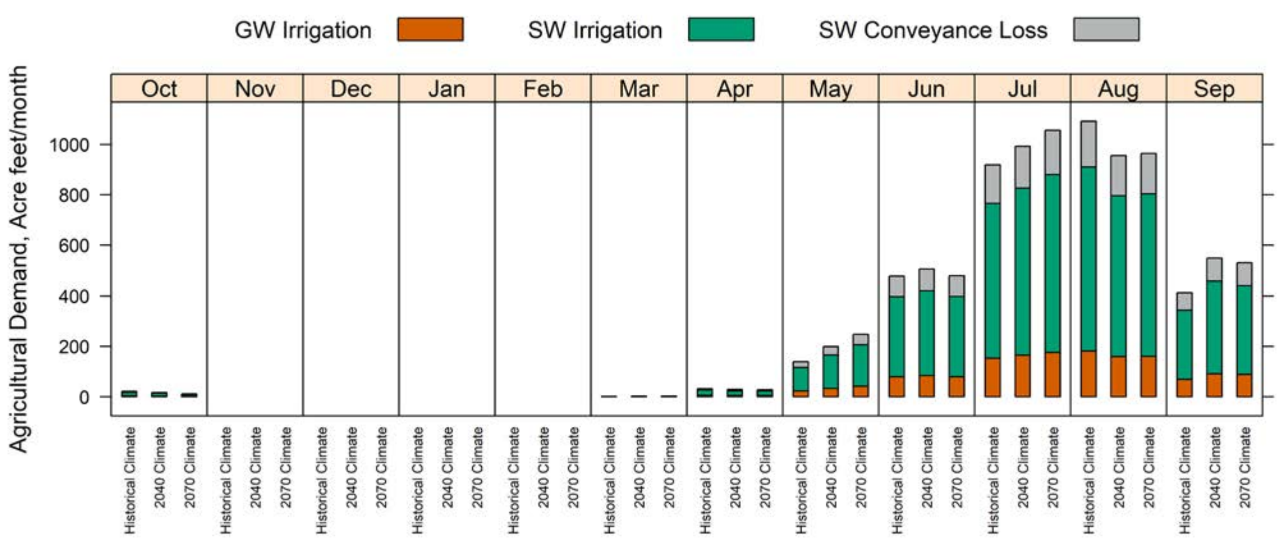
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

Each month has three bars that represent a different scenario:

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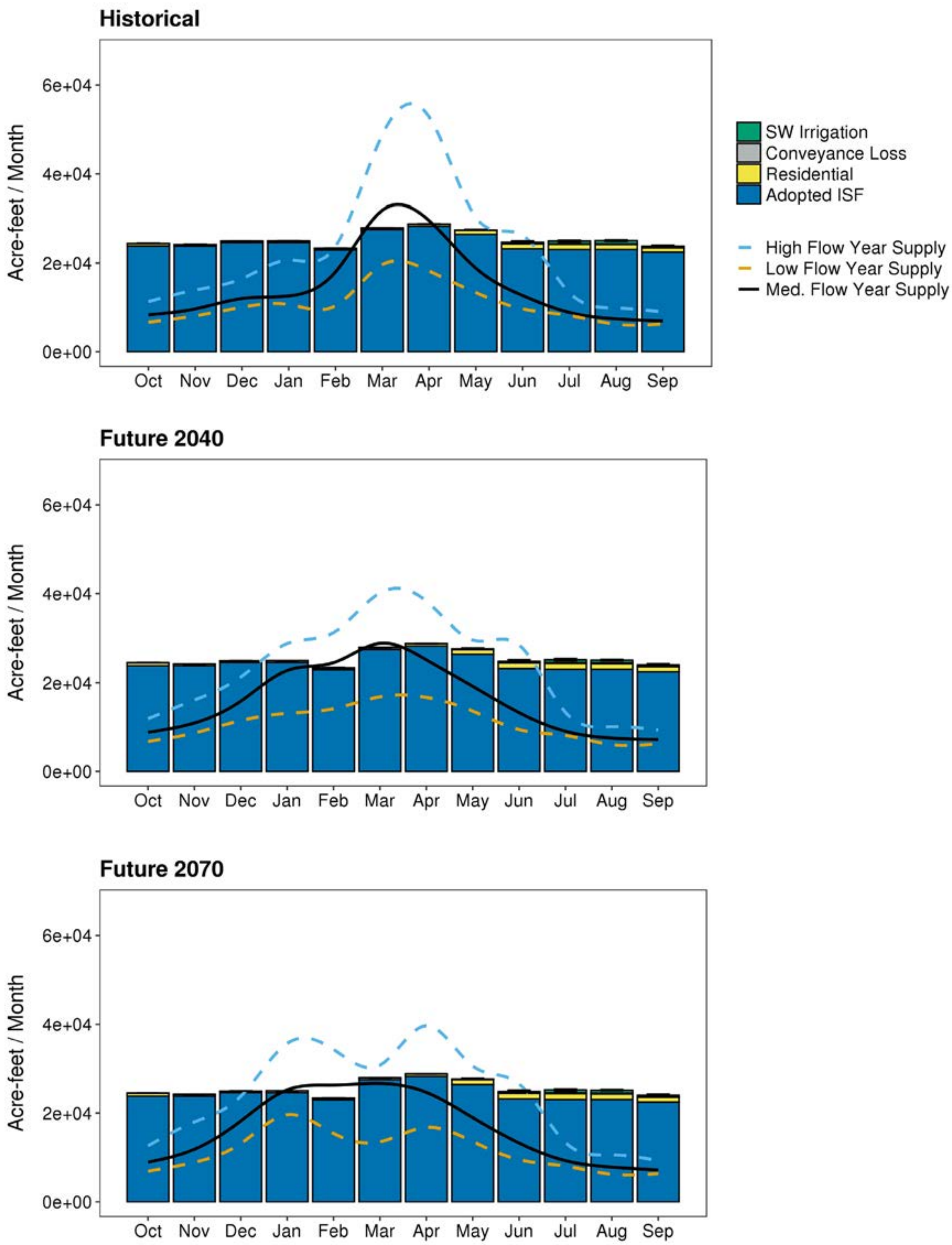
Bar 2
- 2040s Climate

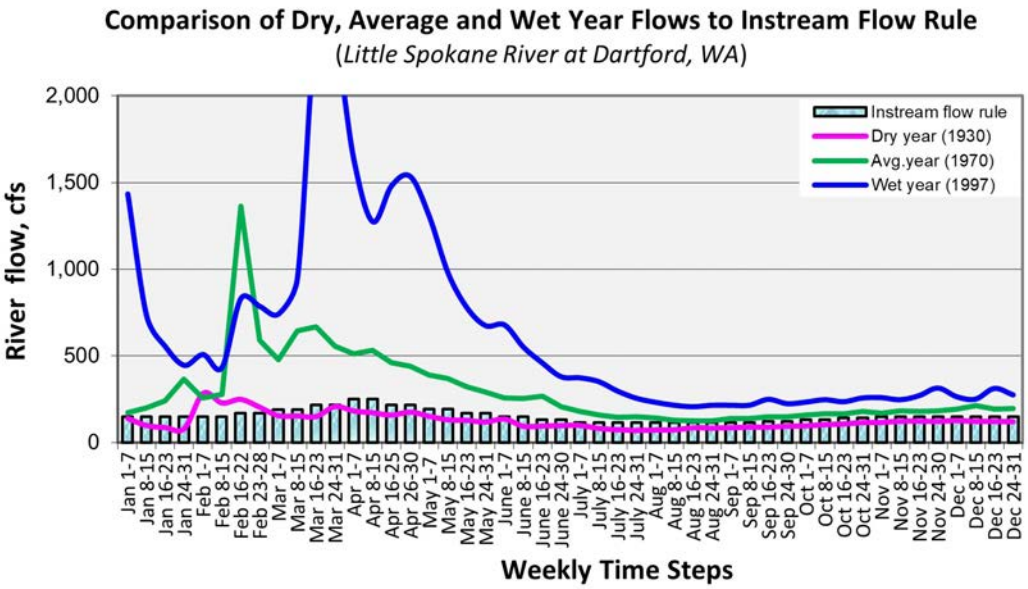
Bar 3
- 2070s Climate

SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

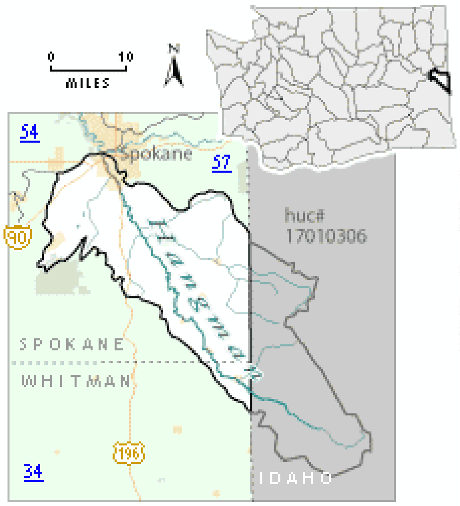
CONSIDERATIONS FOR FISH

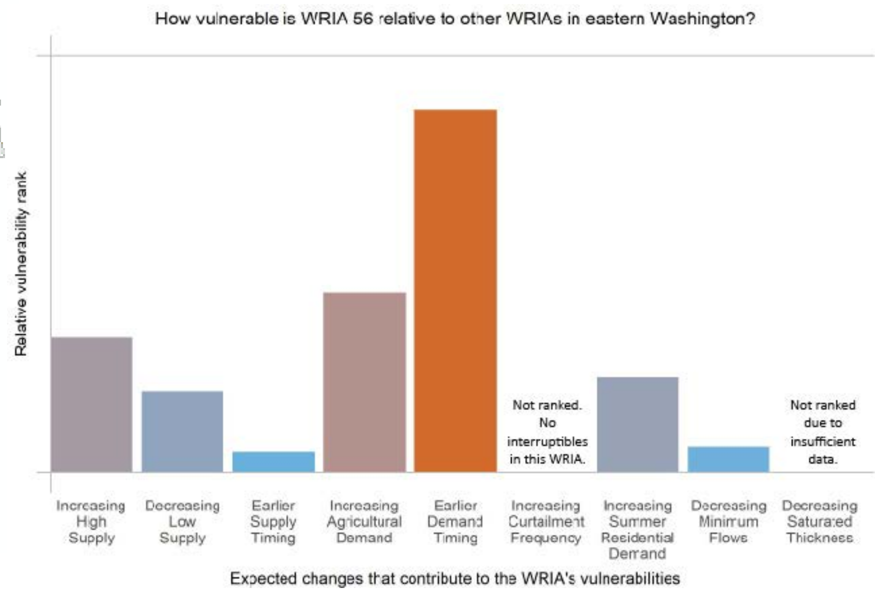


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





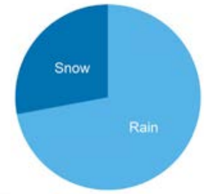
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

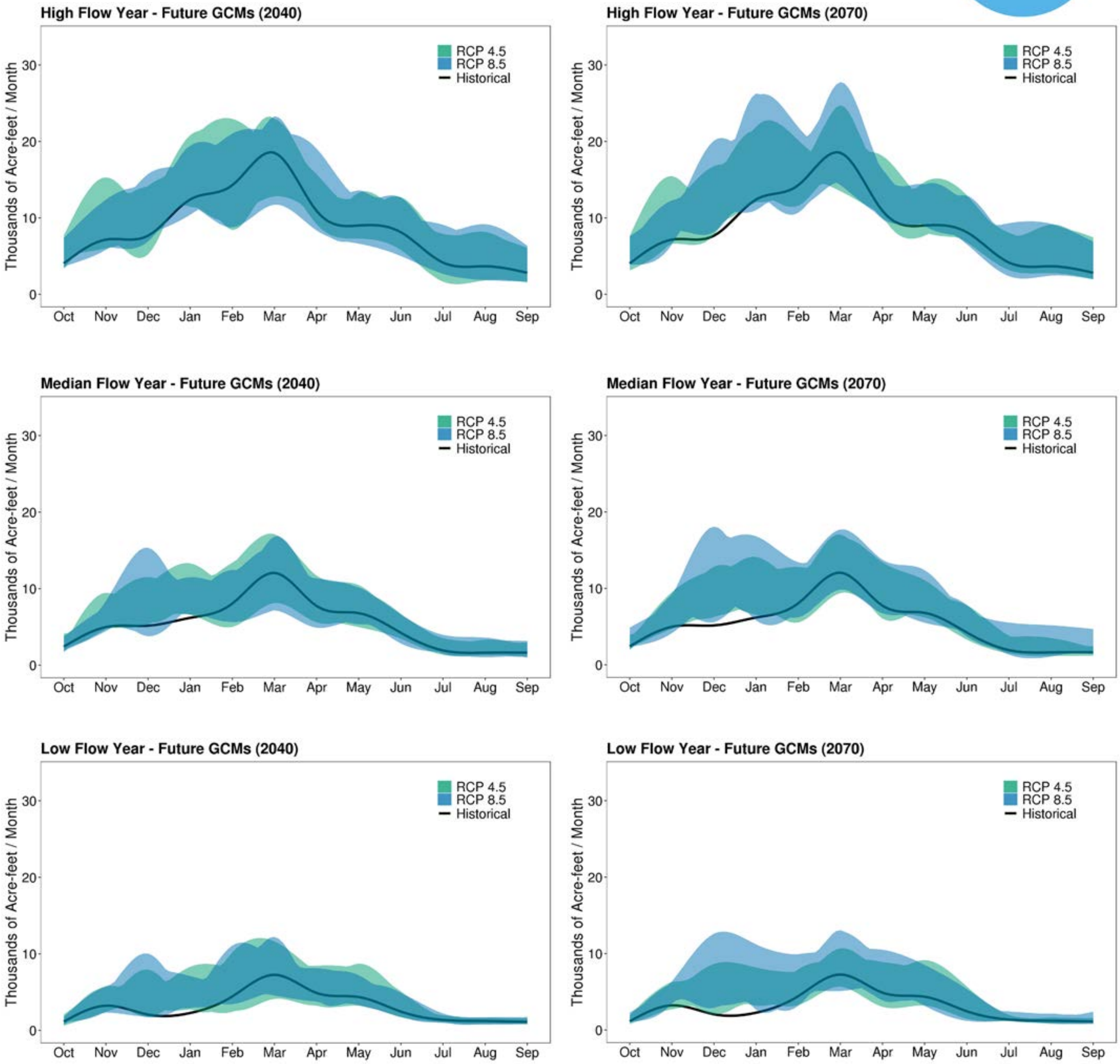
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 13 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 9 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 3 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 28% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand**: Agricultural demand is projected to increase by 6% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day later by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 691 ac-ft by 2040.
- **Decreasing Minimum Flows**: The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.1 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Crystal Springs
Watershed Planning	Phase 4 (Implementation)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	No ESA-listed fish spawn or rear in WRIA waters
Groundwater Subareas Overlapped by WRIA	NONE

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

SUPPLY

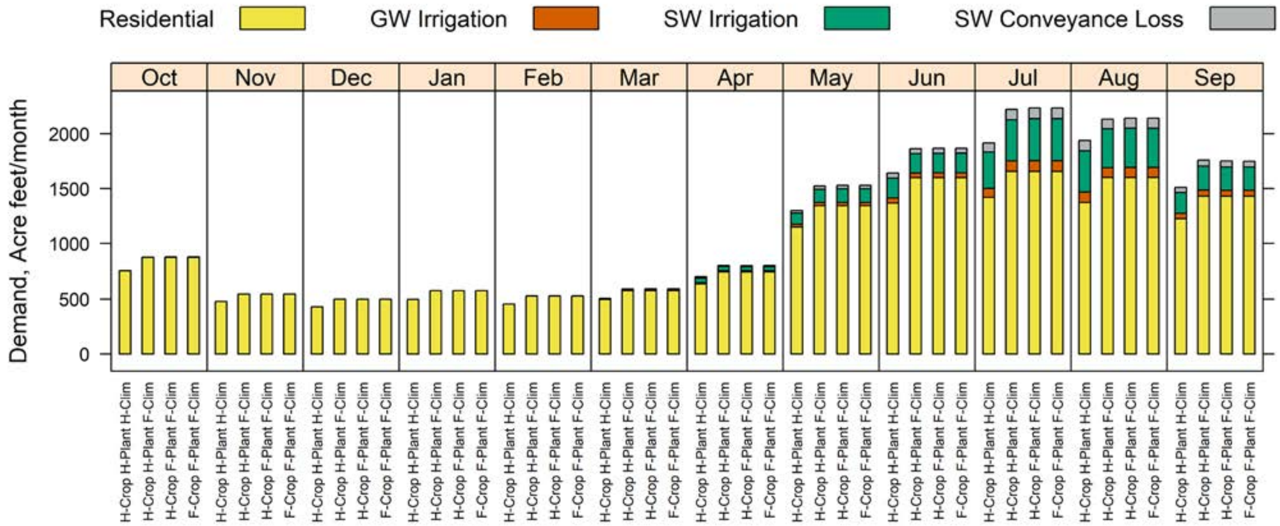




Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

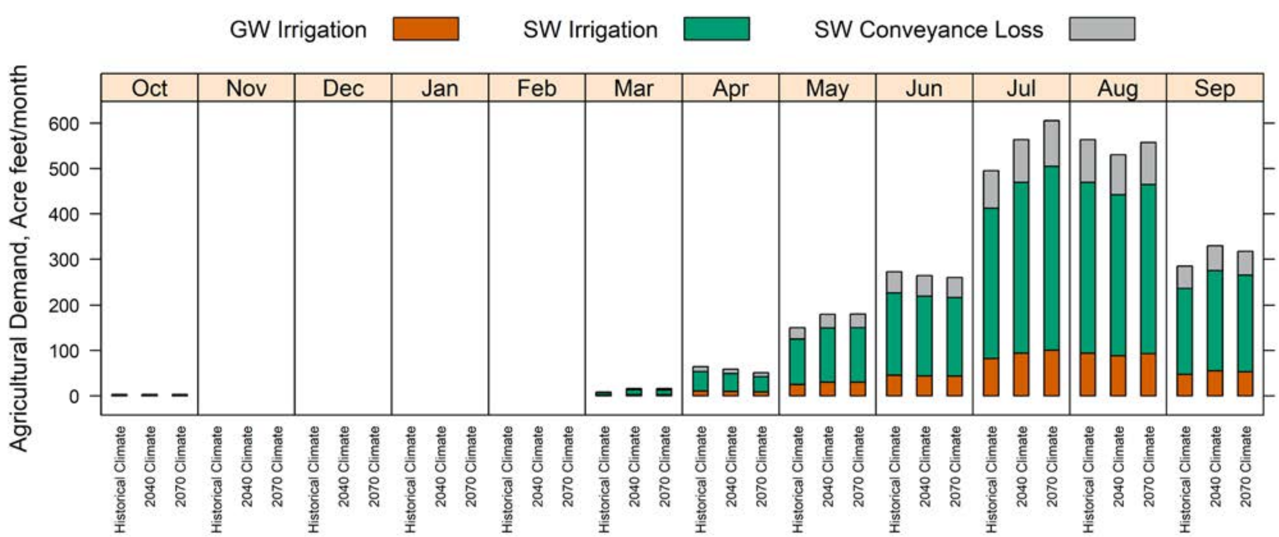
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

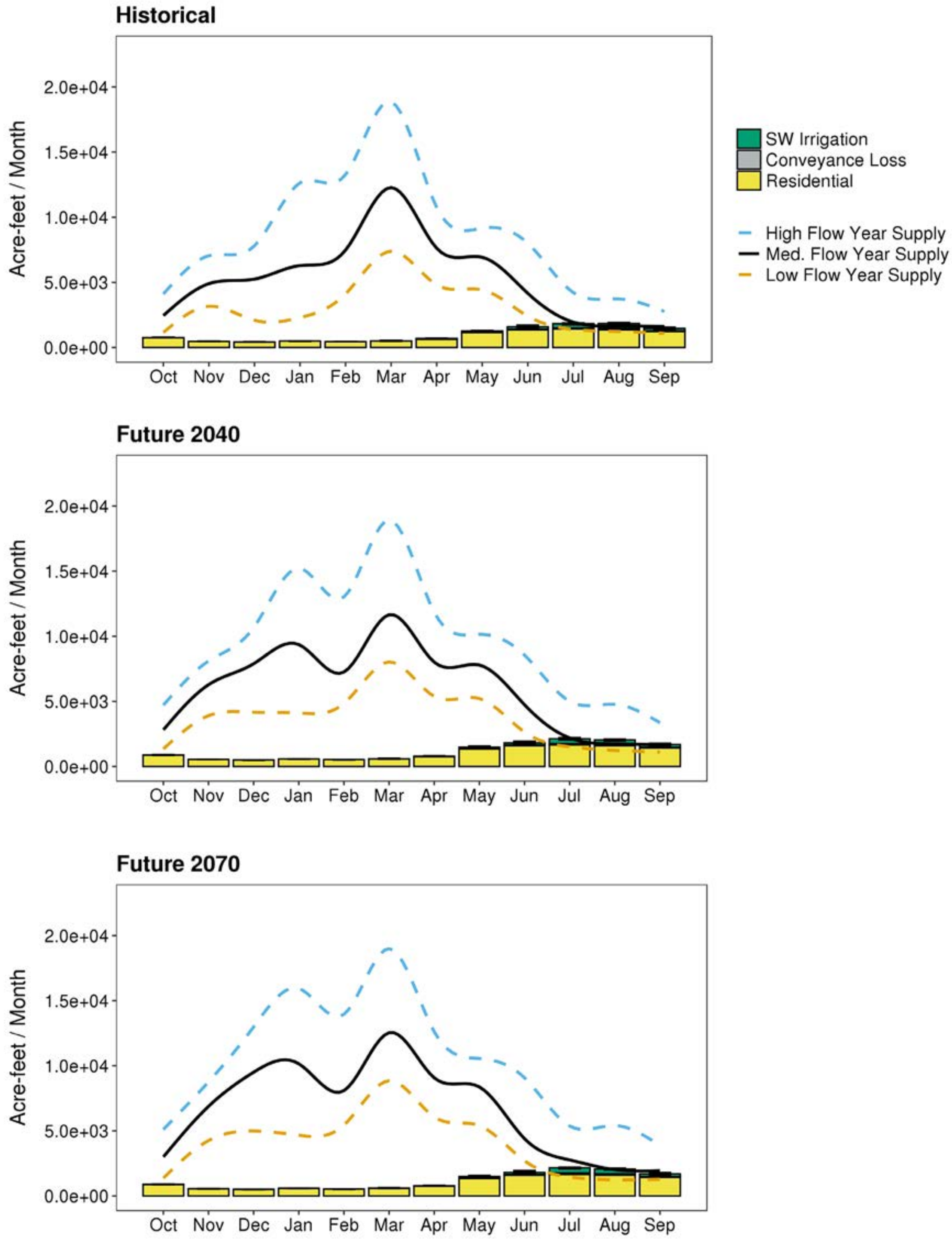
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

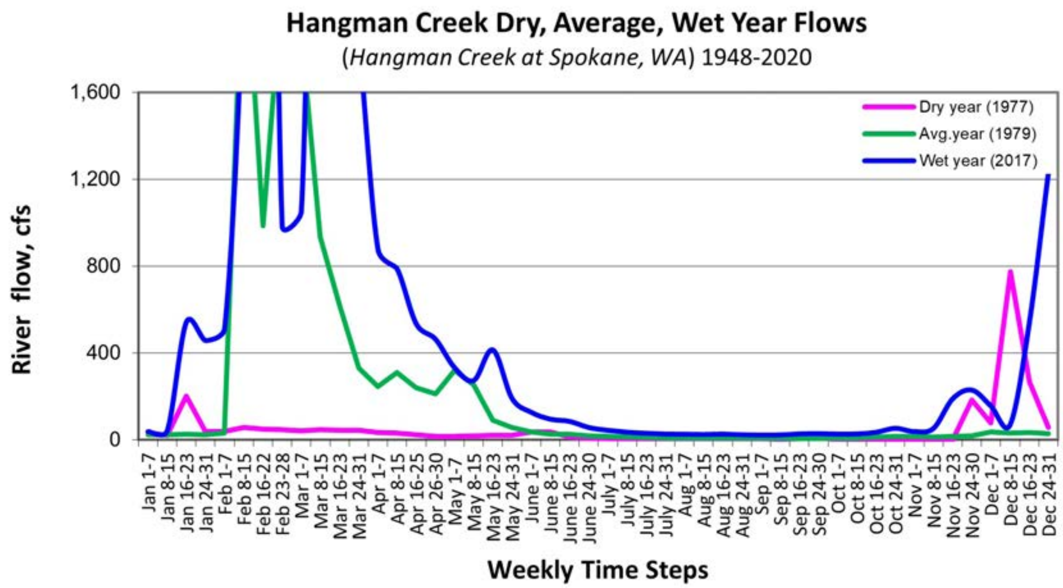
Bar 3
- 2070s Climate

SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

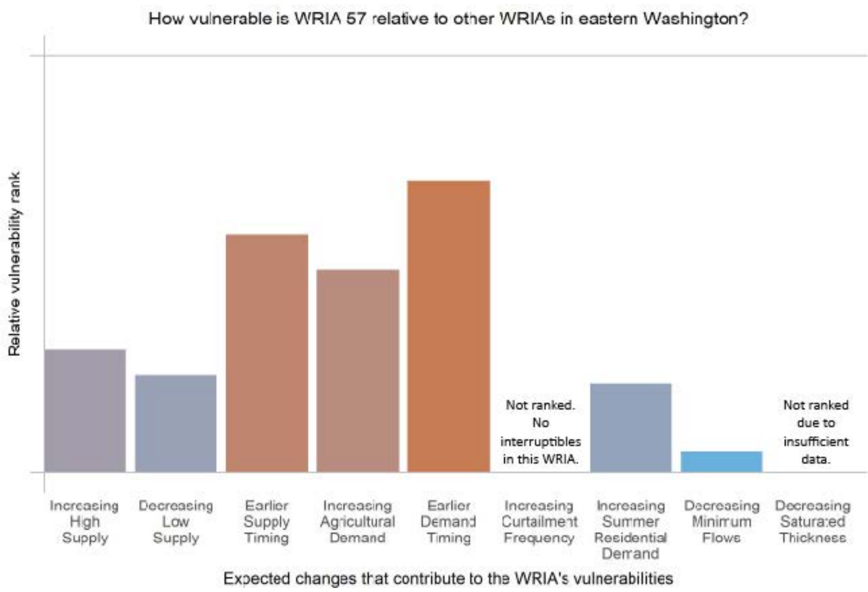
CONSIDERATIONS FOR FISH

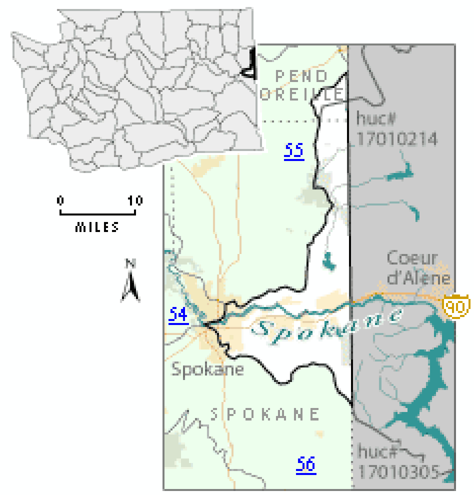


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





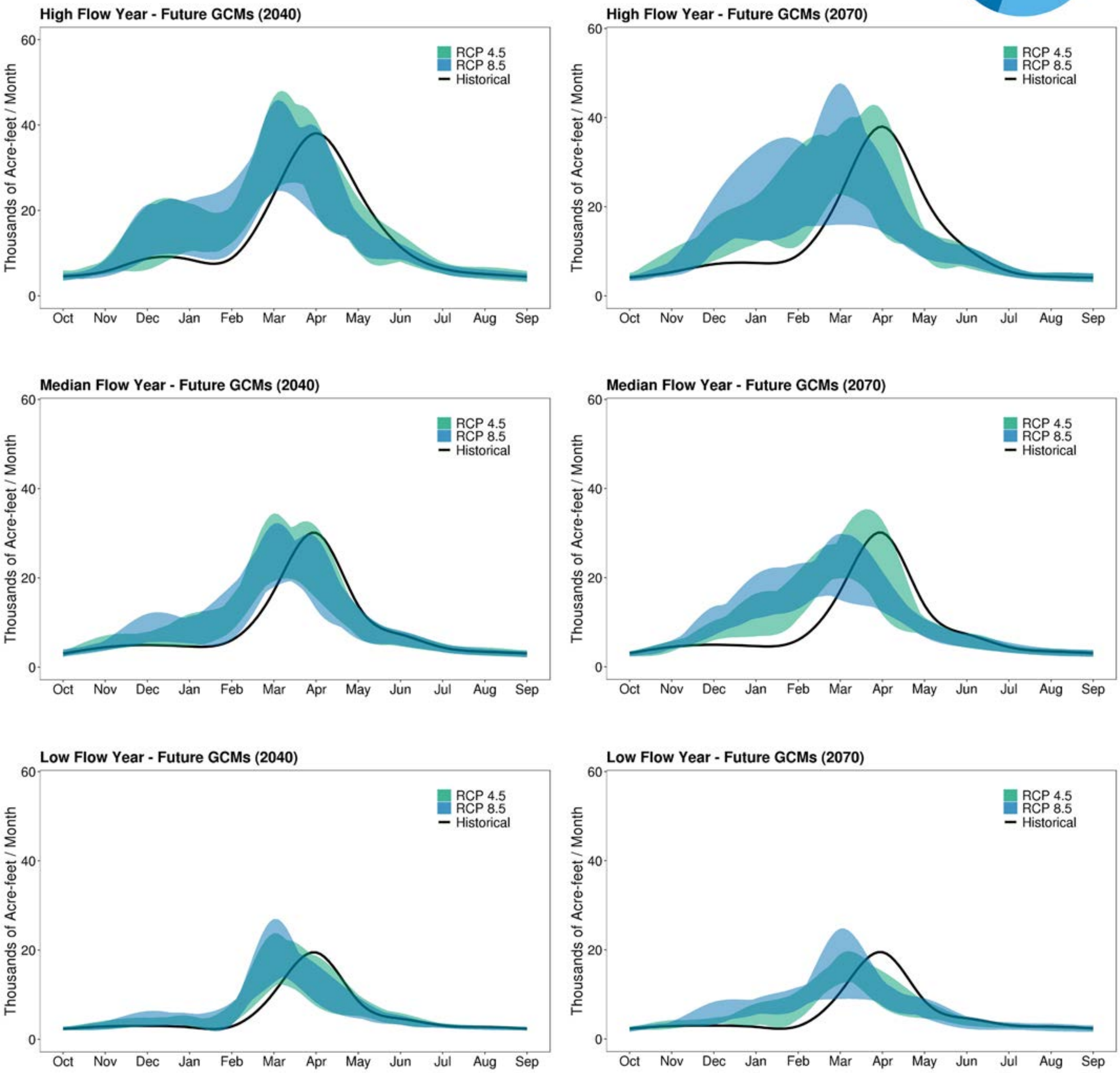
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 8 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 2 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 14 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 45% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 7% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 639 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to increase by 0.3 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
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[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	Spokane

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

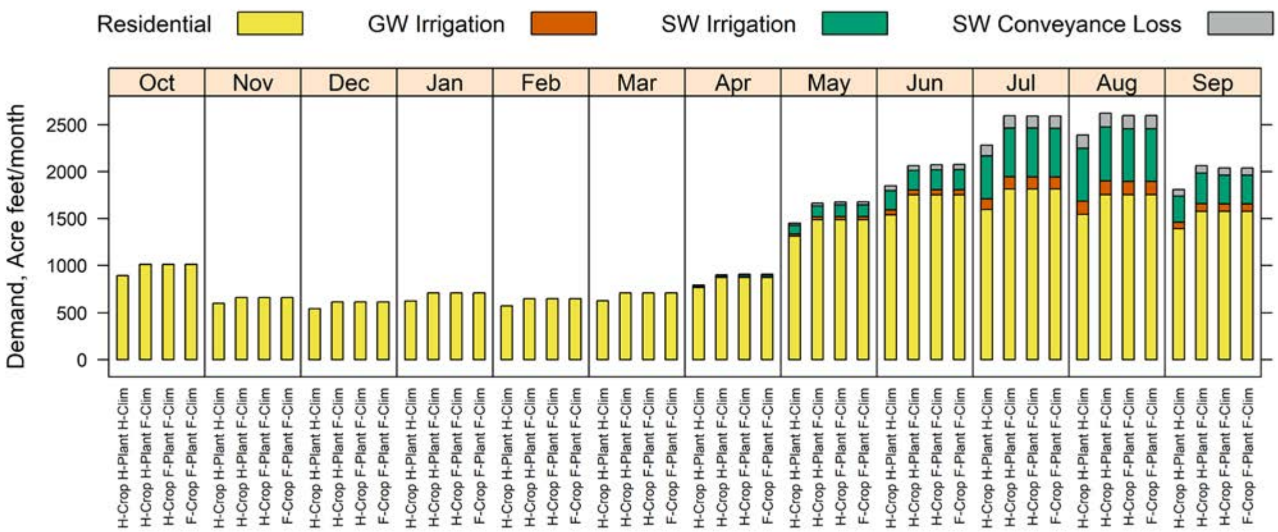
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

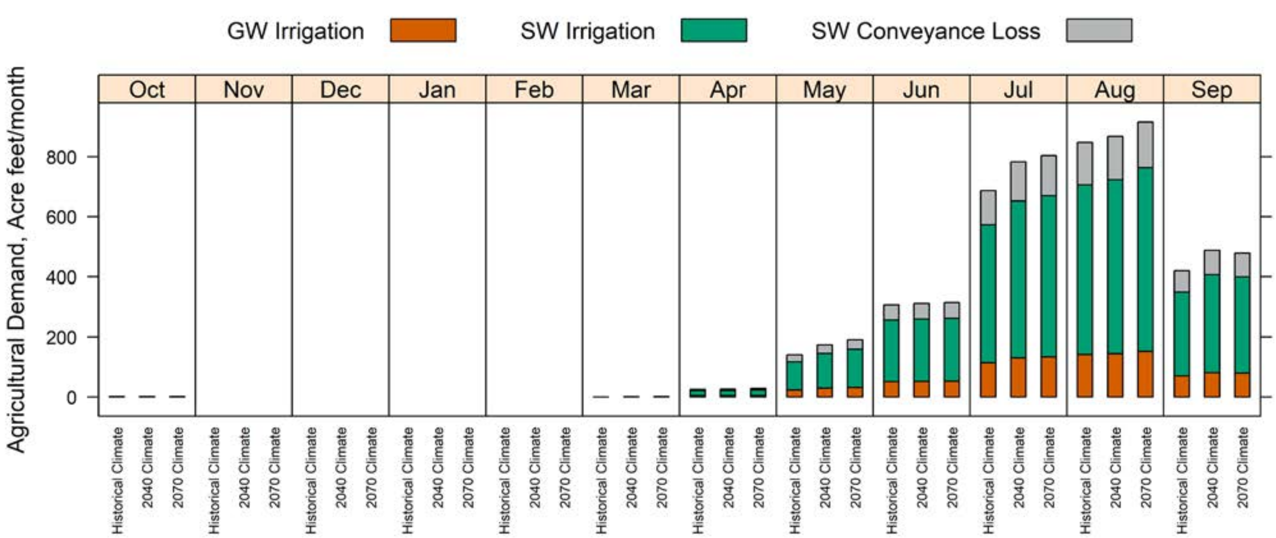
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

Each month has three bars that represent a different scenario:

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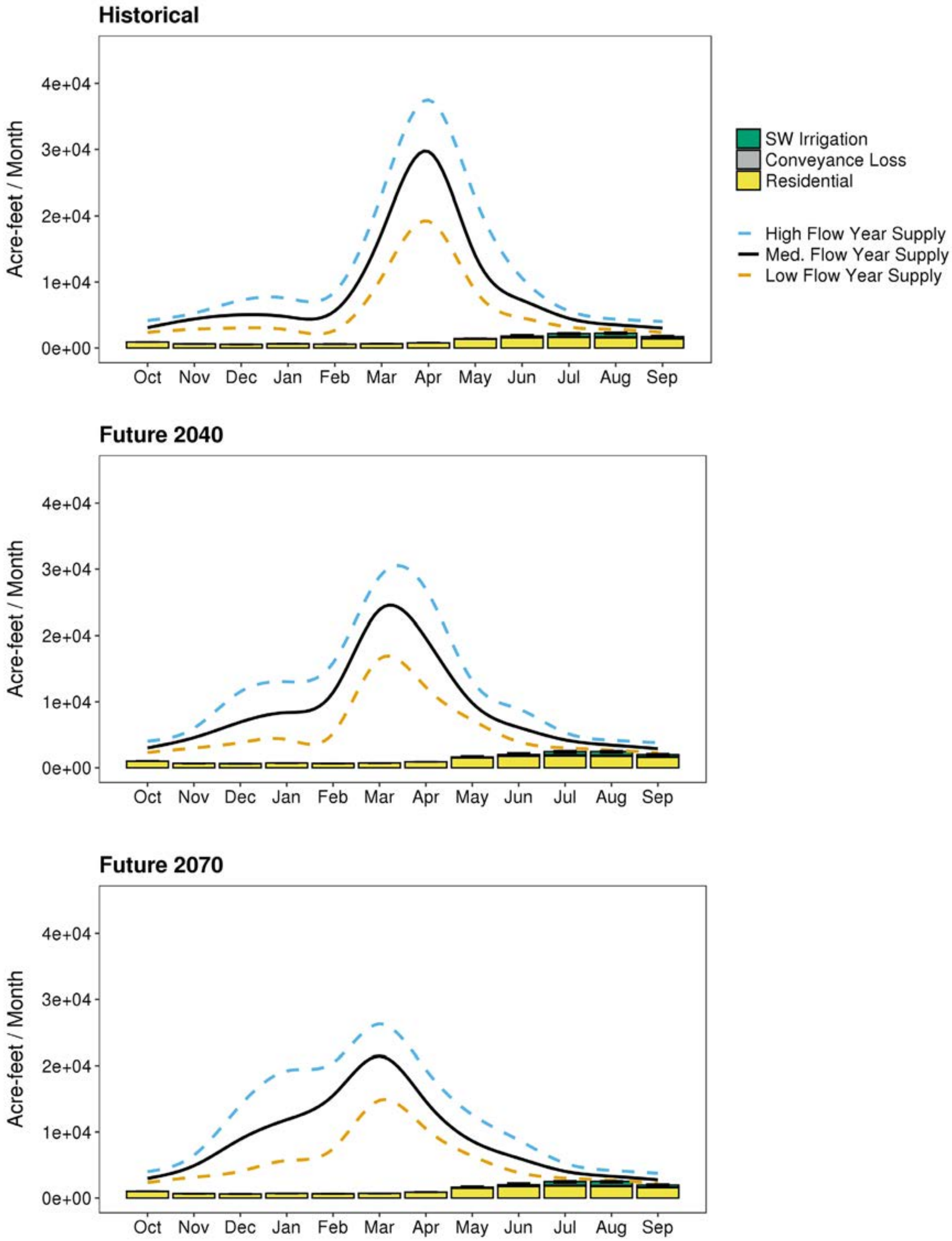
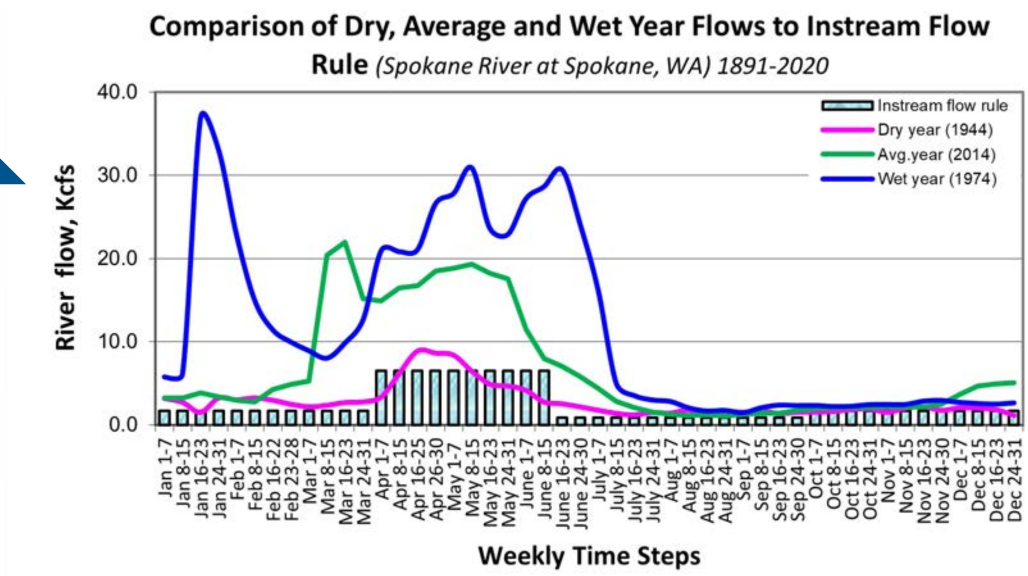
Bar 3
- 2070s Climate

SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

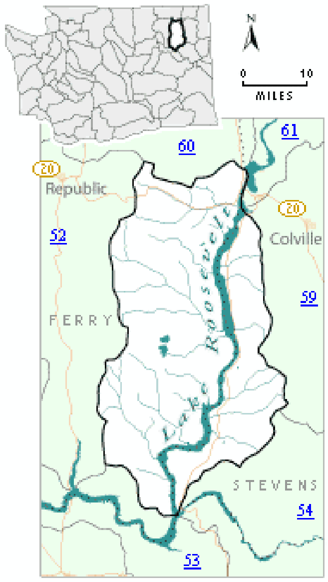
CONSIDERATIONS FOR FISH

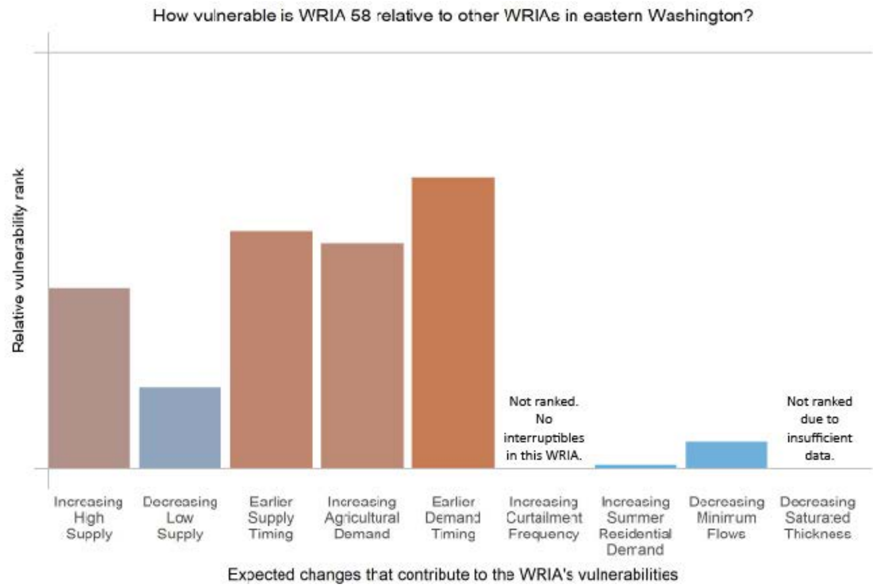


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





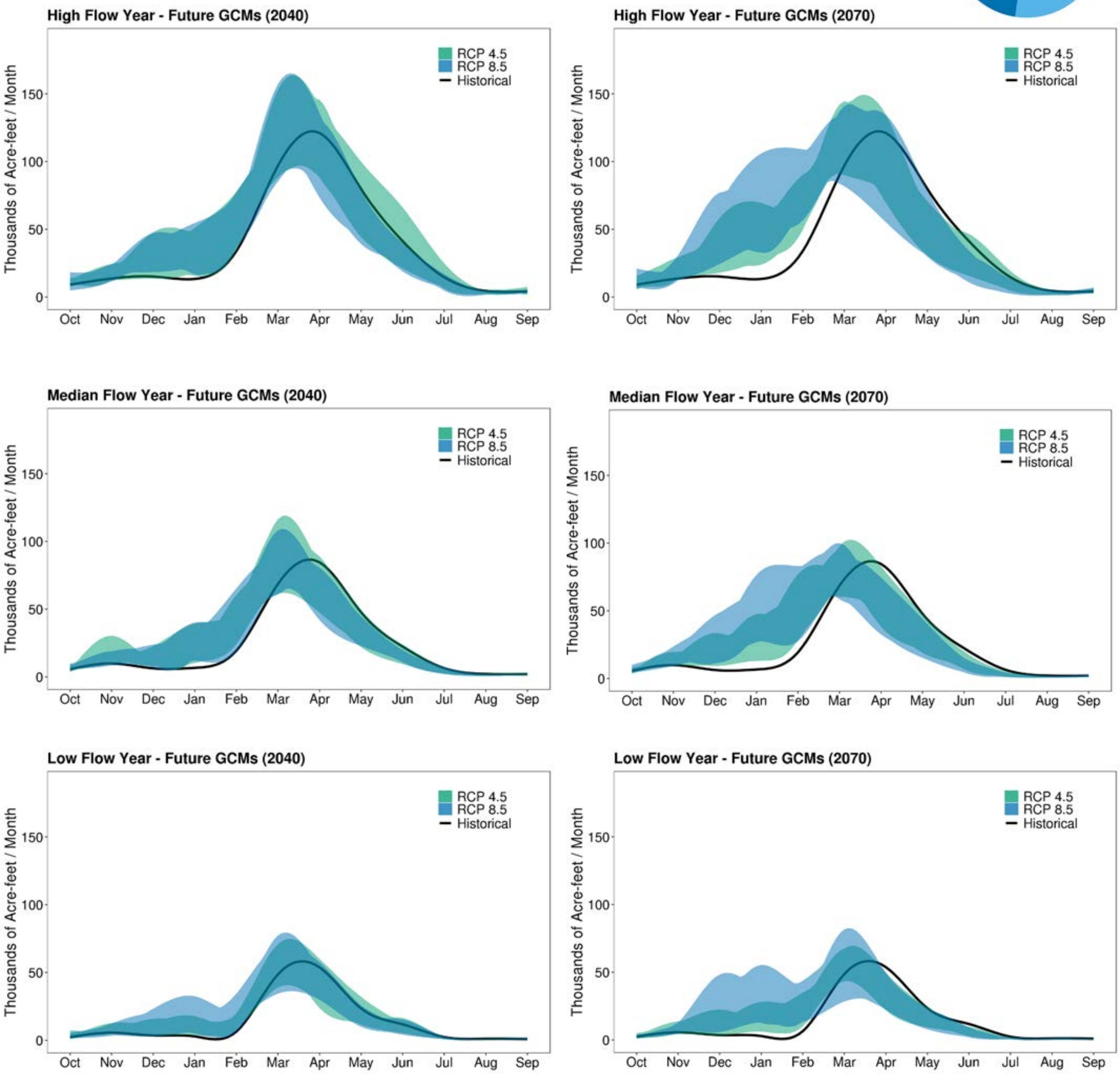
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 31 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to increase by 9 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 14 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 48% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 9% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 15 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is not projected to change by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Quillisascut Creek, Cheweka Creek, Jennings Creek, Magee Creek , Stranger Creek, Harvey Creek, Alder Creek , O-Ra-Pak-En Creek, Corus Creek
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	NONE

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

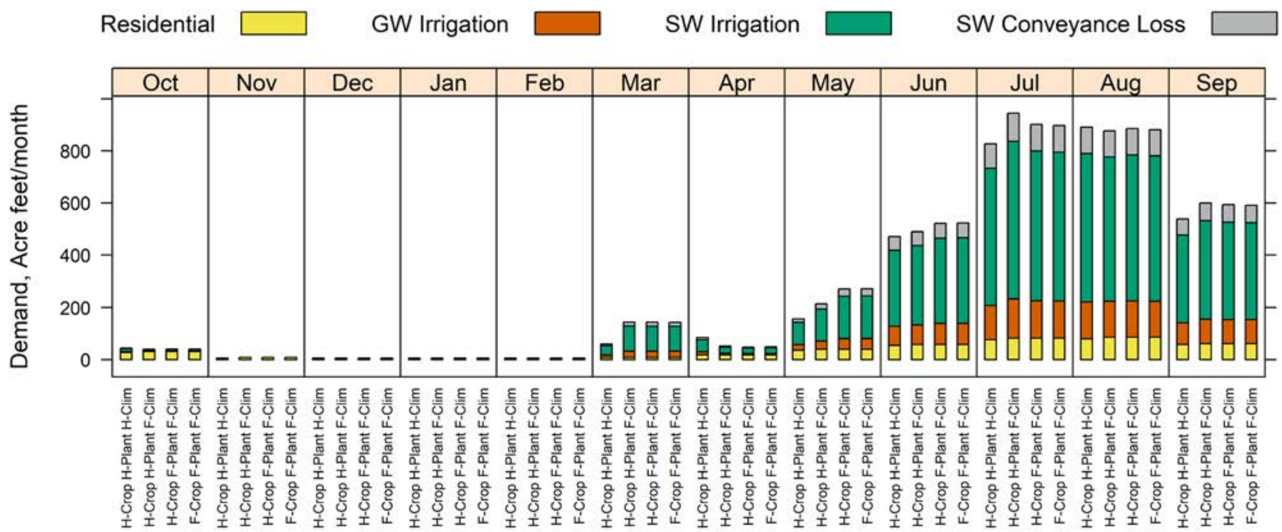
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

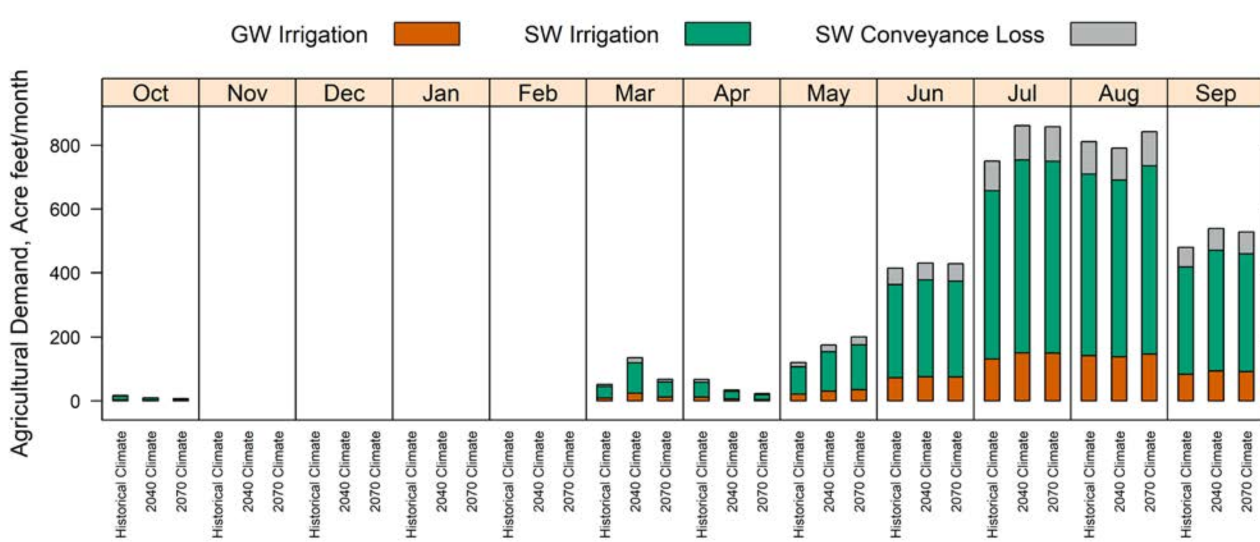
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

Each month has three bars that represent a different scenario:

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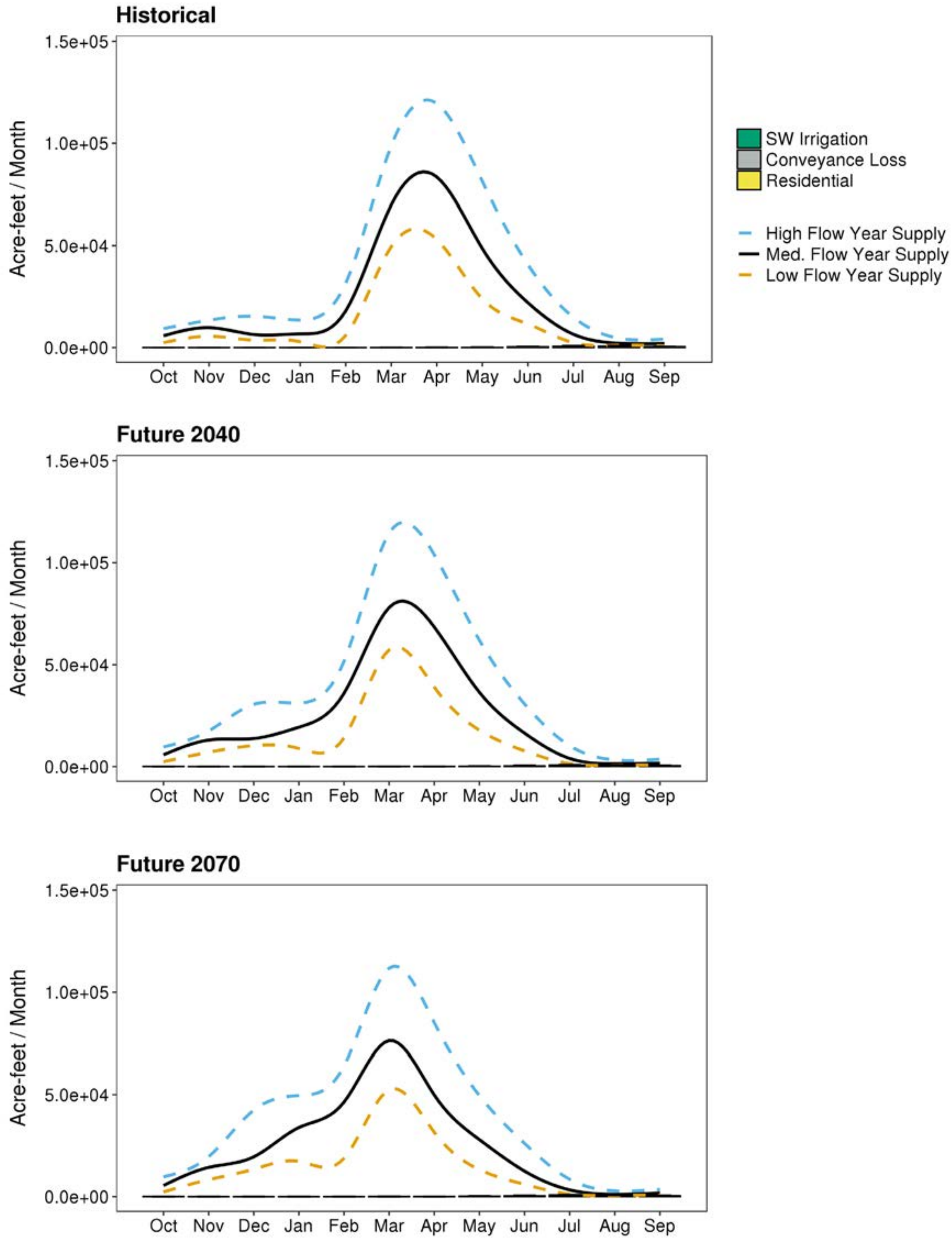
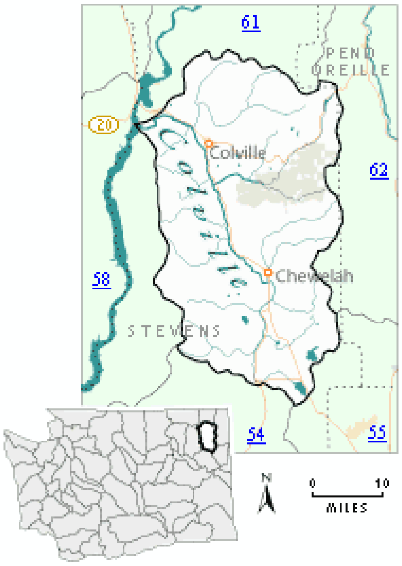
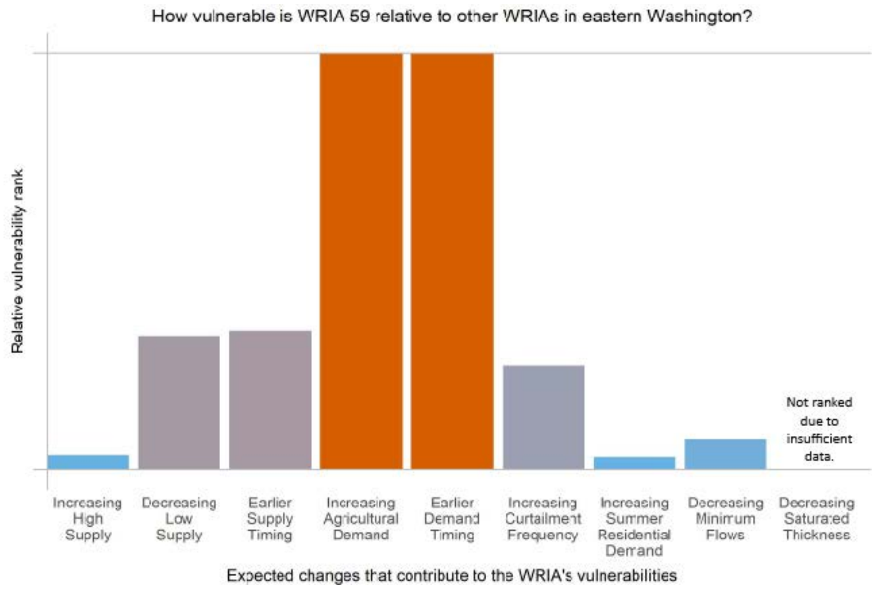
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

SUMMARY





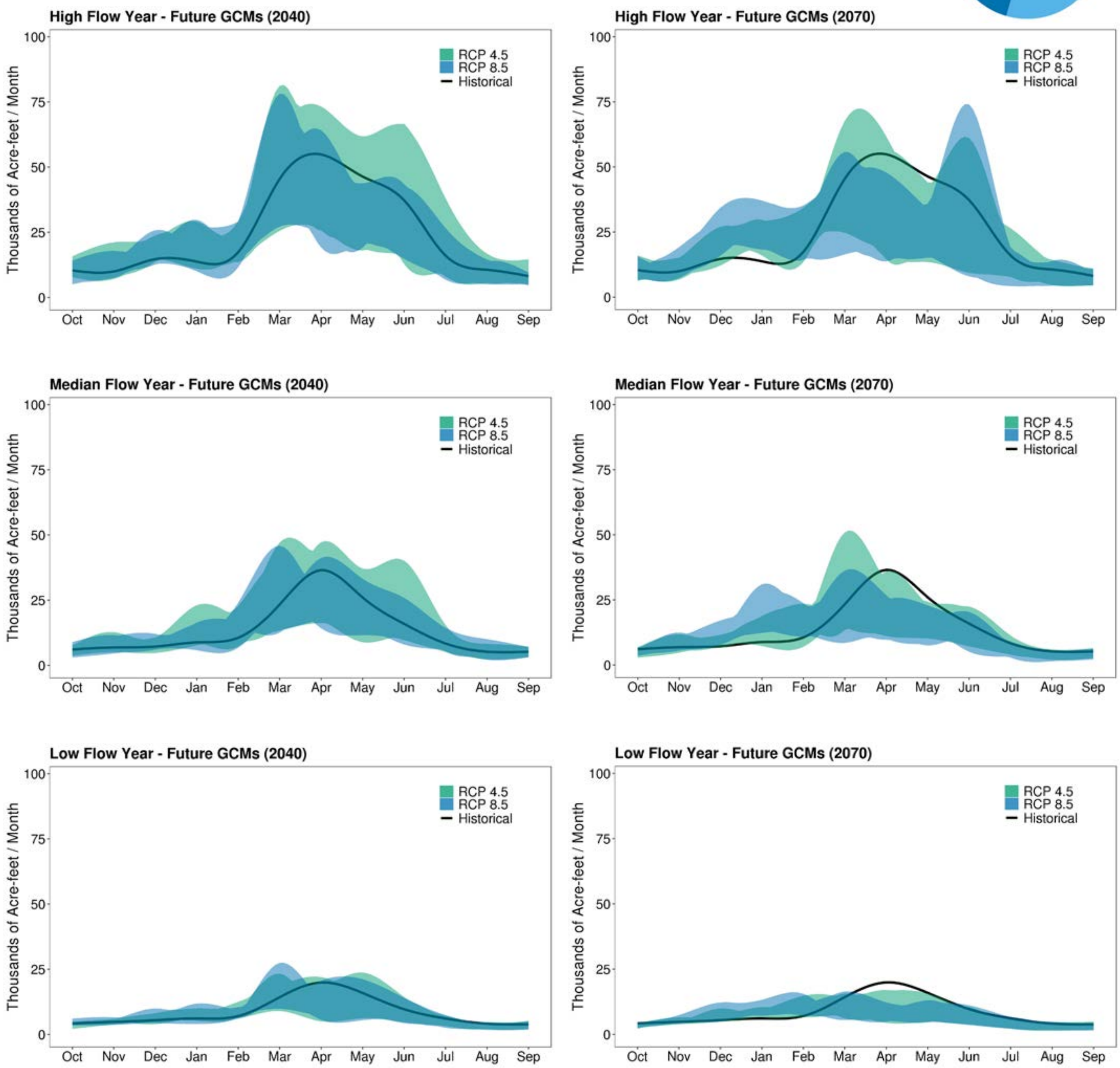
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to decrease by 36 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to decrease by 14 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 9 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 46% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 22% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 3 days later by 2040.
- **Increasing Curtailment Frequency:** The frequency of curtailment for July and August is projected to increase by 13% by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 78 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 0.1 by 2040.

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	Watershed plan addendum adopted on June 25, 2020
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[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	Colville

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

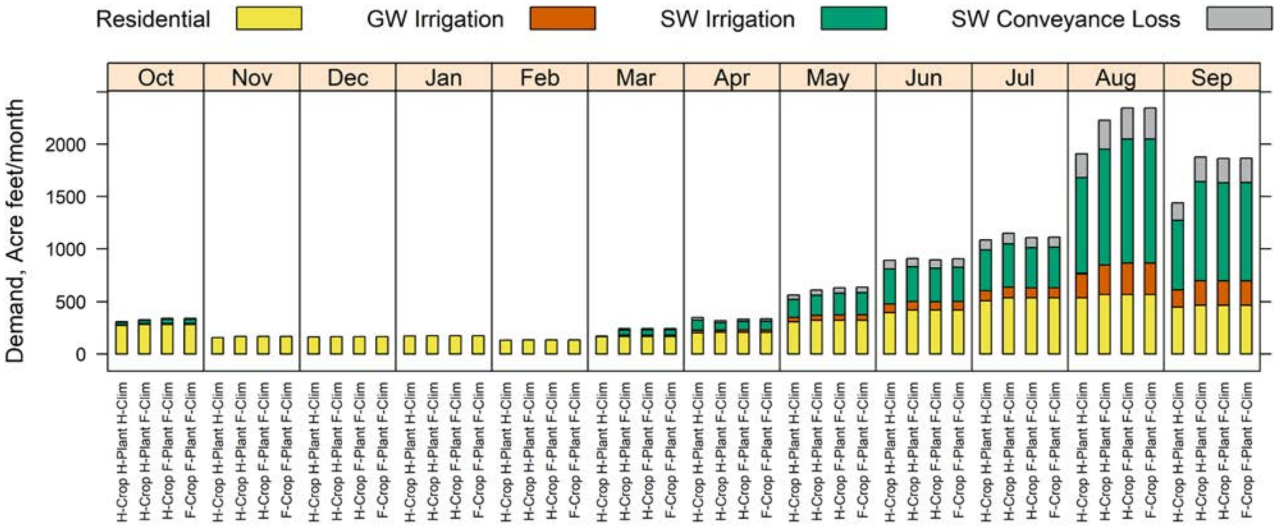
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

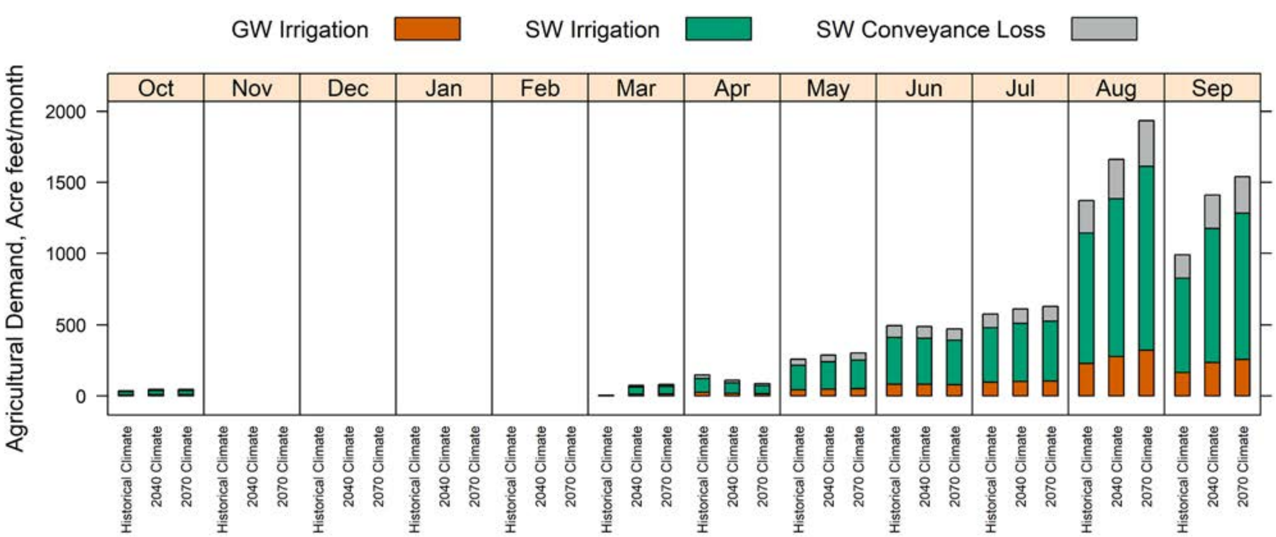
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

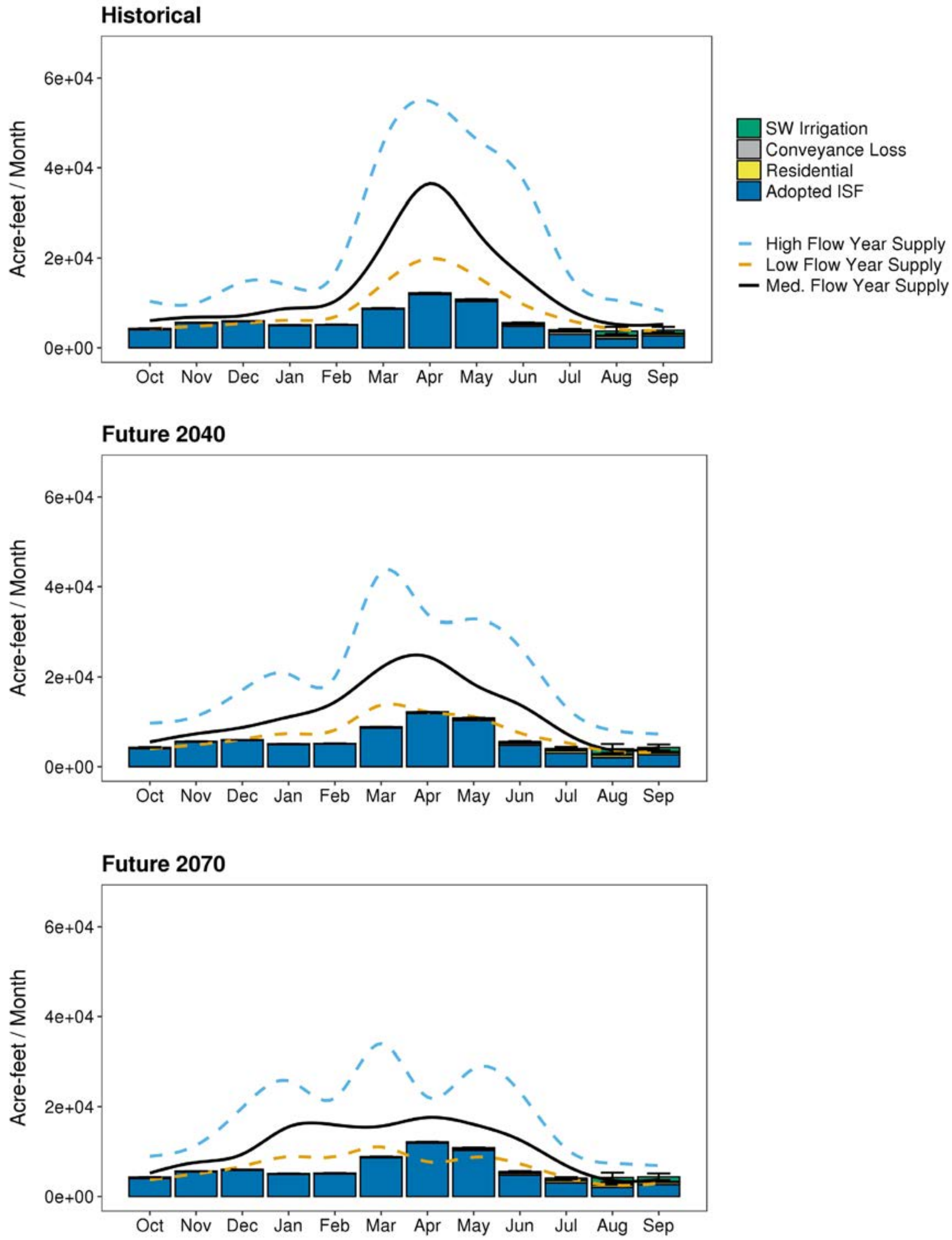
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

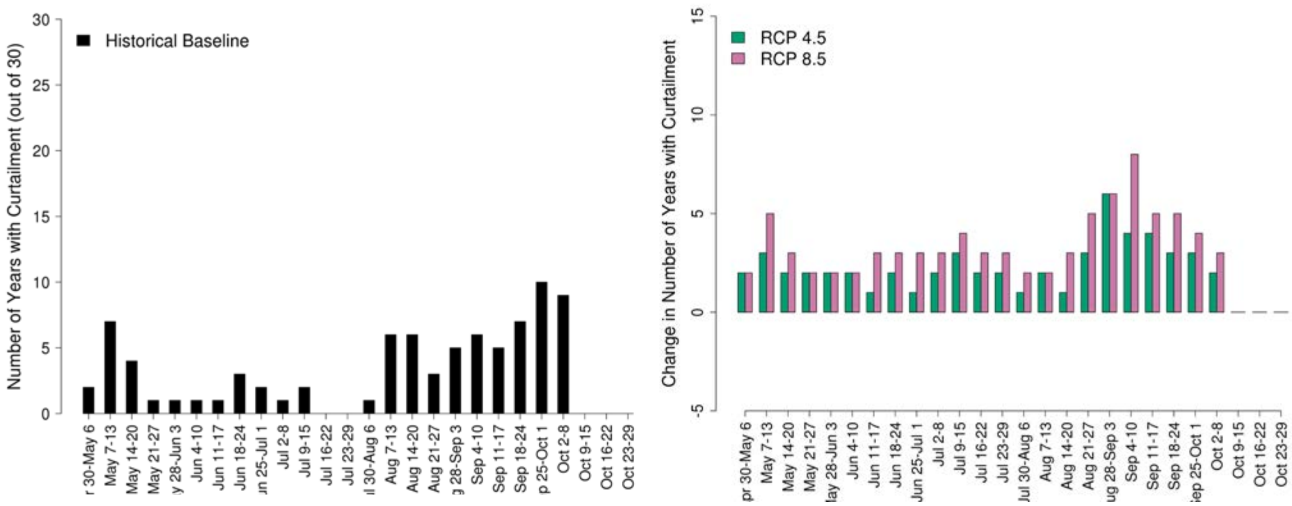
Bar 3
- 2070s Climate

SUPPLY AND DEMAND



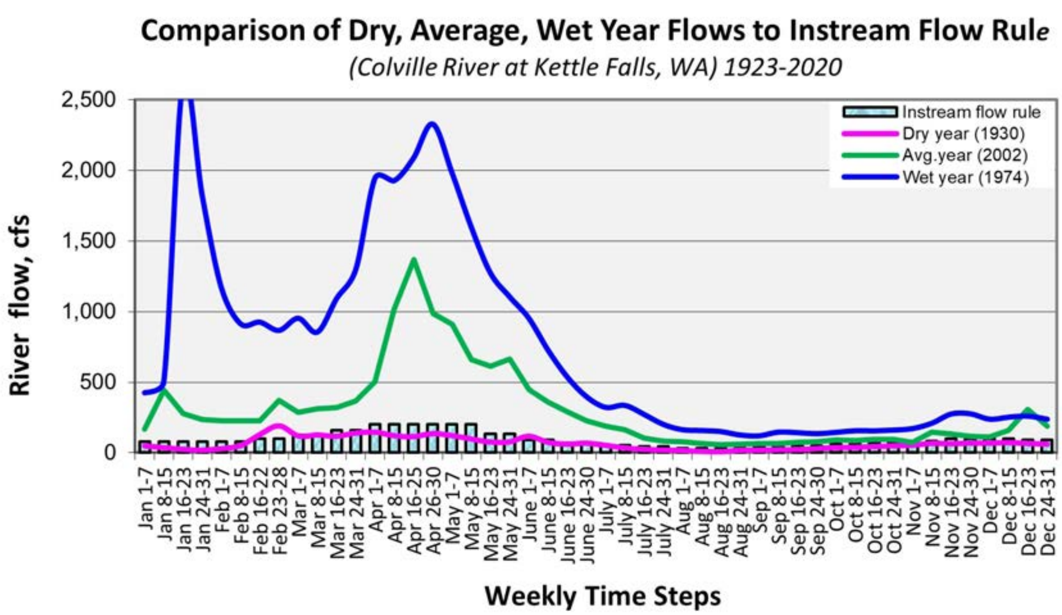
Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (bottom panel), using the middle value of the range of climate change scenarios considered. High (80th percentile), median, and low (20th percentile) supply conditions are shown as different curves. The top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CURTAILMENT



Modeled historical baseline number of years with curtailment from 1986- 2015 for each week (left panel) and change in the number of years with curtailment for each week for RCP 4.5 and RCP 8.5 (right panel) during a future period (2026 – 2055) compared to historical curtailment from 1976-2005. Changes in curtailment frequency include both surface and groundwater interruptions. Change in curtailment is forecasted using the median of the changes (future GCM- historical GCM) predicted by 17 climate GCM scenarios for two emissions scenarios given by IPCC Representative Concentration Pathways (RCP): 4.5 and 8.5.

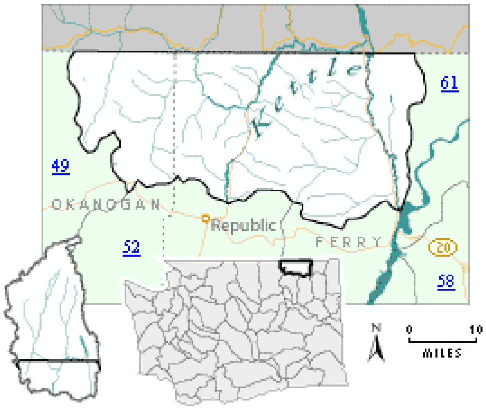
CONSIDERATIONS FOR FISH

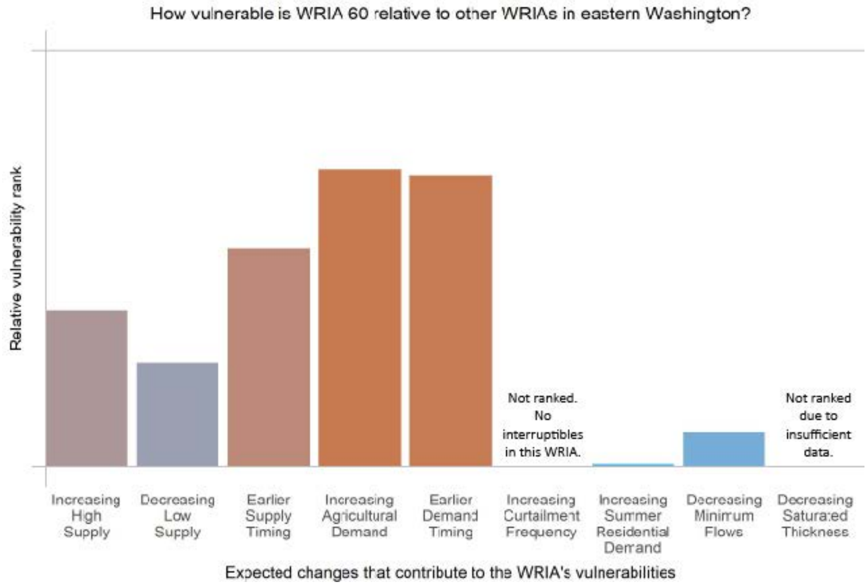


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





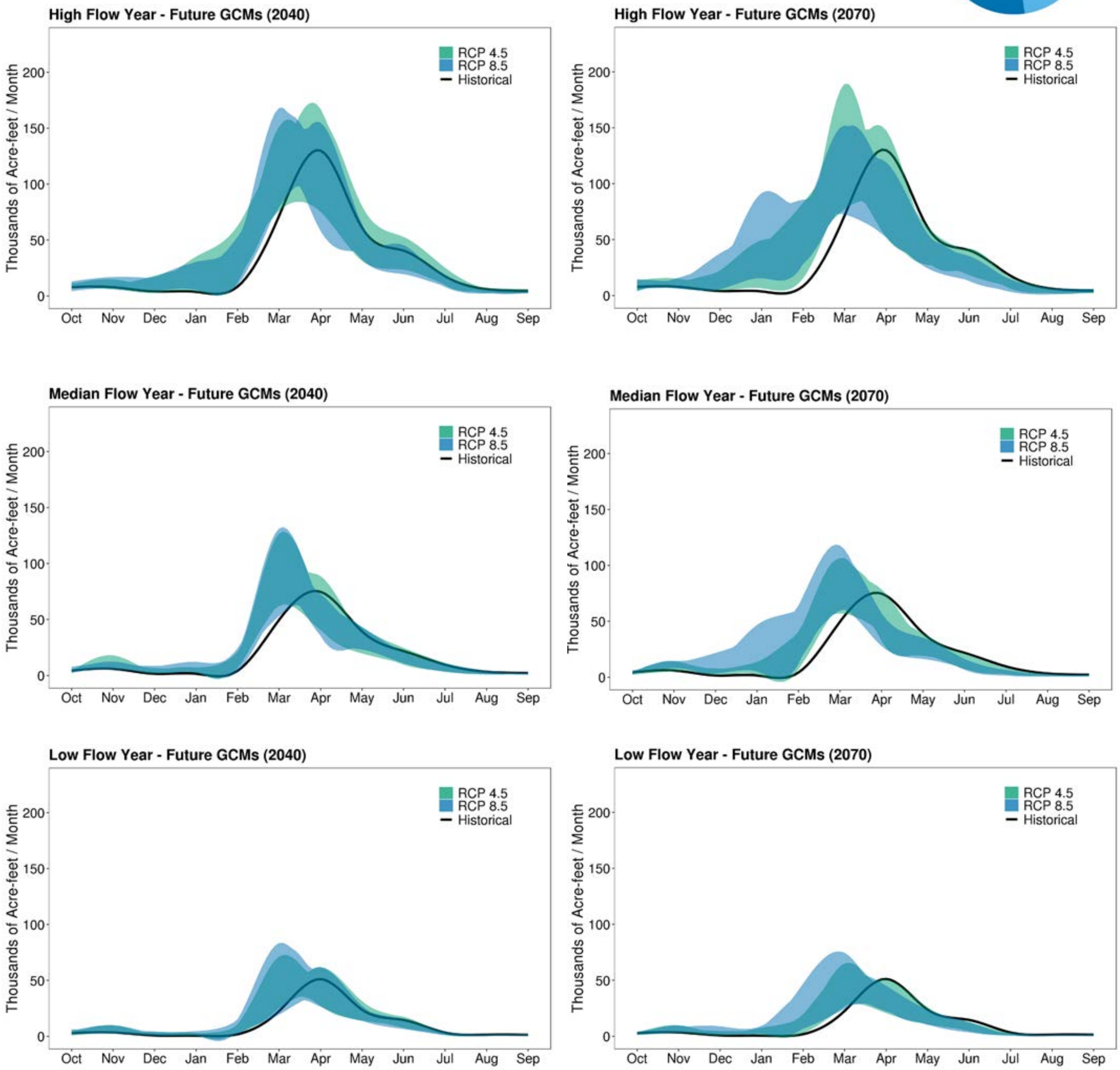
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to increase by 21 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to decrease by 1 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 13 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 52% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 14% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 8 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 0.3 cfs by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	Twin Creek, Myers Creek
Watershed Planning	NO (planning terminated at the end of phase 2)
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	NONE

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

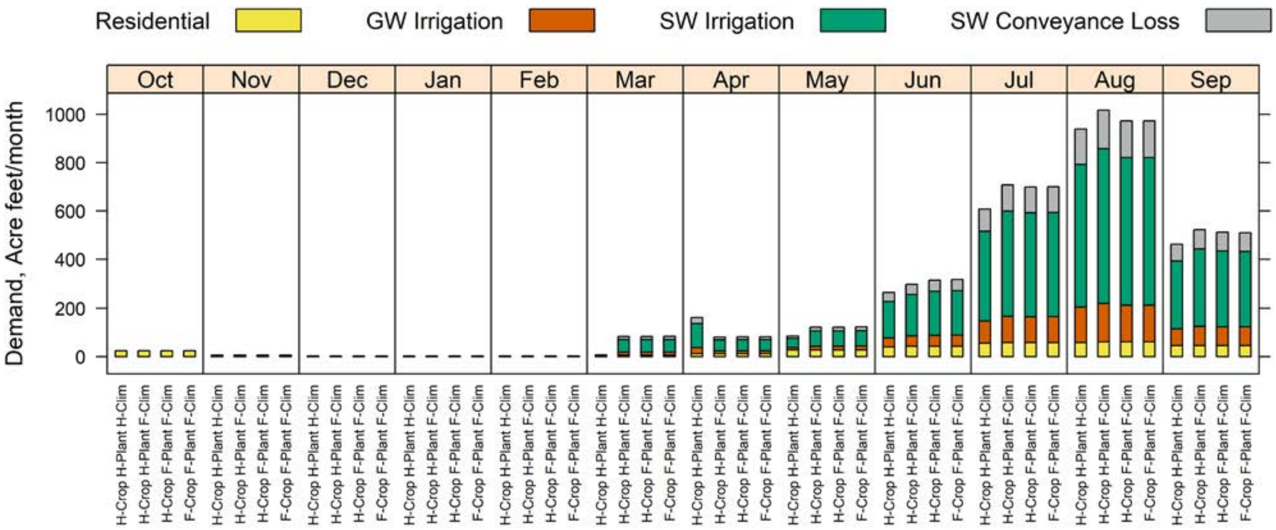
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

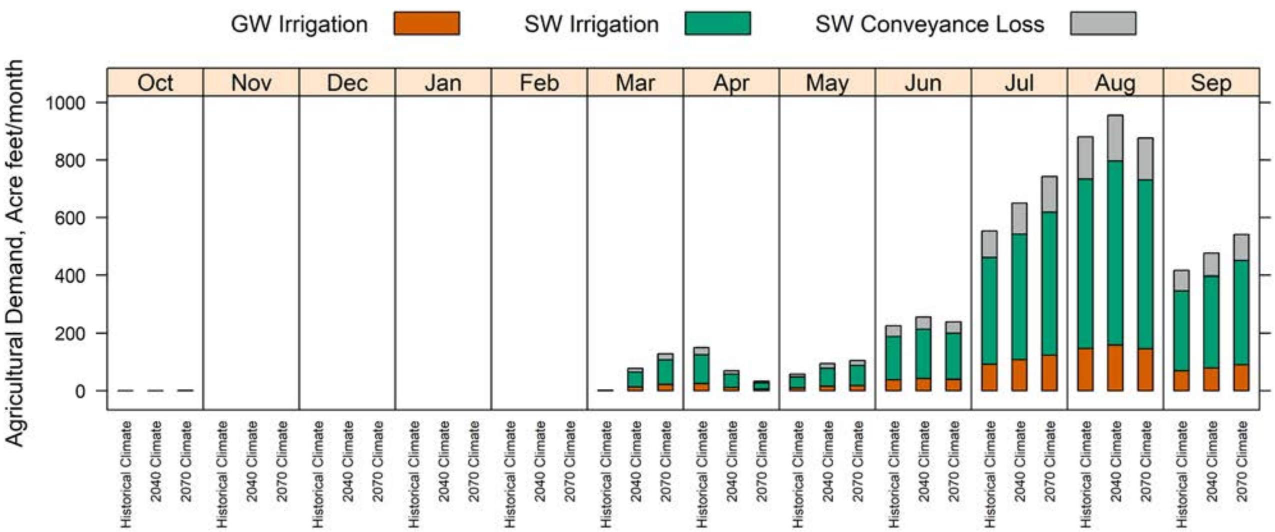
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

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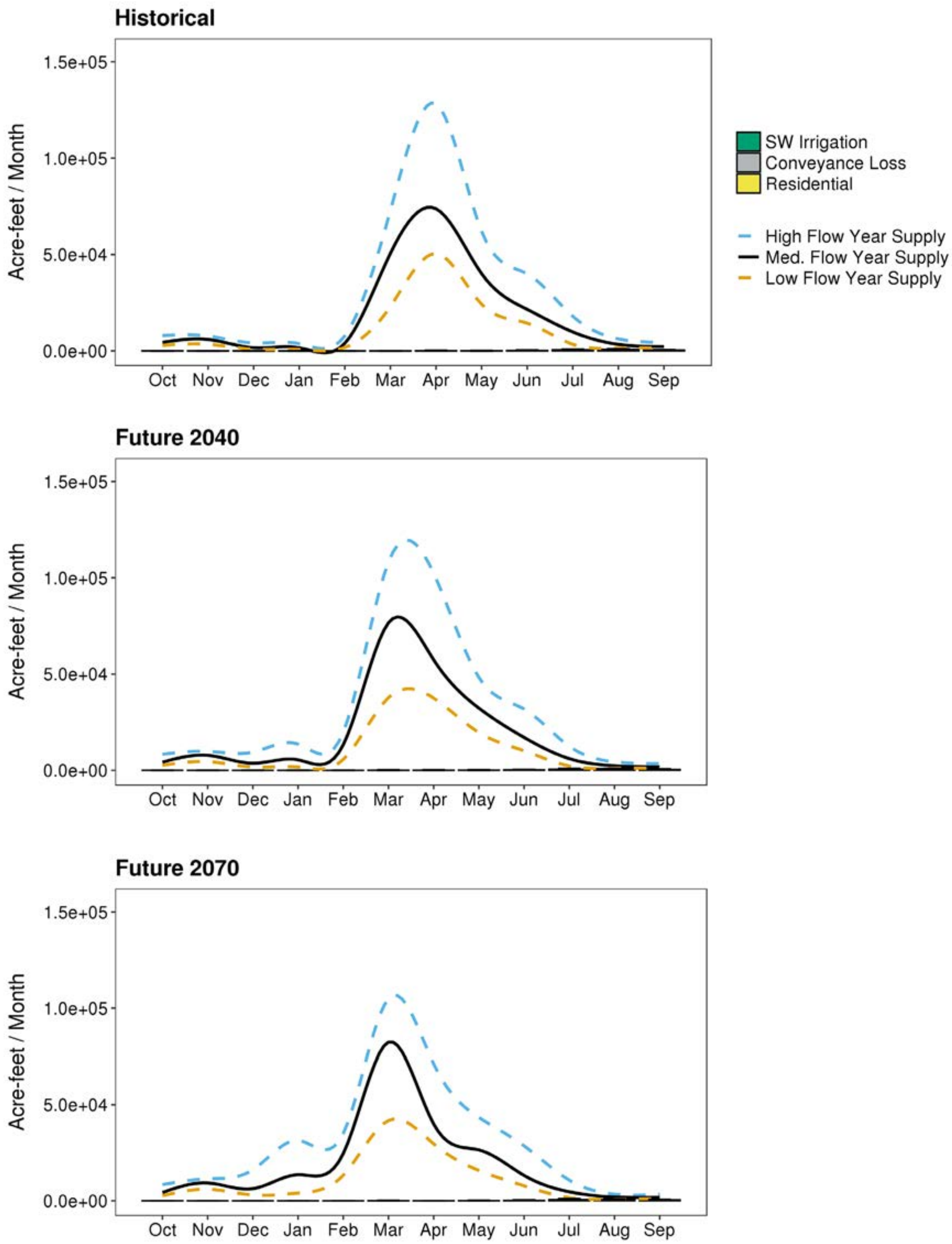
Bar 2
- 2040s Climate

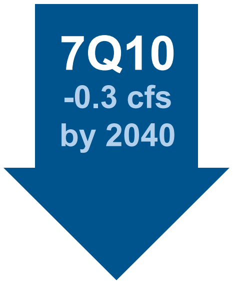
Bar 3
- 2070s Climate

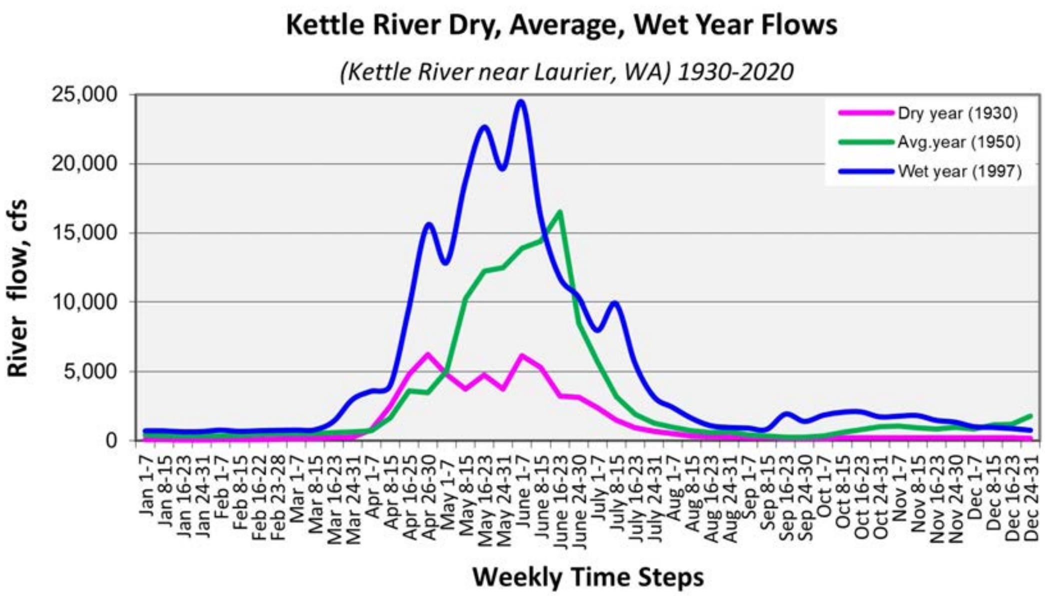
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH

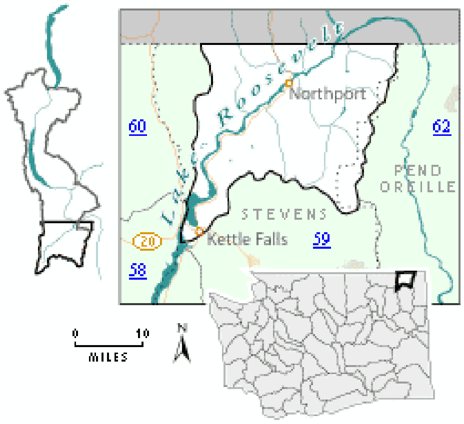


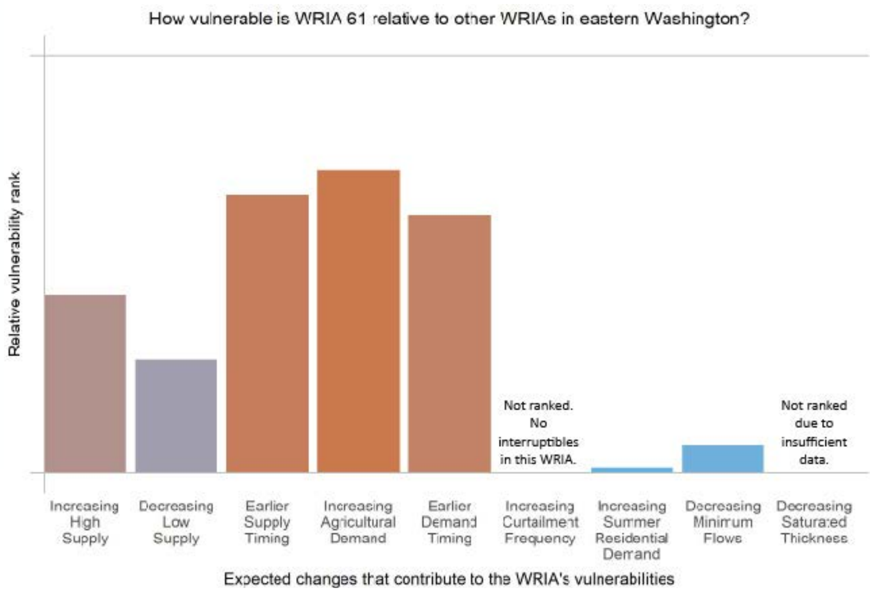


Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), the 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

SUMMARY





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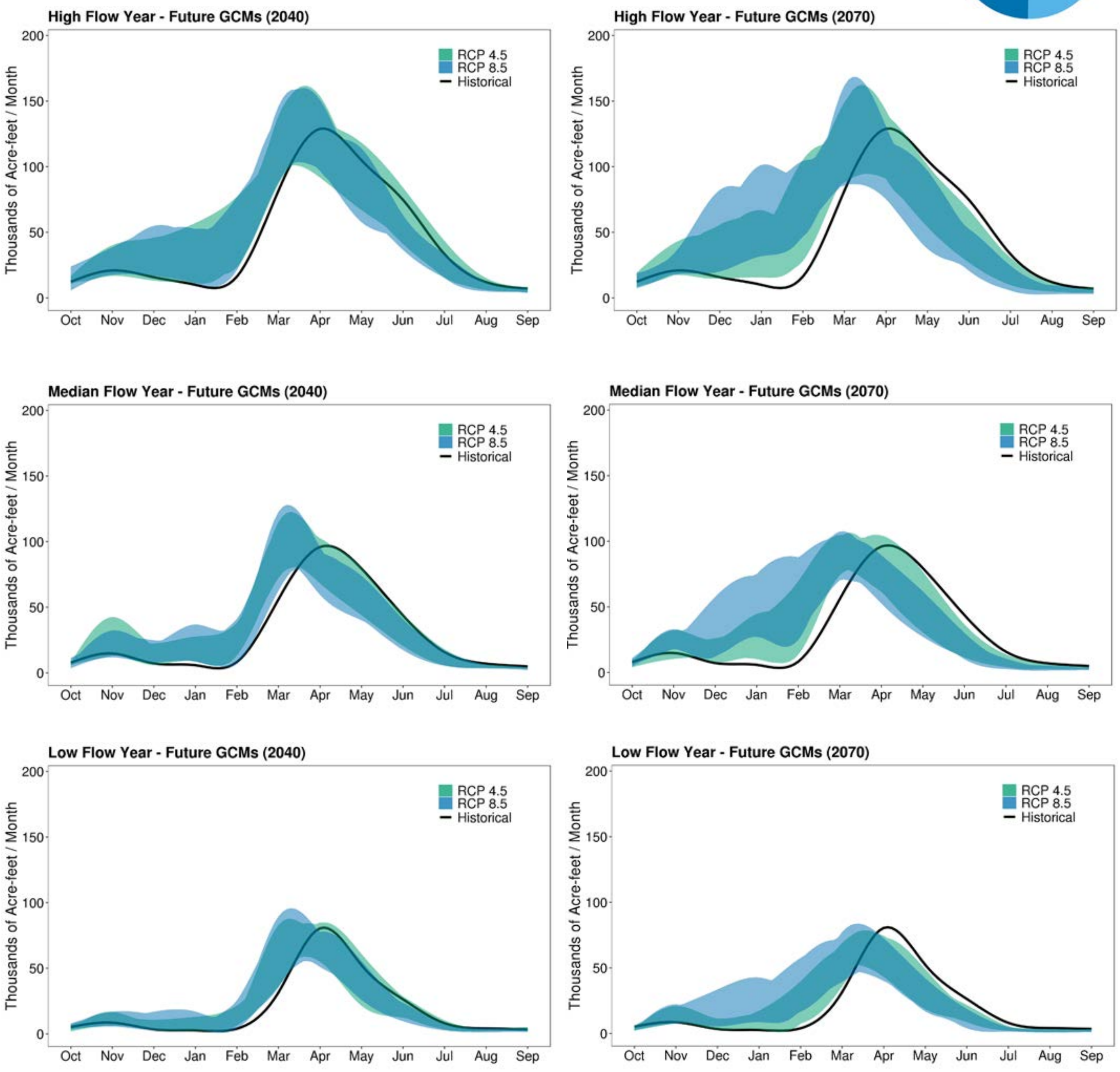
- **Increasing High Supply:** Water supply during high flow years is projected to increase by 30 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to decrease by 5 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 16 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 50% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand**: Agricultural demand is projected to increase by 14% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 2 days earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 26 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is not projected to change by 2040.

MANAGEMENT CONTEXT	
Adjudicated Areas	NO
Watershed Planning	NO
Adopted Instream Flow Rules	NO
Fish Listed Under the Endangered Species Act[1]	Bull Trout spawning and rearing unknown
Groundwater Subareas Overlapped by WRIA	NONE

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

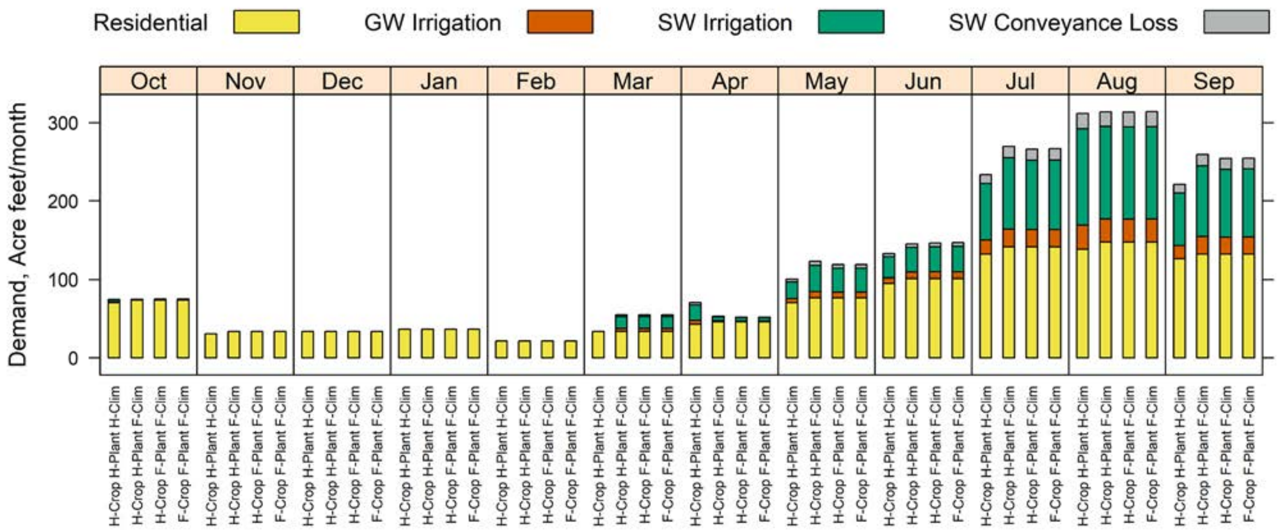
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

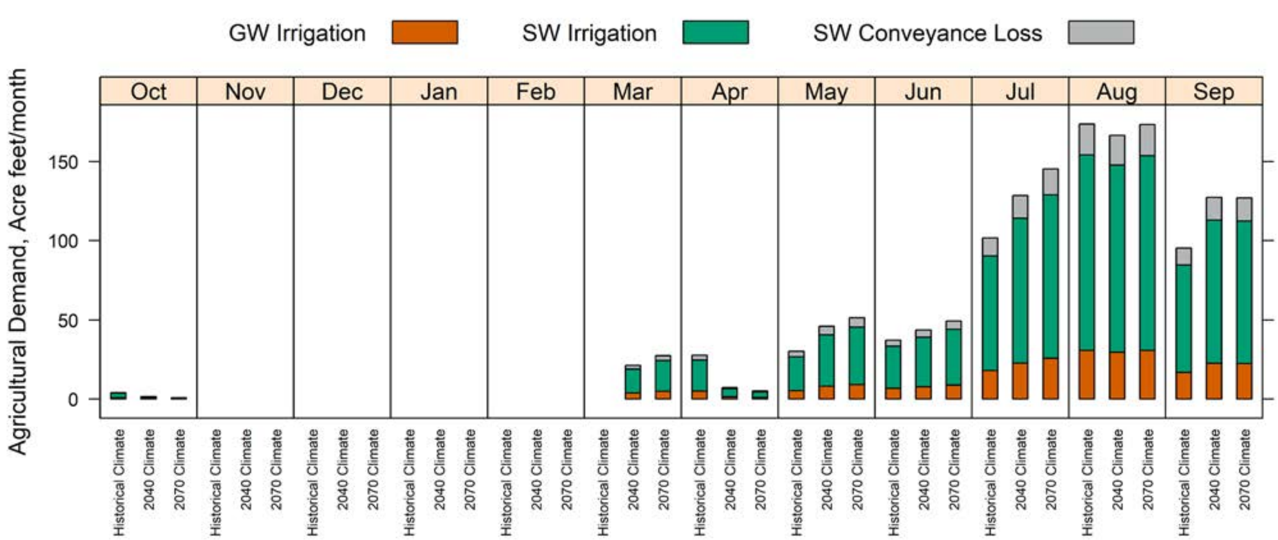
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

Each month has three bars that represent a different scenario:

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- Historical Climate

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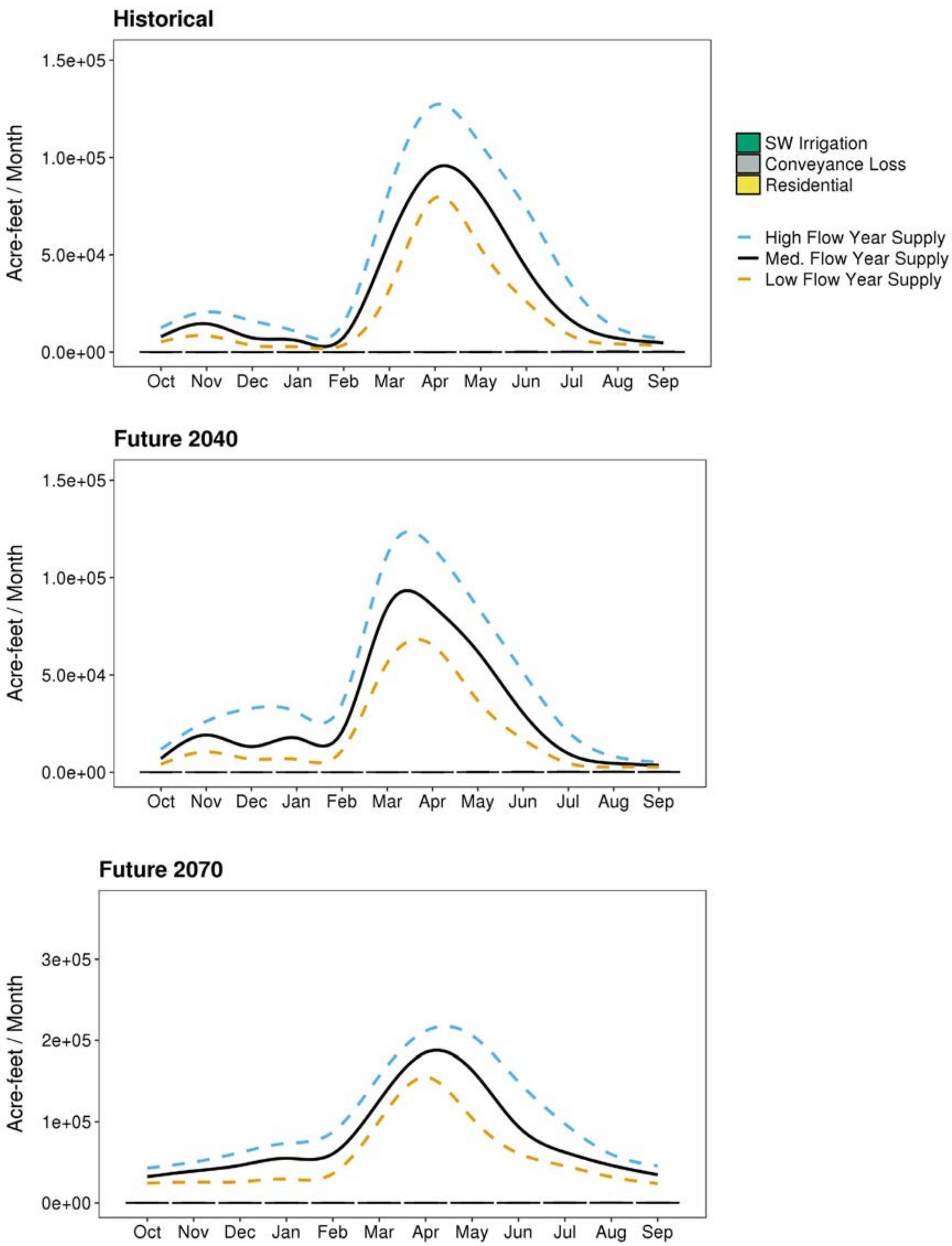
- 2040s Climate

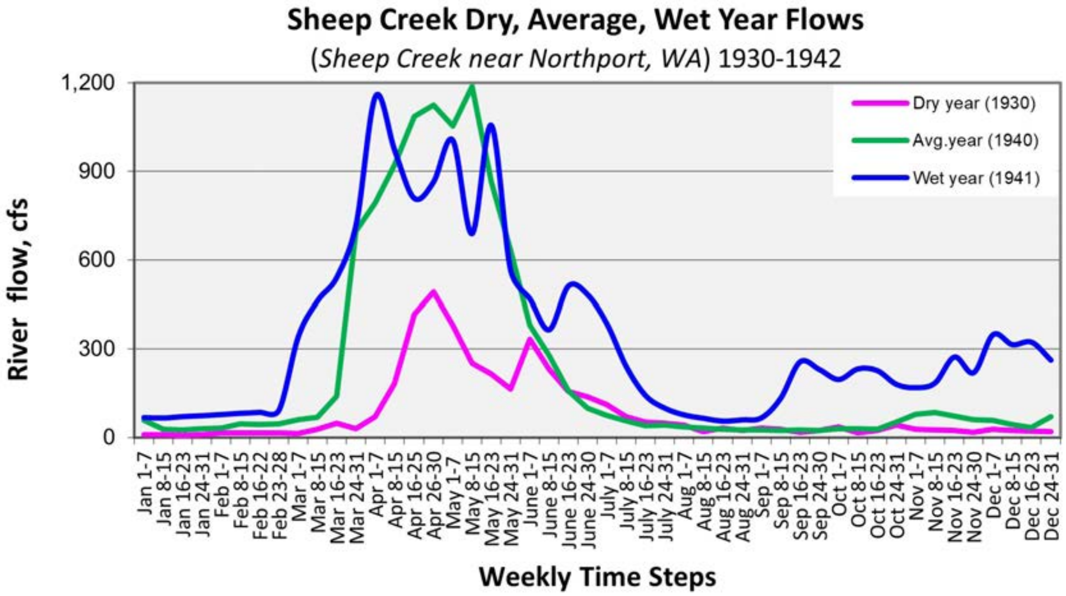
Bar 3
- 2070s Climate

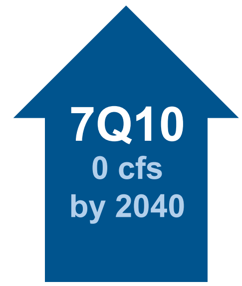
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH



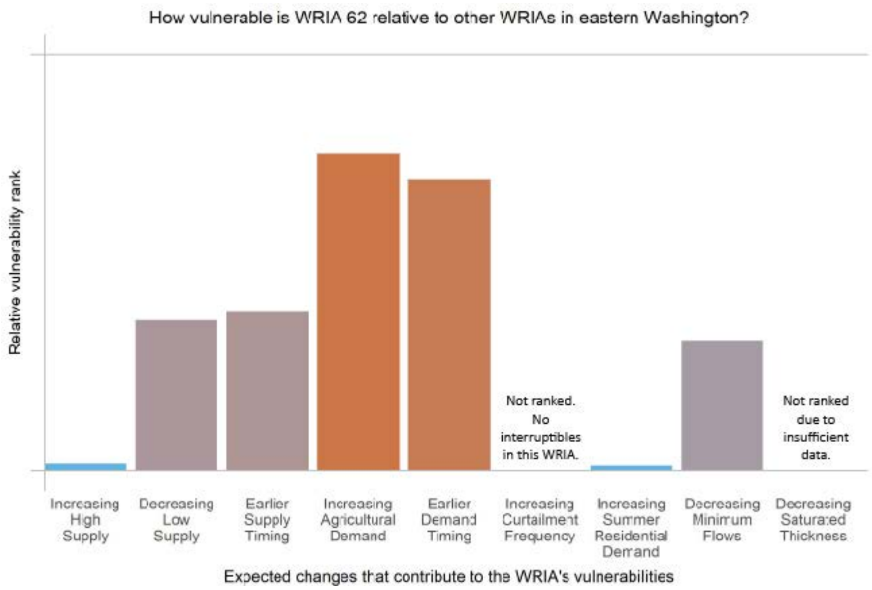


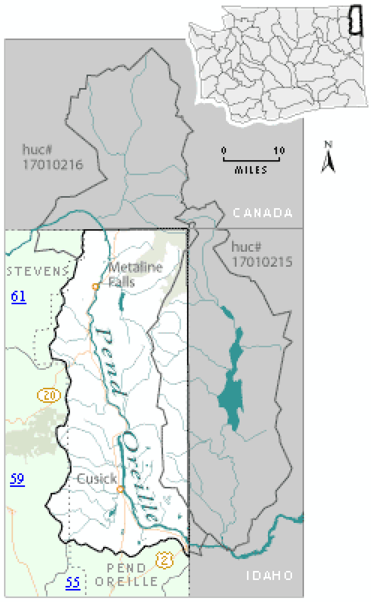
Actual historical flows measured at an existing stream gage (data obtained from the U.S. Geological Survey [link: http://waterdata.usgs.gov/wa/nwis]). The stream gage selected was the one furthest downstream within the WRIA. Flows are shown for the year with the lowest annual flow on record (Dry year), 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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

PEND OREILLE • WRIA 62

SUMMARY





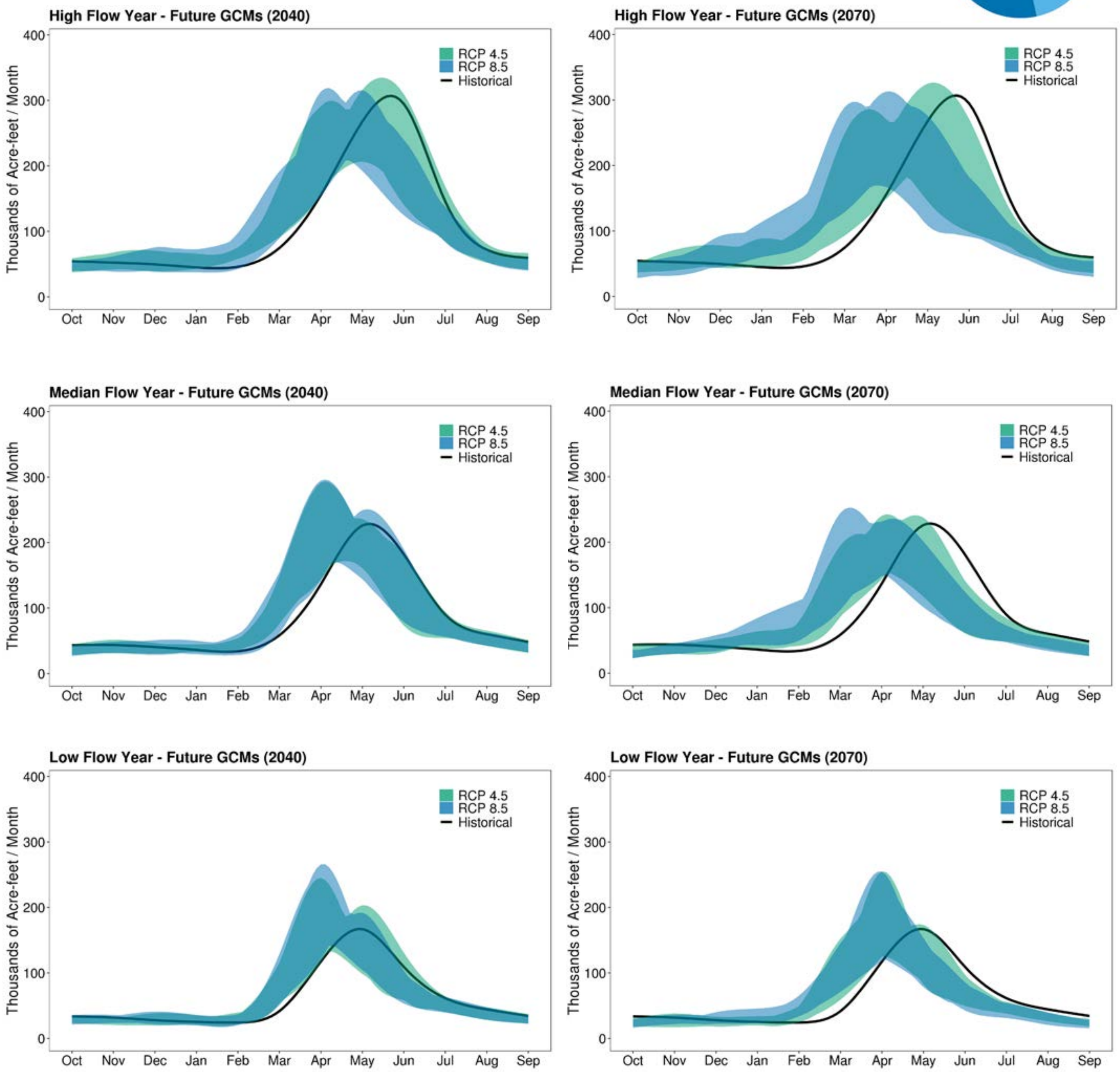
Summary of relative magnitude of changes expected in water supplies and demands in the WRIA by 2040. Each bar is based on a different water supply or demand change. The length of the bar shows how this WRIA compares to all other WRIAs in eastern Washington based on the magnitude of change expected for each metric which has been normalized on a scale of 0 (representing the WRIA with the minimum change) to 1 (representing the WRIA with the maximum change). The higher the bar, the more likely this WRIA is to be vulnerable due to changes in that metric, relative to other WRIAs in the region. Darker shades of orange indicate greater vulnerability and darker shades of blue indicate lesser vulnerability. Note that for increasing curtailment frequency and decreasing saturated thickness, only four and ten WRIAs, respectively, had comparable data.

- **Increasing High Supply:** Water supply during high flow years is projected to decrease by 41 thousands of ac-ft per year by 2040.
- **Decreasing Low Supply:** Water supply during low flow years is projected to decrease by 21 thousands of ac-ft per year by 2040.
- **Earlier Supply Timing:** The timing of center of mass for supply is expected to occur 10 days earlier by 2040.
- **Historical Snowmelt Ratio:** Historically, 53% of runoff has been produced by snowmelt.
- **Increasing Agricultural Demand:** Agricultural demand is projected to increase by 14% by 2040.
- **Earlier Demand Timing:** The timing of center of mass for demand is expected to occur 1 day earlier by 2040.
- **Residential Summer Demand:** Summer residential consumptive water use is projected to increase by 25 ac-ft by 2040.
- **Decreasing Minimum Flows:** The lowest 7-day average flow that occurs (on average) once every 10 years is projected to decrease by 4.2 cfs by 2040.

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[1]	Bull Trout
Groundwater Subareas Overlapped by WRIA	Pend Oreille

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

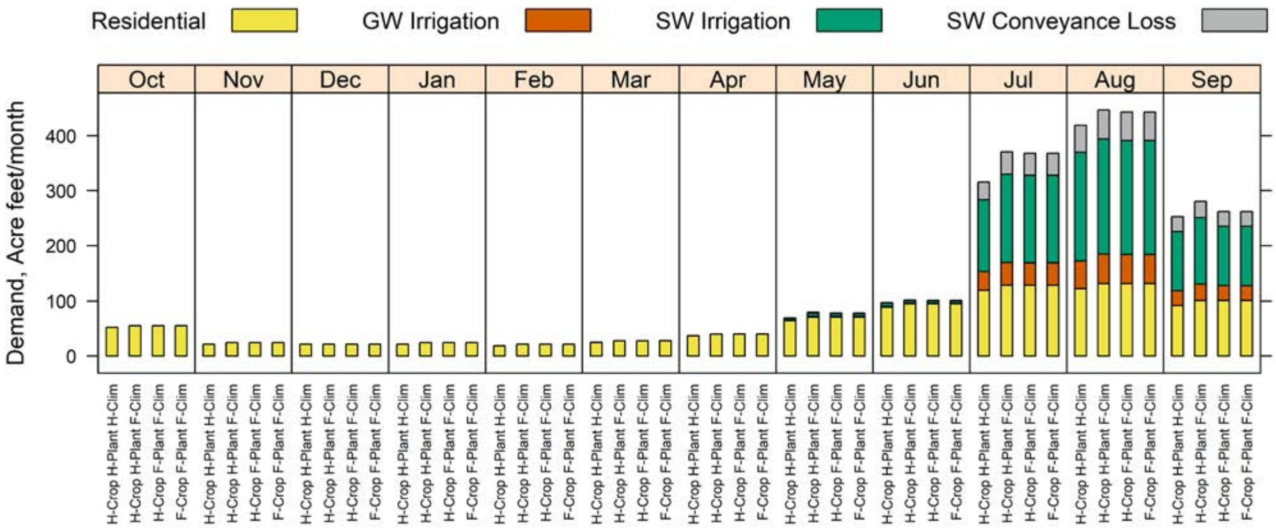
SUPPLY



Modeled historical (Hist; 1986-2015) and forecast (RCP 4.5 and RCP 8.5) surface water supply generated within the WRIA for high (80th percentile, top), median (50th percentile, middle), and low (20th percentile, bottom) supply conditions. Forecast scenarios are for both 2040 (left) and 2070 (right). Water supply was forecast using 17 climate models run under two emissions scenarios given by IPCC Representative Concentration Pathways (RCP) 4.5 and 8.5. The spread of each forecasted 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.

The pie chart (top right) shows the relative amounts of historical (1976-2005) supply generated from snow (dark blue) and rain (light blue) within this WRIA.

DEMAND



Modeled historical (1986-2015) and forecast (2040) residential and agricultural irrigation water demands within the WRIA. Agricultural water demand was forecast under four scenarios: a) "H-Crop H-Plant H-Clim", b) "H-Crop H-Plant F-Clim", c)"H-Crop F-Plant F-Clim", and d) "F-Crop F-Plant F-Clim" where "H-Crop" represents historical crop mix; "F-Crop" as future crop mix; "H-Plant" represents historical planting date, "F-Plant" represents moving planting date forward one week; "H-Clim" as historical climate and "F-Clim" values represent demand forecast for 2040. Each bar represents the median (50th percentile) demand condition. Agricultural surface water (SW, green) irrigation demands are shown as 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 (gray) are estimated separately. Groundwater (GW, orange) irrigation demand is based on modeling assumptions of the proportion of agricultural water demand supplied by groundwater. Consumptive residential demands (yellow) include municipal and self-supplied domestic use but exclude self-supplied industrial use.

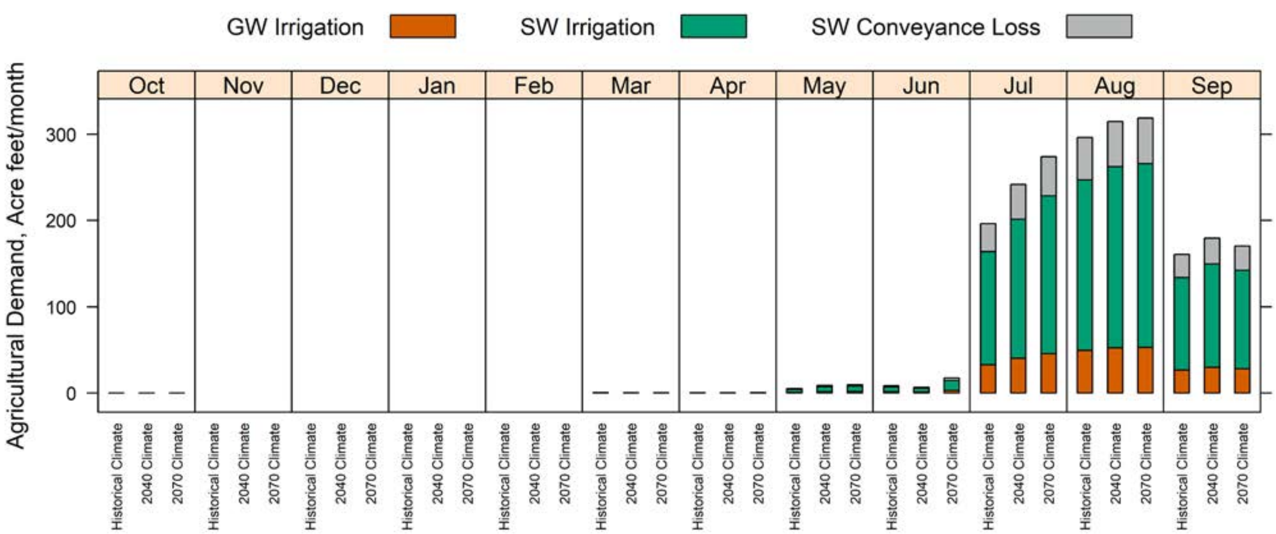
Each month has four bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

Bar 3
- 2040s Climate
- Planting date 1 week earlier

Bar 4
- 2040s Climate
- Planting date 1 week earlier
- Future crop mix



Modeled historical (1986-2015) and forecast (2040 and 2070) agricultural irrigation water demand within the WRIA. All three time periods use historical crop mix and historical planting date. Groundwater (GW), surface water (SW) demands and conveyance losses are defined as in the figure above. **Note: Residential demands were not projected for 2070 and so are not included in this figure.**

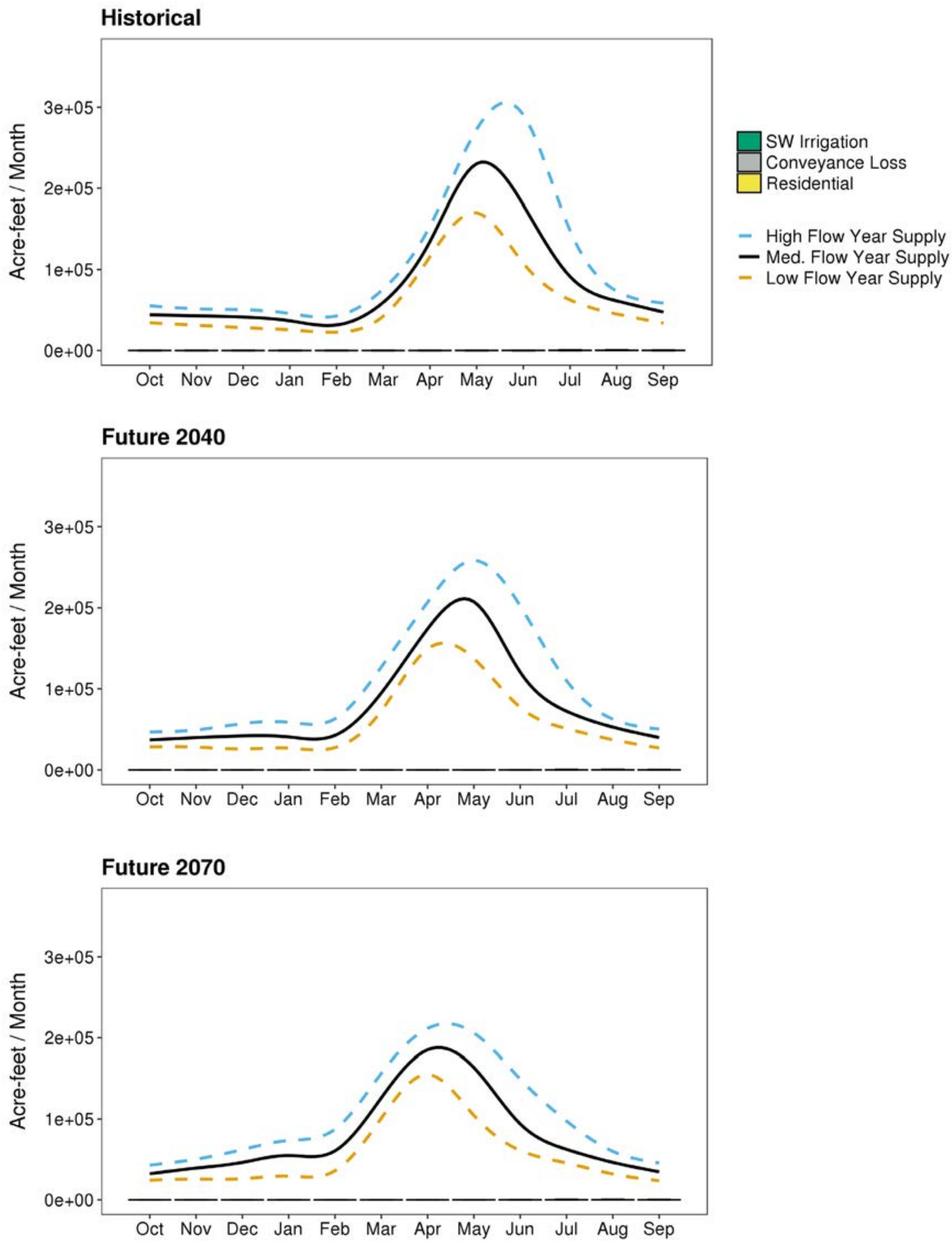
Each month has three bars that represent a different scenario:

Bar 1
- Historical Climate

Bar 2
- 2040s Climate

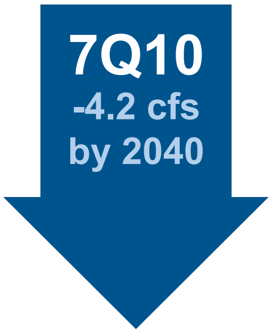
Bar 3
- 2070s Climate

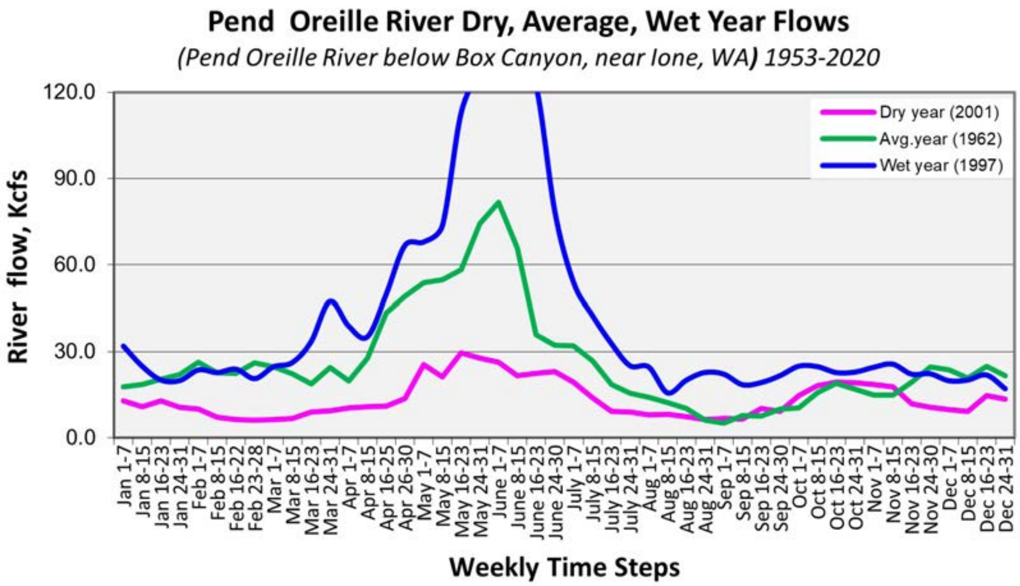
SUPPLY AND DEMAND



Comparison of surface water supply, surface water agricultural and residential demands for historical (1986-2015; top panel), forecast 2040 (middle panel), and forecast 2070 (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 top of the bar for agricultural surface water demand shows the 50th percentile of total surface water demand, and the error bars show the 20th and 80th percentiles of total surface water demands. Residential demand is not forecast for 2070 and so 2040 values are used in the 2070 projections. These results do not consider water curtailment.

CONSIDERATIONS FOR FISH





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.

The blue arrow depicts the amount and direction of change in annual minimum 7-day average streamflow with a 10-year recurrence interval between the historical (1982-2011) and the projected future (2030-2059) time periods.

FORECAST RESULTS FOR AQUIFER LAYERS

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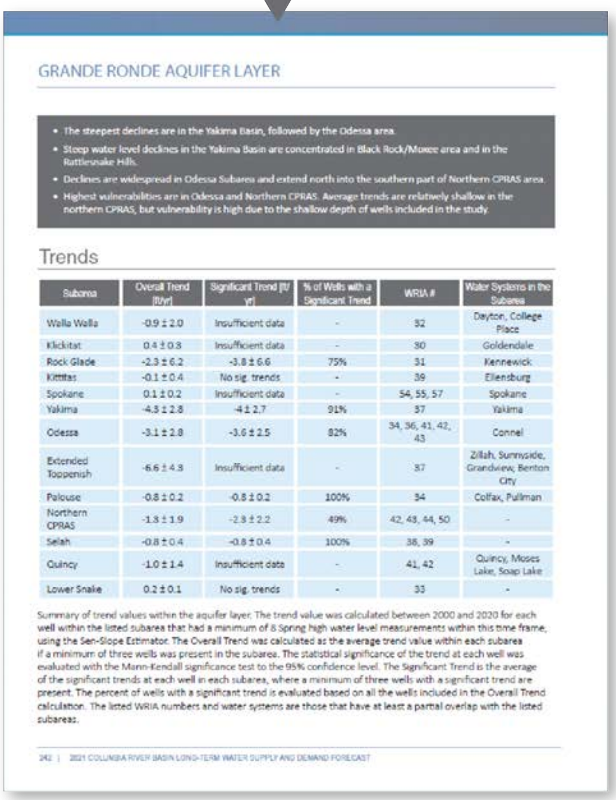
How to Read the Aquifer Results

The Aquifer Text Box highlights key vulnerabilities for the aquifer layer and pinpoints where these vulnerabilities occur within groundwater subareas.

The Trends Table provides metrics for the overall trend, significant trend, and percent of wells with a significant trend by subarea for the given aquifer layer and shows which WRIAs and water systems overlap with each subarea. Note that only subareas that contain well data within the aquifer layer of interest are included in the table.

The Summary of Overall Trends Boxplot shows overall trends for each groundwater subarea within the given aquifer layer. The black line represents the median trend within the subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. The red horizontal line marks zero, where values above represent increasing water levels and values below represent decreasing water levels.

The Interpolated Trends Map shows interpolated trends in groundwater levels within the given aquifer layer. The interpolations allow for prediction of unknown trends in certain areas based on trends from wells with accessible data. Darker shades of orange indicate declining trends, while darker shades of blue indicate increasing trends in groundwater levels. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.



GRANDE RONDE AQUIFER LAYER

- The steepest declines are in the Yakima Basin, followed by the Odessa area.
- Steep water level declines in the Yakima Basin are concentrated in Black Rock/Moxee area and in the Rattlesnake Hills.
- Declines are widespread in Odessa Subarea and extend north into the southern part of Northern CPRAS area.
- Highest vulnerabilities are in Odessa and Northern CPRAS. Average trends are relatively shallow in the northern CPRAS, but vulnerability is high due to the shallow depth of wells included in the study.

Trends

Subarea	Overall Trend [ft/yr]	Significant Trend [ft/yr]	% of Wells with a Significant Trend	WRIA #	Water Systems in the Subarea
Walla Walla	-0.9 ± 2.0	Insufficient data	-	32	Dayton, College Place
Klickitat	0.4 ± 0.3	Insufficient data	-	30	Goldendale
Rock Glade	-2.3 ± 6.2	-3.8 ± 6.6	75%	31	Kennewick
Kittitas	-0.1 ± 0.4	No sig. trends	-	39	Ellensburg
Spokane	0.1 ± 0.2	Insufficient data	-	54, 55, 57	Spokane
Yakima	-4.3 ± 2.8	-4 ± 2.7	91%	37	Yakima
Odessa	-3.1 ± 2.8	-3.6 ± 2.5	82%	34, 36, 41, 42, 43	Connel
Extended Toppenish	-6.6 ± 4.3	Insufficient data	-	37	Zillah, Sunnyside, Grandview, Benton City
Palouse	-0.8 ± 0.2	-0.8 ± 0.2	100%	34	Colfax, Pullman
Northern CPRAS	-1.3 ± 1.9	-2.3 ± 2.2	49%	42, 43, 44, 50	-
Selah	-0.8 ± 0.4	-0.8 ± 0.4	100%	38, 39	-
Quincy	-1.0 ± 1.4	Insufficient data	-	41, 42	Quincy, Moses Lake, Soap Lake
Lower Snake	0.2 ± 0.1	No sig. trends	-	33	-

Summary of trend values within the aquifer layer. The trend value was calculated between 2000 and 2020 for each well within the listed subarea that had a minimum of 8 Spring high water level measurements within this time frame, using the Sen-Slope Estimator. The Overall Trend was calculated as the average trend value within each subarea if a minimum of three wells was present in the subarea. The statistical significance of the trend at each well was evaluated with the Mann-Kendall significance test to the 95% confidence level. The Significant Trend is the average of the significant trends at each well in each subarea, where a minimum of three wells with a significant trend are present. The percent of wells with a significant trend is evaluated based on all the wells included in the Overall Trend calculation. The listed WRIA numbers and water systems are those that have at least a partial overlap with the listed subareas.

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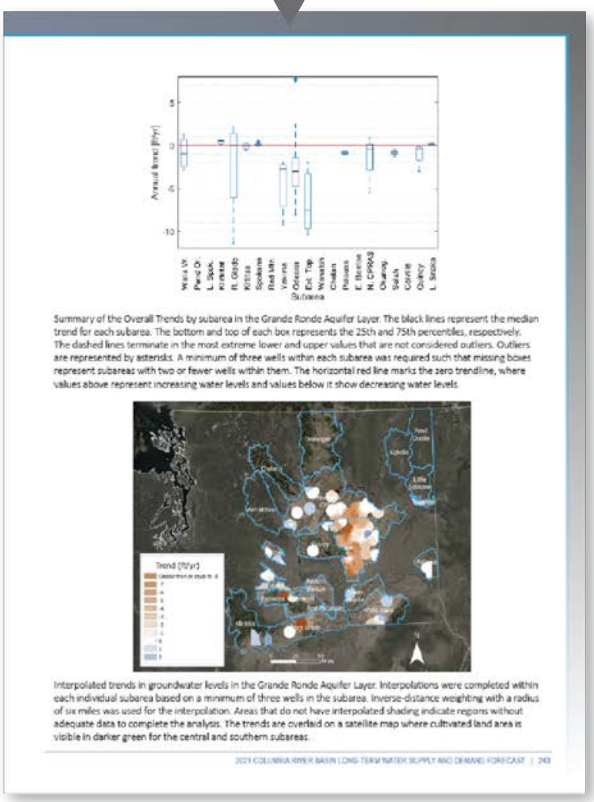

Summary of the Overall Trends by subarea in the Grande Ronde Aquifer Layer. The black lines represent the median trend for each subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. A minimum of three wells within each subarea was required such that missing boxes represent subareas with two or fewer wells within them. The horizontal red line marks the zero trendline, where values above represent increasing water levels and values below it show decreasing water levels.

Interpolated trends in groundwater levels in the Grande Ronde Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells in the subarea. Inverse-distance weighting with a radius of six miles was used for the interpolation. Areas that do not have interpolated shading indicate regions without adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.

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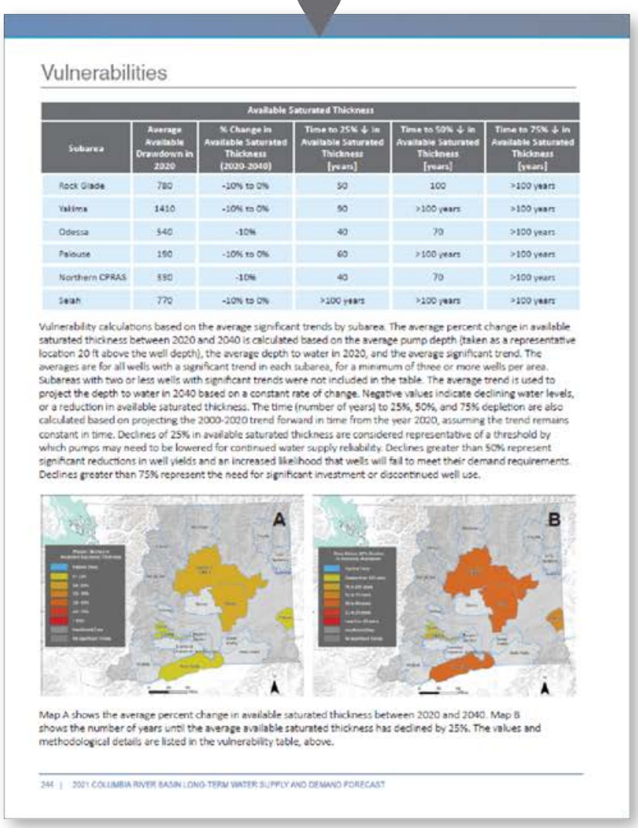
The Available Saturated Thickness Table shows vulnerability according to average significant trends in available saturated thickness by subarea for the given aquifer layer. Available saturated thickness represents how much water level drawdown in wells can be accommodated during pumping without it drawing down below the pump intake. The table shows the amount of average available drawdown in 2020 and the estimated percent change in available saturated thickness from 2020 to 2040 and the number of years before available saturated thickness declines by 25, 50, and 75%, which represent increasingly challenging markers for wells to meet demand requirements.

The Available Saturated Thickness Maps are a spatial representation of the first two vulnerability columns in the Available Saturated Thickness Table. Map A (left) shows the average percent change in available saturated thickness by subarea between 2020 and 2040 and Map B (right) shows the number of years until average available saturated thickness has declined by 25% by subarea for the given aquifer layer. Darker shades indicate greater vulnerability. Subareas without trend data within the aquifer layer are in gray.



Vulnerabilities

Available Saturated Thickness					
Subarea	Average Available Drawdown in 2020	% Change in Available Saturated Thickness (2020-2040)	Time to 25% ↓ in Available Saturated Thickness [years]	Time to 50% ↓ in Available Saturated Thickness [years]	Time to 75% ↓ in Available Saturated Thickness [years]
Rock Glade	780	-10% to 0%	50	100	>100 years
Yakima	1410	-10% to 0%	90	>100 years	>100 years
Odessa	540	-10%	40	70	>100 years
Palouse	190	-10% to 0%	60	>100 years	>100 years
Northern CPRAS	590	-10%	40	70	>100 years
Selah	770	-10% to 0%	>100 years	>100 years	>100 years

Vulnerability calculations based on the average significant trends by subarea. The average percent change in available saturated thickness between 2020 and 2040 is calculated based on the average pump depth (taken as a representative location 20 ft above the well depth), the average depth to water in 2020, and the average significant trend. The averages are for all wells with a significant trend in each subarea, for a minimum of three or more wells per area. Subareas with two or less wells with significant trends were not included in the table. The average trend is used to project the depth to water in 2040 based on a constant rate of change. Negative values indicate declining water levels, or a reduction in available saturated thickness. The time (number of years) to 25%, 50%, and 75% depletion are also calculated based on projecting the 2000-2020 trend forward in time from the year 2020, assuming the trend remains constant in time. Declines of 25% in available saturated thickness are considered representative of a threshold by which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use.

Map A shows the average percent change in available saturated thickness between 2020 and 2040. Map B shows the number of years until the average available saturated thickness has declined by 25%. The values and methodological details are listed in the vulnerability table, above.

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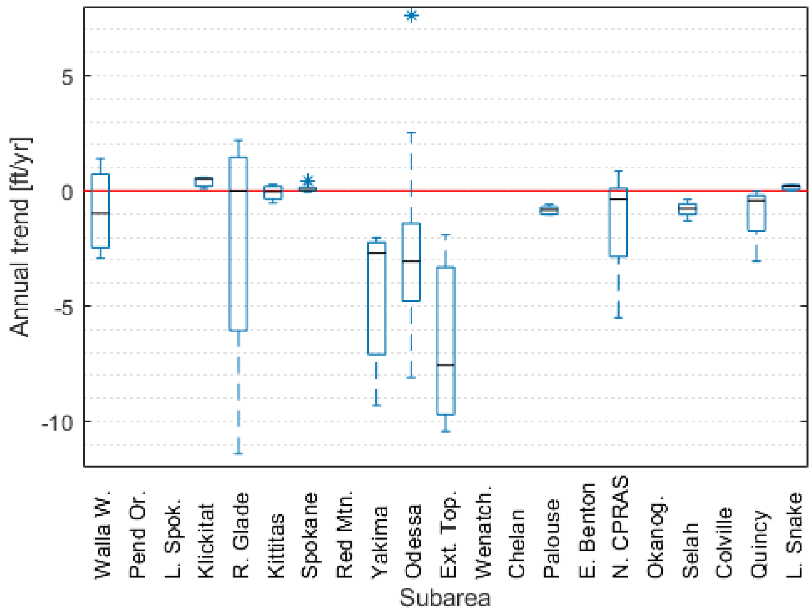
GRANDE RONDE AQUIFER LAYER

- The steepest declines are in the Yakima Basin, followed by the Odessa area.
- Steep water level declines in the Yakima Basin are concentrated in Black Rock/Moxee area and in the Rattlesnake Hills.
- Declines are widespread in Odessa Subarea and extend north into the southern part of Northern CPRAS area.
- Highest vulnerabilities are in Odessa and Northern CPRAS. Average trends are relatively shallow in the northern CPRAS, but vulnerability is high due to the shallow depth of wells included in the study.

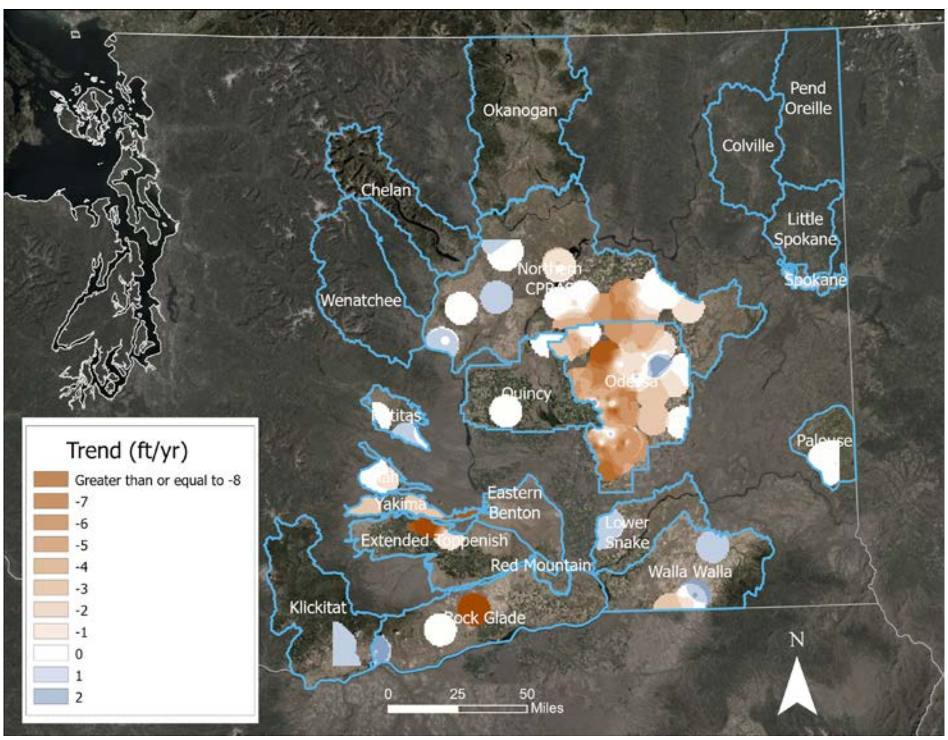
Trends

Subarea	Overall Trend [ft/yr]	Significant Trend [ft/yr]	% of Wells with a Significant Trend	WRIA #	Water Systems in the Subarea
Walla Walla	-0.9 ± 2.0	Insufficient data	-	32	Dayton, College Place
Klickitat	0.4 ± 0.3	Insufficient data	-	30	Goldendale
Rock Glade	-2.3 ± 6.2	-3.8 ± 6.6	75%	31	Kennewick
Kittitas	-0.1 ± 0.4	No sig. trends	-	39	Ellensburg
Spokane	0.1 ± 0.2	Insufficient data	-	54, 55, 57	Spokane
Yakima	-4.3 ± 2.8	-4 ± 2.7	91%	37	Yakima
Odessa	-3.1 ± 2.8	-3.6 ± 2.5	82%	34, 36, 41, 42, 43	Connel
Extended Toppenish	-6.6 ± 4.3	Insufficient data	-	37	Zillah, Sunnyside, Grandview, Benton City
Palouse	-0.8 ± 0.2	-0.8 ± 0.2	100%	34	Colfax, Pullman
Northern CPRAS	-1.3 ± 1.9	-2.3 ± 2.2	49%	42, 43, 44, 50	-
Selah	-0.8 ± 0.4	-0.8 ± 0.4	100%	38, 39	-
Quincy	-1.0 ± 1.4	Insufficient data	-	41, 42	Quincy, Moses Lake, Soap Lake
Lower Snake	0.2 ± 0.1	No sig. trends	-	33	-

Summary of trend values within the aquifer layer. The trend value was calculated between 2000 and 2020 for each well within the listed subarea that had a minimum of 8 Spring high water level measurements within this time frame, using the Sen-Slope Estimator. The Overall Trend was calculated as the average trend value within each subarea if a minimum of three wells was present in the subarea. The statistical significance of the trend at each well was evaluated with the Mann-Kendall significance test to the 95% confidence level. The Significant Trend is the average of the significant trends at each well in each subarea, where a minimum of three wells with a significant trend are present. The percent of wells with a significant trend is evaluated based on all the wells included in the Overall Trend calculation. The listed WRIA numbers and water systems are those that have at least a partial overlap with the listed subareas.



Summary of the Overall Trends by subarea in the Grande Ronde Aquifer Layer. The black lines represent the median trend for each subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. A minimum of three wells within each subarea was required such that missing boxes represent subareas with two or fewer wells within them. The horizontal red line marks the zero trendline, where values above represent increasing water levels and values below it show decreasing water levels.

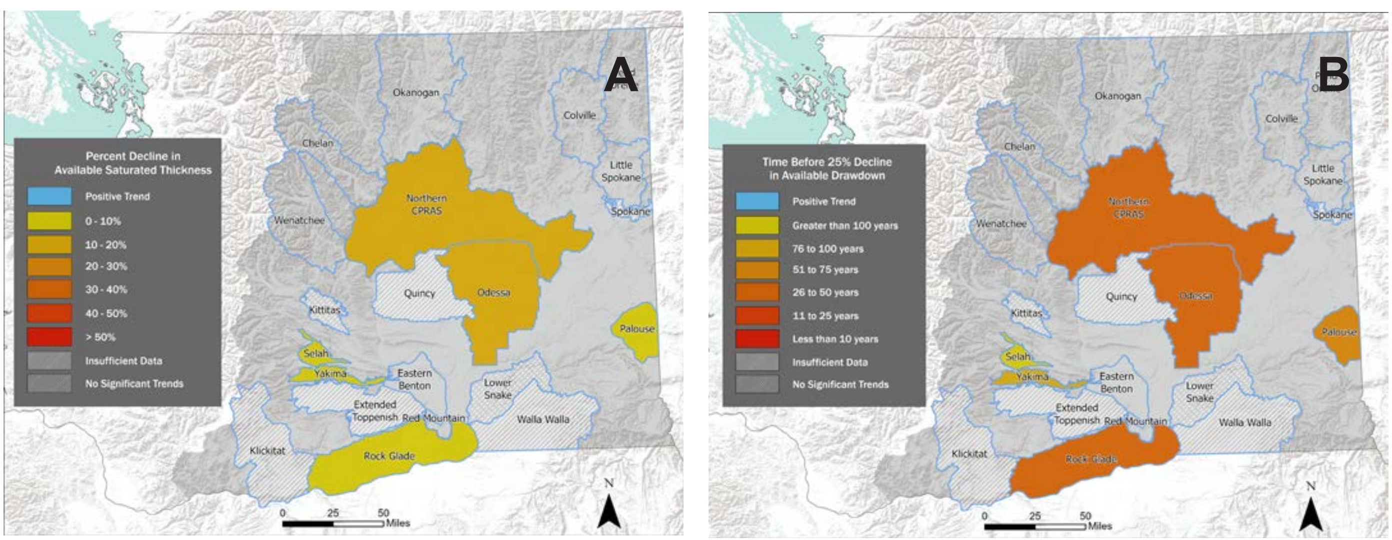


Interpolated trends in groundwater levels in the Grande Ronde Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells in the subarea. Inverse-distance weighting with a radius of six miles was used for the interpolation. Areas that do not have interpolated shading indicate regions without adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.

Vulnerabilities

Available Saturated Thickness					
Subarea	**Average Available Drawdown in 2020**	**% Change in Available Saturated Thickness (2020-2040)**	**Time to 25% ↓ in Available Saturated Thickness [years]**	**Time to 50% ↓ in Available Saturated Thickness [years]**	**Time to 75% ↓ in Available Saturated Thickness [years]**
Rock Glade	780	-10% to 0%	50	100	>100 years
Yakima	1410	-10% to 0%	90	>100 years	>100 years
Odessa	540	-10%	40	70	>100 years
Palouse	190	-10% to 0%	60	>100 years	>100 years
Northern CPRAS	330	-10%	40	70	>100 years
Selah	770	-10% to 0%	>100 years	>100 years	>100 years

Vulnerability calculations based on the average significant trends by subarea. The average percent change in available saturated thickness between 2020 and 2040 is calculated based on the average pump depth (taken as a representative location 20 ft above the well depth), the average depth to water in 2020, and the average significant trend. The averages are for all wells with a significant trend in each subarea, for a minimum of three or more wells per area. Subareas with two or less wells with significant trends were not included in the table. The average trend is used to project the depth to water in 2040 based on a constant rate of change. Negative values indicate declining water levels, or a reduction in available saturated thickness. The time (number of years) to 25%, 50%, and 75% depletion are also calculated based on projecting the 2000-2020 trend forward in time from the year 2020, assuming the trend remains constant in time. Declines of 25% in available saturated thickness are considered representative of a threshold by which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use.



Map A shows the average percent change in available saturated thickness between 2020 and 2040. Map B shows the number of years until the average available saturated thickness has declined by 25%. The values and methodological details are listed in the vulnerability table, above.

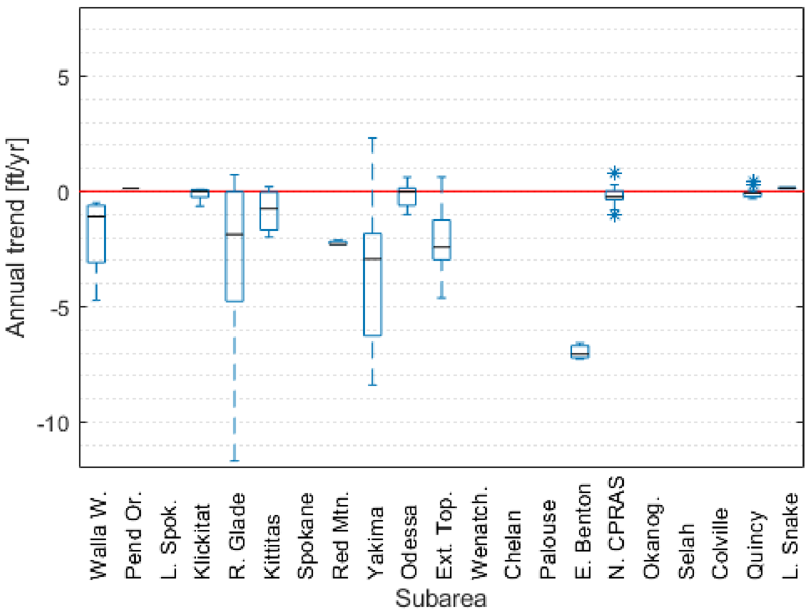
WANAPUM AQUIFER LAYER

- The largest spread of trend values exists in the Wanapum Aquifer Layer compared to the other layers.
- Trends are highly variable in the Wanapum Basalts
- There are steep localized water level declines and high vulnerability in the Rock Glade Area, and in the Yakima and Eastern Benton County areas, centered in the Black Rock/Moxee area.
- The Quincy Area has relatively shallow water level declines but vulnerability is high due to shallow depth of wells included in the study.

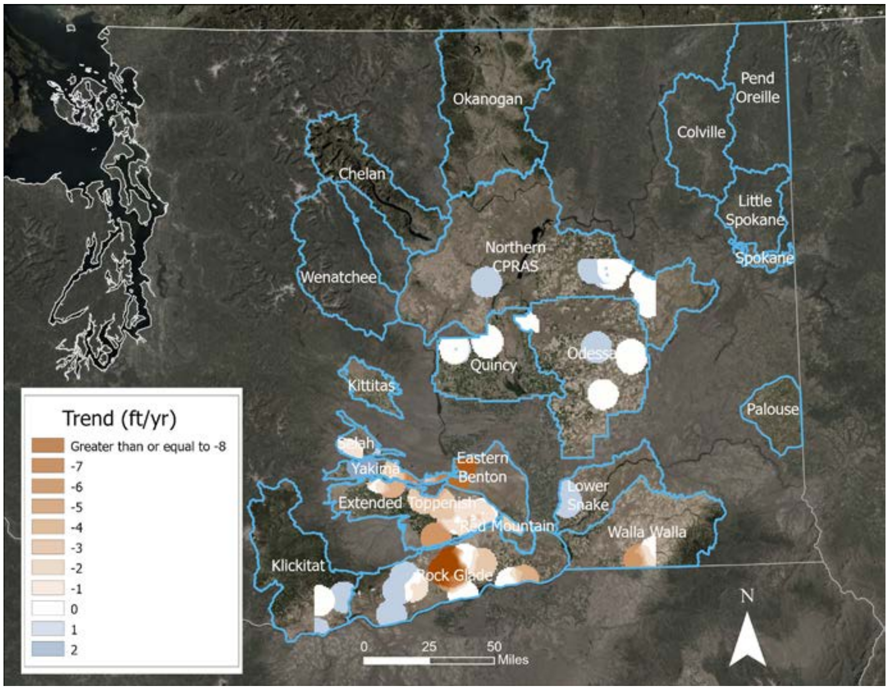
Trends

Subarea	Overall Trend [ft/yr]	Significant Trend [ft/yr]	% of Wells with a Significant Trend	WRIA #	Water Systems in the Subarea
Walla Walla	-1.9 ± 2.0	Insufficient data	-	32	Dayton, College Place
Klickitat	-0.1 ± 0.3	Insufficient data	-	30	Goldendale
Rock Glade	-3.3 ± 4.5	-5.3 ± 4.4	64%	31	Kennewick
Kittitas	-0.8 ± 1.1	Insufficient data	-	39	Ellensburg
Red Mountain	-2.2 ± 0.1	-2.2 ± 0.1	100%	37	-
Yakima	-3.9 ± 3.0	-4.2 ± 3.2	86%	37	Yakima
Odessa	-0.2 ± 0.6	-0.3 ± 0.8	57%	34, 36, 41, 42, 43	Connel
Extended Toppenish	-2.1 ± 1.4	-2.5 ± 1.3	75%	37	Zillah, Sunnyside, Grandview, Benton City
Eastern Benton	-7.0 ± 0.4	-7.0 ± 0.4	100%	37, 40	West Richland
Northern CPRAS	-0.2 ± 0.4	-0.8 ± 0.3	14%	42, 43, 44, 50	-
Quincy	-0.1 ± 0.2	-0.2 ± 0.2	44%	41, 42	Quincy, Moses Lake, Soap Lake
Lower Snake	0.1 ± 0.0	No sig. trends	-	33	-

Summary of trend values within the aquifer layer. The trend value was calculated between 2000 and 2020 for each well within the listed subarea that had a minimum of 8 Spring high water level measurements within this time frame, using the Sen-Slope Estimator. The Overall Trend was calculated as the average trend value within each subarea if a minimum of three wells was present in the subarea. The statistical significance of the trend at each well was evaluated with the Mann-Kendall significance test to the 95% confidence level. The Significant Trend is the average of the significant trends at each well in each subarea, where a minimum of three wells with a significant trend are present. The percent of wells with a significant trend is evaluated based on all the wells included in the Overall Trend calculation. The listed WRIA numbers and water systems are those that have at least a partial overlap with the listed subareas.



Summary of the Overall Trends by subarea in the Wanapum Layer. The black lines represent the median trend for each subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. A minimum of three wells within each subarea was required such that missing boxes represent subareas with two or fewer wells within them. The horizontal red line marks the zero trendline, where values above represent increasing water levels and values below it show decreasing water levels.

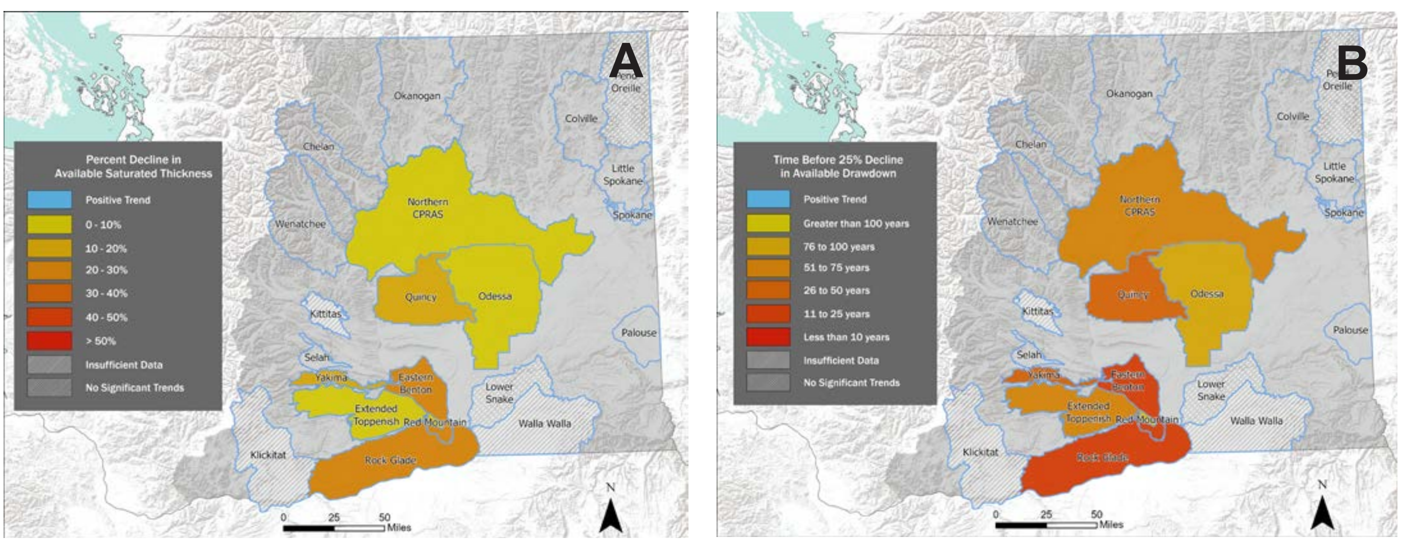


Interpolated trends in groundwater levels in the Wanapum Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells in the subarea. Inverse-distance weighting with a radius of six miles was used for the interpolation. Areas that do not have interpolated shading indicate regions without adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.

Vulnerabilities

Available Saturated Thickness					
Subarea	Average Available Drawdown in 2020	% Change in Available Saturated Thickness (2020-2040)	Time to 25% ↓ in Available Saturated Thickness [years]	Time to 50% ↓ in Available Saturated Thickness [years]	Time to 75% ↓ in Available Saturated Thickness [years]
Rock Glade	510	-20%	20	50	70
Red Mountain	990	-10% to 0%	>100 years	>100 years	>100 years
Yakima	760	-10%	50	90	>100 years
Odessa	100	-10% to 0%	100	>100 years	>100 years
Extended Toppenish	560	-10% to 0%	60	>100 years	>100 years
Eastern Benton	680	-20%	20	50	70
Northern CPRAS	190	-10% to 0%	60	>100 years	>100 years
Quincy	20	-20%	30	50	80

Vulnerability calculations based on the average significant trends by subarea. The average percent change in available saturated thickness between 2020 and 2040 is calculated based on the average pump depth (taken as a representative location 20 ft above the well depth), the average depth to water in 2020, and the average significant trend. The averages are for all wells with a significant trend in each subarea, for a minimum of three or more wells per area. Subareas with two or less wells with significant trends were not included in the table. The average trend is used to project the depth to water in 2040 based on a constant rate of change. Negative values indicate declining water levels, or a reduction in available saturated thickness. The time (number of years) to 25%, 50%, and 75% depletion are also calculated based on projecting the 2000-2020 trend forward in time from the year 2020, assuming the trend remains constant in time. Declines of 25% in available saturated thickness are considered representative of a threshold by which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use.



Map A shows the average percent change in available saturated thickness between 2020 and 2040. Map B shows the number of years until the average available saturated thickness has declined by 25%. The values and methodological details are listed in the vulnerability table, above.

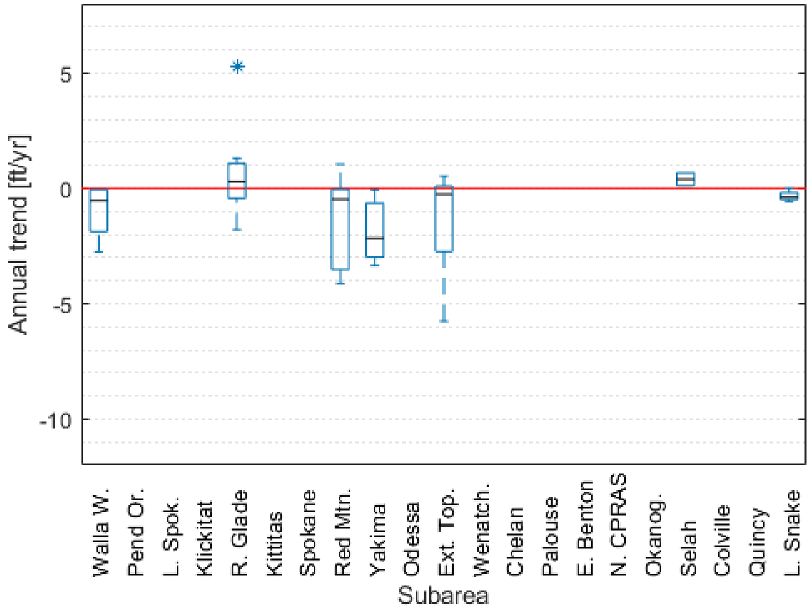
SADDLE MOUNTAIN AQUIFER LAYER

- The steepest water level declines and highest vulnerability in the Saddle Mountain Basalts are in the Yakima Basin (Yakima, Extended Toppenish, Red Mountain).

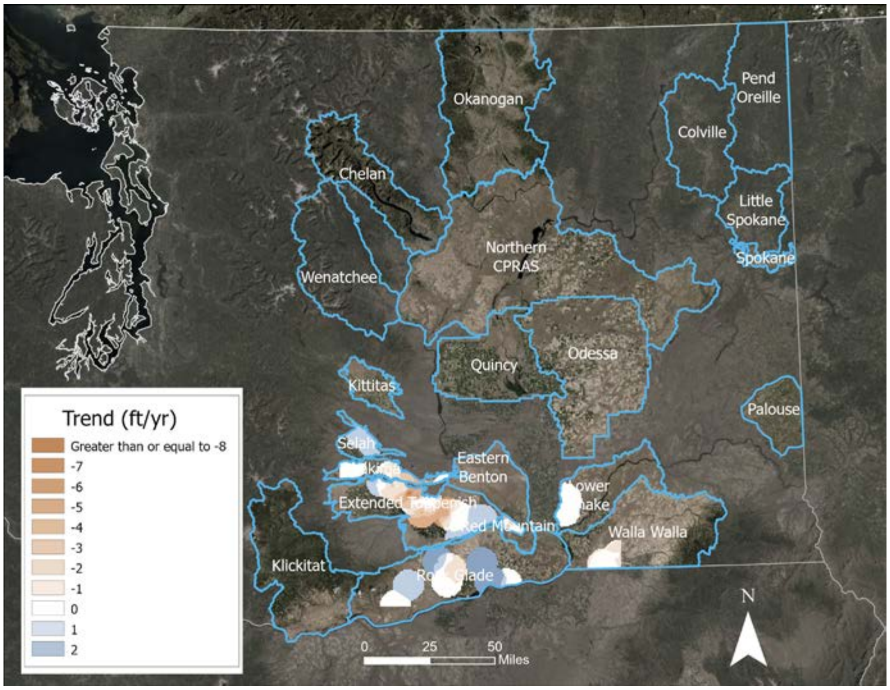
Trends

Subarea	Overall Trend [ft/yr]	Significant Trend [ft/yr]	% of Wells with a Significant Trend	WRIA #	Water Systems in the Subarea
Walla Walla	-1.0 ± 1.3	Insufficient data	-	32	Dayton, College Place
Rock Glade	0.6 ± 2	1.0 ± 2.7	56%	31	Kennewick
Red Mountain	-1.5 ± 2.2	-2.6 ± 1.9	60%	37	-
Yakima	-1.8 ± 1.3	-2.2 ± 1.1	67%	37	Yakima
Extended Toppenish	-1.2 ± 1.9	-2.4 ± 1.8	36%	37	Zillah, Sunnyside, Grandview, Benton City
Selah	0.4 ± 0.4	No sig. trends	-	38, 39	-
Lower Snake	-0.3 ± 0.2	No sig. trends	-	33	-

Summary of trend values within the aquifer layer. The trend value was calculated between 2000 and 2020 for each well within the listed subarea that had a minimum of 8 Spring high water level measurements within this time frame, using the Sen-Slope Estimator. The Overall Trend was calculated as the average trend value within each subarea if a minimum of three wells was present in the subarea. The statistical significance of the trend at each well was evaluated with the Mann-Kendall significance test to the 95% confidence level. The Significant Trend is the average of the significant trends at each well in each subarea, where a minimum of three wells with a significant trend are present. The percent of wells with a significant trend is evaluated based on all the wells included in the Overall Trend calculation. The listed WRIA numbers and water systems are those that have at least a partial overlap with the listed subareas.



Summary of the Overall Trends by subarea in the Saddle Mountain Aquifer Layer. The black lines represent the median trend for each subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. A minimum of three wells within each subarea was required such that missing boxes represent subareas with two or fewer wells within them. The horizontal red line marks the zero trendline, where values above represent increasing water levels and values below it show decreasing water levels.

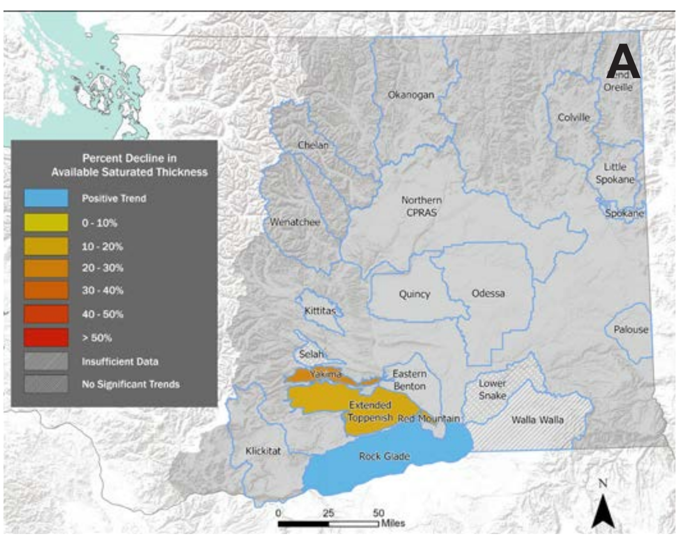


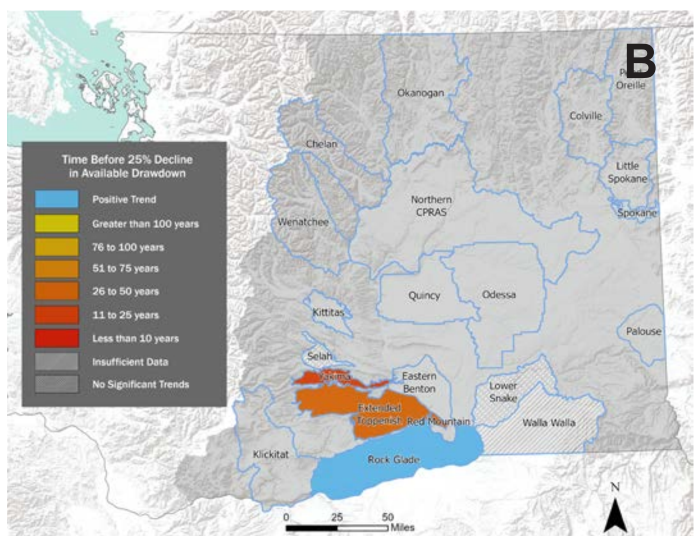
Interpolated trends in groundwater levels in the Saddle Mountain Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells in the subarea. Inverse-distance weighting with a radius of six miles was used for the interpolation. Areas that do not have interpolated shading indicate regions without adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.

Vulnerabilities

Available Saturated Thickness					
Subarea	Average Available Drawdown in 2020	% Change in Available Saturated Thickness (2020-2040)	Time to 25% ↓ in Available Saturated Thickness [years]	Time to 50% ↓ in Available Saturated Thickness [years]	Time to 75% ↓ in Available Saturated Thickness [years]
Rock Glade	160	Positive trend	Positive trend	Positive trend	Positive trend
Red Mountain	340	-20%	30	60	100
Yakima	170	-30%	20	40	60
Extended Toppenish	370	-10%	40	80	>100 years

Vulnerability calculations based on the average significant trends by subarea. The average percent change in available saturated thickness between 2020 and 2040 is calculated based on the average pump depth (taken as a representative location 20 ft above the well depth), the average depth to water in 2020, and the average significant trend. The averages are for all wells with a significant trend in each subarea, for a minimum of three or more wells per area. Subareas with two or less wells with significant trends were not included in the table. The average trend is used to project the depth to water in 2040 based on a constant rate of change. Negative values indicate declining water levels, or a reduction in available saturated thickness. The time (number of years) to 25%, 50%, and 75% depletion are also calculated based on projecting the 2000-2020 trend forward in time from the year 2020, assuming the trend remains constant in time. Declines of 25% in available saturated thickness are considered representative of a threshold by which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use.





Map A shows the average percent change in available saturated thickness between 2020 and 2040. Map B shows the number of years until the average available saturated thickness has declined by 25%. The values and methodological details are listed in the vulnerability table, above.

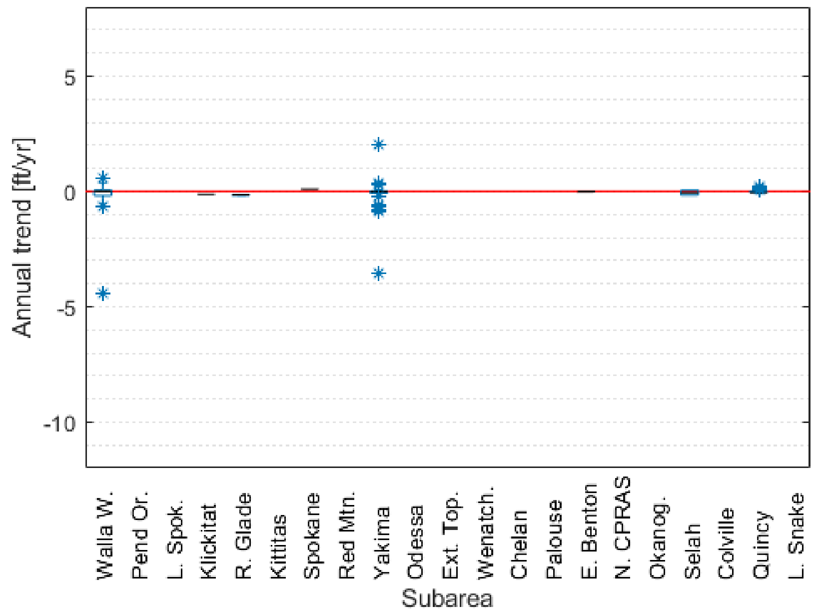
OVERBURDEN AQUIFER LAYER

- The overburden aquifers are generally more closely managed due to a high degree of hydraulic connection to streams and rivers.
- The Walla Walla area has the highest vulnerability and steepest water level declines.

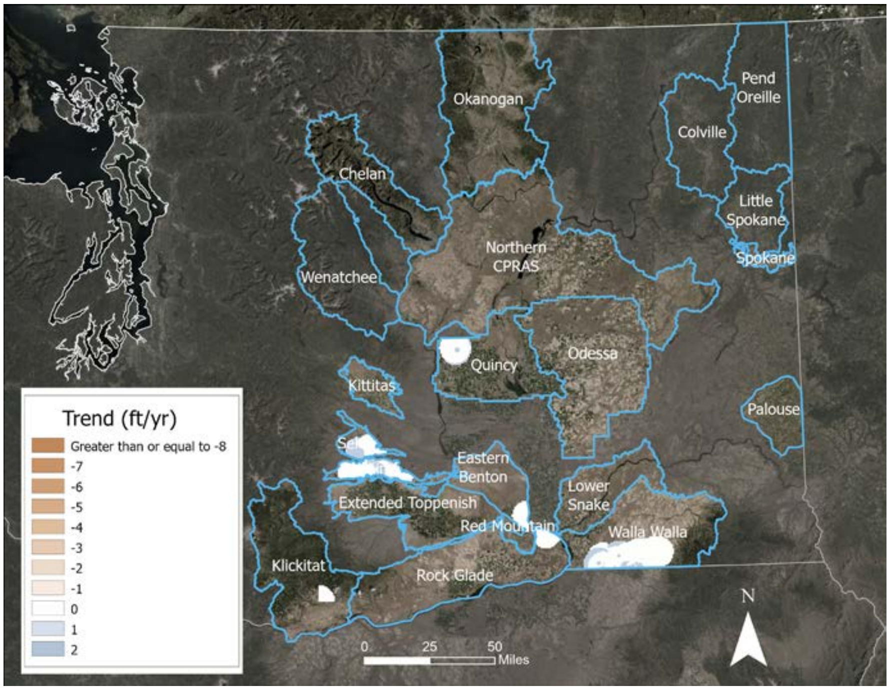
Trends

Subarea	Overall Trend [ft/yr]	Significant Trend [ft/yr]	% of Wells with a Significant Trend	WRIA #	Water Systems in the Subarea
Walla Walla	-0.2 ± 0.7	-1.0 ± 2.3	9%	32	Dayton, College Place
Klickitat	-0.1 ± 0.0	No sig. trends	-	30	Goldendale
Rock Glade	-0.2 ± 0.0	No sig. trends	-	31	Kennewick
Spokane	0.1 ± 0.0	No sig. trends	-	54, 55, 57	Spokane
Yakima	-0.1 ± 0.8	-0.5 ± 1.5	30%	37	Yakima
Eastern Benton	0.0 ± 0.0	No sig. trends	-	37, 40	West Richland
Selah	-0.1 ± 0.2	Insufficient data	-	38, 39	-
Quincy	0.0 ± 0.1	No sig. trends	-	41, 42	Quincy, Moses Lake, Soap Lake

Summary of trend values within the aquifer layer. The trend value was calculated between 2000 and 2020 for each well within the listed subarea that had a minimum of 8 Spring high water level measurements within this time frame, using the Sen-Slope Estimator. The Overall Trend was calculated as the average trend value within each subarea if a minimum of three wells was present in the subarea. The statistical significance of the trend at each well was evaluated with the Mann-Kendall significance test to the 95% confidence level. The Significant Trend is the average of the significant trends at each well in each subarea, where a minimum of three wells with a significant trend are present. The percent of wells with a significant trend is evaluated based on all the wells included in the Overall Trend calculation. The listed WRIA numbers and water systems are those that have at least a partial overlap with the listed subareas.



Summary of the Overall Trends by subarea in the Overburden Aquifer Layer. The black lines represent the median trend for each subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. A minimum of three wells within each subarea was required such that missing boxes represent subareas with two or fewer wells within them. The horizontal red line marks the zero trendline, where values above represent increasing water levels and values below it show decreasing water levels.

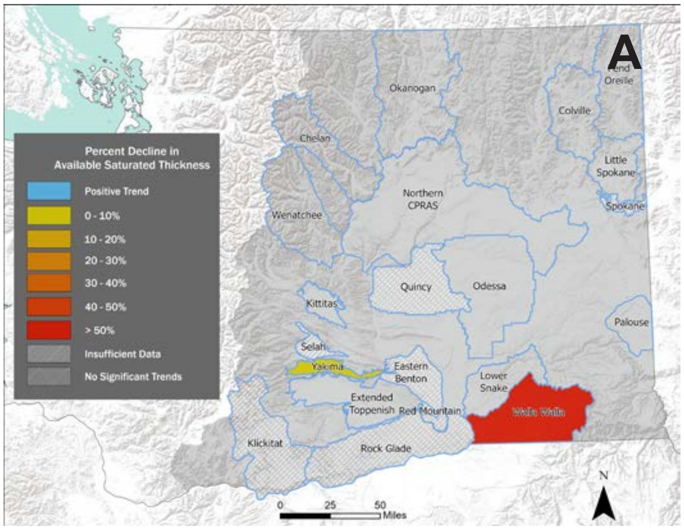


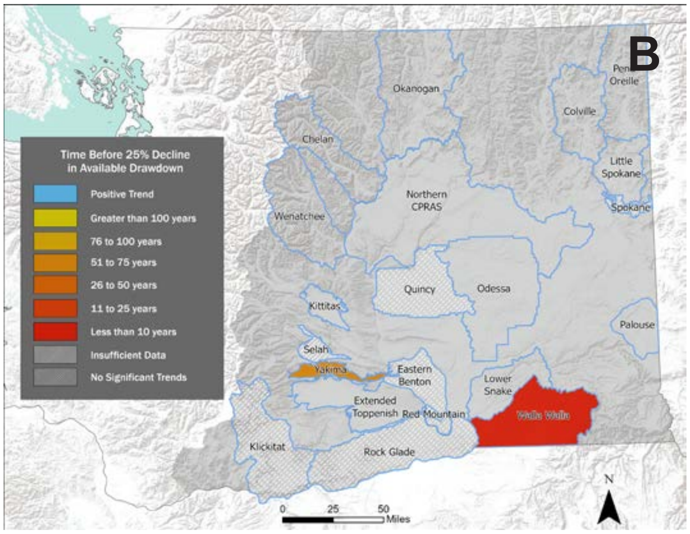
Interpolated trends in groundwater levels in the Overburden Aquifer Layer. Interpolations were completed within each individual subarea based on a minimum of three wells in the subarea. Inverse-distance weighting with a radius of six miles was used for the interpolation. Areas that do not have interpolated shading indicate regions without adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.

Vulnerabilities

Available Saturated Thickness					
Subarea	**Average Available Drawdown in 2020**	**% Change in Available Saturated Thickness (2020-2040)**	**Time to 25% ↓ in Available Saturated Thickness [years]**	**Time to 50% ↓ in Available Saturated Thickness [years]**	**Time to 75% ↓ in Available Saturated Thickness [years]**
Walla Walla	40	-50%	10	20	30
Yakima	120	-10% to 0%	60	>100 years	>100 years

Vulnerability calculations based on the average significant trends by subarea. The average percent change in available saturated thickness between 2020 and 2040 is calculated based on the average pump depth (taken as a representative location 20 ft above the well depth), the average depth to water in 2020, and the average significant trend. The averages are for all wells with a significant trend in each subarea, for a minimum of three or more wells per area. Subareas with two or less wells with significant trends were not included in the table. The average trend is used to project the depth to water in 2040 based on a constant rate of change. Negative values indicate declining water levels, or a reduction in available saturated thickness. The time (number of years) to 25%, 50%, and 75% depletion are also calculated based on projecting the 2000-2020 trend forward in time from the year 2020, assuming the trend remains constant in time. Declines of 25% in available saturated thickness are considered representative of a threshold by which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use.





Map A shows the average percent change in available saturated thickness between 2020 and 2040. Map B shows the number of years until the average available saturated thickness has declined by 25%. The values and methodological details are listed in the vulnerability table, above.

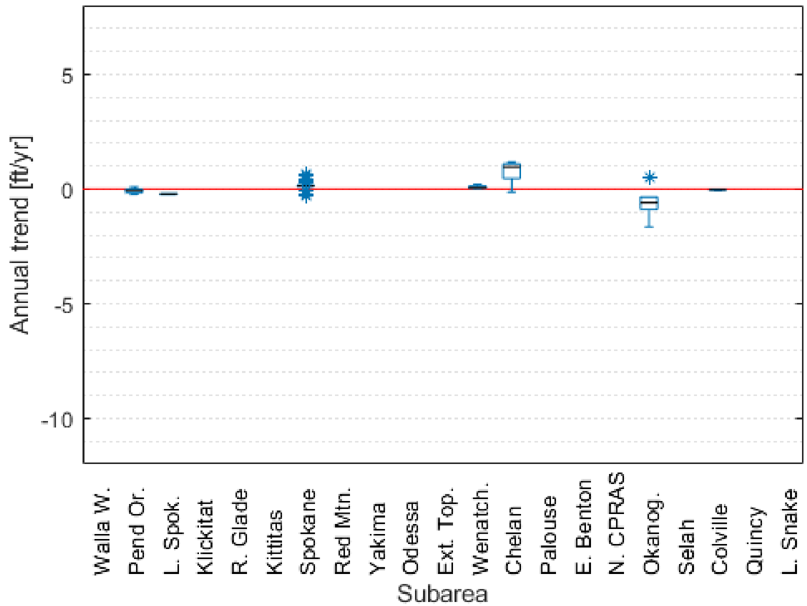
OUTSIDE CPRAS

- Data is sparse outside the CPRAS aquifers and the study identified few significant trends
- The Okanogan Area has relatively shallow water level declines compared to the CPRAS aquifers, but vulnerability is high due to the shallow depth of wells included in the study.

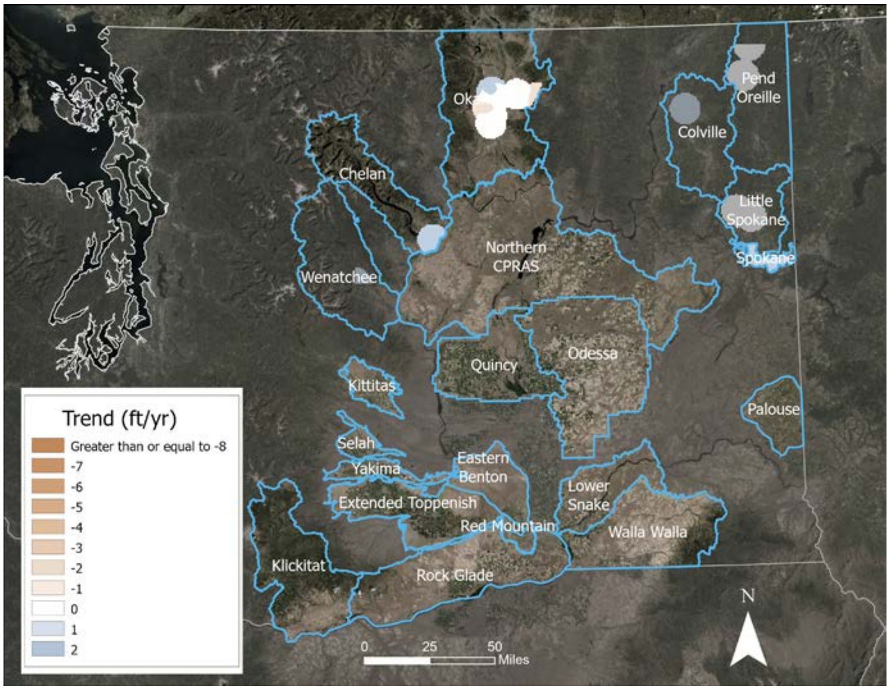
Trends

Subarea	Overall Trend [ft/yr]	Significant Trend [ft/yr]	% of Wells with a Significant Trend	WRIA #	Water Systems in the Subarea
Pend Oreille	-0.1 ± 0.1	No sig. trends	-	62	Newport
Little Spokane	-0.2 ± 0.0	Insufficient data	-	55	Deer Park
Spokane	0.2 ± 0.1	0.5 ± 0.1	2%	-	-
Wenatchee	0.1 ± 0.1	No sig. trends	-	45	Leavenworth, Wenatchee
Chelan	0.8 ± 0.5	Insufficient data	-	47	-
Okanogan	-0.6 ± 0.6	-0.8 ± 0.5	75%	49	Oroville, Omak
Colville	0.0 ± 0.0	No sig. trends	-	59	Kettle Falls, Colville, Chewelah

Summary of trend values Outside CPRAS. The trend value was calculated between 2000 and 2020 for each well within the listed subarea that had a minimum of 8 Spring high water level measurements within this time frame, using the Sen-Slope Estimator. The Overall Trend was calculated as the average trend value within each subarea if a minimum of three wells was present in the subarea. The statistical significance of the trend at each well was evaluated with the Mann-Kendall significance test to the 95% confidence level. The Significant Trend is the average of the significant trends at each well in each subarea, where a minimum of three wells with a significant trend are present. The percent of wells with a significant trend is evaluated based on all the wells included in the Overall Trend calculation. The listed WRIA numbers and water systems are those that have at least a partial overlap with the listed subareas.



Summary of the Overall Trends by subarea in the Outside CPRAS. The black lines represent the median trend for each subarea. The bottom and top of each box represents the 25th and 75th percentiles, respectively. The dashed lines terminate in the most extreme lower and upper values that are not considered outliers. Outliers are represented by asterisks. A minimum of three wells within each subarea was required such that missing boxes represent subareas with two or fewer wells within them. The horizontal red line marks the zero trendline, where values above represent increasing water levels and values below it show decreasing water levels.

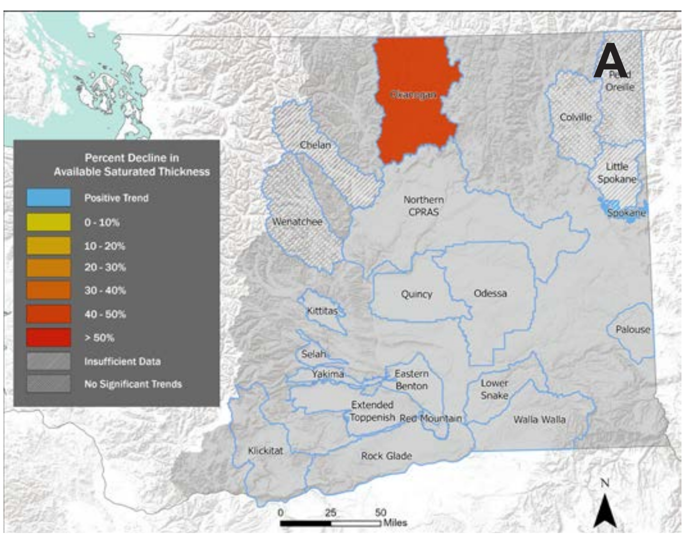


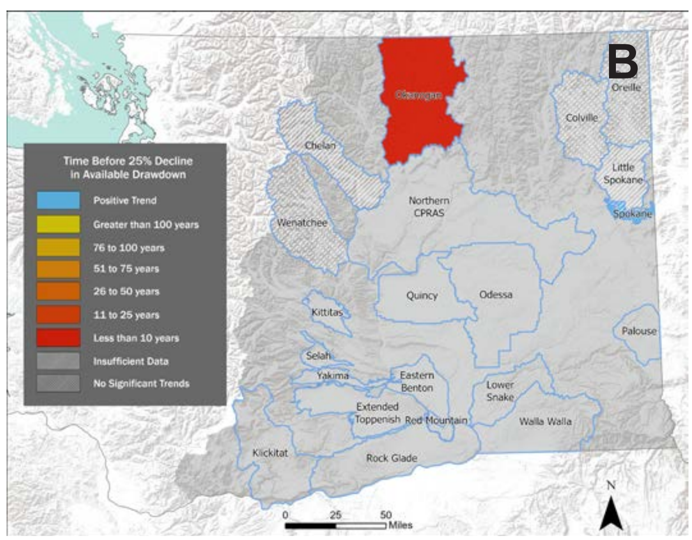
Interpolated trends in groundwater levels Outside CPRAS. Interpolations were completed within each individual subarea based on a minimum of three wells in the subarea. Inverse-distance weighting with a radius of six miles was used for the interpolation. Areas that do not have interpolated shading indicate regions without adequate data to complete the analysis. The trends are overlaid on a satellite map where cultivated land area is visible in darker green for the central and southern subareas.

Vulnerabilities

Available Saturated Thickness					
Subarea	**Average Available Drawdown in 2020**	**% Change in Available Saturated Thickness (2020-2040)**	**Time to 25% ↓ in Available Saturated Thickness [years]**	**Time to 50% ↓ in Available Saturated Thickness [years]**	**Time to 75% ↓ in Available Saturated Thickness [years]**
Spokane	30	Positive trend	Positive trend	Positive trend	Positive trend
Okanogan	30	-50%	10	20	30

Vulnerability calculations based on the average significant trends by subarea. The average percent change in available saturated thickness between 2020 and 2040 is calculated based on the average pump depth (taken as a representative location 20 ft above the well depth), the average depth to water in 2020, and the average significant trend. The averages are for all wells with a significant trend in each subarea, for a minimum of three or more wells per area. Subareas with two or less wells with significant trends were not included in the table. The average trend is used to project the depth to water in 2040 based on a constant rate of change. Negative values indicate declining water levels, or a reduction in available saturated thickness. The time (number of years) to 25%, 50%, and 75% depletion are also calculated based on projecting the 2000-2020 trend forward in time from the year 2020, assuming the trend remains constant in time. Declines of 25% in available saturated thickness are considered representative of a threshold by which pumps may need to be lowered for continued water supply reliability. Declines greater than 50% represent significant reductions in well yields and an increased likelihood that wells will fail to meet their demand requirements. Declines greater than 75% represent the need for significant investment or discontinued well use.





Map A shows the average percent change in available saturated thickness between 2020 and 2040. Map B shows the number of years until the average available saturated thickness has declined by 25%. The values and methodological details are listed in the vulnerability table, above.

GROUNDWATER SUBAREA MANAGEMENT CONTEXT

CHELAN	
Overlapping WRIAs	47
Groundwater Management Area	None
Groundwater Management Policy	2017 Ecology/Chelan PUD amendment to 1992 agreement (groundwater tributary to Lake Chelan subject to 65,000 acre-ft reserve)
Formal Basin Committee	Lake Chelan Watershed Planning Group
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

COLVILLE	
Overlapping WRIAs	59
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	WRIA 59 Planning Group
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

EASTERN BENTON	
Overlapping WRIAs	37, 40
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	Yakima Basin Integrated Plan Workgroup and Subcommittees
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

KITTITAS	
Overlapping WRIAs	39
Groundwater Management Area	None
Groundwater Management Policy	Groundwater is closed to new withdrawals or appropriations including those exempt from permitting (WAC 173-539A)
Formal Basin Committee	Yakima Basin Integrated Plan Workgroup and Subcommittees
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

KLICKITAT	
Overlapping WRIAs	30
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	WRIA 30 Planning Group
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

LITTLE SPOKANE	
Overlapping WRIAs	55
Groundwater Management Area	None
Groundwater Management Policy	Groundwater withdrawals from SVRP aquifer are managed under WAC 173-557 and subject to instream flow rule, including those exempt from permitting
Formal Basin Committee	WRIA 55 Planning Group
Drought Authorization (Ecy, 2018)	None during 2001, 2005, or 2015 droughts

LOWER SNAKE	
Overlapping WRIAs	33
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	None
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

NORTHERN CPRAS	
Overlapping WRIAs	43, 42, 44, 50
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	None
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

ODESSA	
Overlapping WRIAs	43, 36, 41, 34, 42
Groundwater Management Area	Odessa Subarea (WAC 173-128A)
Groundwater Management Policy	Prevent spring static water table from lowering > 300 ft relative to 1967, Limit rate of decline < 30 ft in 3 years, Relinquishment exception due to unavailability of water (ESSB 6151) No well may be drilled closer than one-quarter mile to the centerline of the East Low Canal. (WAC 173-130A)
Formal Basin Committee	Columbia Basin Development League
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

OKANOGAN	
Overlapping WRIAs	49
Groundwater Management Area	Duck Lake GWMA (WAC 173-132)
Groundwater Management Policy	None
Formal Basin Committee	WRIA 49 Planning Group, Methow Watershed Council
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

PALOUSE	
Overlapping WRIAs	34
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	Palouse Basin Aquifer Committee
Drought Authorization (Ecy, 2018)	None during 2001, 2005, or 2015 droughts

PEND OREILLE	
Overlapping WRIAs	62
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	None
Drought Authorization (Ecy, 2018)	None during 2001, 2005, or 2015 droughts

QUINCY	
Overlapping WRIAs	41, 42
Groundwater Management Area	Quincy Subarea (WAC 173-124)
Groundwater Management Policy	The Quincy subarea is divided into two depth zones (shallow and deep) under which different permit requirements apply per WAC 173-134A
Formal Basin Committee	Columbia Basin Development League, Quincy Subarea Technical Committee (WAC 173-134A-100)
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

RED MOUNTAIN	
Overlapping WRIAs	37
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	Yakima Basin Integrated Plan Workgroup and Subcommittees
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

ROCK GLADE	
Overlapping WRIAs	31
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	WRIA 31 Planning Group
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

SELAH	
Overlapping WRIAs	39, 38
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	Yakima Basin Integrated Plan Workgroup and Subcommittees
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

SPOKANE	
Overlapping WRIAs	57, 55, 54
Groundwater Management Area	None
Groundwater Management Policy	Groundwater withdrawals from SVRP aquifer are managed under WAC 173-557 and subject to instream flow rule, including those exempt from permitting.
Formal Basin Committee	Spokane Aquifer Joint Board
Drought Authorization (Ecy, 2018)	None during 2001, 2005, or 2015 droughts

EXTENDED TOPPENISH	
Overlapping WRIAs	37
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	Yakima Basin Integrated Plan Workgroup and Subcommittees
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

WALLA WALLA	
Overlapping WRIAs	32
Groundwater Management Area	None
Groundwater Management Policy	Gravel (overburden) aquifers subject to seasonal closure to further appropriations (WAC 173-532), Walla Walla Water 2050 Strategic Plan (draft pending)
Formal Basin Committee	Walla Walla Water 2050 Strategic Planning Workgroup
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

WENATCHEE	
Overlapping WRIAs	45
Groundwater Management Area	None
Groundwater Management Policy	None
Formal Basin Committee	WRIA 45 Planning Group
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

YAKIMA	
Overlapping WRIAs	37
Groundwater Management Area	Lower Yakima Valley Groundwater Management Area
Groundwater Management Policy	None
Formal Basin Committee	Yakima Basin Integrated Plan Workgroup and Subcommittees
Drought Authorization (Ecy, 2018)	New supplemental wells authorized on a case by case basis during drought years

GLOSSARY

Water Supply

Surface Water Supplies reflect the total amount of surface water generated in a watershed, quantifying the water available for instream 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.

Groundwater Supplies reflect the amount of groundwater (from aquifers) available to meet different water demands. Groundwater supplies were not modeled in the 2021 Forecast. To evaluate vulnerability in groundwater supplies, we estimated trends in depth to groundwater using available data from existing wells. In the integrated modeling of surface water supplies and agricultural water demand, certain assumptions were made about existing groundwater supplies, described in the **Groundwater Irrigation Demand** definition, below.

Historical Supplies indicate surface water supplies modeled for 1986-2015, based on historical climate data. To characterize variability in supplies, historical supply curves are provided for low, median, and high supply conditions. Low, median, and high flow conditions were determined as the 20th, 50th, and 80th percentile conditions for the 30-year time period, respectively.

Forecast Supplies indicate forecasted supplies for the year 2040 and for the year 2070. 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 17 global climate models, obtained using two different assumptions as to how greenhouse gases in the atmosphere are expected to increase, leading to 34 different future climate scenarios. Major reservoir rules were assumed not to change in response to changes in forecasted (2040 or 2070) 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.

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 2040. 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. We hope the evaluation of trends in groundwater levels and the effort to target opportunities for expanding monitoring in existing wells will provide the necessary foundation for integration of surface and groundwater supply modeling in future Forecasts.

Residential Demand represents water used in and around the home and includes water provided by municipal water providers (**Municipal Demand**) and self-supplied water (**Domestic Demand**). For each county in a WRIA, estimates of residential demand were computed as the sum of water for domestic and municipal demands. The source of water can be surface or groundwater.

Domestic Demand includes estimates of water obtained from small water providers (have less than 15 service connections or less than 25 people served per day), or by self-supplied means, such as exempt wells. Domestic demand was only estimated within Washington State and data for self-supplied or publicly supplied demands were obtained from the U.S. Geological Survey. For the purposes of this study, all domestic demands are assumed to come from groundwater. Domestic demand has a consumptive portion and a non-consumptive portion. The non-consumptive portion includes water that is lost through system leakages or septic field drainage. Together, the consumptive and the non-consumptive portion represent domestic demand.

Municipal Demand includes estimates of water delivered through large municipal water provider systems (have 15 or more service connections or 25 or more people served for more than 60 days a year). Municipal demand was only estimated within Washington State and was derived from historical demand information as provided in comprehensive water system plans, that are required for large municipal water providers by Washington State. The source of water can be surface or groundwater. Municipal demand 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 week 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. The Forecast explores possible changes in future demand for hydroelectric power. Estimating what additional demand for power means in terms of demand for instream water depends on many complex factors associated with the facilities that produce that power, and so is beyond the scope of the Forecast.

Historical Water Demand indicates demands modeled for 1986-2015 water years, based on historical climate data. Low, average, and high demand conditions were determined as the 20th, 50th, and 80th percentile demands in that historical time period, respectively.

Forecast Demand indicates demands projected for the 2026-2055 water years, evaluating year-to-year variability expected by 2040. 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 decisions. The climate change effects were explored by modeling demands under 34 climate change scenarios (described in the **Forecast Supplies** definition, above). The effects of trends in agricultural production were explored by modeling three additional scenarios: 1) assuming the current planting dates and the current crop mix remain unchanged, 2) assuming planting dates occur one week earlier by 2040, while the current crop mix remains unchanged, and 3) under earlier planting dates and a projected crop mix that was developed by using a statistical model to extend recent trends in crop mix into the future. In these three future 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 decisions were explored by estimating how much additional water might be available for irrigation by 2040, given planned water development projects.

Other Definitions

Available Saturated Thickness is a measure of groundwater availability for existing well infrastructure and, more specifically, represents how much water level drawdown in wells can be accommodated during pumping without it drawing down below the pump intake. For an individual well, available saturated thickness is estimated as the difference between the depth to the static water level and the depth to that well's pump intake. The depth to the static water level was assumed to be equal to the 2020 spring high water level for that well, which occurs in the spring before pumping starts (see the **Spring High Depth to Water** definition, below). The pump intake was assumed to lie 20 feet above the well bottom. Available saturated thickness values were averaged within subareas in an effort to quantify vulnerability of groundwater supplies.

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.

Groundwater Subareas represent geographic areas with similar hydrogeological characteristics and groundwater connectivity, at a scale similar to the WRIAs, which are delineated based on surface hydrological conditions. Groundwater Subarea boundaries within the Yakima Basin were based on the groundwater basins defined by Ely et al., 2011 . Additional subareas outside the Yakima Basin were defined to correspond to the groundwater management subareas established under WAC 173-100, a combination of WAC 173-100 subarea boundaries and the extent of the Columbia Plateau Regional Aquifer System (CPRAS), as well as WRIA boundaries.

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.

Actual 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.

Spring High Depth to Water represents the groundwater level at a well location during the time of year when it is generally highest and least affected by the dynamic effects of pumping. Generally, these highest groundwater levels are achieved during the spring, before most of the pumping occurs to meet the irrigation and larger summer water needs. Spring High Depth to Water was estimated by selecting the shallowest depth to water below ground surface measured between February through May of a given year, based on a well's water level data records. These Spring High Depth to Water values were the basis for the trend analysis of groundwater levels.

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