US Army Corps
of Engineers®
Portland District

WILLAMETTE VALLEY SYSTEM OPERATIONS AND MAINTENANCE

DRAFT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

APPENDIX F1: QUALITATIVE ASSESSMENT OF CLIMATE CHANGE IMPACTS

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CHAPTER 1 – INTRODUCTION AND BACKGROUND

This appendix document supports the Willamette Valley system (operations) draft environmental impact assessment (WVS DEIS). The climate change assessment herein is derivative of the “Qualitative Assessment of Climate Change Impacts, Willamette River Basin, Oregon” (USACE, 2019). That climate change assessment was prepared for the Portland District Dam Safety, CENWP-ENC-HC.

This qualitative assessment of climate change impacts is required by U.S. Army Corps of Engineers (USACE, “the Corps”) Engineering and Construction Bulletin (ECB) 2018-14 (revision 1, expires 10-Sep 2022), “Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects.” This document supports the Willamette Valley System Operations Environmental Impact Statement (WVS EIS) effort. There are no sea level rise impacts within study area.

This assessment documents the qualitative effects of climate change on hydrology in the region and informs the climate change assessment being performed by the USACE for the Willamette Valley System Environmental Impact Statement (EIS). The original assessment was performed for the USACE Risk Management Center (RMC) to assess the potential impacts and risks drivers which can potentially be attributed to climate change.

USACE projects, programs, missions, and operations have generally proven to be robust enough to accommodate the range of natural climate variability over their operating life spans. However, recent scientific evidence shows that in some places and for some impacts relevant to USACE operations, climate change is shifting the climatological baseline about which that natural climate variability occurs and may be changing the range of that variability as well.

This is relevant to USACE because the assumptions of stationary climatic baselines and a fixed range of natural variability as captured in the historic hydrologic record may no longer be appropriate for long-term projections of the climatologic parameters, which are important in hydrologic assessments for water management operations in watersheds, such as the Willamette River Basin. As part of the EIS, the project delivery team, PDT, identified relevant climate change factors early on. They were:

- Ambient temperature (warming)
- Reservoir evaporation/ reach evapotranspiration (ET) effects
- Precipitation change (shift to abnormal seasonal patterns)
- Seasonal timing change of flow peak and volumes
- Wildfire intensity/frequency increase
- Wildfire- impacts to water quality (increased sediment transport)
- Low summer flow- shortage/volume/frequency

- April 1st, May 1st SWE and seasonal/monthly/regional/elevation snowpack
- Water temperature change (warming)

The above factors were seen as driving the impacts to future flood risk management, fish operations as well as likely effects to recreation, operations, and maintenance (O&M) in the future. Refer to EIS Appendix F2 for additional discussion and analysis of these climate factors.

Relevant climate change factors were consequential for the future climate vulnerability analyses and identification of residual risk. The Corps Climate Preparedness and Response (CPR) Community of Practice (CoP) defines residual risk as the risk that remains after measures have been put into place. The Corps' response to climate change is adaptation focused and formulates measures and alternatives to be as resilient as possible. A more resilient feature is one that is conceptually more resistant to likely future conditions, and/or possesses inherent flexibility to adapt successfully to projected changes.

The Willamette Valley System EIS study affected environment encompasses the Willamette River Basin, to Willamette Falls, at Oregon City. The overall Willamette River basin is Oregon's largest river basin. It contains nearly 70% of Oregon's population, its most productive agricultural land, and significant habitat for anadromous fish populations. The Willamette River Basin drainage area is approximately 11,230 square miles at its downstream confluence with the Columbia River near the City of Portland, OR. The Willamette River Basin falls within the U.S. Geologic Survey (USGS) region 17 and makes up the entirety of the 4-digit Hydrologic Unit Code (HUC) 1709. The watershed is bounded by the Oregon Coast Mountain Range to the west and the Cascade Mountain Range to the east. The river basin is approximately 160 miles in length and 100 miles in width. Elevations within the watershed range from approximately 20 ft above sea level at upper Willamette Falls. to well beyond 10,000 ft in the Cascade Mountain Range. Tidal influence is up to the face of Willamette Falls.

The Corps operates 13 dams and reservoir projects within the Willamette Basin, as part of the Willamette Valley System (WVP). For purposes of this report, WVP is synonymous with the Willamette Valley system, WVS.

The WVS provides function for flood risk management, as well as other congressionally authorized purposes such as: hydropower generation, irrigation, water supply, and ecologic/water-quality supplementation.

The first of the individual dams which constitute the WVP completed construction in 1941 and the last was completed in 1968, with filling complete in 1970. Cumulatively, the WVP provides nearly 1.7 million acre-ft of flood control storage. In addition to the 13 USACE flood risk management projects within the Willamette Basin, there are numerous other dams in the basin. Except for Scoggins Dam on the Tualatin River, all the other dams are run-of-the-river in nature, meaning they contribute have very little flood storage (i.e., flood space).

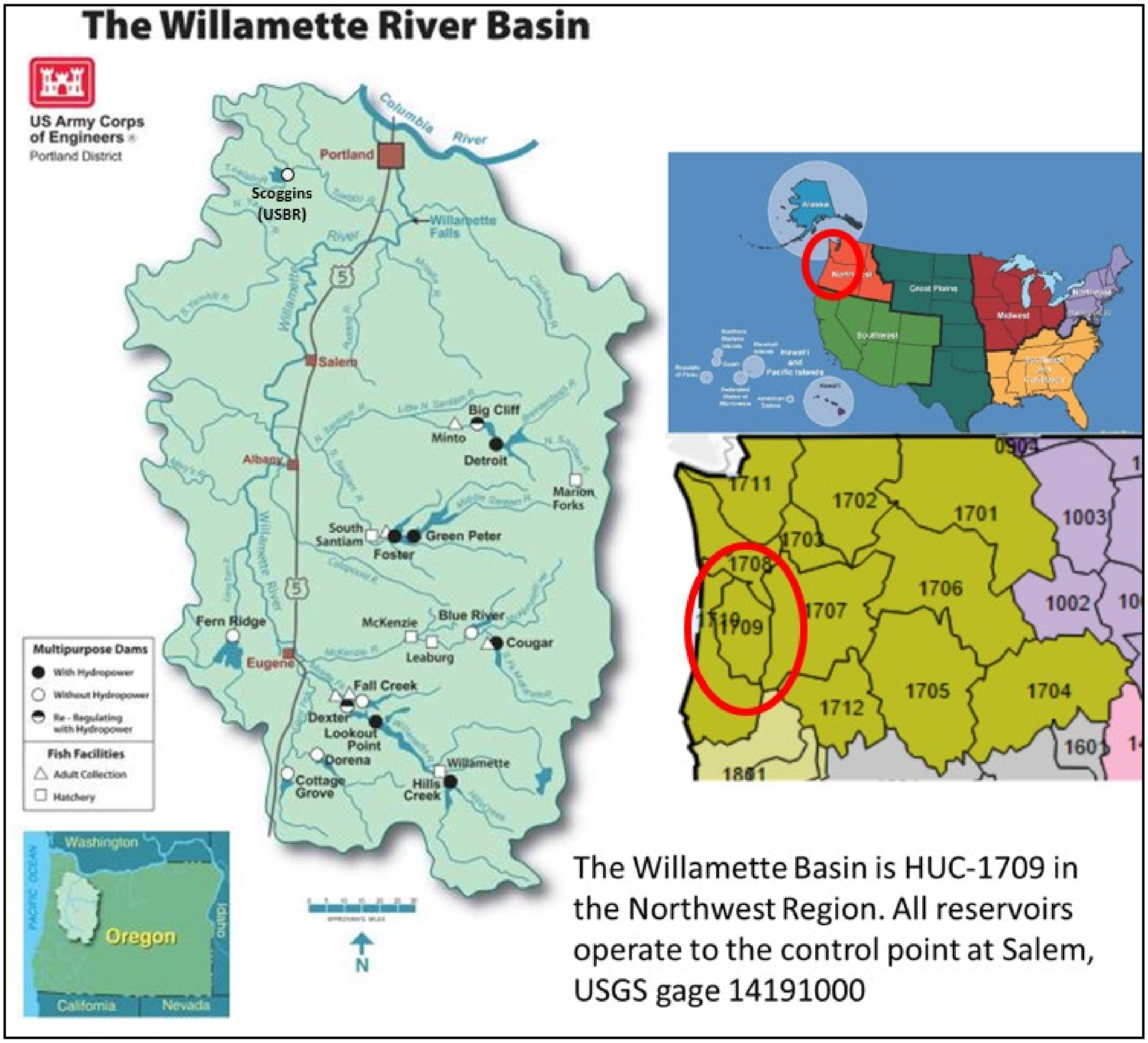


Figure 1-1. Map of the Willamette River Basin

Table 1-1 displays the names, flood storage capacity, top of dam elevation, and date of construction for the 13 USACE reservoir projects within the Willamette Basin, as well as USBR's Scoggins Dam. Scoggins dam is not part of the WVEIS but will be kept in this document as legacy information.

Figure 1-1displays the location of these projects within the watershed. Additionally, the Oregon Climate Change Research Institute (OCCRI 2015), whose report is summarized in the 'Projected Trends in Future Climate' section below, categorizes the reservoirs into 5 hydrologic groups based upon the similarity of their sensitivity and response to various hydrologic and climatic drivers. These reservoir groups are correlated to elevation and shown in Table 1-1. USACE Reservoir Projects within the Willamette Basin. Note that while Blue River Dam is in a group of its own, it appears to respond similarly to climate impacts as the dams in group C. Additional discussion and descriptions of these reservoir groups is found below in the 'Projected Trends in Future Climate and Climate Change' section.

Table 1-1. USACE Reservoir Projects within the Willamette Basin

Reservoir Group	Name of Dam	Flood Control Storage (acre-ft)	Top of Dam Elevation (ft. NGVD29)	Date of Construction
A	Big Cliff Dam	1,740	1,212	1953
A	Cougar Dam	147,800	1,705	1964
A	Detroit Dam	300,253	1,579	1953
A	Hills Creek Dam	199,600	1,548	1961
B	Cottage Grove Dam	29,791	791	1942
B	Dorena Dam	70,420	865	1949
B	Fern Ridge Dam	94,480	382	1942
C	Dexter Dam	12,134	702	1954
C	Fall Creek Dam	113,657	839	1966
C	Lookout Point Dam	337,430	941	1953
D (C)	Blue River Dam	85,500	1,362	1968
E	Foster Dam	29,700	646	1968
E	Green Peter Dam	268,170	1,020	1967
USBR	Scoggins Dam	53,600	313	1975

In total, there are 85 active stream gages distributed throughout the Willamette Basin watershed and approximately 94 additional inactive gages. Many of these gages are affected by WVP regulation and more still, are impacted by upstream impoundment of another sort. To separate out the hydrologic influence of observed climate change from other significant anthropogenic impacts, such as upstream regulation, an effort was made to identify relatively "pristine" gages which are largely free of the effects of watershed modification. These gages represent natural run-of-the-river morphologic conditions, allowing for greater insight into the impacts which may have been caused by climate change. While the pristine gages chosen for analysis were selected primarily because of the lack of regulation within their upstream watershed, preference was also given to sites with lengthy annual peak streamflow period of record and to sites with relatively large drainage areas. Land use change over time, such as urbanization and changing forestry practices, were not considered when selecting pristine gages, which may have some impact on nonstationarity analysis.

In addition to analyzing the relatively pristine gages, various other gages of interest were selected as hydrologically representative of the Willamette Basin. These gages are dispersed spatially throughout the watershed as well as through a range of elevations, as both variables influence the hydrology of the gage. Both observed streamflow data and naturalized/unregulated streamflow data were analyzed in the various toolsets discussed below. The naturalized streamflow datasets represent simulated streamflows with the influence of regulation and irrigation removed. These gages and relevant parameters such as drainage area, peak streamflow period of record (POR) and nearby WVP locations are in Table 1-2. For gages marked as "regulated" in the right most column of the table, both observed peak streamflow measured at the gage as well as simulated naturalized peak streamflow were analyzed. It should be noted that reservoir operation was assumed to be consistent and uniform across the period of regulation. While there have been numerous deviations from the authorized water control plan, these changes were assumed to be relatively minor from a statistical and operational perspective.

The stream gage located at Salem, Oregon is of particular interest to this analysis as Salem is the most downstream, real-time, reservoir regulation control point on the mainstem Willamette River that receives outflow from all thirteen WVP USACE dams. Salem is a major control point used during flood risk management in the flood season, roughly November through June, and the location where minimum flow targets are specified for Fish and Wildlife by the Biological Opinion for April through October. The drainage area for this gage is 7,280 square miles (65% of the 11,200 square miles that encompasses the entire Willamette River Basin). At the Salem gage, daily discharge measurements became available in 1909. Annual peak streamflow records are available from 1893 to 2018, with three earlier data points of historical significance available for 1862, 1881, and 1890. The WVP total drainage areas (areas above all reservoirs) represent 42% of the total Salem drainage area, and about half (51%) of the annual water volume passing through Salem has passed through at least one WVP dam.

Table 1-2. Relevant Gages used in Qualitative Analysis

USGS Gage Num.	USGS Site Name	Reservoir Group	Peak Streamflow POR	Peak Streamflow Observations	Drainage Area	WVP Proximity	Regulated or Pristine?
14191000	WILLAMETTE RIVER AT SALEM, OR	-	1861 - 2017	128	7280	Salem	Regulated
14190500	LUCKIAMUTE RIVER NEAR SUVER, OR	-	1906 - 2016	83	240	-	Pristine
14178000	NO SANTIAM R BLW BOULDER CRK, NR DETROIT, OR	A	1907 - 2017	92	216	-	Pristine
14181500	NORTH SANTIAM RIVER AT NIAGARA, OR	A	1909 - 2017	91	453	Big Cliff, Detroit	Regulated
14153500	COAST FORK WILLAMETTE R BLW COTTAGE GROVE DAM, OR	B	1939 - 2017	79	104	Cottage Grove	Regulated
14154500	ROW RIVER ABOVE PITCHER CREEK, NEAR DORENA, OR	B	1936 - 2016	82	211	-	Pristine
14150000	MIDDLE FORK WILLAMETTE RIVER NEAR DEXTER, OR	C/D	1946 - 2016	71	1001	Lookout Point	Regulated
14187200	SOUTH SANTIAM RIVER NEAR FOSTER, OR	E	1974 - 2017	44	557	Foster, Green Peter	Regulated

The first USACE dam in the Willamette basin was completed in 1941 and the last in 1968, with first refill in 1970. Therefore, flow data available at the USGS Salem gage has been influenced by reservoir operations since that time. Scoggins Dam was constructed in 1975 but is located downstream of the Salem gage and is not located at on any of the other gaged tributaries whose streamflow records are being analyzed as part of this study. Thus, Scoggins Dam does not impact the homogeneity of any of the streamflow records being assessed.

Other hydrologic effects on the Salem gage include changing amounts of irrigation within the basin and changes in land use. The areas upstream of Salem have experienced substantial urbanization with an approximate doubling in population over the past 50 years. The rate of population increase has been relatively steady over that time. The Willamette River at Salem is an important downstream location used as a control point for reservoir hydro-regulation and planning purposes. USACE projects in the basin work together to provide flood damage reduction at Salem, along with other local control points in the basin, and all the projects provide supplemental storage during the summer months to help maintain the Biological Opinion required minimum flow targets, including at Salem.

CHAPTER 2 – HISTORIC CLIMATE WITHIN THE WILLAMETTE BASIN

Climate in the Willamette Basin is driven primarily by proximity to the Pacific Ocean. The valley summers are warm and dry, and winters are cool and wet, with extreme winter conditions in the Cascades Mountain reaches on the eastern boundary of the valley. Most precipitation occurs between November and March, with spring snowmelt prolonging runoff into June or July (Willamette Master Water Control Manual, 2017).

Temperature. Annual and diurnal temperature ranges are relatively small because the basin is largely dominated by maritime air from the Pacific Ocean. Mean air temperatures in the Willamette Valley (low elevations) range from about 40° F in January to 68° F in July. Mean mountain temperatures range from about 28° F in January to about 55° F in July. Plates 3-7, Willamette Master Water Control Manual, 2017)

Precipitation. Relatively high precipitation occurs in the Cascade Range, the eastern boundary of the Willamette Basin watershed, reaching 140 inches or more per year. Precipitation in the Valley is considerably less, varying from 35 to 50 inches per year. Most of the precipitation falling as rain in the low elevations. Roughly one-third of the precipitation falls as snow at the 4,000-foot elevation, and more than three-fourths falls at the 7,000-foot elevation. For the entire basin, the average annual precipitation total is about 63 inches. Of this, 60 percent occurs during November through March.

An assessment of observed trends in historic temperature and precipitation was conducted using local climate data available from the National Weather Service at Salem, OR. Data analyzed includes monthly mean and maximum average annual temperature, as well as annual precipitation and monthly maximum annual precipitation. This data, associated trends, and statistical significance values are displayed in Figure 2-1 and Figure 2-2. Statistically significant, increasing trends were identified within the temperature datasets analyzed at a 95% confidence level (p-value < 0.05). Neither of the precipitation datasets analyzed presented a statistically significant trend. Since Salem is only one specific location in the Willamette Valley, regional temperature and precipitation trends is discussed in more detail within the literature review below.

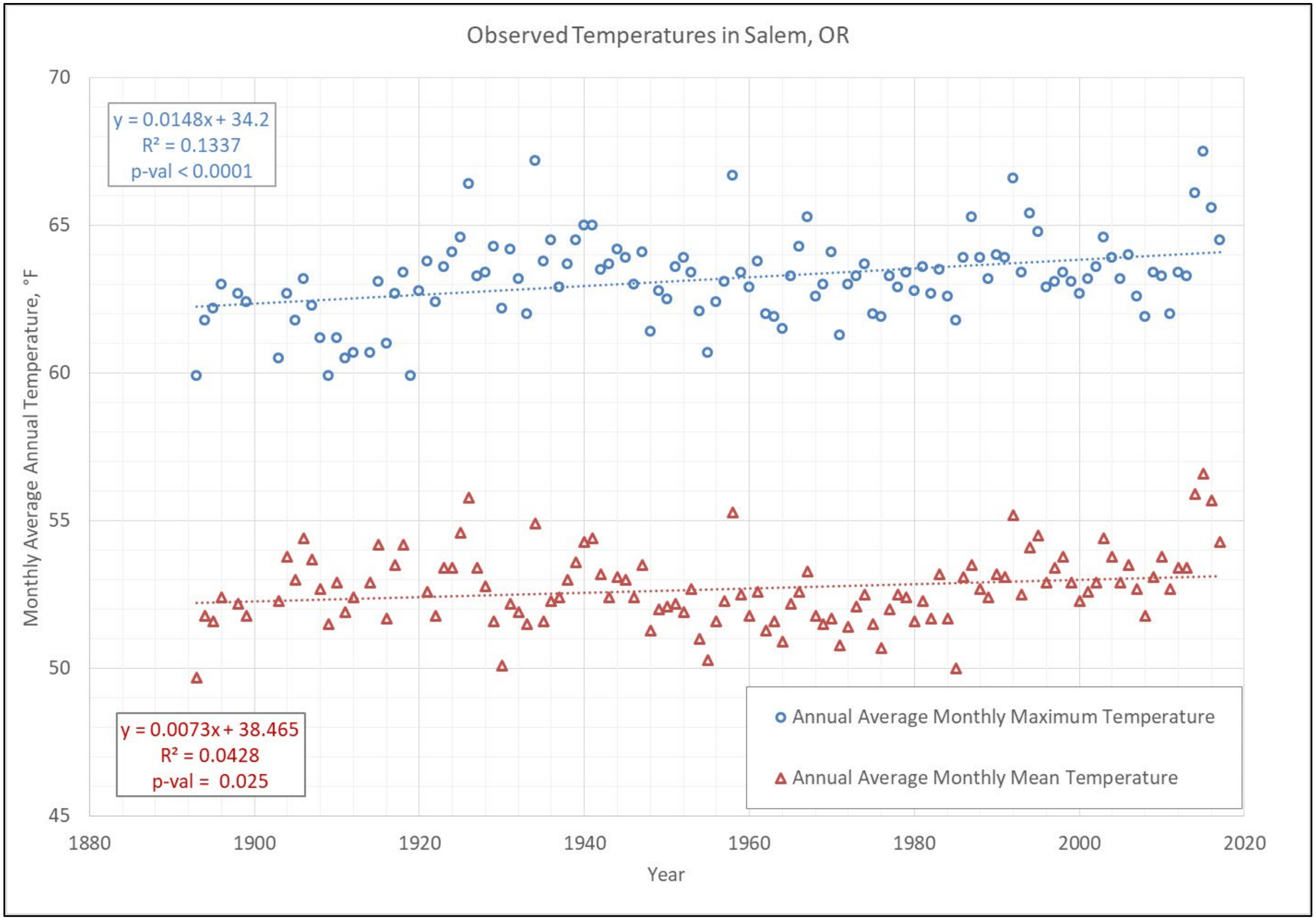


Figure 2-1. Trends in Observed Temperature at Salem, Oregon

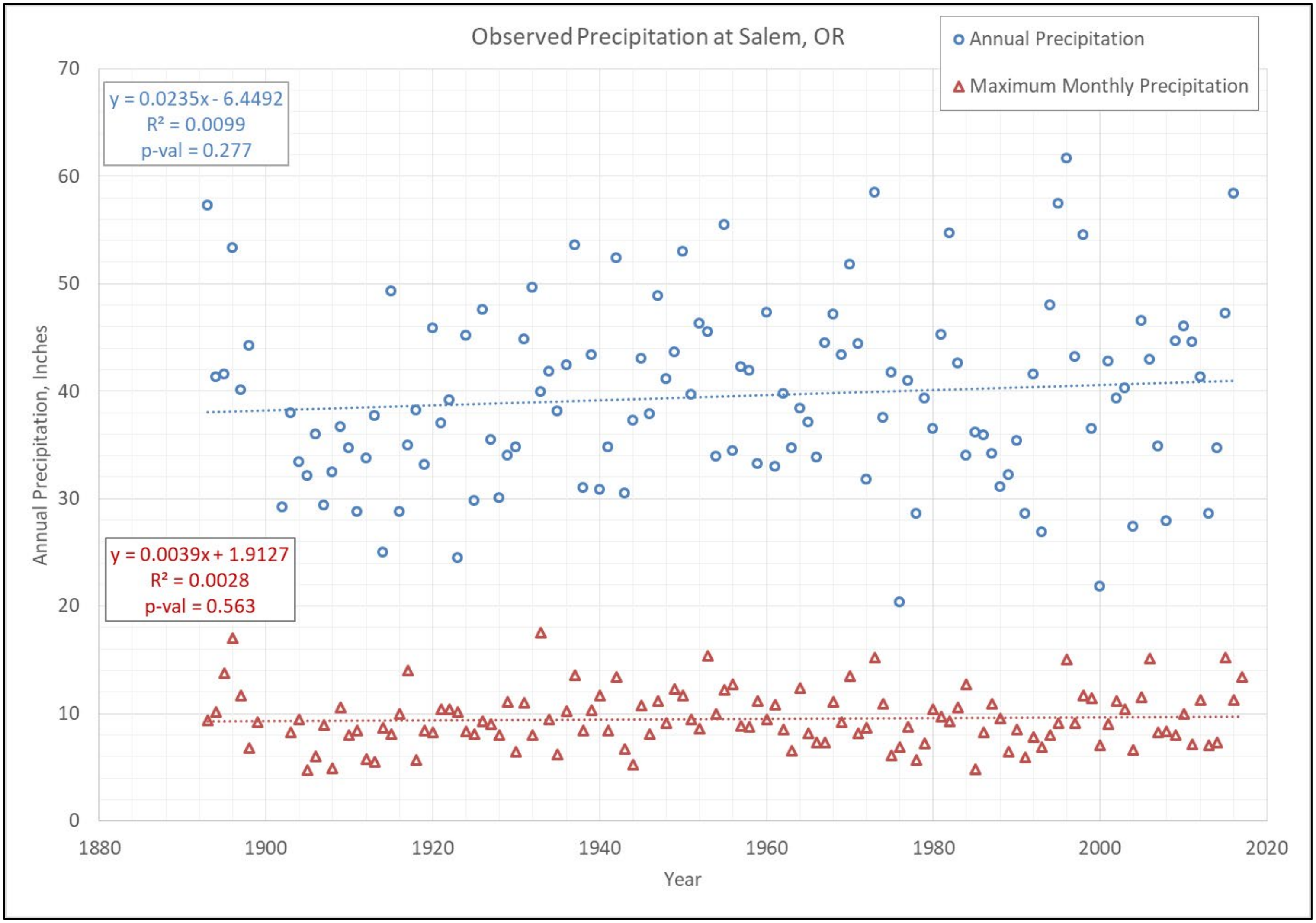


Figure 2-2. Trends in Annual and Maximum Monthly Precipitation

CHAPTER 3 – OBSERVED TRENDS IN CURRENT CLIMATE LITERATURE REVIEW

3.1 CLIMATE CHANGE LITERATURE SYNTHESES

A September 2015 report conducted by the USACE Institute of Water Resources (IWR) summarizes the available peer reviewed literature related to trends in both observed and projected hydrometeorological variables for the Pacific Northwest Region (HUC02 17), which includes the Willamette River Basin. Figure 3-1 below summarizes the findings from the literature synthesis and results are discussed in additional detail in the following paragraphs. It should be noted that this figure was produced in 2015 and substantial research has occurred since its publication. Were this figure to be updated, the number of relevant literature studies reviewed would likely increase for all hydrologic variables.

Temperature. The 2015 USACE Literature Synthesis found a strong consensus supporting increasing trends in observed temperature for the Pacific Northwest Region. The trends were apparent in average, minimum, and maximum temperature observations. Confidence in these increasing trends is supported most strongly in the region's coastal areas, which encompasses the Willamette Basin.

Precipitation. According to the USACE Literature Synthesis: "Overall increasing trends have been identified in the Pacific Northwest Region's annual average precipitation data for the latter half of the 20th century, especially in the coastal areas. Note, there is only a moderate consensus across the literature for annual average precipitation trends and this increasing trend is variable depending upon location and season."

Hydrology / Streamflow. The 2015 USACE Literature Synthesis found a strong consensus supporting decreasing trends in the region's annual streamflow, particularly spring and summer flows, and 1 April Snow Water Equivalent (SWE) data for the latter half of the 20th century.

Note, that the identified trends of increasing precipitation and decreasing streamflow are not necessarily contradictory because of the complexity of Pacific Northwest hydrology. For example, lower SWE could have a larger impact than increased rainfall on the seasonal streamflow. Spring and summer time flows are particularly sensitive to the region's SWE, and therefore respond inversely to increasing trends in temperature. Also, the region's increasing trend in temperature correlates to an increased loss in water due to evaporation as well as decreases in snowpack.

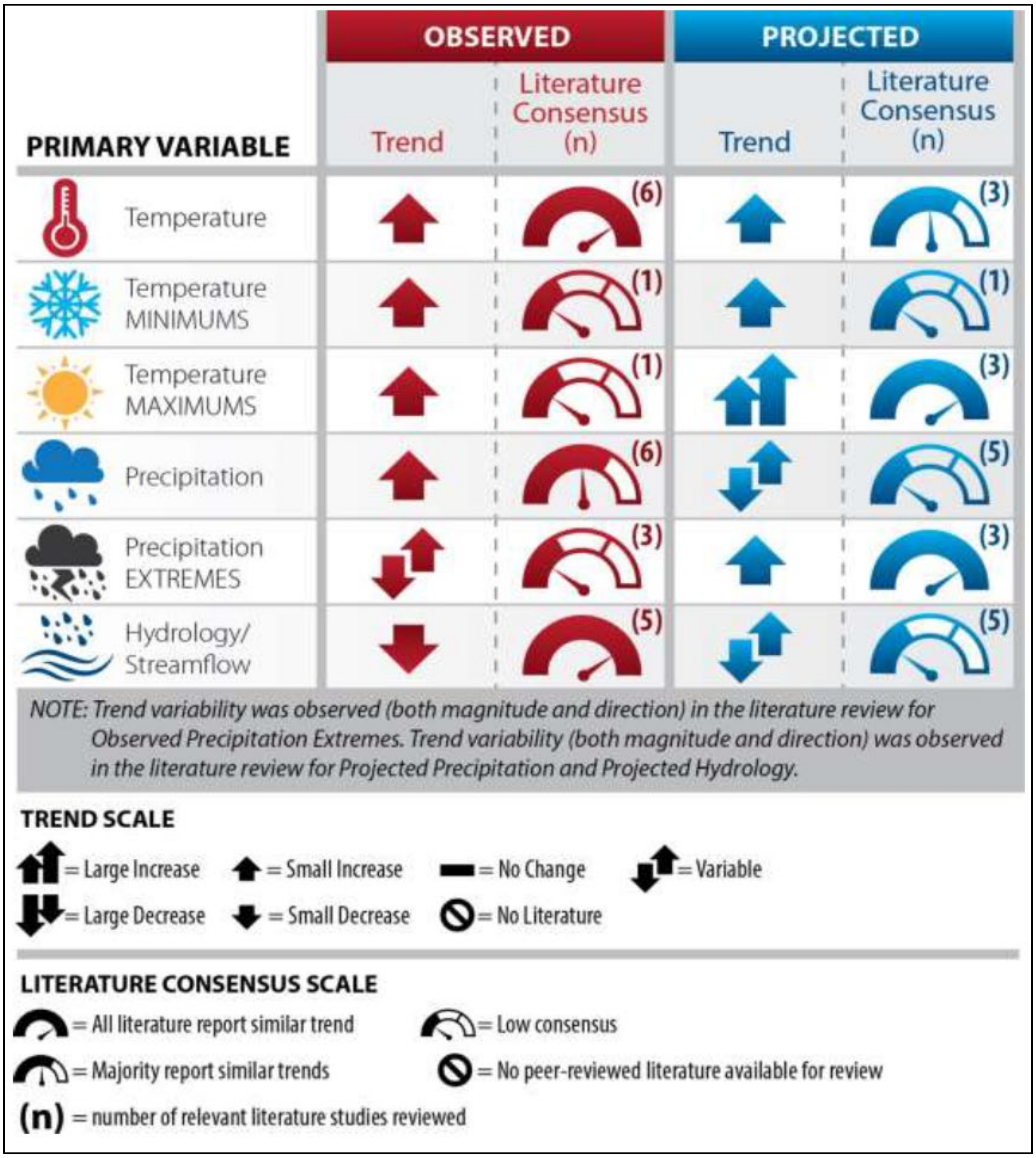


Figure 3-1. Summary of Literature Review Findings

3.2 FOURTH NATIONAL CLIMATE ASSESSMENT

The Fourth National Climate Assessment (NCA4) Volume II, released in 2018, draws on science described in NCA4 Volume I and focuses on human welfare, societal, and environmental elements of climate change and variability for 10 regions and 18 national topics. Particular attention is paid to observed and projected risks, impacts, consideration of risk reduction, and implications under different mitigation pathways. Of particular interest to this qualitative analysis are the chapters regarding changing climate, water, and the Northwest region, which includes the states of Oregon, Washington, and Idaho.

Temperature. Nationally, annual average temperatures have increased over the continental U.S. by 1.2°F over the last few decades and 1.8°F relative to the beginning of the last century. Figure 3-2, adapted from NCA4, displays observed changes in temperature for the period from 1986–2016, as compared with the historic average from the period of 1901–1960 (for the continental U.S.). Note that virtually the entire Pacific Northwest region, and much of the Western U.S., has experienced warming of 1 to 2 degrees Fahrenheit. The approximate study area is circled in red in the following figures.

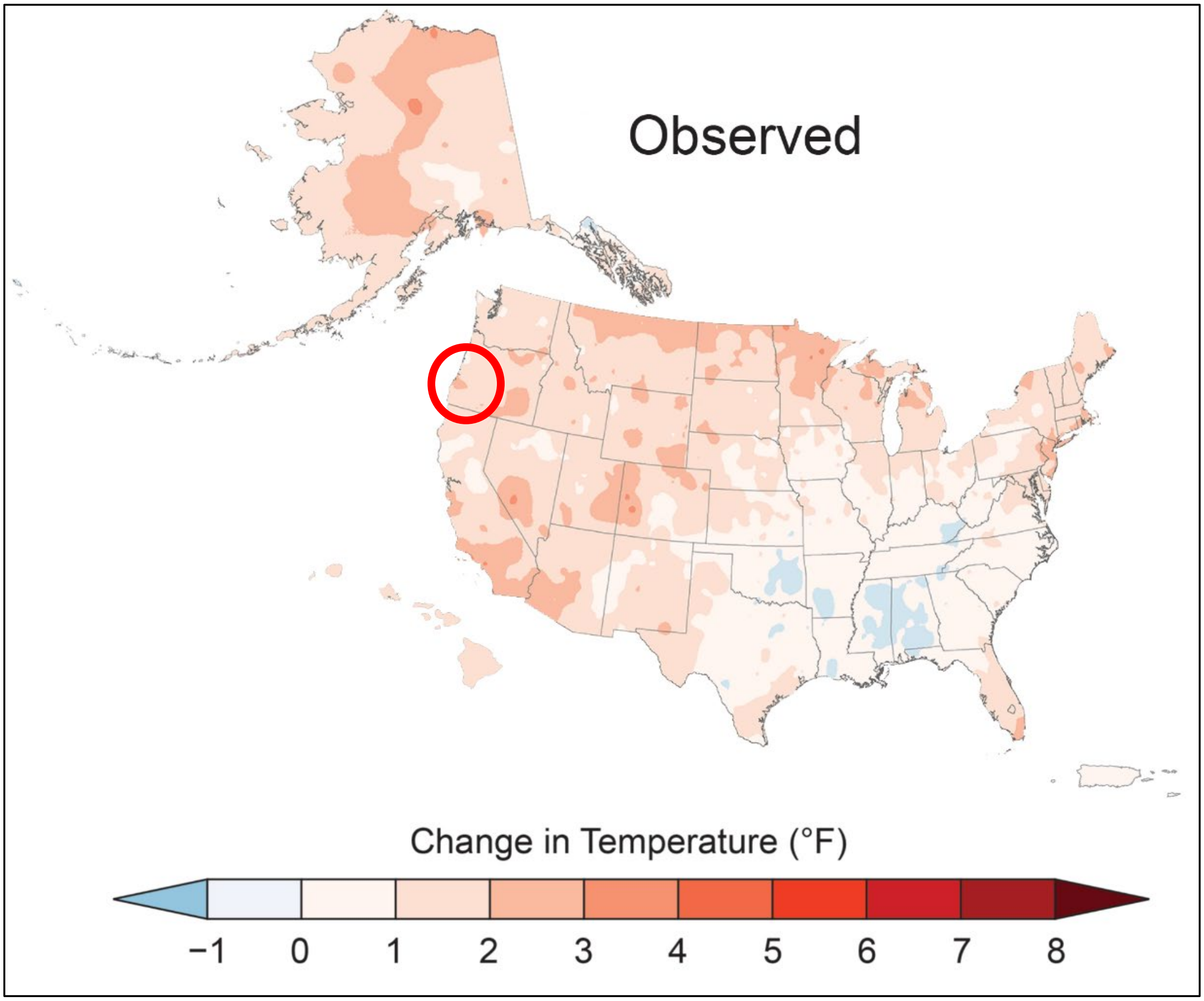


Figure 3-2. Observed changes in Temperature

Precipitation. Annual Precipitation since the beginning of the last century has increased across most of the northern and eastern U.S, whereas decreases have been observed across much of the southern and western U.S. There is much more regional variation in observed precipitation change as compared with observed temperature change, as the influence of temperature on precipitation varies greatly based upon terrain, elevation, and proximity to moisture sources. Figure 3-3 displays the percent change in annual precipitation for the period of 1986 – 2015, as compared with the historic baseline of 1901 – 1960. Looking more closely at the Pacific

Northwest, most of the state of Oregon near the vicinity of the Willamette Basin has observed an increase in annual precipitation between 0% and 5%, with some isolated areas experiencing a change between -5% and 10%.

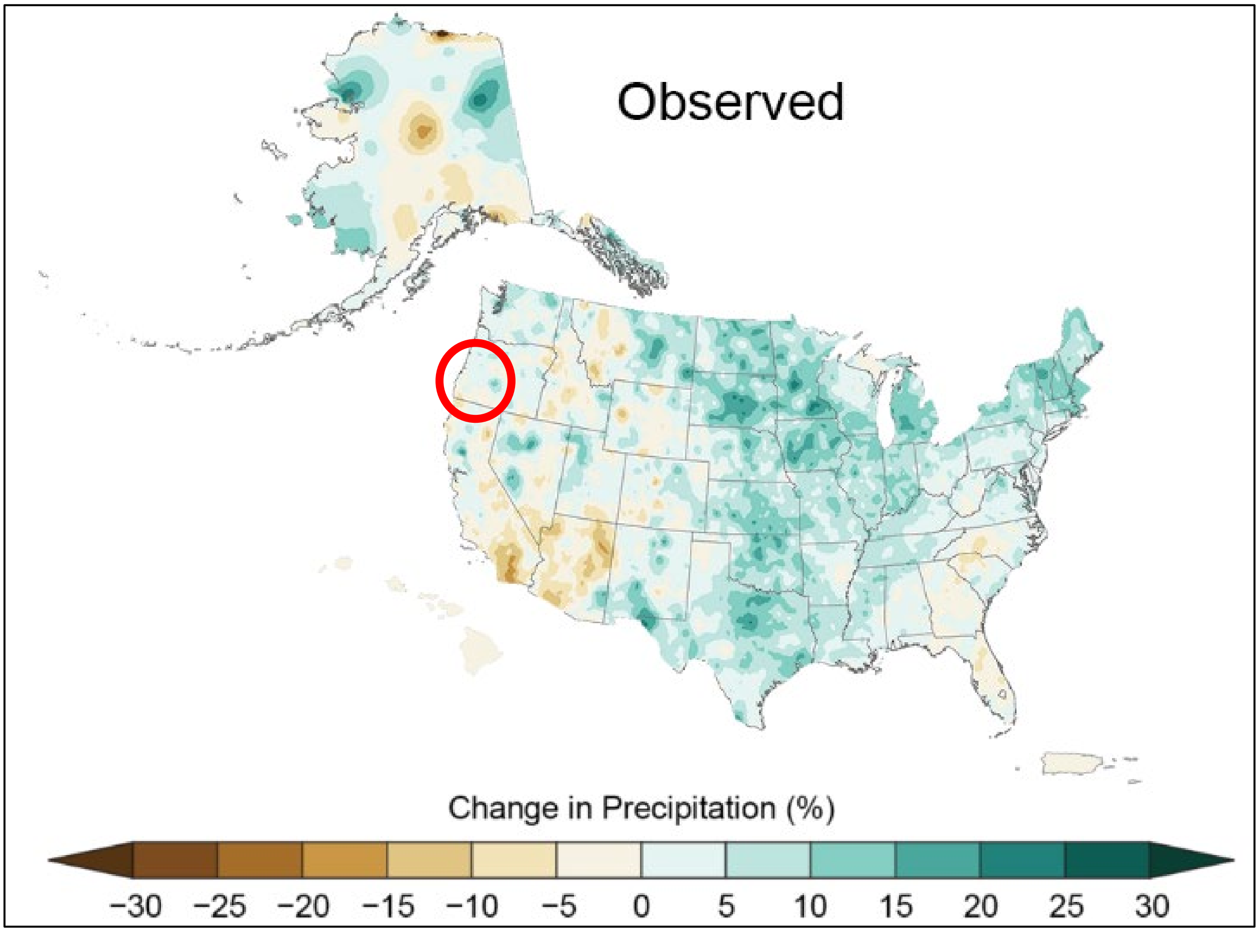


Figure 3-3. Observed changes in Precipitation

There have been observed increases in the frequency and intensity of heavy precipitation events throughout much of the U.S. Figure 3-4 displays the percent increase in the amount of precipitation falling during the heaviest 1% of events (99th percentile of the distribution). The left map within Figure 3-4 displays the percent difference between the 1901-1960 historic baseline versus the 1986-2016 period, whereas the right map displays linear trend changes over the period between 1958 and 2016. Note that in both the left and right side of the figure, the Pacific Northwest has experienced a moderate increase in the precipitation falling during extreme events. This indicates that extreme events have been becoming increasingly intense over the past decades. The observed trends in heavy precipitation are supported by well-established physical relationships between temperature and humidity. These increases in annual and extreme precipitation depths and volumes have various implications for reservoirs, particularly those intended for flood risk management.

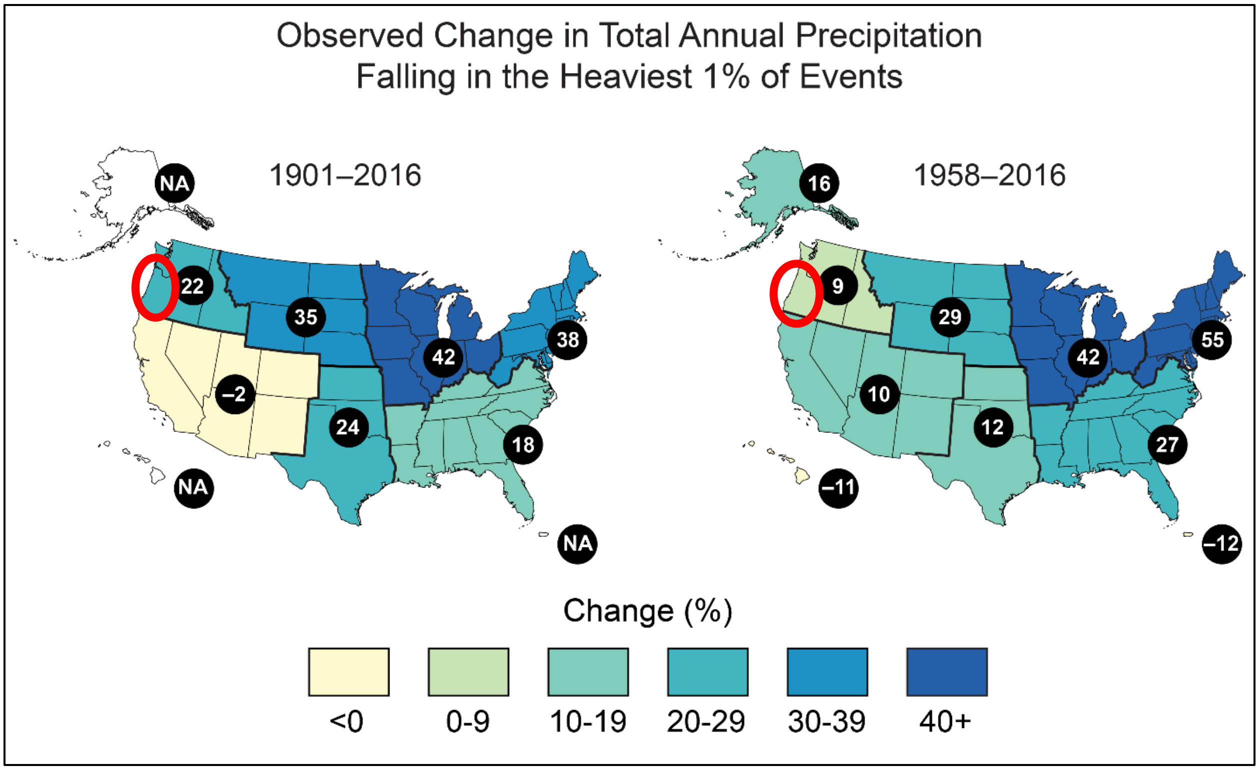


Figure 3-4. Observed precipitation change during the heaviest 1% events

3.3 CLIMATE HYDROLOGY ASSESSMENT

The Climate Hydrology Assessment Tool (CHAT) developed by USACE and was utilized to examine trends in observed annual peak streamflow for the various gage locations shown in Table 1-2. The CHAT tool is used to fit a linear regression to peak streamflow data in addition to providing a p-value indicating statistical significance of any given trend. The CHAT results presented in this section are focused on flood peaks. For discussion of other streamflow metrics of interest to the study, such as low flow periods and conservation season runoff volume, refer to Section 3.5.

Many of the flow gages selected for CHAT analysis have been heavily impacted by regulation over different periods of time. For gages where the observed period of record (POR) includes regulation effects, the annual peak streamflow dataset cannot be considered homogeneous, and it is difficult to draw conclusions based upon the trends identified within these datasets. In addition to assessing the entire period of record at regulated gage sites, subsets of data prior to and after reservoir construction were also analyzed.

The streamflow gage on the Willamette River at Salem (USGS number 14191000) can be used to illustrate how periods of reservoir regulation influence trends in streamflow. Peak annual flow for this gage is available on a continuous basis from 1893 until 2014 in the CHAT. The annual peak data from 1893 – 1940 represents a pre-regulation dataset as no reservoirs were constructed upstream of the gage until 1941. The time period of 1941 – 1970 represents an era of dam building and reservoir filling; this period disrupts the homogeneity and homoscedasticity of the streamflow dataset. After 1970, reservoir operations became established and once again the period of record can roughly be considered homogeneous in terms of reservoir operation. For these reasons, the period of record for the Willamette River at Salem was analyzed over 3 time periods: 1. complete heterogeneous period of record, 2. pre-regulation period, and 3. post-regulation period.

When dividing the period of record into different intervals of regulation for each gage, consideration was given to ensure that the shortened record length remained adequate for trend analysis. Of the gages whose record was divided based on regulation, the shortest record length was at the Willamette River at Salem gage with a post-regulation record length of 44 years. This length was deemed sufficient for linear regression analysis. Additionally, there is uncertainty regarding whether the post-regulation period of record reflects homogenous reservoir operation, since reservoir regulation is not always consistent over time and operational deviations are common. However, for the purposes of this analysis, reservoir operations were assumed to be consistent and the impacts of changes in regulation and deviations from typical operation were considered to be minor. Nonstationarity detection results, discussed below, offer further insight into the homogeneity of the peak streamflow dataset.

For gages where naturalized flow datasets are available, regression analysis was performed within Microsoft Excel using the entire period of record available. These regression results can be directly compared with the output from the CHAT.

A summary of the regression trends and their statistical significance is shown in Table 3-1. Individual graphical output for each gage and period of record analyzed is shown in Figure 3-5 through Figure 3-22. Note that only 5 strongly statistically significant trends (p-value < 0.05) were detected. Four of these trends were in the downward direction and were found when looking at the entire period of recorded flows at sites impacted by regulation. This is to be expected because the primary function of flood risk management regulation is to reduce peak flows. Thus, relative to the pre-regulation period, the post –regulation period consists of lower flood peaks resulting in the observed, downward trend. When these same gages were examined either by limiting the period of record to pre-regulation or post-regulation, the trends became statistically insignificant. Additionally, when simulated naturalized flow datasets were examined at these same locations, no statistically significant trends were found.

For the Coast Fork near Cottage Grove statistically significant decreasing trends were found both within the complete, observed record and the portion of the record post-regulation. A weak decreasing trend was also observed within the naturalized streamflow record. It should be noted that the magnitude of these decreases is relatively minor, slightly above 12 cfs/year, when compared with peak annual flows, which have a median value of 2,650 cfs.

The agreement across the watershed and through various time periods indicates that all statistically significant trends are likely due to the influence of upstream regulation, and likely not due to climatic shifts driving changes in hydrology. Trend detection and statistical significance was verified using the trend analysis tab of the nonstationarity detection tool.

Table 3-1. Summary of Observed Streamflow Trends in Annual Peak Streamflow

Fig. Num.	Gage Number	Gage Name and Location	POR Used	POR Note	Regression Slope	P-value	Trend Direction	Trend Significance	NSD Tool Trend?
8	14191000	Willamette at Salem	1892 - 2014	Complete, minus gaps	**-824.5**	**<0.0001**	**Downward**	**Strong**	Yes
9			1892 - 1941	Pre-regulation	-1026.3	0.142	Downward	Weak	No
10			1970 - 2014	Post-regulation	-493.5	0.306	Downward	Insignificant	No
11			1928 - 2008	Naturalized	-198.5	0.589	Downward	Insignificant	N/A
12	14190500	Luckiamute at Suver	1941 - 2014	Complete, minus gaps, pristine	-15.6	0.660	Downward	Insignificant	No
13	14178000	No Santiam Blw Boulder	1929 - 2014	Complete, pristine	2.6	0.896	Neutral	Insignificant	No
14	14181500	North Santiam at Niagara	1939 - 2014	Complete, minus gaps	**-138.4**	**<0.0001**	**Downward**	**Strong**	Yes
15			1955 - 2014	Post-regulation	-34.0	0.143	Downward	Weak	No
16			1928 - 2008	Naturalized	41.6	0.344	Upward	Insignificant	N/A
17	14153500	Coast Fork near Cottage Grove	1939 - 2014	Complete	**-12.8**	**0.002**	**Downward**	**Strong**	Yes
18			1943 - 2014	Post-regulation	**-12.1**	**0.009**	**Downward**	**Strong**	Yes
19			1928 - 2008	Naturalized	-11.4	0.178	Downward	Very Weak	N/A
20	14154500	Row River near Dorena	1936 - 2014	Complete, pristine	-15.5	0.578	Downward	Insignificant	No
21	14150000	Middle Fork Willamette near Dexter	1947 - 2014	Complete	**-263.1**	**<0.0001**	**Downward**	**Strong**	Yes
22			1967 - 2014	Post-regulation	18.6	0.552	Upward	Insignificant	No
23			1928 - 2008	Naturalized	-22.0	0.761	Downward	Insignificant	N/A
24	14187200	South Santiam near Foster	1974 - 2014	Complete/Post-regulation	-17.6	0.705	Downward	Insignificant	No
25			1928 - 2008	Naturalized	23.2	0.725	Upward	Insignificant	N/A

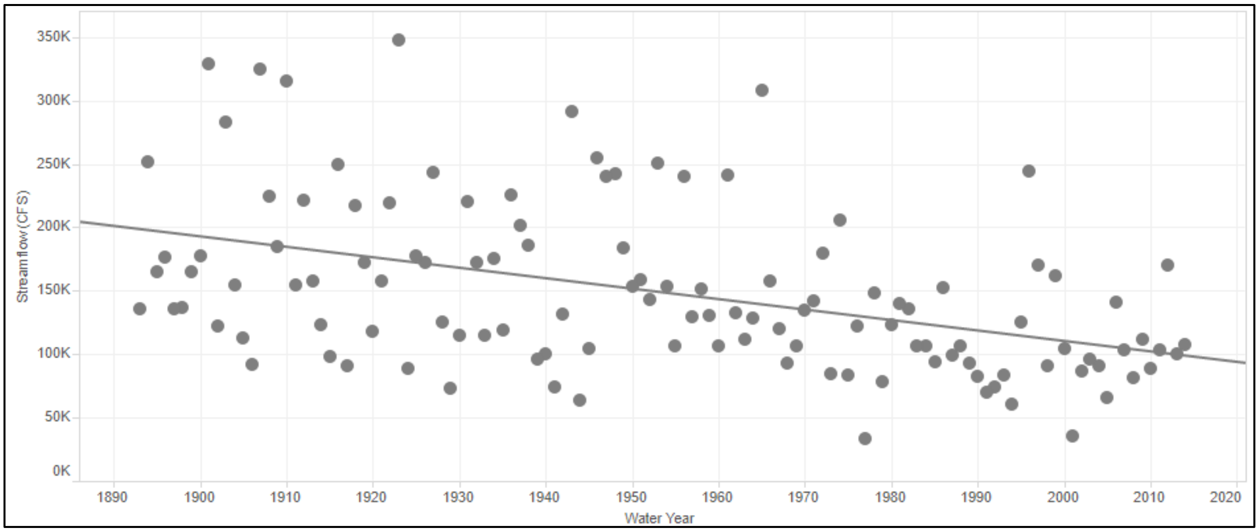


Figure 3-5. Willamette at Salem. Complete POR. 1892 - 2014

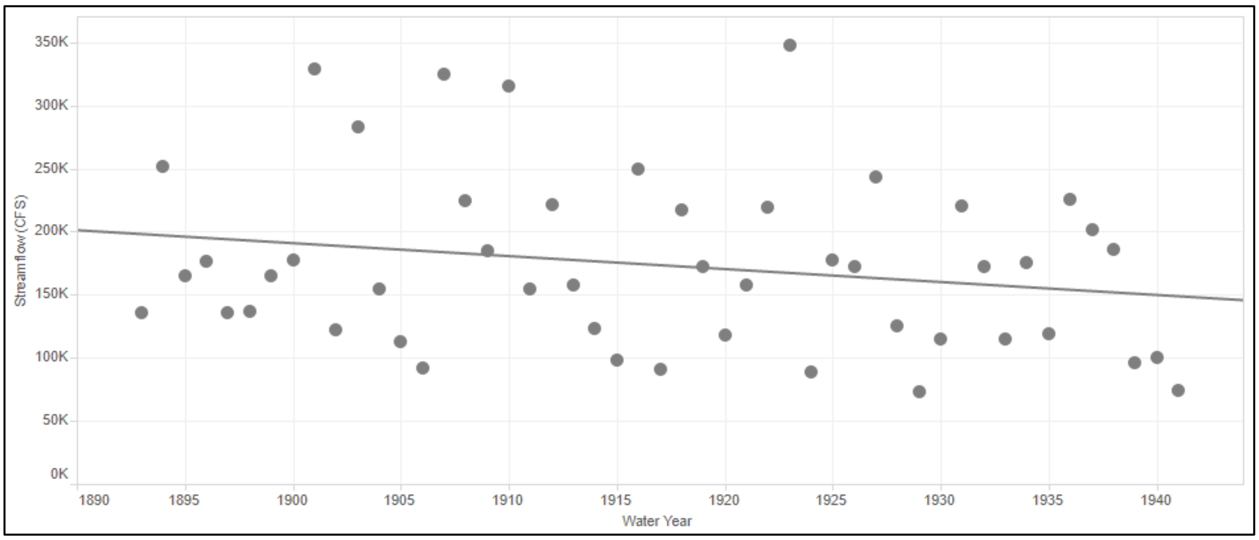


Figure 3-6. Willamette at Salem. Pre-Regulation. 1892 - 1941

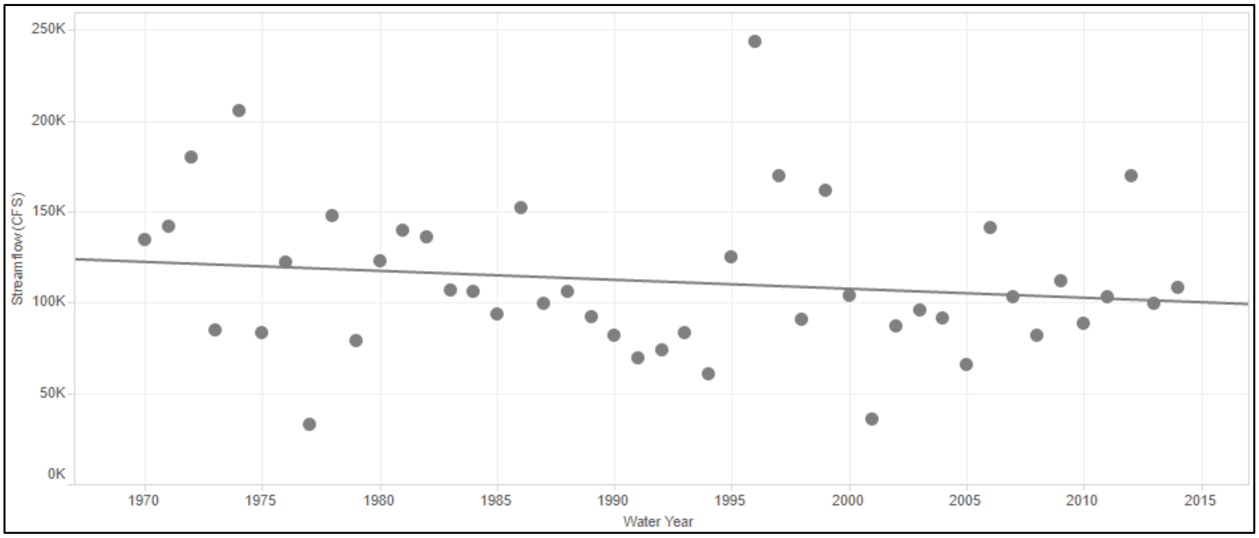


Figure 3-7. Willamette at Salem. Post-Regulation. 1970-2014

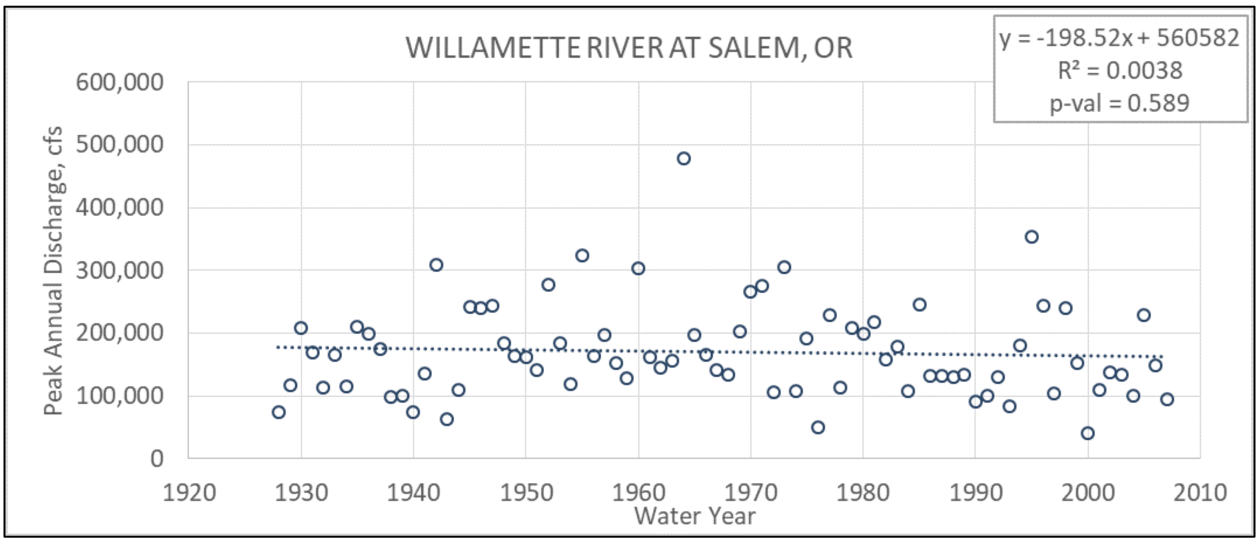


Figure 3-8. Willamette at Salem. Naturalized Flows. 1928-2008

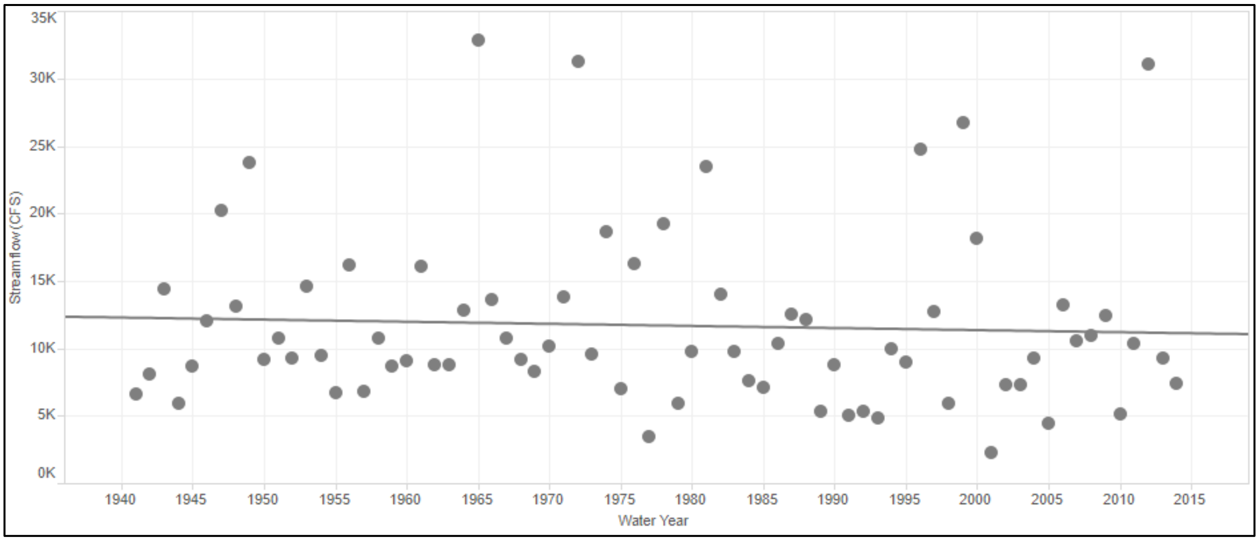


Figure 3-9. Luckiamute River near Suver. Complete POR, minus data gaps. 1941-2014. Pristine.

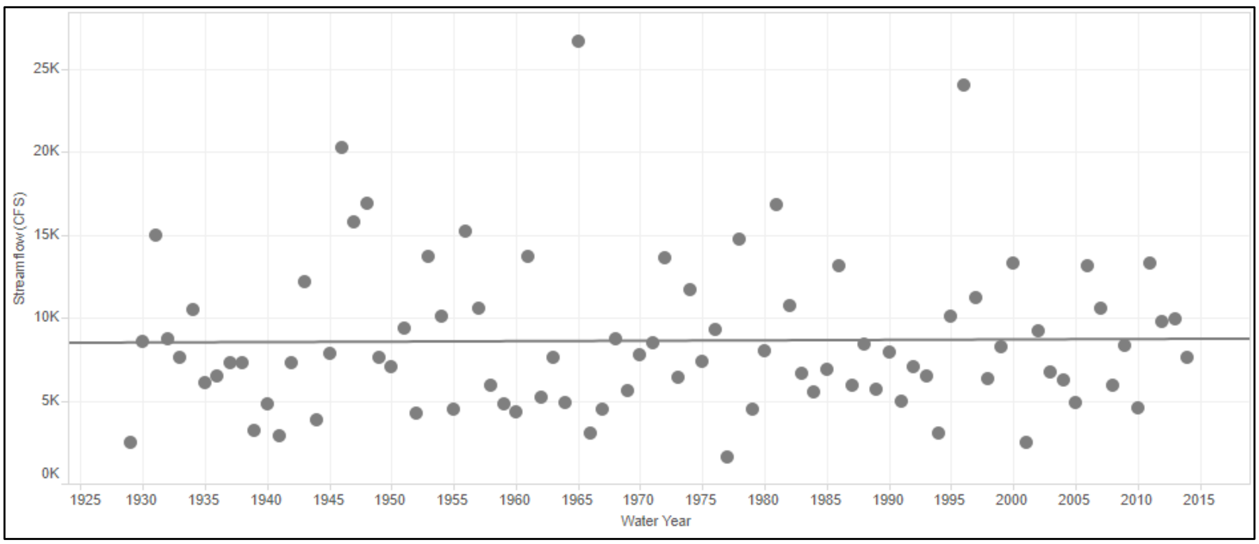


Figure 3-10. N. Santiam River below Boulder. Complete POR. 1929-2014. Pristine.

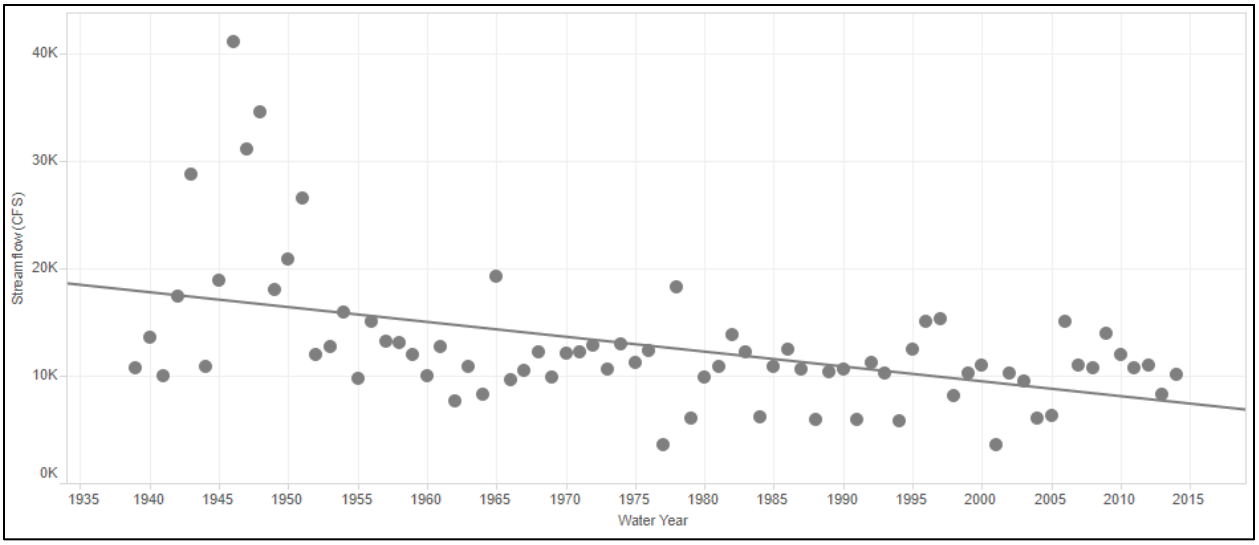


Figure 3-11. N. Santiam River at Niagara. Complete POR minus data gaps. 1939-2014

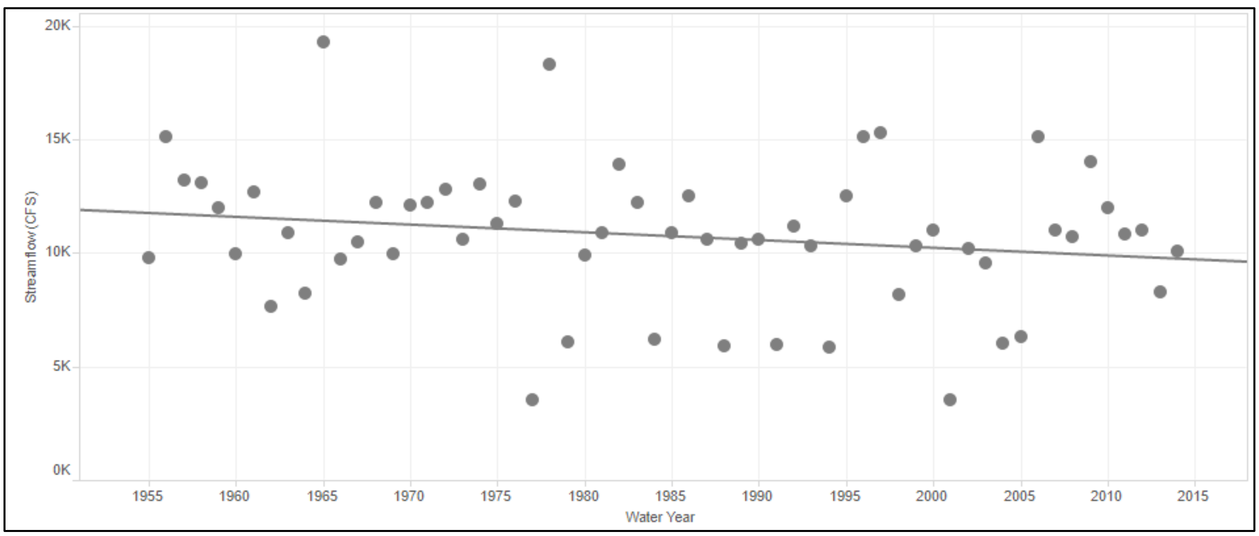


Figure 3-12. N. Santiam River at Niagara. Post-Regulation. 1955 -2014

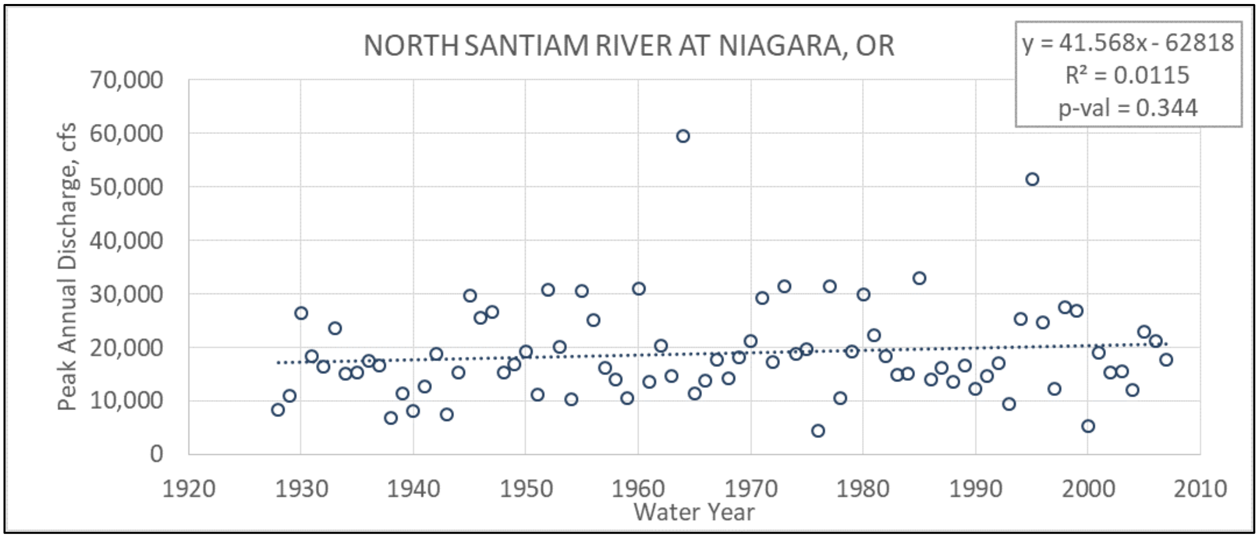


Figure 3-13. N. Santiam River at Niagara. Naturalized Flows. 1928 – 2008

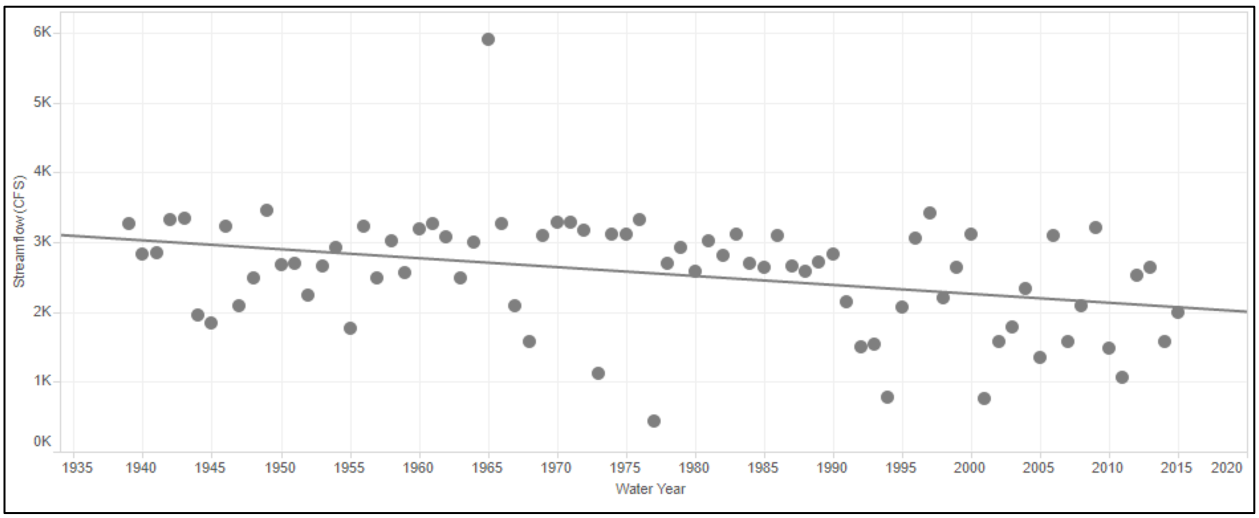


Figure 3-14. CF Willamette River below Cottage Grove Dam. Complete POR. 1939 – 2014

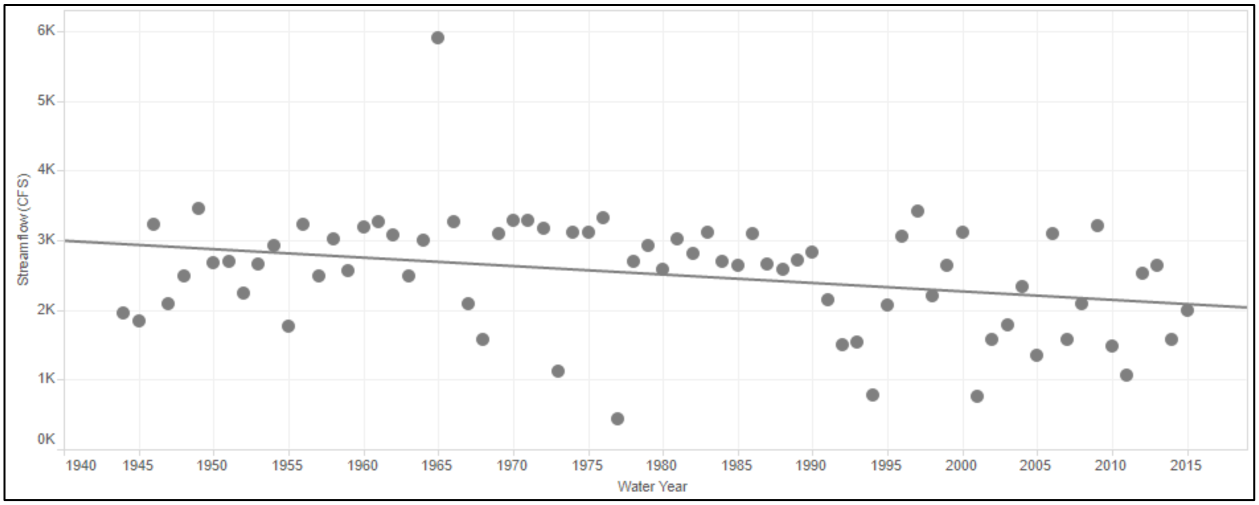


Figure 3-15. CF Willamette River below Cottage Grove Dam. Post-Regulation. 1943 – 2014

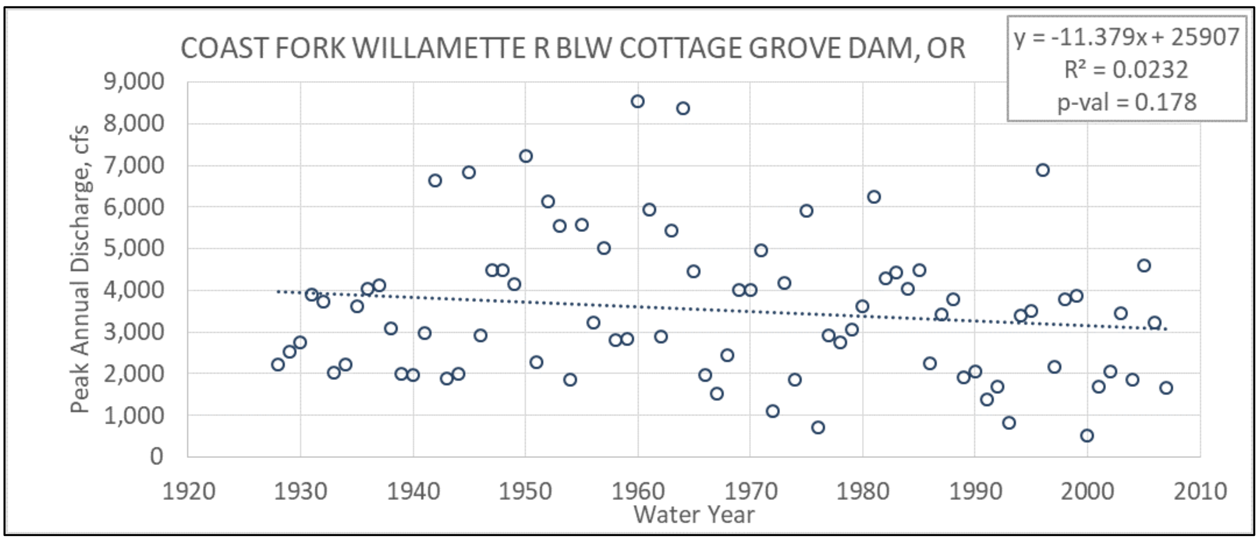


Figure 3-16. CF Willamette River below Cottage Grove Dam. Naturalized Flows. 1928 - 2008

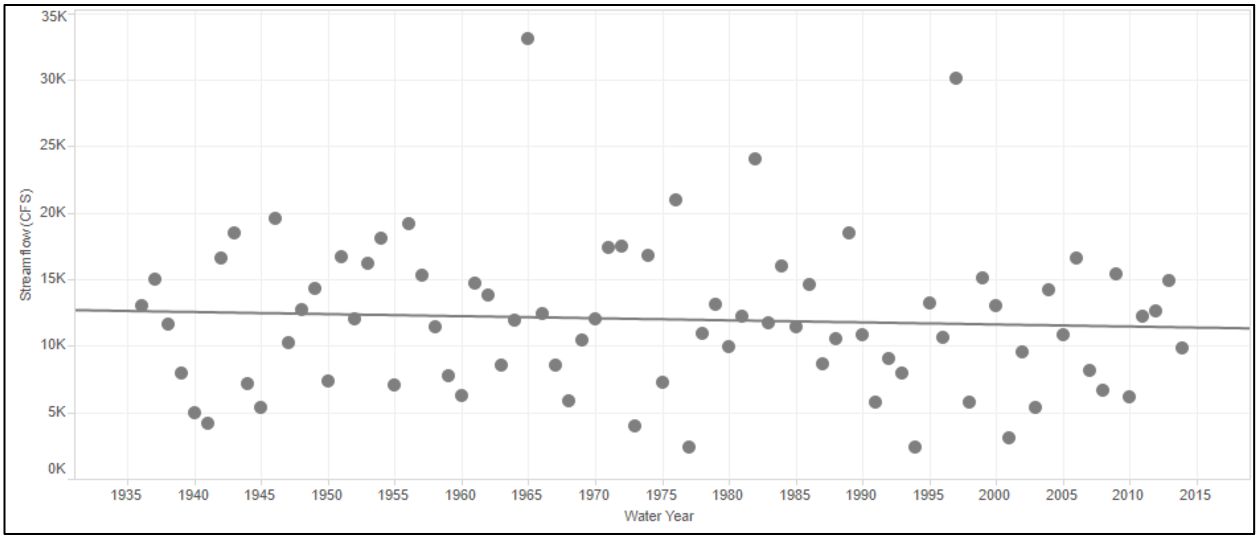


Figure 3-17. Row River above Pitcher Creek. Complete POR. 1936 - 2014. Pristine.

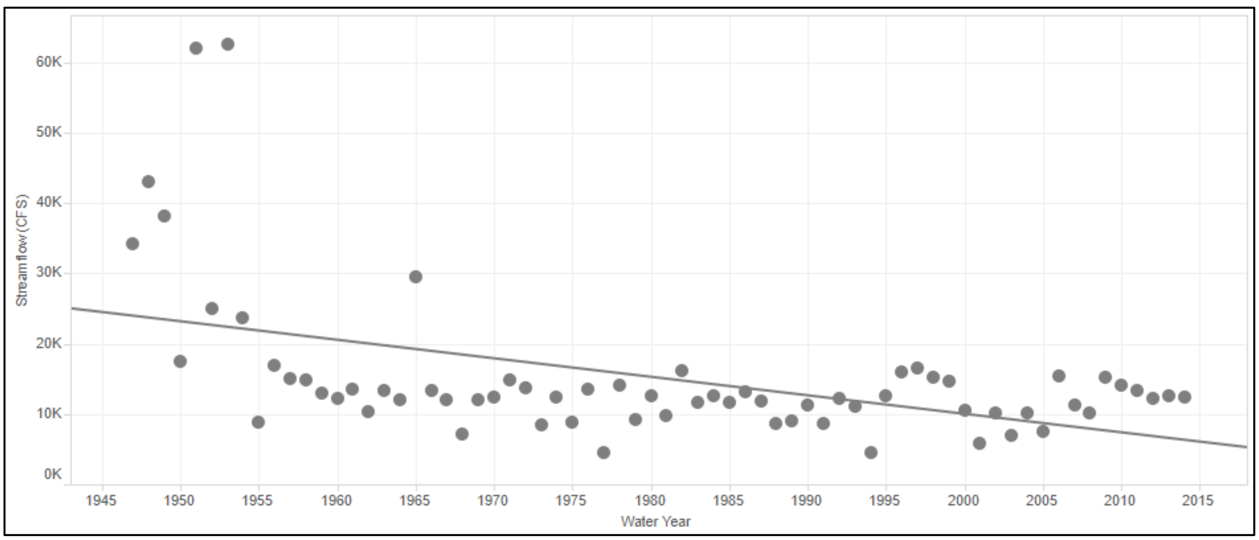


Figure 3-18. MF Willamette River near Dexter. Complete POR. 1947 – 2014

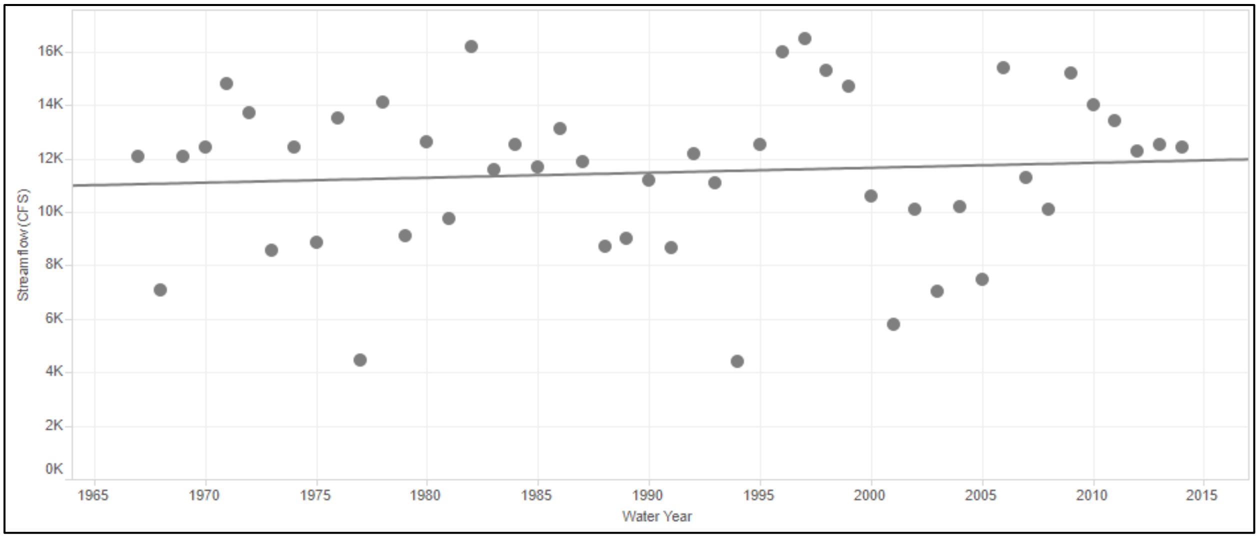


Figure 3-19. MF Willamette River near Dexter. Post-Regulation. 1967 – 2014

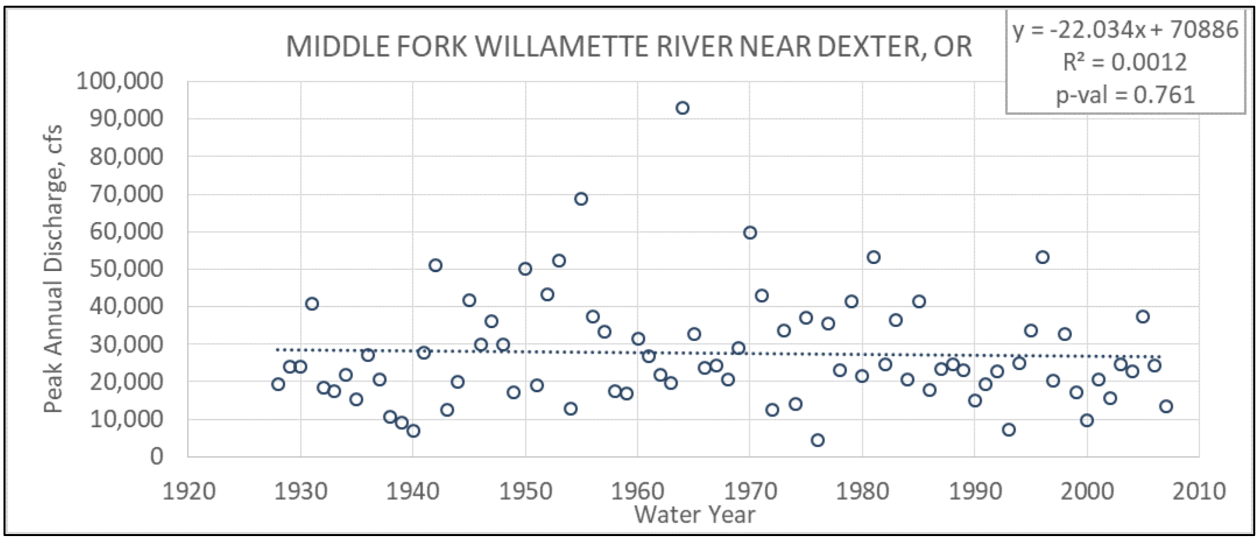


Figure 3-20. MF Willamette River near Dexter. Naturalized Flows. 1928 – 2008

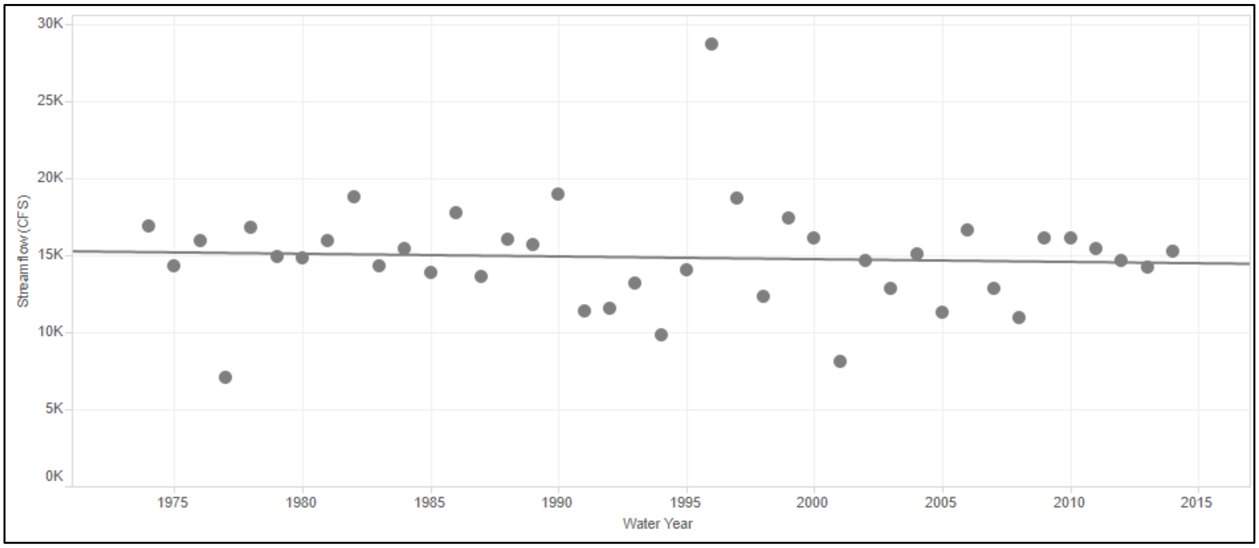


Figure 3-21. S. Santiam River near Foster. Complete POR / Post-Regulation. 1974 – 2014

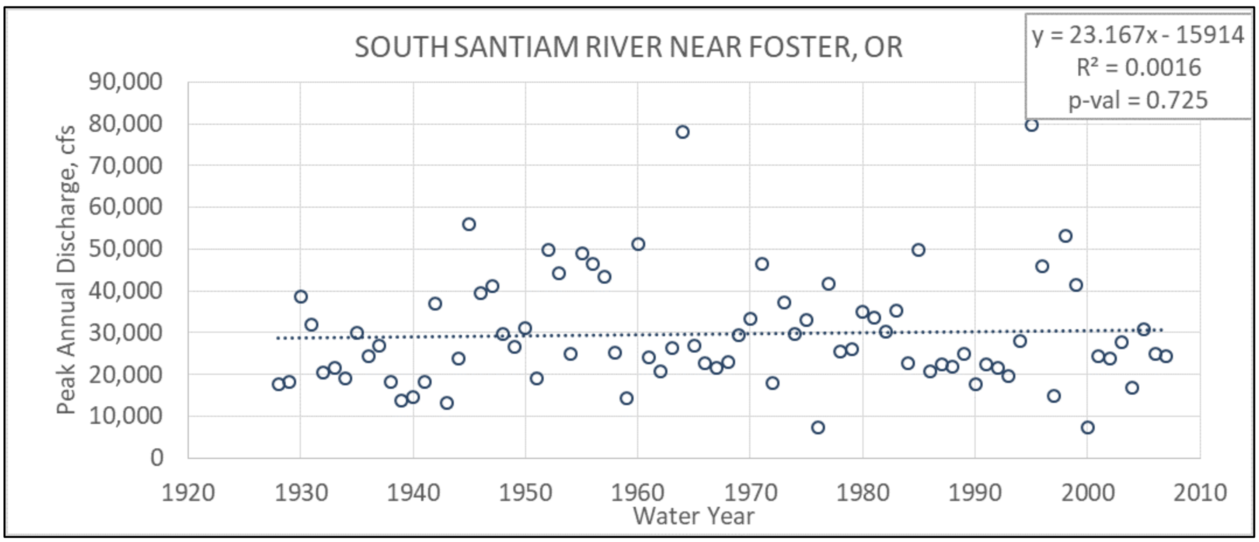


Figure 3-22. S. Santiam River near Foster. Naturalized Flows. 1928 – 2008

3.4 NONSTATIONARITY DETECTION

The USACE Nonstationarity Detection (NSD) Tool was used to assess whether the assumption of stationarity, which is the assumption that the statistical characteristics of a time-series dataset are constant over the period of record, is valid for a given hydrologic time-series dataset. Nonstationarities are detected using 12 different statistical tests which examine how the statistical characteristics of the dataset change with time (Engineering Technical Letter (ETL) 1100-2-3, Guidance for Detection of Nonstationarities in Annual Maximum Discharges; Nonstationarity Detection Tool User Manual, version 1.2). The NSD Tool was applied to the same stream gage sites listed previously in Table 3-1; both the observed period of record and naturalized stream flow datasets were analyzed. For the simulated naturalized streamflow datasets, the USACE Time Series Toolbox was used to perform the nonstationarity detection routines. A nonstationarity can be considered “strong” when it exhibits consensus among multiple nonstationarity detection methods, robustness in detection of changes in statistical properties, and a relatively large change in the magnitude of a dataset’s statistical properties. Many of the statistical tests used to detect nonstationarities rely on statistical change points, these are points within the time series data where there is a break in the statistical properties of the data, such that data before and after the change point cannot be described by the same statistical characteristics. Similarly, to nonstationarities, change points must also exhibit consensus, robustness, and significant magnitude of change. For discussion of other streamflow metrics of interest to the study, such as low flow periods and conservation season runoff volume, refer to Section 3.5.

Figure 3-23 displays the NSD Tool output for the complete period of record (minus historic flows with large data gaps) for the Willamette River at Salem, OR. Note that there are multiple nonstationarities detected throughout the period of record. Most notably are the five nonstationarities detected between 1965 and 1967. These nonstationarities can be attributed to a significant decrease in mean annual peak flow. Also, during the period between 1952 and 1988, a gradual or smooth nonstationarity was detected by the Lombard Wilcoxon test. These nonstationarities show both consensus and robustness as they are detected by multiple statistical tests targeting different statistical properties (mean and overall distribution) all around the same time. The timing of this strong nonstationarity aligns neatly with the completion of many of the WVP flood risk reduction projects, whose primary intent is to lower peak flows, and allows this nonstationarity to be attributed to the upstream regulation. The smooth nonstationarity detected from 1952 to 1988 also aligns well with the period in which the WVPs were coming on-line as flood risk reduction projects.

Figure 3-24 displays the application of 12 nonstationarity detection tests for the naturalized peak discharge record for the Willamette River at Salem. Since these simulated flows are absent of the influence of regulation and irrigation, it would be anticipated that the previously detected nonstationarities attributed to the construction of the dams would be absent. As is shown in the figure, only one uncorroborated nonstationarity was detected. Because this single nonstationarity in 1984 does not exhibit either consensus or robustness, it is unlikely to be operationally significant and the naturalized annual peak flow dataset can be homogenous across the period of record. It should be noted that just because the annual peak streamflow data was shown to be homogeneous, this does not imply that all other aspects of the flow regime are homogeneous. Other aspects of the flow regime, such as seasonal low flow, are discussed in Section 3.5.

Figure 3-25 and Figure 3-26 display NSD tool results for two gages which were deemed to be 'pristine' and largely free of influence from upstream regulation; respectively these gages are the Luckiamute River near Suver and North Santiam River below Boulder. Neither of these gages indicate strong evidence of non-homogeneity.

Figure 3-27 and Figure 3-28 display nonstationarity detection results for the North Santiam River at Niagara. The figures show the results of applying the nonstationarity detection tests to the observed annual peak flows (NSD Tool) and naturalized annual peak flows (Time Series Toolbox). Note that there appears to be a strong nonstationarity indicated by multiple statistical tests targeting changes in sample mean and distribution. This nonstationarity represents a significant decrease in sample mean detected around 1958 in the observed streamflow record. Additionally, a smooth nonstationarity was detected by the Lombard Wilcoxon statistical test spanning 1950 to 1961. This smooth nonstationarity indicates that the mean of the dataset is in flux throughout a period of time. The nonstationarities detected can be attributed to the construction of the Big Cliff and Detroit Dams which are located just upstream of the gage. Both dams were constructed in 1953 with the reservoirs filling to their normal pools soon afterwards. When the influence of these reservoirs is removed no nonstationarities were detected.

Figure 3-29 and Figure 3-30, respectively, display the results of the nonstationarity detection tests for the Coast Fork Willamette River below Cottage Grove Dam for the observed and naturalized annual peak streamflow datasets. In the observed record, there appears to be a strong nonstationarity being detected around 1990. This nonstationarity is indicated by multiple statistical tests targeting changes in sample mean and overall statistical distribution. The detected nonstationarity coincides with a significant decrease in sample mean. This nonstationarity is not present in the naturalized flow record. This 1990 nonstationarity is more difficult to attribute to reservoir regulation as compared with the datasets analyzed thus far because it does not coincide with the recent construction of a reservoir. However, because the nonstationarity is not detected in the naturalized flow record, it is possible that a shift in reservoir operation may be causing this shift in hydrologic response. However, documentation of a shift in reservoir operations does not exist in the Water Control Manual. Further investigation is required to fully rule out attribution of this nonstationarity to human-driven climate change or another less easily identifiable source of nonstationarity (gradual land use/land cover change, long-term persistent climate trends etc.).

For the Coast Fork Willamette River below Cottage Grove, significant decreases in post-regulation annual peak streamflow were detected by both the nonstationarity detection tool and indicated by the linear regression performed within the CHAT. Without documentation of a change in the reservoir's regulation procedure around the late 1980's or early 1990's, there appears to be at least a weak signal indicated here that cannot necessarily be attributed to regulation.

Figure 3-31 displays the nonstationarity detection results for the Row River above Pitcher Creek, near Dorena. This gage was identified as being considered 'pristine' and shows no evidence of nonstationarity within its period of record.

Figure 3-32 displays nonstationarity detection results for the observed, annual peak streamflow record at Middle Fork Willamette River near Dexter and Figure 3-33 displays nonstationarity detection results for the naturalized flow record. A strong nonstationarity is detected in the observed period of record centered around 1954, in addition to a smooth Lombard Wilcoxon nonstationarity spanning 1947 to 1961, and a Lombard Mood nonstationarity spanning 1952 to 1956. Nonstationarity detection tests targeted at identifying changes in mean, overall distribution and variance indicate a nonstationarity around 1954. These nonstationarities coincide with a significant decrease in sample mean and variance. This nonstationarity is not present in the naturalized period of record. The detected nonstationarity can likely be attributed to the construction of Lookout Point Dam which is located immediately upstream and was constructed in 1953.

Nonstationarities were not detected in either the observed or naturalized peak streamflow record for the South Santiam River near Foster, OR. Figures for this gage are not included in this report.

The nonstationarity detection tool's trend analysis tab was used to independently verify the linear trend analysis performed above in the CHAT section. Agreement upon trend direction and statistical significance was found between the NSD tool and CHAT for all gages analyzed.

After performing the nonstationarity detection analysis across the Willamette Basin for various gages, as well as for observed and naturalized streamflow conditions, various conclusions can be drawn.

- When the regulated annual peak streamflow period of record is analyzed, nonstationarity is widespread and can be attributed to the construction and operation of reservoirs upstream from the stream gages.
- However, when the influence of regulation is removed the previously detected nonstationarities generally disappear.
- Additionally, no strong nonstationarities are detected at relatively pristine (headwater) gage sites.
- Together, it appears that climate change, long-term natural climate trends, and land use/land cover changes are not significantly undermining the stationarity of the historically, observed, peak streamflow records in the Willamette Basin.

Note that for all outputs generated from the Timeseries Toolbox, the following abbreviations apply for the statistical nonstationarity detection tests. CPM indicates a change point method.

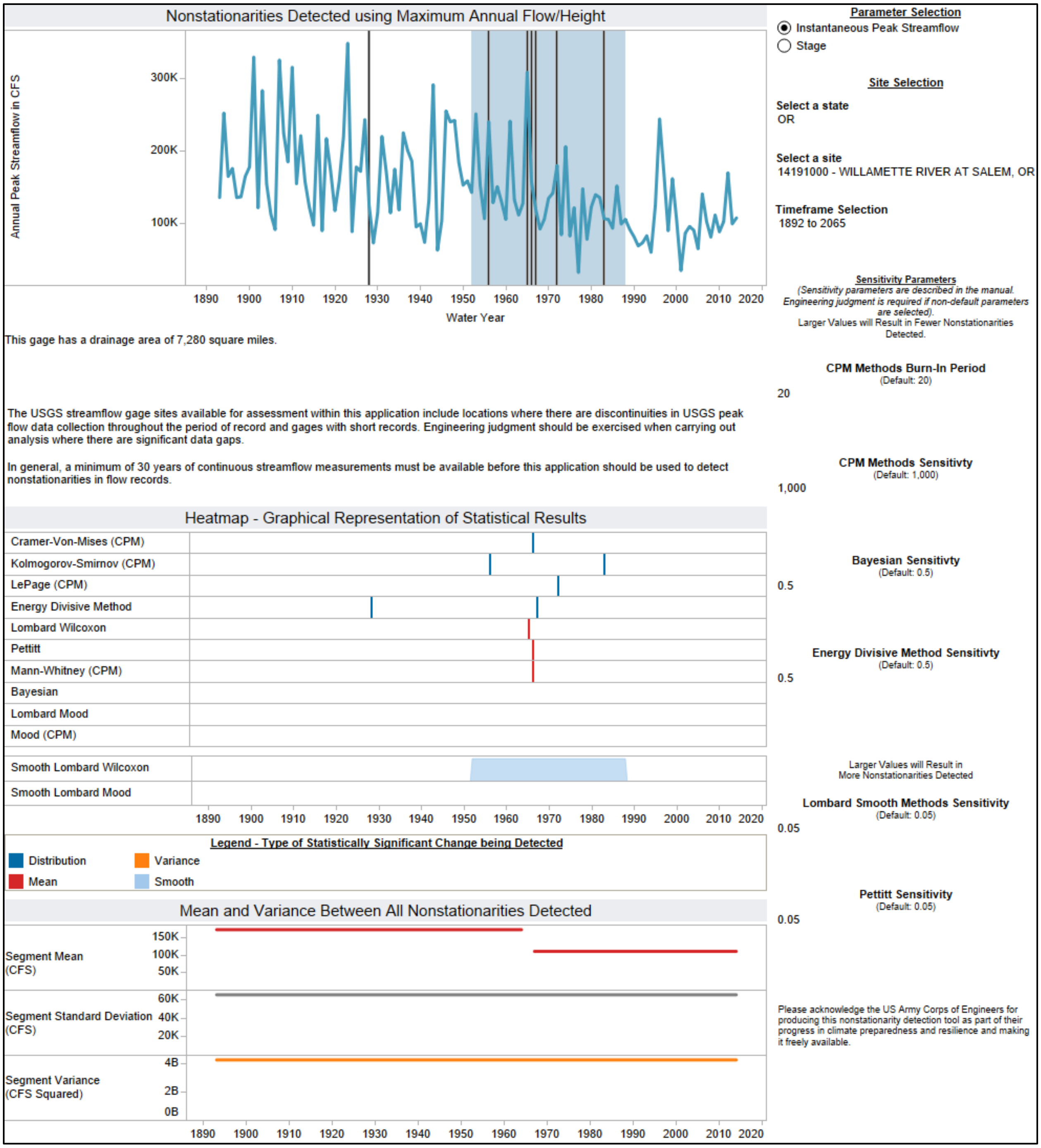


Figure 3-23. NSD for Willamette River at Salem.1892-2014

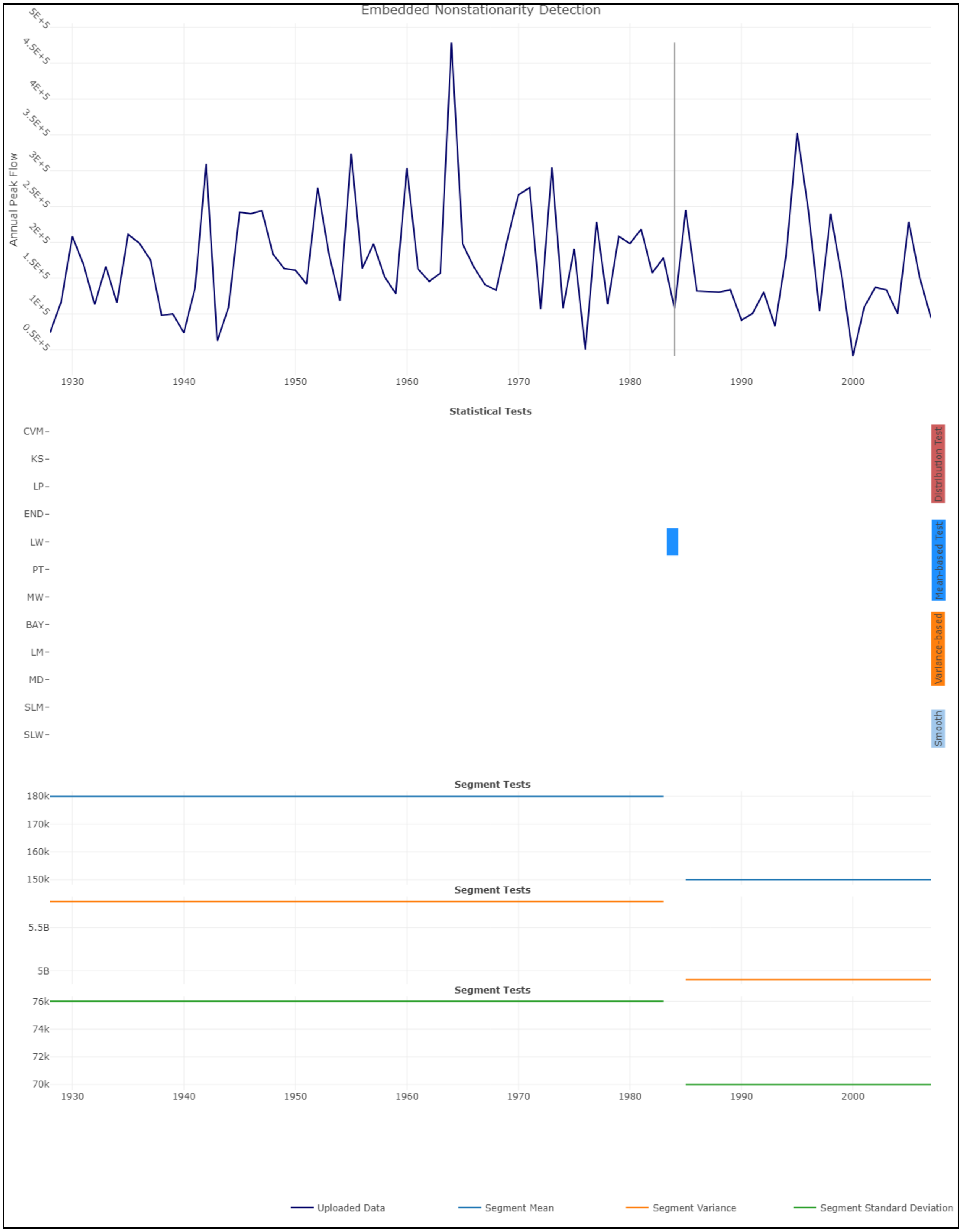


Figure 3-24. NSD Willamette River at Salem. Naturalized flows. 1928-2008

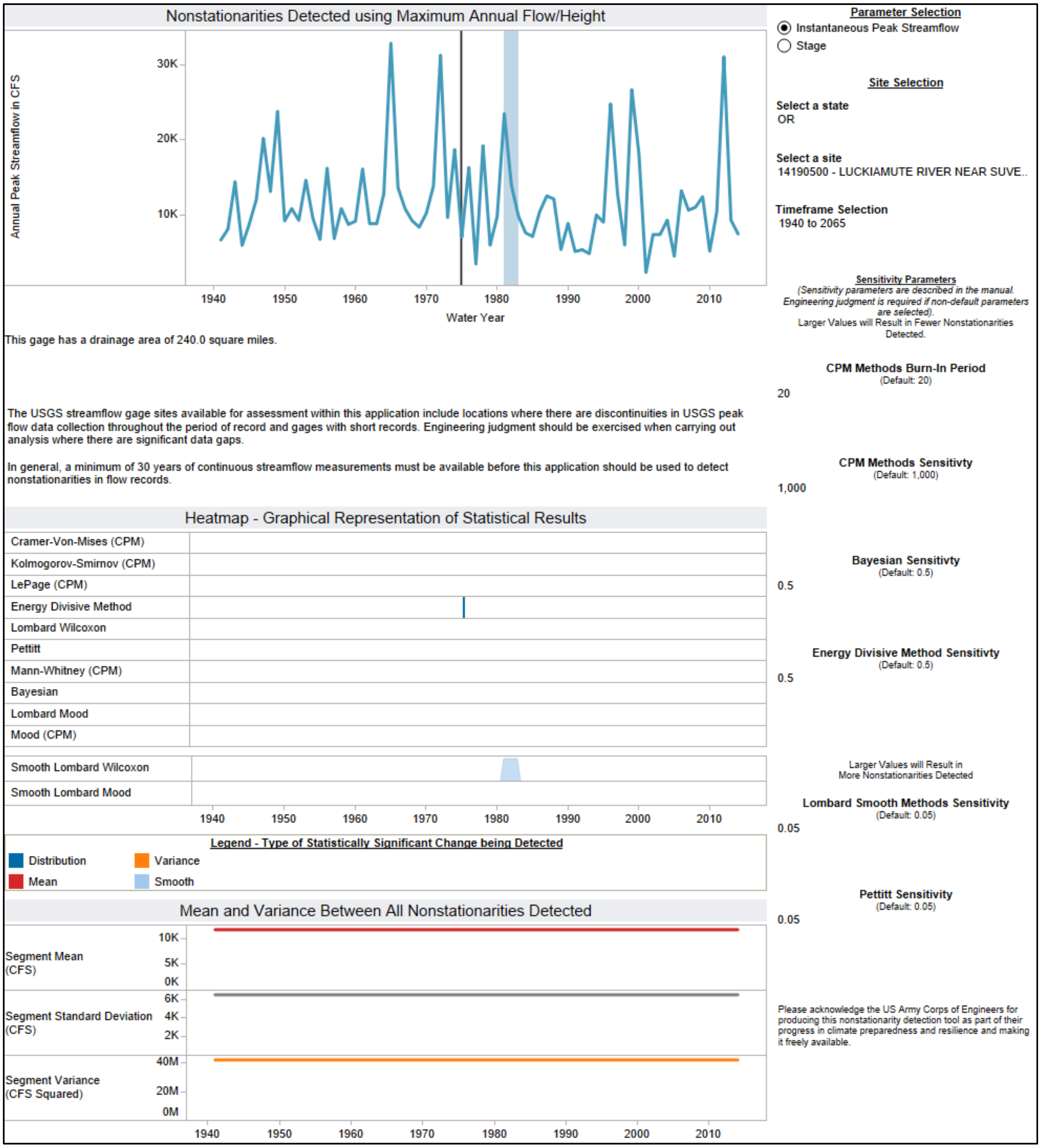


Figure 3-25. NSD Luckiamute River nr Suver. 1940 - 2014

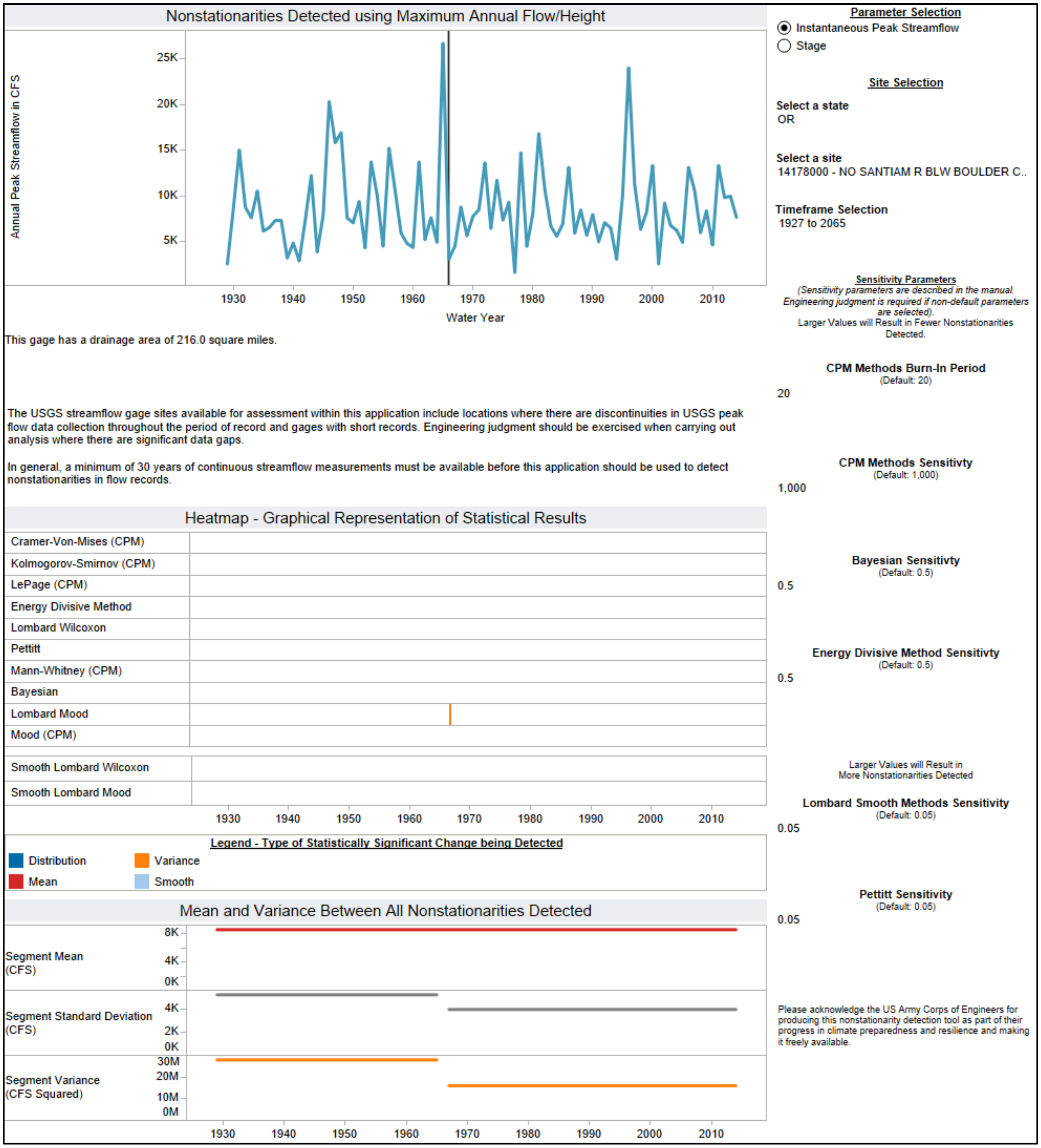


Figure 3-26. NSD N.Santiam River below Boulder. 1927 - 2014

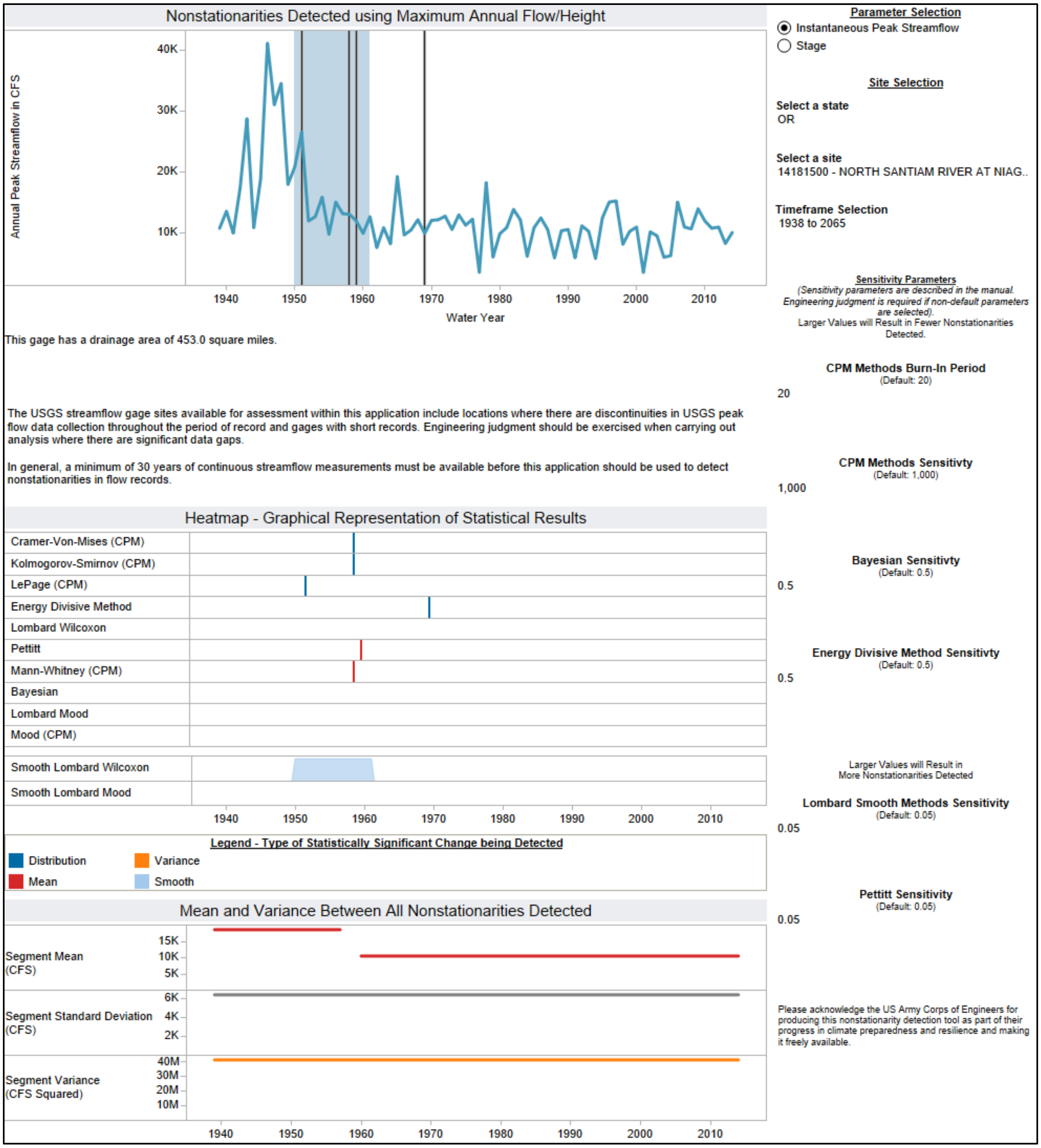


Figure 3-27. NSD N. Santiam River at Niagara.1938-2014

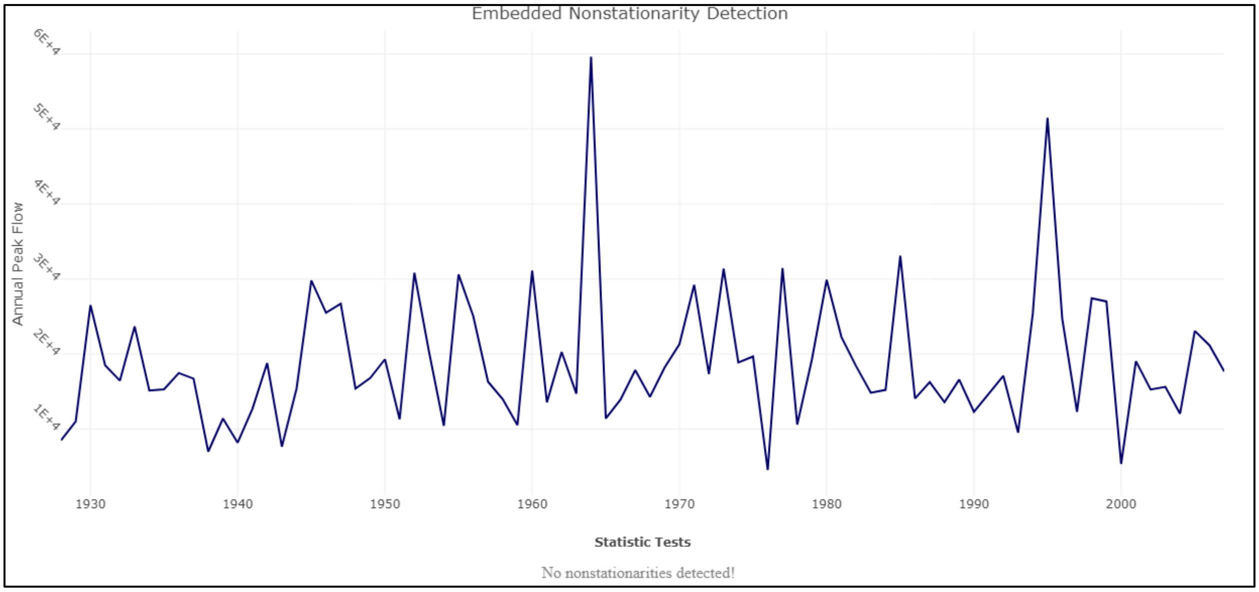


Figure 3-28. NSD N. Santiam River at Niagara. Naturalized Flows. 1928-2008

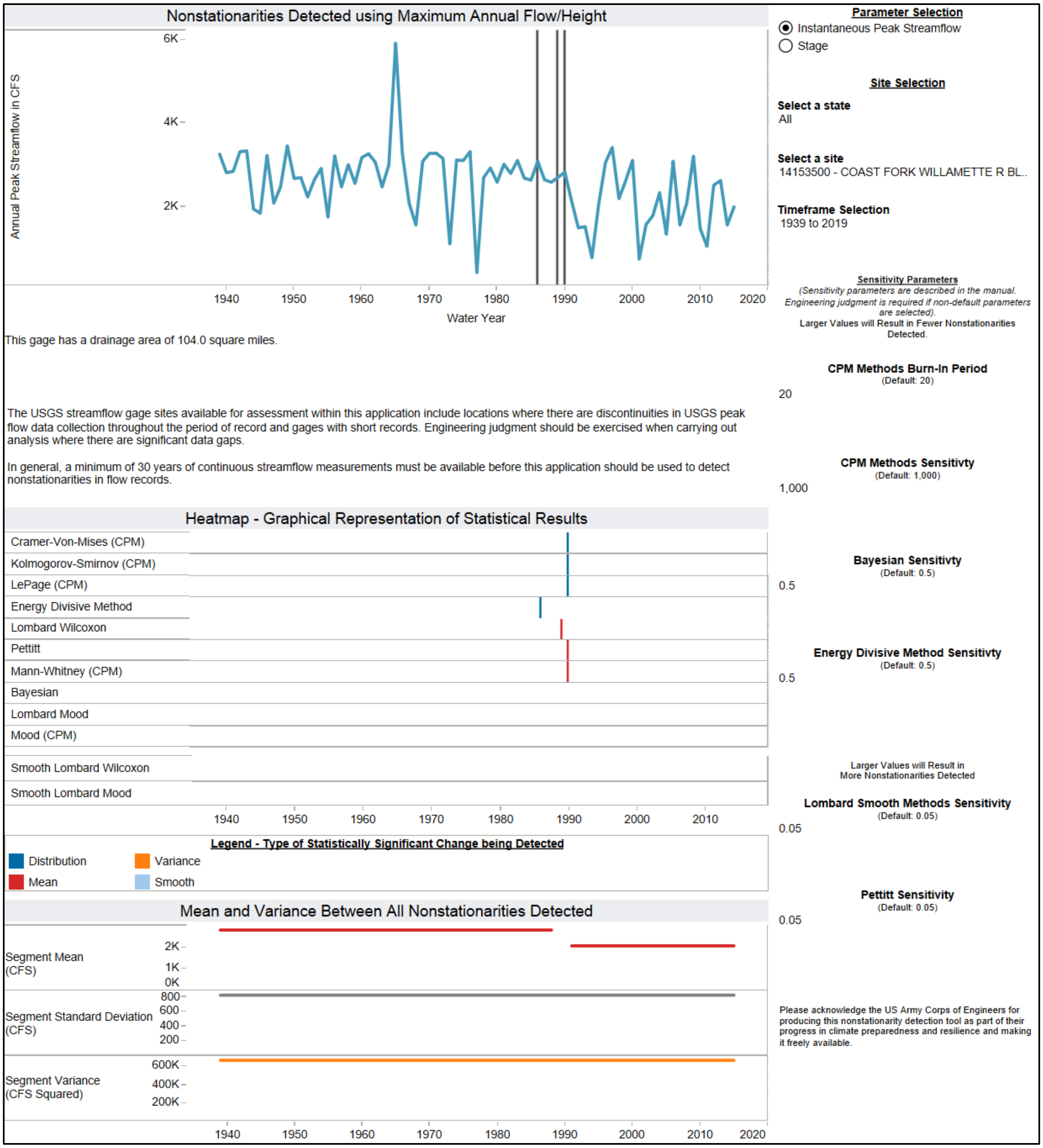


Figure 3-29. NSD CF Willamette River below Cottage Grove.1939-2014

Figure 3-30. NSD CF Willamette River below Cottage Grove. Naturalized Flows. 1928-2008

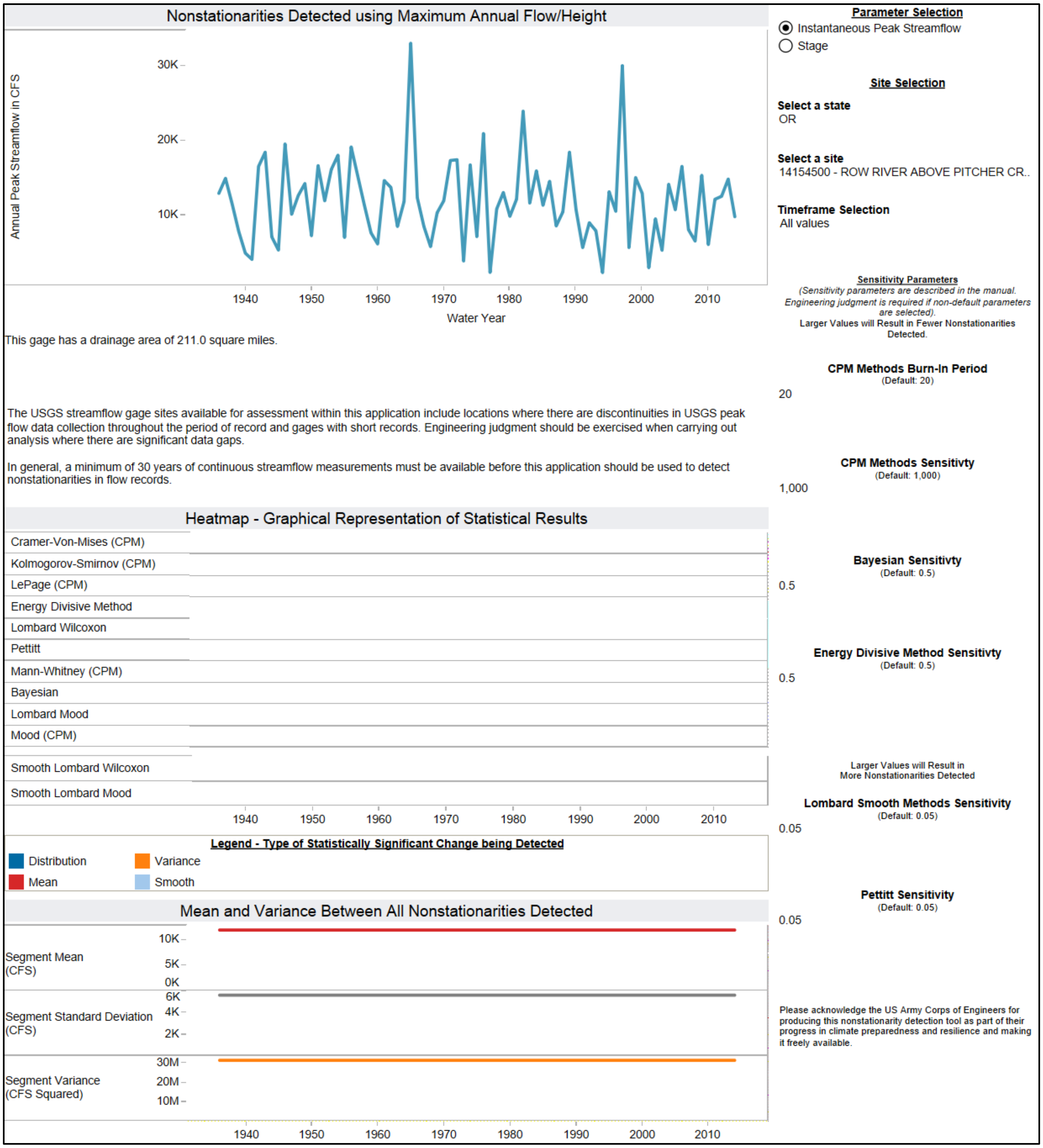


Figure 3-31. NSD for the Row River at Pitcher Creek, nr Dorena. 1936-2014

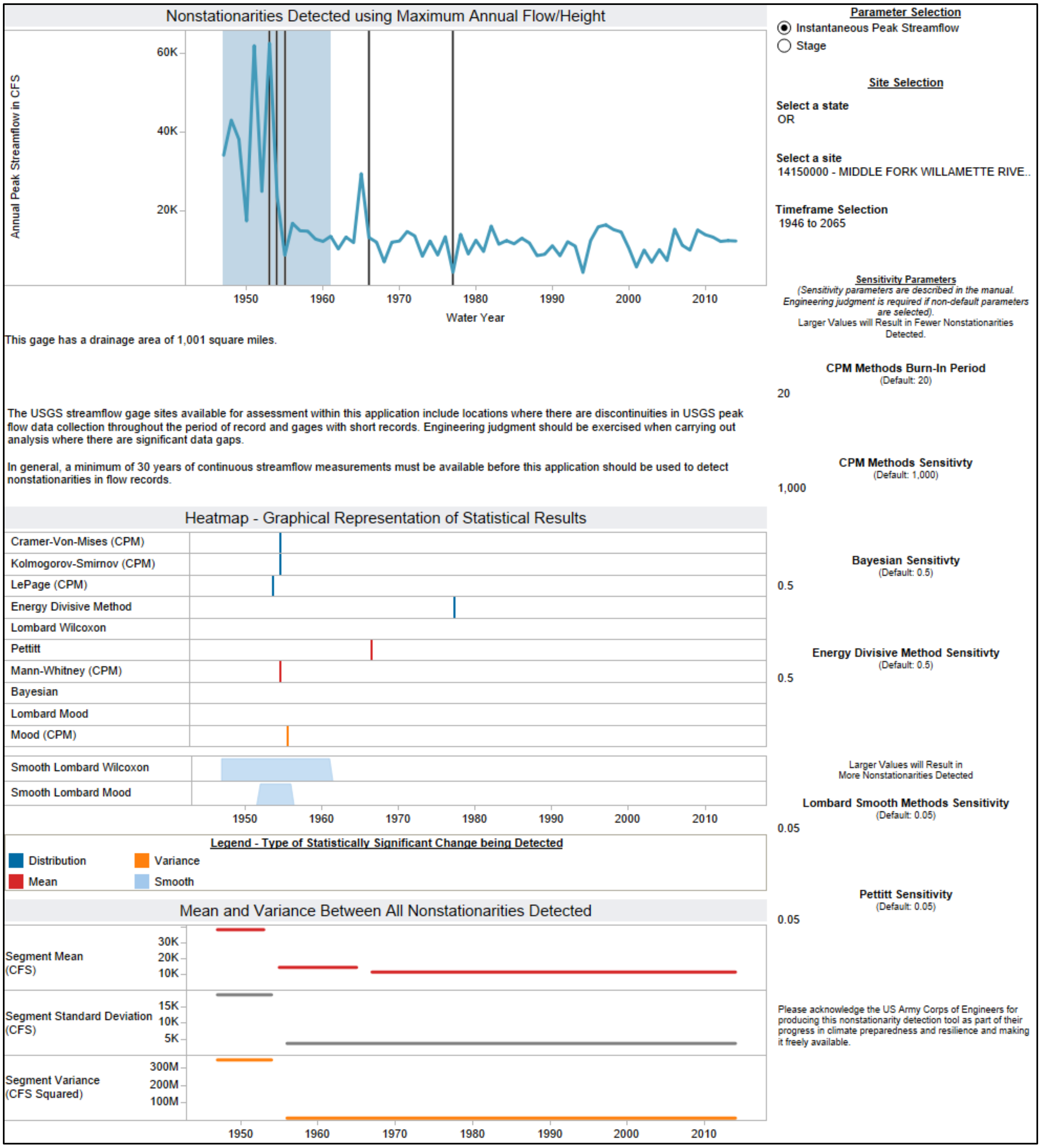


Figure 3-32. NSD MF Willamette River nr Dexter. 1946-2014

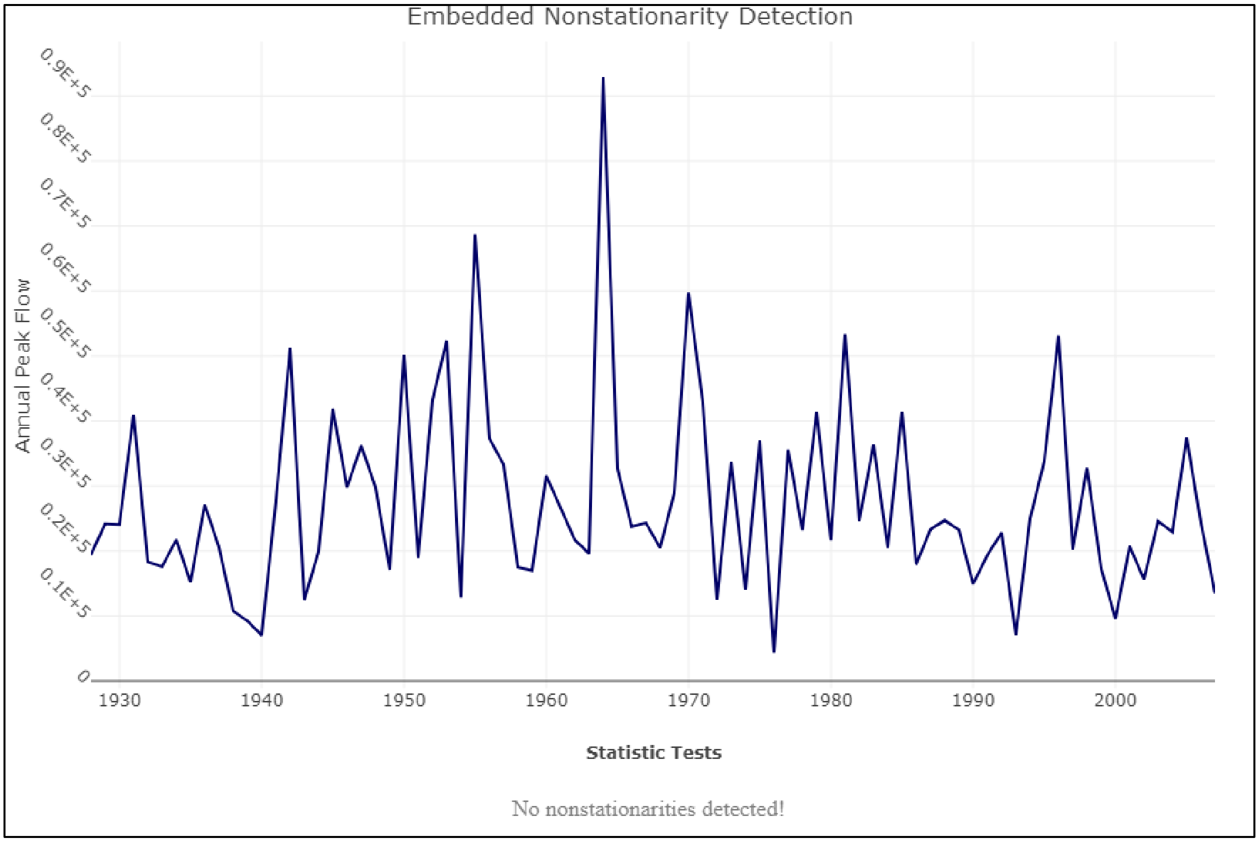


Figure 3-33. NSD MF Willamette River near Dexter. Naturalized Flows. 1928-2008

3.5 ADDITIONAL HYDROLOGIC TREND ANALYSES.

NMFS and others asked USACE whether a truncation of the historical period of record (i.e., last 30-or 40-year subsets) would be appropriate base on the hypothesis that the last 30 years represented trends that were was more representative of likely climate change expected in the future?

To address this concern, USACE prepared trend and non-stationarity analyses. There did not appear to be strong evidence that climate change was driving any streamflow non-stationarities in the basin. Analyses did identify trends but only for the 1-day average annual minimum flows, was there a t(negatively sloped) trends across the POR, which was also statistically significant (p-value, less than 0.05); see below, Table 3-2. USACE technical review requires strong evidence to accept truncating the record and discarding the earlier years of record. Supporting Mann-Kendell analyses did not appear to demonstrate this had been achieved. These analyses showed that this requirement was not met. The details and results of the analyses are discussed below.

Daily unregulated flow at Salem, 1928 thru 2019, 91 years were used for analyses purposes. Note, that the EIS ResSim analysis POR is WYs 1935-2019. An additional 7 year was added to the trend analyses dataset. The source of these 7 additional years the Modified Flow dataset (BPA,

2020) .The Mann-Kendell test was performed to determine whether trends were statistically relevant. The critical periods within a water year (WY):

- Lowest 30-day flow period of the year (typically sometime in Aug-Sep)
- April 1 -September 30 flows
- March 1 – May 31 flows
- June 1 – September 30 flows

Analyses were performed at Salem, OR. Salem is a primary regulation control point and possess a significant period of quality flow data. Although regulation effects are removed , the data would still include diversion and (irrigation) depletions. Results are graphically summarized. below. Overall, the evaluated periods did not show any statistically significant trends or differences between the recent years.

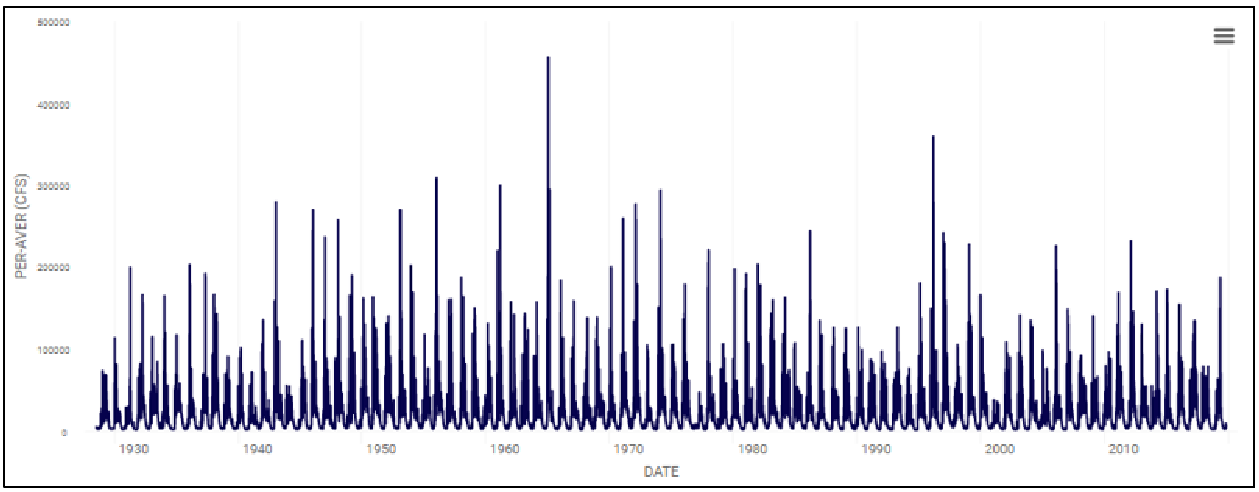


Figure 3-34. Salem, OR Unregulated Daily Average Flows. 1928- 2019

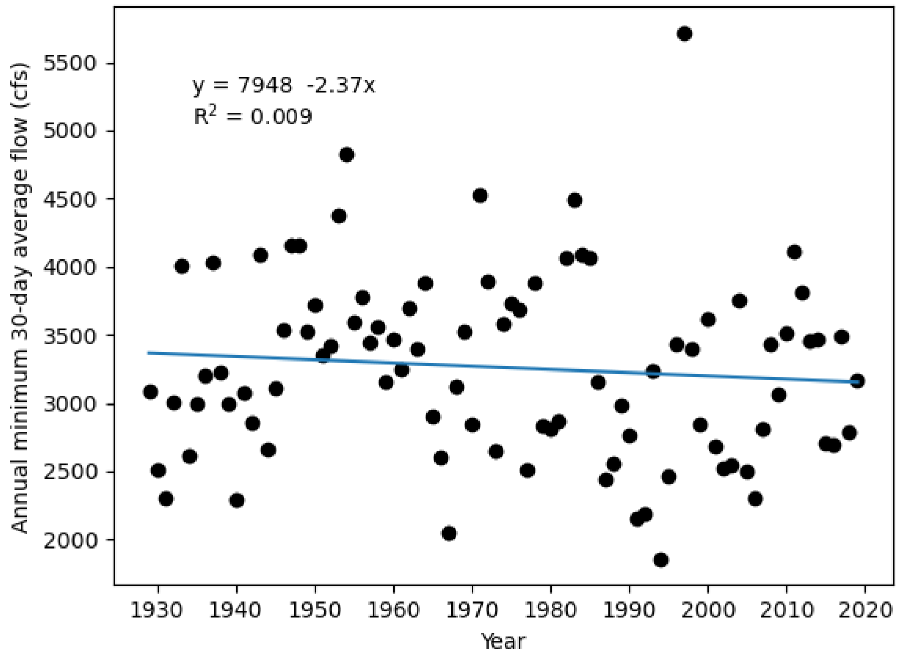


Figure 3-35. Salem, OR 30-Day minimum

For the 30-day minimum flow, there was no discernible trend through the POR. The Mann-Kendall Test, p-value of 0.35, which is > 0.05, indicated that this trend was not statistically significant.

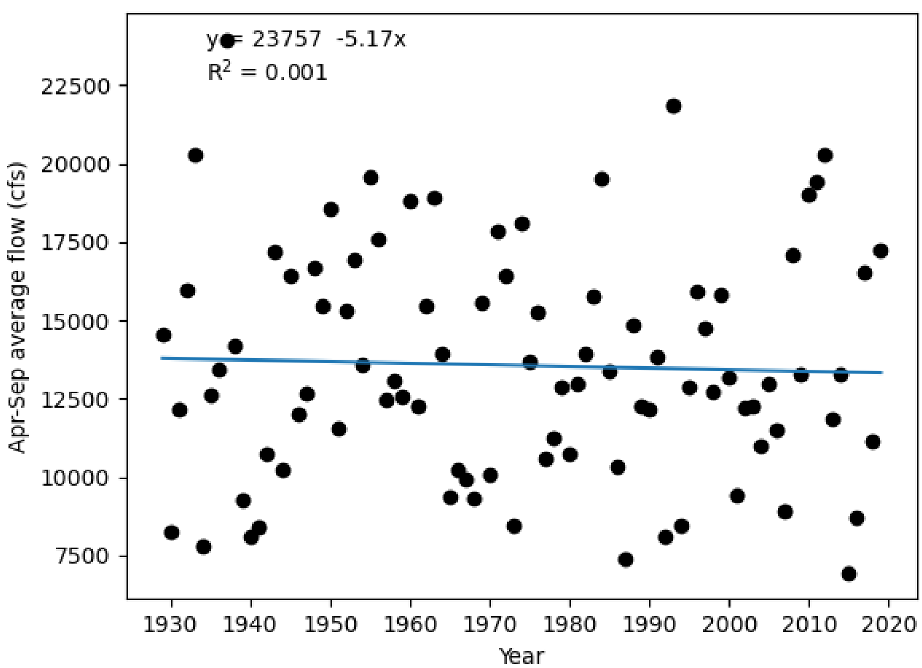


Figure 3-36. Salem, OR Apr-Sep.

For the April 1 through September 30 average flow, there was no discernible trend through the POR. The Mann-Kendall Test, p-value of 0.82, which is > 0.05, indicated that this trend was not statistically significant.

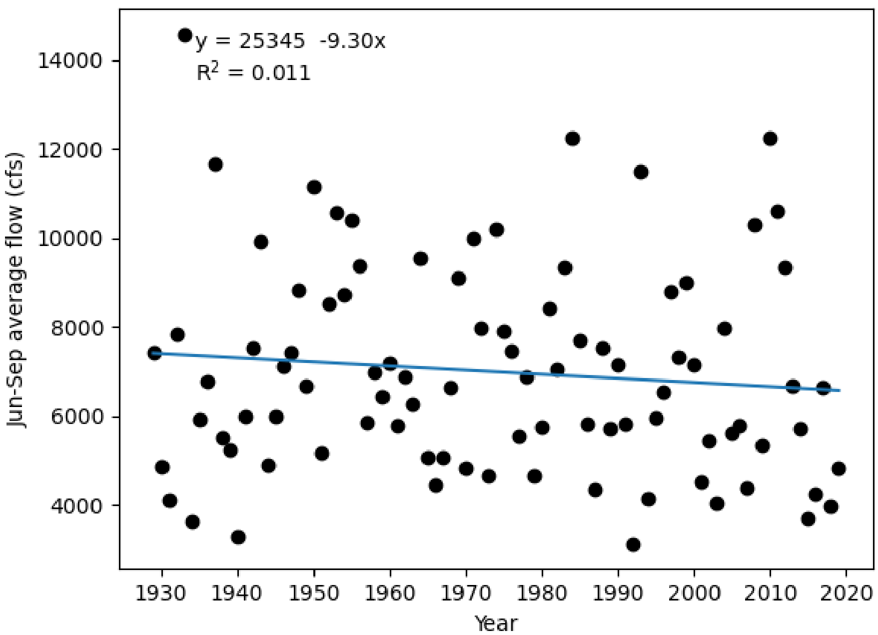


Figure 3-37. Salem, OR Jun-Sep.

For the June 1st through September 30th average flow, there was no discernible trend through the POR. The Mann-Kendall Test, p-value of 0.25, which is > 0.05, indicated that this trend was not statistically significant.

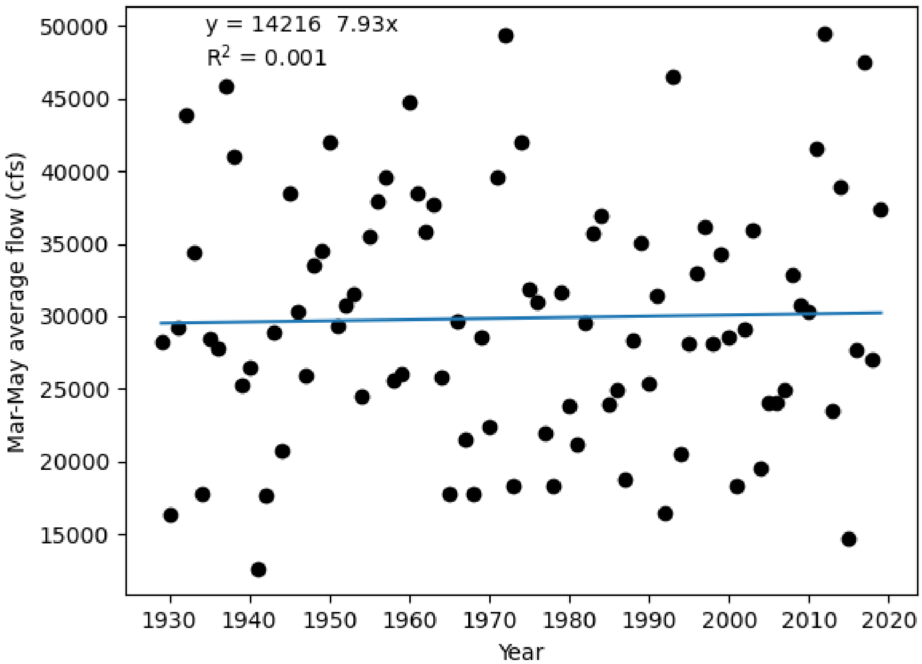


Figure 3-38. Salem, OR Mar-May.

For March through May average flow, there was no discernible trend through the POR. The Mann-Kendall Test, p-value of 0.90, which is > 0.05, indicated that this trend was *not* statistically significant.

Additional analyses of the same unregulated Salem daily flow (e.g., “SLM unReg Flow”) were also performed with the CPR’s time-series tool, summarized in Table 1-1Table 3-2

The CRP time series tool (TST) is a web-web-centric application that performs trend analyses as well as non-stationarity analyses on a given timeseries. The tool is located at: https://climate.sec.usace.army.mil/tst_app/

Annual monthly and seasonal means flows (cfs) were analyzed to determine if there were statistically relevant trends. Mann-Kendall and Spearman significance tests were performed on the timeseries. The annual and minimum trends were also of interest. As can be seen below, most trends for the daily unregulated flows at Salem, trended negative. The exception wintertime months and the refill season (March thru May), which trended positive (increasing flows). However, p-values were greater than 0.05 and therefore were not considered statistically significant trends. The only significant trend was found in the annual 1-day minimum flows, since 1-day annual minimum flow estimates have significant variability due to the computation method for producing unregulated flows. Removing the effects of reservoirs and routing naturalized flows downstream introduces some computational errors, since the streamflow models do not perfectly replicate real streamflow lag and attenuation. At longer durations, such as 7-days, these computational effects are minimal. There was no evidence of a strong and consistent trend in the record evaluated. One might have expected stronger seasonal trends, e.g., summer, winter, etc. This was not the case.

Non-stationarity detection was also evaluated. The threshold for instantaneous NSD significance, is a positive detection across 3 or more NSD tests. The tests leveraged by the TST are the same as those in the NSD tool, https://climate.sec.usace.army.mil/nsd/. The only difference is that the NSD evaluates annual maximum flow, while the TST is configured to evaluate on a customized dataset, as was the case for the Salem unregulated flow.

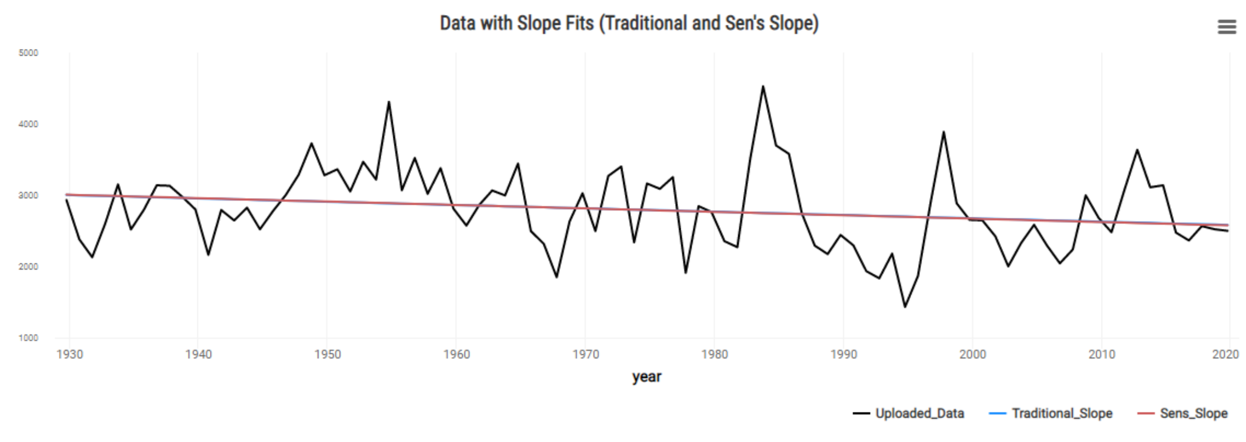
Table 3-2. Unregulated Salem time-series, Trend and Non-Stationarity Analyses

SLM UnReg Flow (Wys 1929-2019)				
Trend Variable	**Sen's Slope (cfs/year)**	**p-value (Mann-Kendall)**	**p-value (Spearman Rank-Order)**	**Statistically, Significant Strong Abrupt Nonstationarities Detected Yes (Year[s]) or No?**
Annual Maximum 1-day	-235.23	0.32	0.36	No
Annual Minimum 1-day	-4.78	**0.03**	**0.01**	**Yes(1946,1985,1986,1995)**
Annual Minimum 7-day Mean	-1.94	0.49	0.30	**Yes(1946,1985)**
Annual Apr-Sep Average	-4.03	0.82	0.81	No
Annual Jun-Sep Average	-10.06	0.25	0.28	No
Annual Mar-May Average	4.88	0.90	0.95	No
Annual Mean Jan	24.11	0.83	0.74	No
Annual Mean Feb	-71.54	0.35	0.34	**Yes(1948)**
Annual Mean Mar	16.57	0.80	0.82	No
Annual Mean Apr	4.77	0.91	0.83	No
Annual Mean May	-20.56	0.61	0.66	No
Annual Mean Jun	-30.65	0.19	0.22	No
Annual Mean July	-9.19	0.28	0.29	No
Annual Mean Aug	-0.54	0.91	0.85	No
Annual Mean Sep	-0.42	0.91	0.64	**Yes(1986)**
Annual Mean Oct	-2.76	0.80	0.80	**Yes(1946)**
Annual Mean Nov	9.37	0.87	0.80	No
Annual Mean Dec	58.67	0.52	0.53	No

Note: Annual max. and min. mean daily flow and monthly mean flow. Green = increasing trend; red= decreasing trend. Statistically significant trends (p-value < 0.05) are in bold. NSD is tested for changes in the data mean, variance, and/or distribution.

Only the 1-day annual minimum flow estimates held statistical significance, with the p-value being 0.05 or less. Figure 3-39 shows the negative sloped trend line. Figure 3-40 graphically shows the non-stationarity detections. Of the 8 detections, 4 were deemed significant, because 3 or more of the NSD tests were positive for a given NSD water year.

SLM_UNREG_TS_1-DayMin.csv



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Negative	-5	12008
Sen's Slope	Negative	-5	12232

Trend Hypothesis Test

Test	P-Value
t-Test	0.033804
Mann-Kendall	0.033255
Spearman Rank-Order	0.014314

- **A statistically significant trend (at the alpha = .05 level) was detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 3-39. Salem unregulated 1-Day Minimum Flow Trend

SLM_UNREG_TS_1-DayMin.csv

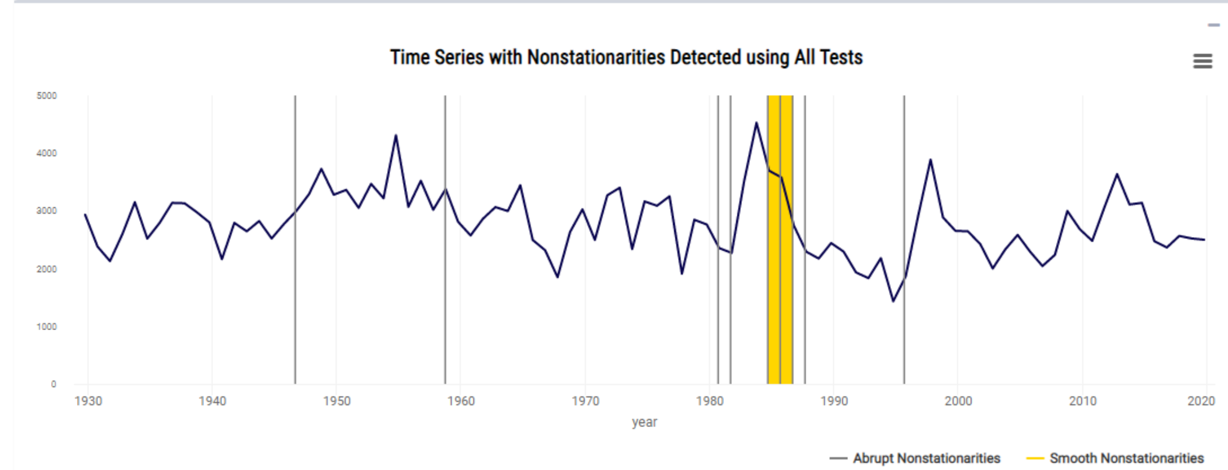


Figure 3-40. Salem unregulated 1-Day Minimum Flow Non-Stationarity Detections

3.6 SUMMARY OF OBSERVED TRENDS IN CLIMATE

Based on the literature review, there is consistent consensus among the available sources supporting trends of increasing temperatures within Willamette Basin. Observed changes in precipitation however are more variable and fluctuate by season and location. Even with the observed increases in precipitation, annual streamflow and particularly spring and summer flows have been observed as decreasing in the Pacific Northwest Region. This is largely attributed to the greater proportion of precipitation falling as rain as opposed to snow, which has altered the seasonality of the streamflow response with increasing flows in the winter/spring and decreasing flows in the summer/fall.

Based on the results of the linear regression analysis performed with the CHAT and the nonstationarity analysis, there is little evidence of statistically significant increasing or decreasing trends or nonstationarities within the Willamette Basin that can be attributed to climate change. There are statistically significant decreasing trends and nonstationarities in observed, peak streamflow that can be directly attributed to the construction of flood risk management projects.

CHAPTER 4 – PROJECTED TRENDS IN FUTURE CLIMATE AND CLIMATE CHANGE

4.1 LITERATURE REVIEW

4.1.1 Recent US Climate Change and Hydrology Literature Syntheses

In addition to the observed trends discussed previously, the 2015 USACE Literature Synthesis for the Pacific Northwest Region 17 also summarizes available literature for projected future trends in various hydrometeorological variables. These variables are projected using a variety of statistical methods in conjunction with global circulation models (GCMs). Figure 2 above summarizes the findings of the literature synthesis regarding projected climatic trends. Additional discussion is provided in the following paragraphs.

Temperature. The 2015 USACE Literature Synthesis found strong consensus in the literature that maximum temperature extremes in the Pacific Northwest show an increasing trend over the next century. A moderate consensus was found supporting an increasing trend in annual average temperature and minimum temperature extremes. The increases in temperature will likely occur in the summer months. Additionally, it was found that extreme temperature events, including more frequent, longer, and more intense summer heat waves, can be expected in the long-term future as compared with the recent past.

Precipitation. A strong consensus was found in the literature indicating that the intensity and frequency of extreme storm events will increase in the future in the Pacific Northwest Region. However, low consensus exists with respect to projected changes in total annual precipitation; results regarding total annual precipitation varied depended on location, season, GCM, and emission scenario.

Hydrology / Streamflow. Low consensus exists amongst the literature with regards to projected changes in hydrology for the region. Large variability in the projected hydrologic parameters (e.g., runoff, streamflow, SWE) exist across the literature and varied with location, hydrologic modeling approach, GCM used, and adopted emission scenario.

4.1.2 Fourth National Climate Assessment

In addition to the observed trends discussed previously, the NCA4 (2018) offers some insight into future climatic projections, as well as the implications of these projections on risk, infrastructure, engineering, and human health.

Temperature. Increases in temperature of about 2.5°F are expected over the next few decades regardless of future greenhouse gas emissions. Temperature increases ranging from 3°F to 12° are expected by the end of the century, depending on whether the world follows a higher or lower future emission scenario. Extreme temperatures are expected to increase proportionally to the average temperature increases. Figure 4-1 displays future projected, annual, average temperatures for two future time periods, the mid-21st century and late 21st century. These are compared with the historic baseline period of 1986-2015. Additionally, projections are shown for two emission scenarios, or representative concentration pathways (RCPs) of greenhouse gases. RCP8.5 is a higher emission scenario and RCP4.5 is a moderate emission scenario.

Note that in general, increases in projected temperature are greater in higher latitudes and lessen farther south in the country. Coastal states, such as Oregon, are largely projected to experience less warming than interior regions. Regardless of spatial variation, temperature increases are projected for the entire country under all emission scenarios.

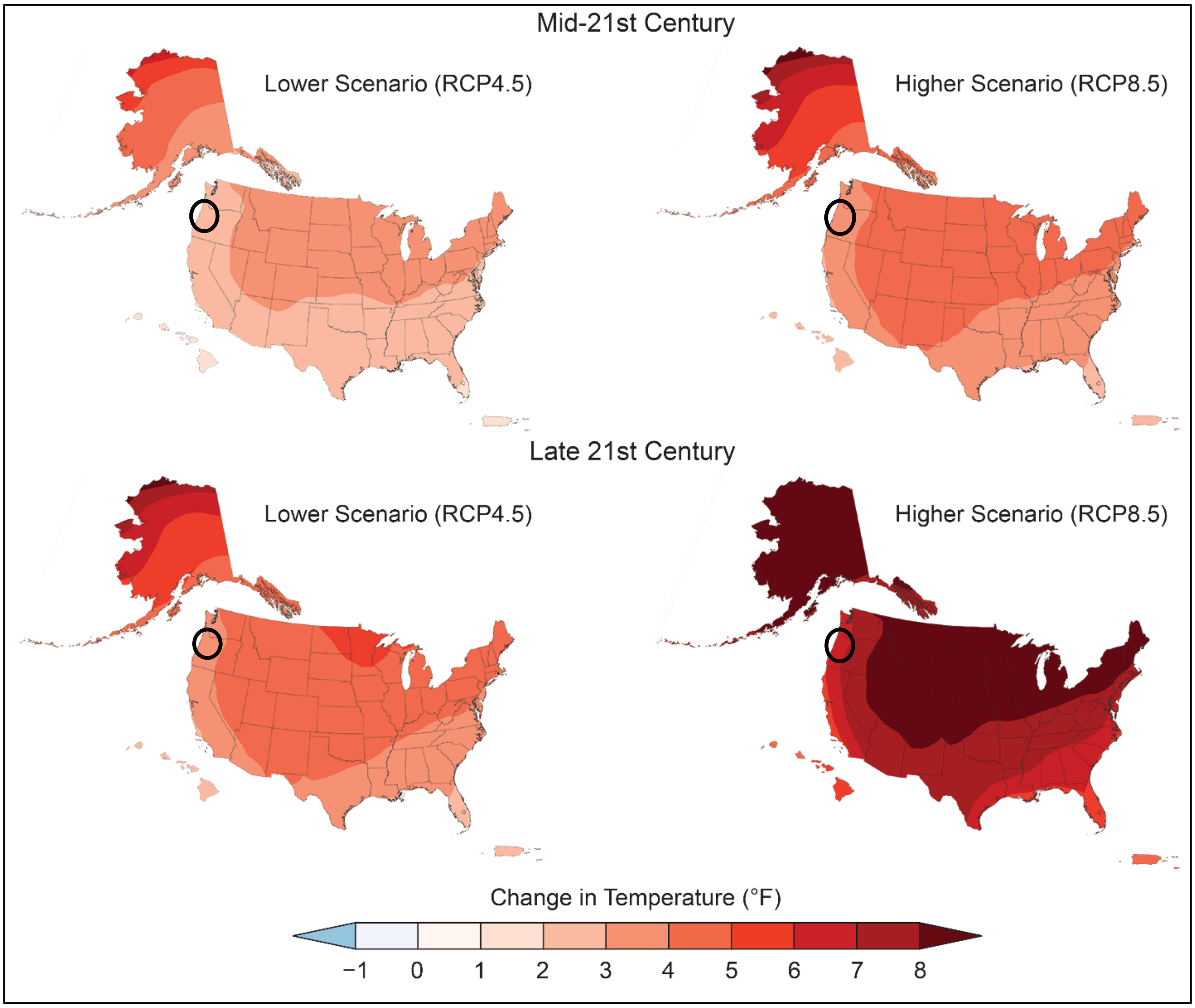


Figure 4-1. Future projections of temperature

Precipitation. Both increase and decreases in average annual precipitation are expected over the coming decades depending on location, season, and various other factors. Figure 4-2 displays the seasonal variation in annual precipitation in the later part of the century as compared with the historic period of 1986-2015. Note that there is significant variation in projections depending on location and season. Also note that red dots indicate that the projected trends due to climate change are large as compared with natural variations in climate, whereas the hatched areas show areas where the projected trends due to greenhouse gas emissions are relatively insignificant when compared to natural climate variability. Looking more closely at the Pacific Northwest and Willamette Basin project area, most of the trends in precipitation can be considered relatively insignificant except for a summertime decreases in precipitation. Surface soil moisture is expected to decrease across most of the U.S. and will be accompanied by large declines in snowpack in the western U.S. as winter precipitation shifts from falling as snow to falling as rain. This hydrologic shift will likely cause additional stress on water supply, irrigation, and ecologic minimum flow needs.

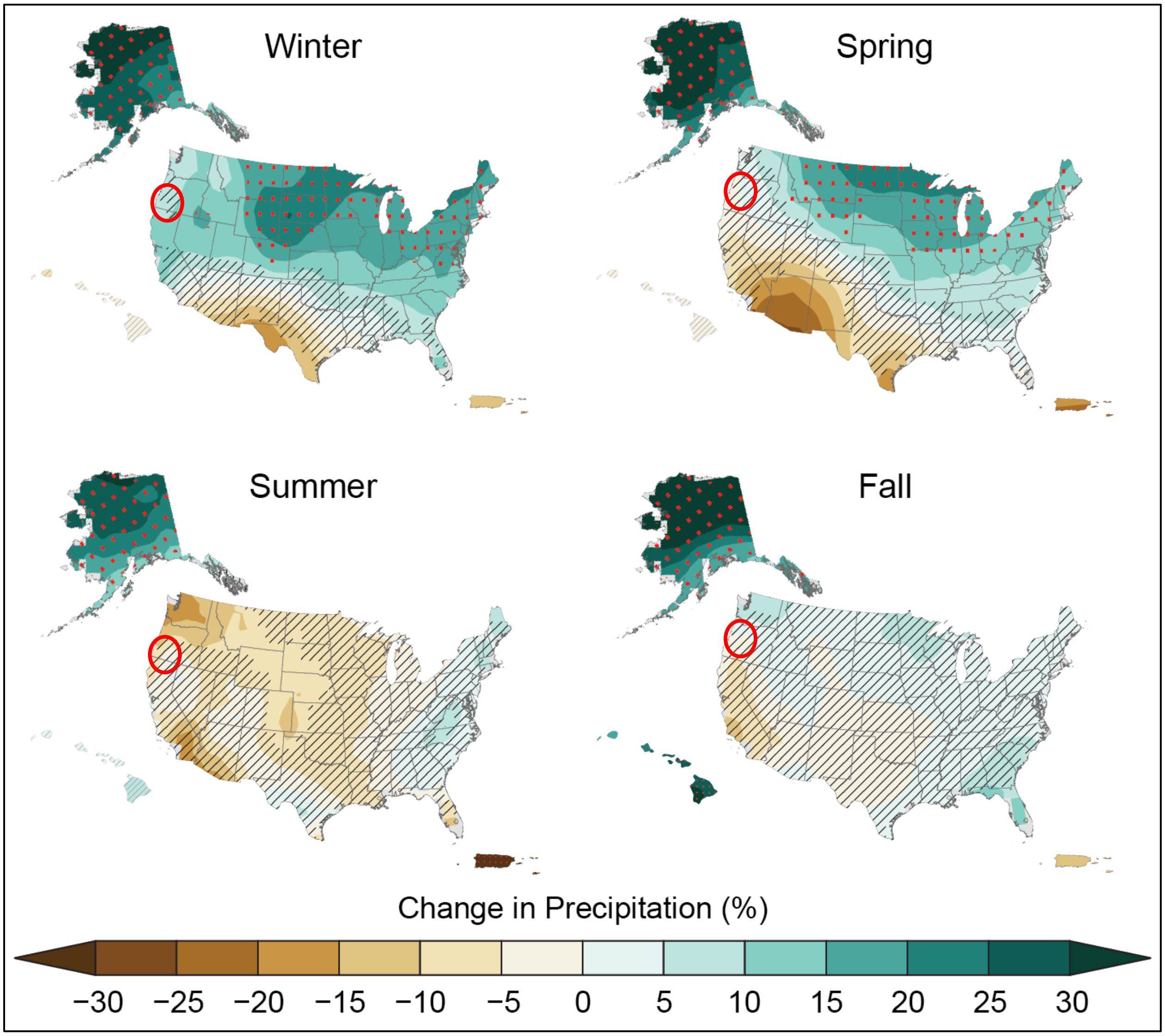


Figure 4-2. Observed percent change in precipitation during the 1% event

The observed increases in frequency and intensity of heavy precipitation discussed earlier are projected to continue, with higher emission scenarios producing stronger increasing trends. Figure 4-3 displays the projected change in total annual precipitation falling during the heaviest 1% of storms for a time between 2070 and 2099. Note in the vicinity of the Willamette Basin, under a moderate emission scenario (4.5), the annual precipitation falling during the heaviest 1% of events is expected to increase by approximately 10% to 19%. Under a higher emission scenario (RCP8.5), the basin is expected to experience extreme event precipitation increases of 30% to 39%. These trends are consistent with what would be expected with warmer temperatures, as increased evaporation rates lead to higher levels of water vapor in the atmosphere which in turn leads to more frequent and intense precipitation events.

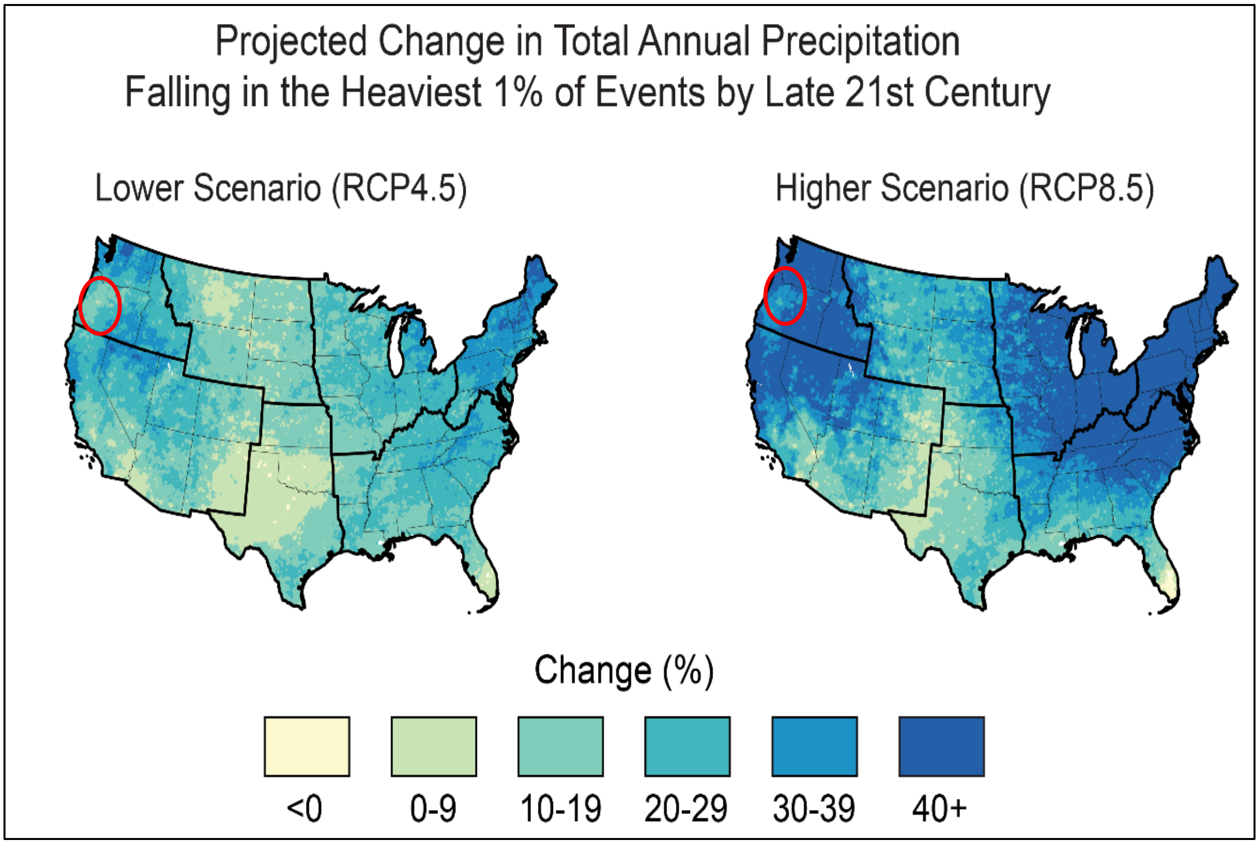


Figure 4-3. Projected change in future precipitation (RCP4.5/8.5)

There is potential for climate change driven changes to hydrologic conditions to increase stress on infrastructure and water supply within the Willamette River Basin. As higher temperatures increase the proportion of cold season precipitation falling as rain rather than snow, higher streamflow is projected to occur in many basins, raising flood risks. Shifts in the timing of water supply, such as earlier snowmelt and declining summer flows can adversely impact crop irrigation. This may increase stress on reservoirs for water supply. Many basins which have historically relied on snowmelt are anticipating declining streamflows in spring and summer months; for these basins, low flow periods are projected to be more prolonged and severe. If observed declines in higher elevation precipitation continue, this would exacerbate low streamflow conditions, resulting in decreased water supply and reservoir storage. Climate change is also expected to increase the risk from extreme events, both drought and flooding, potentially compromising the reliability of water supply, hydropower, and transportation. Isolated communities and those with systems that lack redundancy are the most vulnerable.

The NCA4 goes on to qualitatively discuss some of the risks associated with projected, future climate conditions. The NCA4 report emphasizes that the likelihood of hydrometeorological phenomena like droughts, extreme storms and flood events may be misrepresented when defined using historic records that are limited in length (approximately 10-100 years). Selected points from this discussion relevant to the Willamette Basin include:

- Extreme precipitation events are projected to increase in a warming climate and may lead to more severe rainfall driven floods and a greater risk of infrastructure failure.
- Long-lasting droughts and warm spells can compromise earthen dams and levees as a result of soil cracking due to drying, resulting in a reduction of soil strength, erosion, and land subsidence.
- The procedures used to design water resources infrastructure, estimations of probability of failure, and risk assessments for infrastructure typically rely on 10-100 years of observed data to define flood and rainfall intensity, frequency, and duration. This approach assumes that frequency and severity of extremes do not change significantly with time. However, numerous studies suggest that the severity and frequency of climatic extremes, such as precipitation and heat waves, have in fact been changing due to human-driven climate change. These changes represent a regionally variable risk of increased frequency and severity of floods and drought. Additionally, tree ring-based reconstructions of climate over the past 500 years for the U.S. illustrates a much wider range of climate variability than does the instrumental record (beginning around 1900). This historic variability includes wet and dry periods with statistics very different from those of the 20th century. Infrastructure design that uses recent historic data may underrepresent the risk seen from the paleo record, even without considering future climate change.
- Statistical methods have been developed for defining climate risk and frequency analysis that incorporate observed and/or projected changes in extremes. However, these methods have not yet been widely incorporated into infrastructure design codes, risk assessments, or operational guidelines.
- Climate change is expected to increase the frequency and/or intensity of many extreme events that affect infrastructure in the Northwest. Available vulnerability assessments for infrastructure show the prominent role those future extremes play. Since much of the existing infrastructure was designed and is managed for an unchanging climate, changes in the frequency and intensity of flooding, drought, wildfire, and heat waves affect the reliability of water, transportation, and energy services.

4.2 OREGON CLIMATE CHANGE RESEARCH INSTITUTE

In 2015, the Oregon Climate Change Research Institute (OCCRI) produced a report for the USACE Portland District titled “Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins.” OCCRI utilized projected climate datasets generated by the Pacific Northwest Hydroclimate Scenarios Project (Climate Impacts Group, 2010), also known as the Columbia Basin Climate Change Scenarios Project, to generate this report. The studies routed GCM based projected, climate changed meteorology through the Variable Infiltration Capacity (VIC) model for the Columbia River Basin, of which the Willamette Basin is a part. The resulting streamflow projections were based on 9 GCMs, two Coupled Model Intercomparison Project Phase 3 (CMIP3) emission scenarios (A1B and B1) and examined three time periods (30-year averages centered around 2025, 2045, and 2085). CMIP

In total, 19 unique combinations of GCMs and emission scenarios were considered; 8 based on scenario A1B, 8 based on scenario B1, and 1 historic baseline scenario.

CMIP3 GCM scenarios A1B and B1 respectively represent moderate and optimistically low greenhouse gas emission scenarios. Scenario A1B corresponds to an average global temperature increase between 1.7°C and 4.4°C, with a best estimate of 2.8°C. Scenario B1 corresponds to an average global temperature increase of 1.1°C to 2.9°C, with a best estimate of 1.8°C. These scenarios, published in 2000, are outdated when compared with the CMIP5 greenhouse gas emission scenarios, also known as representative concentration pathways (RCPs), published in 2014. While the CMIP3 and CMIP5 emission scenarios are not interchangeable, CMIP3 scenarios A1B and B1 very roughly correspond to CMIP5 scenarios RCP6.0 and RCP4.5 respectively.

According to the Willamette Basin Review Feasibility Study (2018): the OCCRI report describes general climate projections for 2030-2059 as having higher regional minimum and the maximum temperatures, meaning that both winters and summers will be warmer, with a greater increase in summer temperatures than winter temperatures. This trend is described as having a high degree of confidence, since all the GCM models reviewed had the same result. The amount of precipitation, however, varied among the various GCM models by both season and by the sign of the change (increases or decreases in precipitation). Regardless of the precipitation changes, the models show that the warming temperatures decrease the amount of the snow water equivalent (SWE) as a proportion of the cumulative precipitation (P) in the Willamette Basin. Willamette Sub-basins, such as the North Santiam, that historically receive the most snow will have significant declines in the projected winter ratio of SWE/P .The more southern sub-basins, such as the Middle Willamette, are projected to receive little or no snow in the future. The models that did show projected increases in winter precipitation also showed less snow accumulation, which affects the streamflows in each sub-basin.

The combination of changes in precipitation patterns and increasing temperatures result in future streamflows which have higher wintertime flows and lower summertime flows on average. Sub-basins within the Willamette Basin display differing sensitivity to these changes which are largely correlated to the sub-basin's projected loss of snow fall and that sub-basin's hydrologic dependence on snow accumulation. The OCCRI report summarizes the impacts that projected changes in climate and streamflow response will have on USACE projects. Reservoir projects that are likely to be similarly affected by climate change. In the OCCRI report, the Hills Creek, Cougar, and Detroit, and Big Cliff dams are highly sensitive to projected changes in streamflow (Group A). This is largely because they are located at high topographic elevations and snowmelt has historically been a key hydrologic forcing at these sites. In 18 of the 19 future climate scenarios, these projects are described as exhibiting a projected increase in mean flow during the period of December through March, with all 19 scenarios showing a projected decrease in mean flow for May through September.

The Cottage Grove, Dorena, and Fern Ridge reservoir projects are considered to have low streamflow sensitivity, because snow accumulation and melt have a small influence on hydrologic response at these locations (Group B). These projects are described as exhibiting a trend toward increasing winter flows transitioning towards a trend in decreasing flow around April. There is relatively low variability in this trend across the results produced by the 19 GCM based scenarios.

Lookout Point, Dexter, and Fall Creek projects are described as having moderate-to-high streamflow sensitivity (Group C). The contributing drainage area above these reservoirs is governed less by snowpack than by variability in total precipitation. These projects are described as exhibiting a projected increase in mean flow during the period December through March in the majority of the 19 future climate scenarios. All 19 future scenarios show decreasing summer flows. The Blue River project (Group C/D) is also considered to have a moderate-to-high streamflow sensitivity, with overall results like those described above for Lookout Point, Dexter, and Fall Creek dams, but this project's results were described separately in the OCCRI report because the project is slightly more sensitive to melting snowpack due to its higher topographic elevation and because the number of scenarios showing increasing wintertime flows is slightly different.

The OCCRI report describes the Green Peter and Foster reservoir projects as having low-to-moderate streamflow sensitivity (Group E). Slightly more than half of the future scenarios show increasing winter flow volumes, but all scenarios show decreasing summer flows.

4.3 PORTLAND STATE UNIVERSITY

Portland State University (PSU) published a report titled "Climate Change and Freshwater Resources in Oregon" in 2010. The report summarizes existing literature for the state of Oregon in a similar manner to the USACE literature syntheses discussed previously. In general, the PSU study agrees with many of the conclusions previously mentioned throughout this literature review, stating: "Many Oregon streams will experience higher winter flow and reduced summer flows as temperature rises and the variability of precipitation increases."

4.4 WILLAMETTE BASIN REVIEW

The Willamette Basin Review (WBR) Study, completed in 2019, is primarily concerned with reviewing and assessing reservoir operations within the Willamette Basin for the purposes of municipal and industrial water supply, agricultural irrigation, and fish and wildlife minimum inflows. The climate change analysis within this report applied a semi-quantitative analysis, i.e., using quantitative GCM simulation output to qualitatively inform how climate change might impact future operations within the basin. The climate changed hydrology used, was for the most part based upon the same data used in the OCCRI report, which was initially developed by the Pacific Northwest Hydroclimate Scenarios Project. The objective of the WBR focused primarily on water supply, which is driven by volume of runoff.

The feasibility study references much of the same literature included within this analysis and in general draws very similar conclusions to those previously mentioned. The report concludes that: "the warming climate [of the Willamette Basin] is expected to bring warmer, drier summers to the basin, while the winters may have more rain and less snow. There is some indication that the maximum flows will increase in the wintertime and that less water will be available to meet water supply objectives in the summer months."

The report also comments on the lack of research available targeted at identifying the timing of potential, future shifts in seasonality. For the Willamette Basin, understanding how climate change might shift the timing of snowmelt driven processes is particularly important. The current temporal resolution of projected meteorological data is too coarse to identify shifts in seasonality at a sub-monthly scale.

Changes in total inflow volume and seasonal shifts in precipitation and runoff from later to earlier in the year will likely influence the WVP's ability to refill their reservoirs. However, the impacts that climate change could potentially have on the ability of WVP to refill are very sensitive to the seasonality of inflows and therefore there is a great deal of uncertainty associated with how climate change could potentially impact WVP's ability to provide for water supply and environmental releases. Additional analysis and modeling are required to fully understand and quantify how refill will be impacted by climate change. The feasibility study does state that currently water demand exceeds available water supply during drier years; this is true for both regulated and unregulated streams. Additionally, the study found that increased water storage will likely be required in the future to meet the minimum required environmental flows.

4.5 CHANGES IN WINTER ATMOSPHERIC RIVERS

Warner, Mass, and Salathe (2015) published a paper in the Journal of Hydrometeorology examining projected changes in atmospheric rivers along the west coast of North America using CMIP5 GCMs and RCP8.5. RCP8.5 represents a relatively high emission scenario corresponding to an ultimate radiative forcing of 8.5 W/m2. Watersheds like the Willamette River Basin located along the west coast of the United States receive a majority of their precipitation during the winter months, with the most extreme events associated with atmospheric rivers (ARs). According to the 2015 journal article, "ARs are narrow regions of large water vapor transport that extend from the tropics or subtropics into the extratropics [such as the Pacific Northwest]."

The report focuses on latitudes ranging between 33.75°N and 48.75°N. The centroid of the Willamette Basin is located at approximately 44.5°N. Looking specifically at the latitude associated with WVPs, the paper projects extreme precipitation events (1% chance exceedance or 99th percentile) to increase from approximately 20 mm/day to 24 mm/day; an increase of 20% over historical norms. Increases in precipitation are projected to be directly tied to increases in temperature. For a latitude of 44.5°N, an increase in precipitation of approximately 6% is projected per degree (°C) of warming. Additionally, the report states: "precipitation is greatly enhanced as atmospheric rivers intersect the coastal terrain [such as the Cascade Mountain Range located in the Willamette River Basin], but it is uncertain how global warming will alter orographic enhancement."

4.6 UBIQUITOUS INCREASES IN FLOOD MAGNITUDE

Queen et al. (published January 2021) analyzed changes in water year (WY) maximum daily streamflows at 396 locations in the Columbia River basin. The climate changed hydrology used, was based upon previous climate change datasets prepared by the University of Washington and used in recent Columbia River basin regional climate studies. The flow frequency analysis of the Columbia River basin was performed using some 40 GCM projections, focusing the analysis on the highest emission scenario (RCP 8.5) The flow frequency analysis estimated the 10- through 100-year recurrence flood statistics for time windows, 1950-1999 and 2050-2099 .Flood statistics from the two 50-year periods were compared to report projected relative changes in flood magnitude (flood ratios) for 65 river locations in the Pacific Northwest, 15 being in the Willamette Valley .Increases in the ensemble means in flood magnitudes were found for all locations in the basin. The Willamette River had calculated average flood ratios ranging from approximately 1.2 to a bit over 1.6, for both return periods (10- and 100-year). These changes were high in headwater basins. The largest changes and highest variability between projections were at headwater locations.

The report found that for the rain-dominant basin of the Willamette River, the future was projected to increase in quantity and frequency of rain driven floods at the expense of floods from snowmelt and rain-on-snow events. It also noted that the flood ratio estimates determined may be biased low, due to modeling spatial and temporal duration resolution, 7-day versus daily, etc. .The reduction in snowpack was also theorized to reduce the impacts from more frequent or higher magnitude rain-on-snow events. Increasing projections for future precipitation intensity (e.g., driven by atmospheric rivers) contained in the GCMs will still lead to more severe future flood ratios in the Valley.

4.7 NOAA STATE CLIMATE SUMMARY FOR OREGON, 2022

National Oceanic and Atmospheric Administration (NOAA) through their, National Centers, for Environmental Information (NCEI)., publishes state climate change summaries. The following summarizes observed and projected warming through 2100. The source of the figure is NOAA's state climate summaries for 2022, https://statesummaries.ncics.org/chapter/or/.

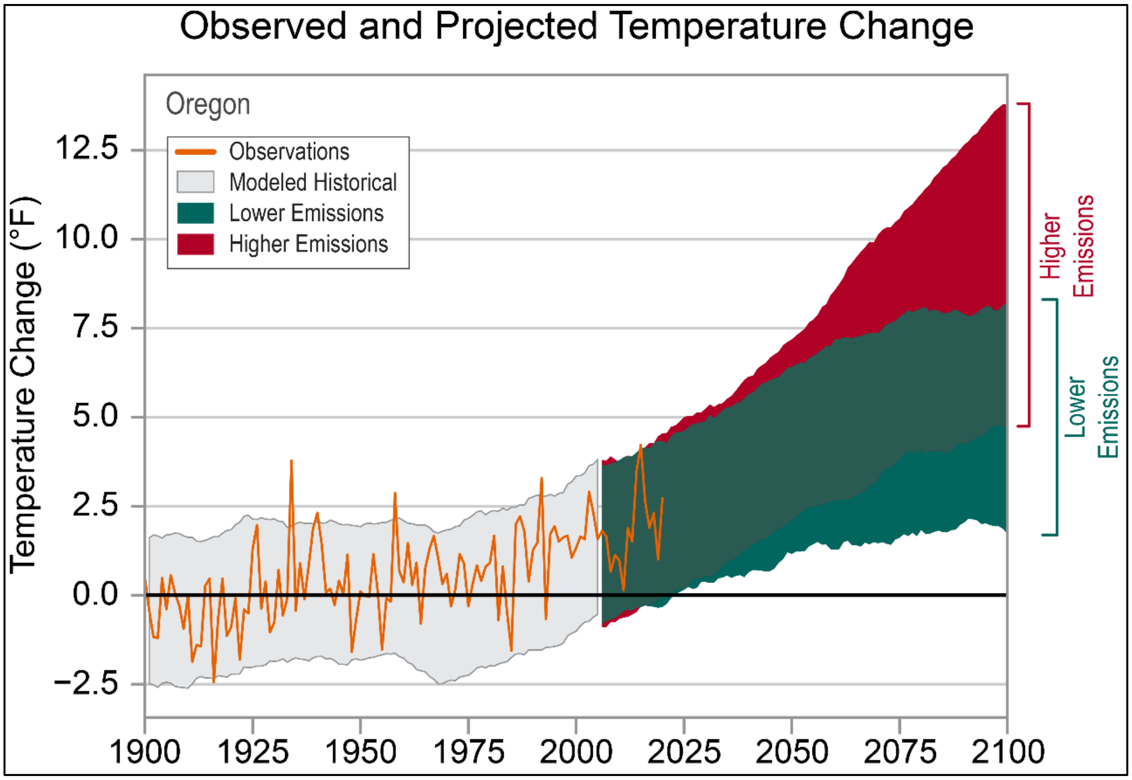


Figure 4-4. Observed and projected temperature change for Oregon

Observed and projected changes are shown above for Oregon. Warming, both observed and projected, is the primary driver for other hydroclimate and hydrology trends associated with climate change in Oregon. The baseline 0 point, (black line) is the 1901–1960 average temperature. Temperatures are near-surface air temperature. The observed period is 120 years, 1900–2020. Projected changes for 2006–2100 are from an ensemble of GCM scenarios, for RCP 4.5 (lower) and 8.5 (higher) emissions scenarios. Observed, temperatures (orange line) have risen about 2.5°F since the beginning 1900. Shading indicates the range of annual temperatures from the set of models.

Other primary findings for Oregon, pertaining to the Willamette Valley area of interest, were:

- Temperatures in Oregon have risen about 2.5°F since the beginning of the 20th century, and temperatures in the 1990s and 2000s were higher than any other historical period.
- Precipitation varies widely across the state and from year to year, with areas west of the Cascades also experiencing a large variation in rainfall amounts across the seasons.
- Unlike many areas of the United States, Oregon has not experienced an upward trend in the frequency of extreme precipitation events
- Under a higher emissions pathway, historically unprecedented warming is projected during this century. See Figure 4-4.

- Projected rising temperatures will raise the snow line—the average lowest elevation at which snow falls. This will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at lower elevations that are now on the margins of reliable snowpack accumulation.
- Although projections of overall annual precipitation are uncertain, winter precipitation is projected to increase.
- The combination of drier summers, higher temperatures, and earlier melting of the snowpack is projected to increase the frequency and severity of wildfires.

4.8 SUMMARY OF PROJECTED TRENDS IN CLIMATE

Across the range of literature reviewed in this analysis, there is general agreement regarding the hydrologic trends which can be expected in the future. In general, the following statements represent the probable hydrologic future that can be expected within the Willamette Basin:

- Wintertime precipitation and streamflows are anticipated to increase over historical norms. This projection emphasizes the continued need for reservoirs to function as flood risk management projects into the future. The associated increases in reservoir inflow may lead to more frequent high pool events and prolonged periods of flood operation in the winter and spring seasons.
- Summertime streamflows are consistently projected to decrease in the future relative to historical norms. There is strong consensus for this trend across the spectrum of climate model scenarios and within existing literature. This indicates that while reservoirs may be tasked to serve an increasing role in flood risk management, they may also be stressed in the summertime months to supply adequate quantities of water for irrigation, water supply, and required ecologic minimum flows.
- The seasonal timing of the transition from higher wintertime flows to lower summertime flows is not adequately addressed in the literature. This timing is of particular importance to anticipating required changes in reservoir operation.
- Projected future temperatures are anticipated to increase significantly over historic norms. This has various hydrologic implications including increased atmospheric moisture, evapotranspiration rates, frequency of wildfires, hydropower demand, and water supply demand.

CHAPTER 5 – CLIMATE HYDROLOGY ASSESSMENT (CHAT)

The USACE Climate Hydrology Assessment Tool (CHAT) was used to assess projected, future trends within the Willamette Basin watershed, HUC-1709. The tool displays the range of projected annual maximum monthly streamflows from 1950 - 2099, with the projections from 1950 – 1999 representing hindcast projections and 2000 – 2099 representing forecasted projections.

Figure 5-1 displays the range of projections for 93 combinations of CMIP5 GCMs and RCPs produced using BCSD statistical downscaling. These flows are simulated using an unregulated VIC hydrologic model at the outlet of the Willamette River Basin (HUC-1709) which is just below the City of Portland, OR. At this outlet, the Willamette River has a drainage area of approximately 11,200 mi2, as compared with the 7,280 mi2 watershed of the Willamette River at Salem, OR. It should be noted that the hindcast projections do not replicate historically observed precipitation or streamflow and should therefore not be compared directly with historical observations. This is in part because observed streamflows are impacted by regulation, while the VIC model used to produce the results displayed in Figure 38 is representative of the unregulated condition.

Upon examination of the range of model results, there is a clear increasing trend in the higher projections, whereas the lower projections appear to be relatively stable and unchanging through time. The spread of the model results also increases with time, which is to be expected as uncertainty in future projection increases as time moves away from the model initiation point. Sources of variation and the significant uncertainty associated with these models include the boundary conditions applied to the GCMs, as well as variation between GCMs and selection of RCPs applied. Each GCM and RCP independently incorporate significant assumptions regarding future conditions, thus introducing more uncertainty into the climate changed projected hydrology. Climate model downscaling and a limited temporal resolution further contribute to the uncertainty associated with CHAT results. There is also uncertainty associated with the hydrologic models. The large spread of results shown in Figure 5-1 highlights current climatic and hydrologic modeling limitations and associated uncertainty.

Figure 5-2 displays only the mean result of the range of the 93 projections of future, climate changed hydrology which are shown in Figure 5-1. A linear regression line was fit to this mean and displays an increasing trend with a slope of approximately 102 cfs/yr. It should be noted that the p-value associated with this trend is less than 0.0001, indicating that the trend should be considered as statistically significant.

These outputs from the CHAT qualitatively suggest that annual maximum monthly flows, and therefore annual peak flows, are expected to increase in the future relative to the current time. Another important caveat is that the CHAT tool is simulating an unregulated watershed, comparable to the naturalized streamflows which have been discussed throughout this report. Reservoir operations can be expected to decrease the variance of flows shown in the CHAT, as well as decrease the magnitude of their peaks. The results indicated by the CHAT largely agree with many of the trends found within the literature review regarding projected future extreme event streamflow.

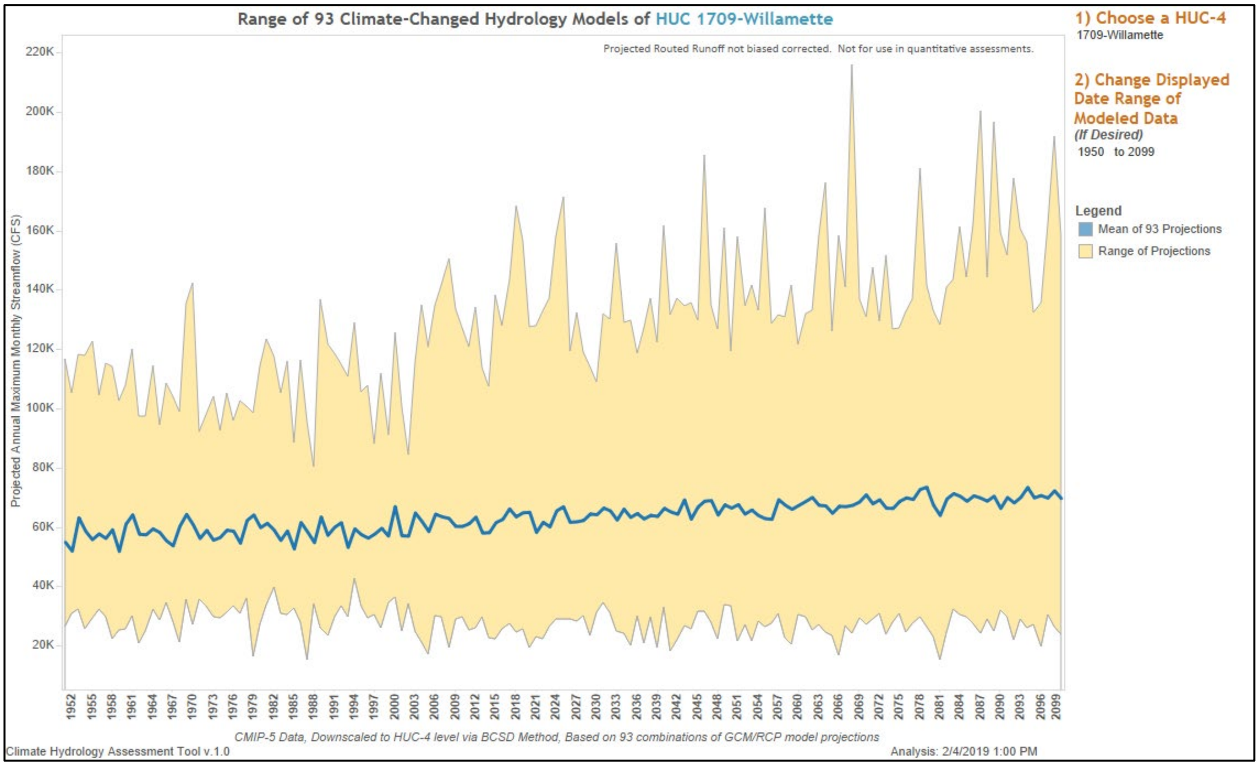


Figure 5-1. Range of GCM/RCP projections for the Willamette Basin, HUC-1709

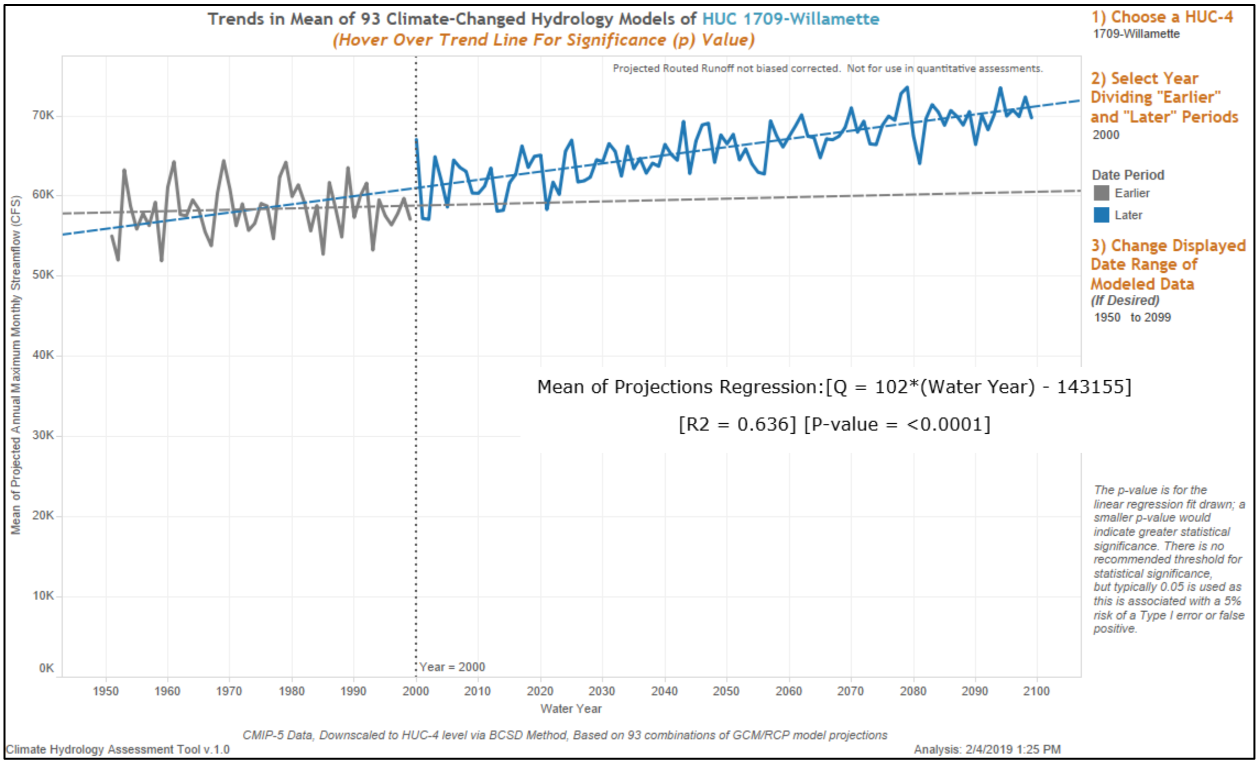


Figure 5-2. Mean of GCM/RCP projections for the Willamette Basin, HUC-1709

CHAPTER 6 – VULNERABILITY ASSESSMENT (VA)

The USACE Watershed Climate Vulnerability Assessment Tool (VA Tool) facilitates a screening level, comparative assessment of how vulnerable a given HUC-4 watershed is to the impacts of climate change relative to the other 202 HUC-4 watersheds within the continental United States (CONUS). The tool uses the Weighted Ordered Weighted Average (WOWA) method to represent a composite index of how vulnerable a given HUC-4 watershed (Vulnerability Score) is to climate change specific to a given business line. The HUC-4 watersheds with the top 20% of WOWA scores are flagged as being vulnerable.

When assessing future risk projected by climate change, the USACE Climate VA Tool makes an assessment for two 30-year epochs of analysis centered on 2050 and 2085.These two periods were selected to be consistent with many of the other national and international analyses. The VA tool assesses how vulnerable a given HUC-4 watershed is to the impacts of climate change for a given business line using climate hydrology based on a combination of projected climate outputs from the GCMs and RCPs resulting in 100 traces per watershed per time-period. The top 50% of the traces is called "wet" and the bottom 50% of the traces is called "dry." Meteorological data projected by the GCMs is translated into runoff using the VIC macro-scale hydrologic model. For this assessment, the default National Standards Settings are used to carry out the vulnerability assessment.

It is also important to note the variability displayed in the VA tool's results highlights some of the uncertainty associated with the projected climate change data used as an input to the VA tool. Because the wet and dry scenarios each represent an average of 50% of the GCM outputs, the variability between the wet and dry scenarios underestimates the larger variability between all the underlying projected climate changed hydrology estimates. This variability can also be seen between the 2050 and 2085 epochs, as well as within various other analyses within this report, such as output from the CHAT.

6.1 VA TOOL ANALYSES FOR THE EIS

The tool can be used to assess the vulnerability of specific USACE business lines such as "Flood Risk Reduction" or "Ecosystem Restoration" to projected climate change impacts. Assessments using this tool help to identify and characterize specific climate threats and particular sensitivities or vulnerabilities, at least in a relative sense, across regions and business lines. Business lines can be proxies for the vulnerabilities not expressly covered by the tool. For example, vulnerability of the "Ecosystem Restoration" may be a proxy for aquatic or wildlife habitat vulnerability. All business lines available within the VA tool were examined for outstanding vulnerability and none were found. For the designated business lines, the Willamette Basin (HUC 1709) is not within the top 20% of vulnerable watersheds within the CONUS for any of the four scenarios, which is not to say that there is not any vulnerability to future climate change existing within the basin. From that perspective, the VA tool is an "order or magnitude" assessment tool and are most suited to general qualitative determinations. The VA business lines analyzed for this EIS are listed below.

- Flood Risk Reduction
- Navigation
- Ecosystem Restoration
- Hydropower
- Recreation
- Water Supply
- Regulatory
- Emergency Management

The WVS EIS encompasses a range of resource areas and associated climate change vulnerabilities. The primary EIS resource areas (RAs) are listed below. For each, the most relevant VA business line(s) of interest are noted.

- **Hydrology and hydraulics.** The RA focus is on the EIS proposed action, effects, and impacts to the WSV dams/reservoirs and downstream control points. “Flood Risk Reduction”, “Navigation”, Ecosystem Restoration, Water Supply, Hydropower and “Regulatory” were primary VA business lines for this RA.
- **Water Quality.** The RA focus is on WVS streamflow temperature and total dissolved gas levels. Hazardous algal blooms (HABs) have also become an issue for water quality. The proxy VA business line is primarily “Ecosystem Restoration”.
- **Fish and Aquatic Habitat.** The focus is on WVS management and impacts to Chinook, Bull Trout and Lamprey. The proxy for this RA is primarily the “Ecosystem Restoration” and “Regulatory”, business line.
- **Hydraulics-Sediment-Transport.** The focus is on WVS proposed action impacts to change in sediment transport in Willamette Valley subbasin reaches. “Flood Risk Reduction”, “Ecosystem Restoration”, and “Regulatory” were primary VA business lines for this RA.
- **Wetland-Veg-Wildlife.** The focus is on overall impacts to the terrestrial habitats such as wetlands, upland forested areas, etc. “Ecosystem Restoration”, and “Regulatory” were primary VA business lines for this RA.
- **Cultural.** Impacts are focused on the archeological and cultural resource, for this resource area. “Regulatory” was considered the primary VA business lines for this RA.
- **Recreation.** This resource area vulnerability focuses on impacts to reservoirs and other USACE managed recreational areas. “Recreation” was directly assessed by the VA tool analyses.
- **Hydropower.** Bonneville Power Administration (BPA) manages WVS power production at USACE projects. Corps coordinates operations and its re-reg projects help manage power peaks downstream. “Power” was also directly assessed by the VA tool analyses.

- **Water Supply.** This resource area focuses on the conservation authorities that USACE manages too in the WVS. "Water Supply" business line was also directly assessed by the VA tool analyses.

6.2 VA TOOL RESULTS AND CONCLUSIONS

The results of the VA analyses are presented below. For reader convenience, the EIS specific, VA tool indicators are summarized in the following table, Table 6-1. The following output graphics and tables summarize the 8 business line VA analyses.

Table 6-1. VA Tool WOWA score Indicators for WIL HUC 1709

Indicator ID	Indicator Short Name	Indicator Name
8	8_AT_RISK_FRESHWATER_PLANT	% of freshwater plant communities at risk
65C	65C_MEAN_ANNUAL_RUNOFF	Mean annual runoff (cumulative)
65L	65L_MEAN_ANNUAL_RUNOFF	Mean annual runoff (local)
95	95_DROUGHT_SEVERITY	Drought Severity Index
130	130_FLOODPLAIN_POPULATION	Population in 500-year floodplain
156	156_SEDIMENT	Change in sediment load due to change in future precipitation
175C	175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)
175L	175L_ANNUAL_COV	Annual CV of unregulated runoff (local)
192	192_URBAN_SUBURBAN	% of land that is urban/suburban
221C	221C_MONTHLY_COV	Monthly CV of runoff (cumulative)
221L	221L_MONTHLY_COV	Monthly CV of runoff (local)
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
297	297_MACROINVERTEBRATE	Macroinvertebrate index of biotic condition
441A	441A_0.2AEPFLOODPLAIN_AREA	Area in 0.2% Annual Exceedance Probability floodplain
443	443_POVERTY_POPULATION	Number of people below poverty line
447	447_DISABLED	% of people disabled
448	448_PAST_EXPERIENCE	Disaster resilience due to experience
450	450_FLOOD_INSURANCE_COMMUNITIES	Number of communities with flood insurance
568C	568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)
568L	568L_FLOOD_MAGNIFICATION	Flood magnification factor (local)
570C	570C_90PERC_EXCEEDANCE	Low flow (monthly flow exceeded 90% of time; cumulative)
570L	570L_90PERC_EXCEEDANCE	Low flow (monthly flow exceeded 90% of time; local)
571C	571C_10PERC_EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; cumulative)
571L	571L_10PERC_EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; local)
590	590_URBAN_500YRFLOODPLAIN_AREA	Acres of urban area within 500-year floodplain
700C	700C_LOW_FLOW_REDUCTION	Low flow reduction factor (cumulative)
700L	700L_LOW_FLOW_REDUCTION	Low flow reduction factor (local)

The link below directs the reader to pdf fact sheets that describe the VA driver metrics in greater detail.

https://maps.crrel.usace.army.mil/apex/f?p=201:7:11301322170318::NO:::

Note that "COV" is the coefficient of variation (COV, CV) for each year is the ratio of the standard deviation to the mean.

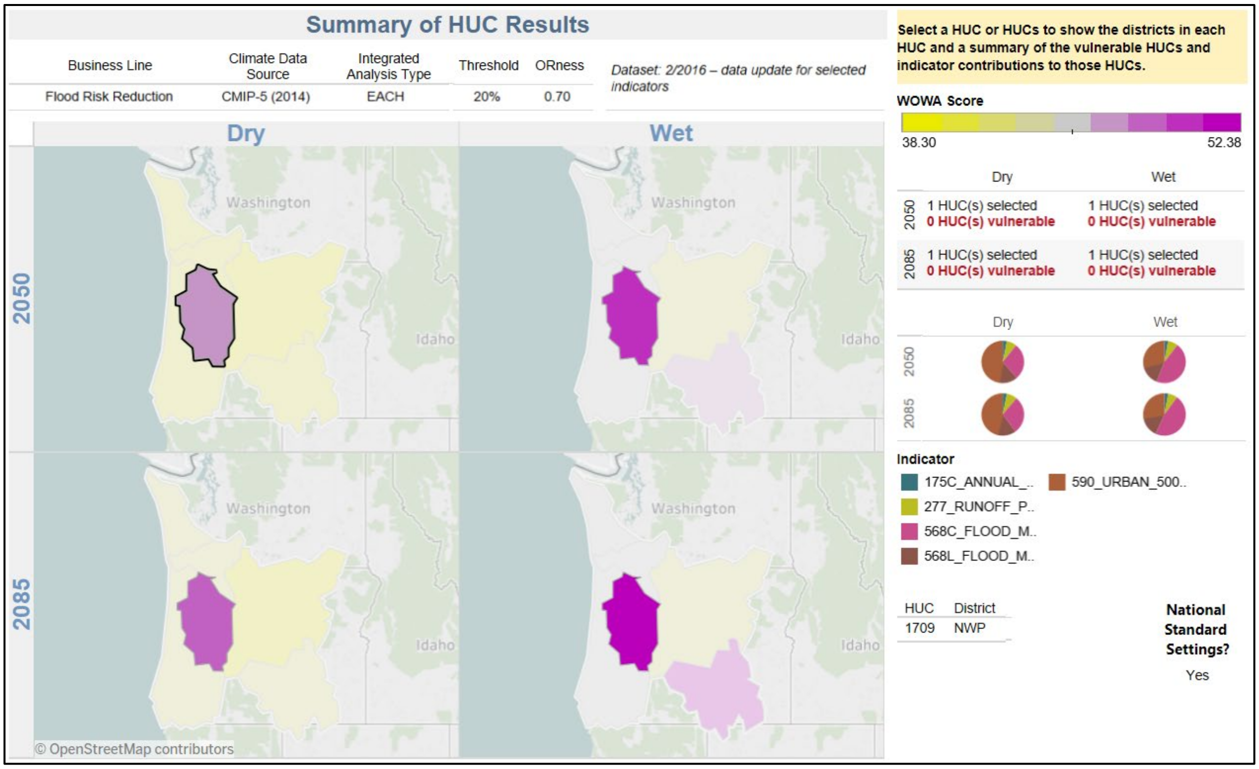


Figure 6-1. VA Tool Flood Risk Reduction business-line

Table 6-2. VA Flood Risk Indicators

Flood Risk Reduction		
Indicator Code	**Indicator Name**	**Description**
175C	175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
568C	**568C_FLOOD_MAGNIFICATION**	**Flood magnification factor (cumulative)**
568L	**568L_FLOOD_MAGNIFICATION**	**Flood magnification factor (local)**
590	**590_URBAN_500YRFLOODPLAIN_AREA**	**Acres of urban area within 500-year floodplain**

(Note: Red indicates the top vulnerability indicators)

Table 6-3. WOWA score for Flood Risk Reduction business-line

WIL HUC 17094	**Flood Risk Reduction**	
Epoch:	**2050**	**2085**
Dry Scenarios	46.84	49.4
Wet Scenarios	48.38	51.5

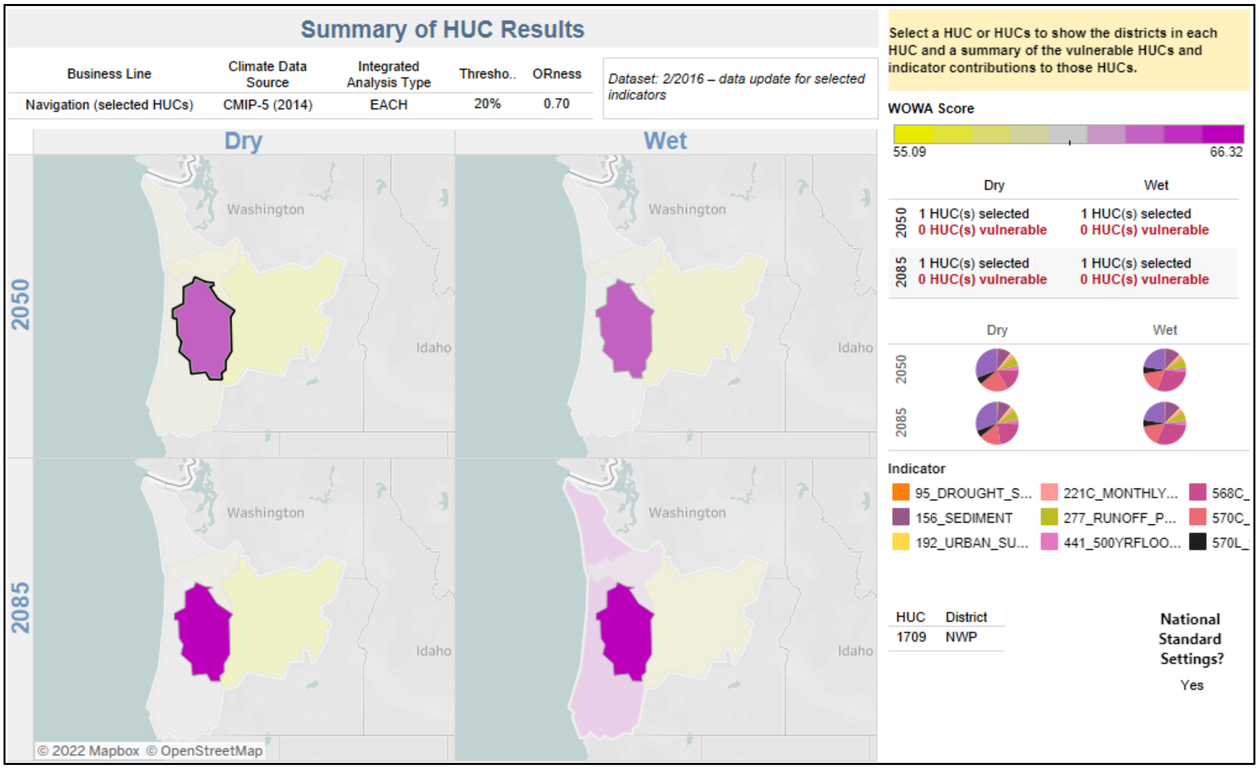


Figure 6-2. VA Tool for Navigation business line

Table 6-4. VA Navigation Indicators

Navigation		
Indicator Code	**Indicator Name**	**Description**
95	95_DROUGHT_SEVERITY	Drought Severity Index
156	**156_SEDIMENT**	**Change in sediment load due to change in future precipitation**
192	192_URBAN_SUBURBAN	% of land that is urban/suburban
221C	**221C_MONTHLY_COV**	**Monthly CV of runoff (cumulative)**
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
441A	441A_0.2AEPFLOODPLAIN_AREA	Area in 0.2% Annual Exceedance Probability floodplain
568C	**568C_FLOOD_MAGNIFICATION**	**Flood magnification factor (cumulative)**
570L	570L_90PERC_EXCEEDANCE	Low flow (monthly flow exceeded 90% of time; local)

(Note: Red indicates the top vulnerability indicators)

Table 6-5. VA WOWA score for Navigation

WIL HUC 17094	**Navigation**	
Epoch:	**2050**	**2085**
Dry Scenarios	63.09	65.24
Wet Scenarios	63.82	66.32

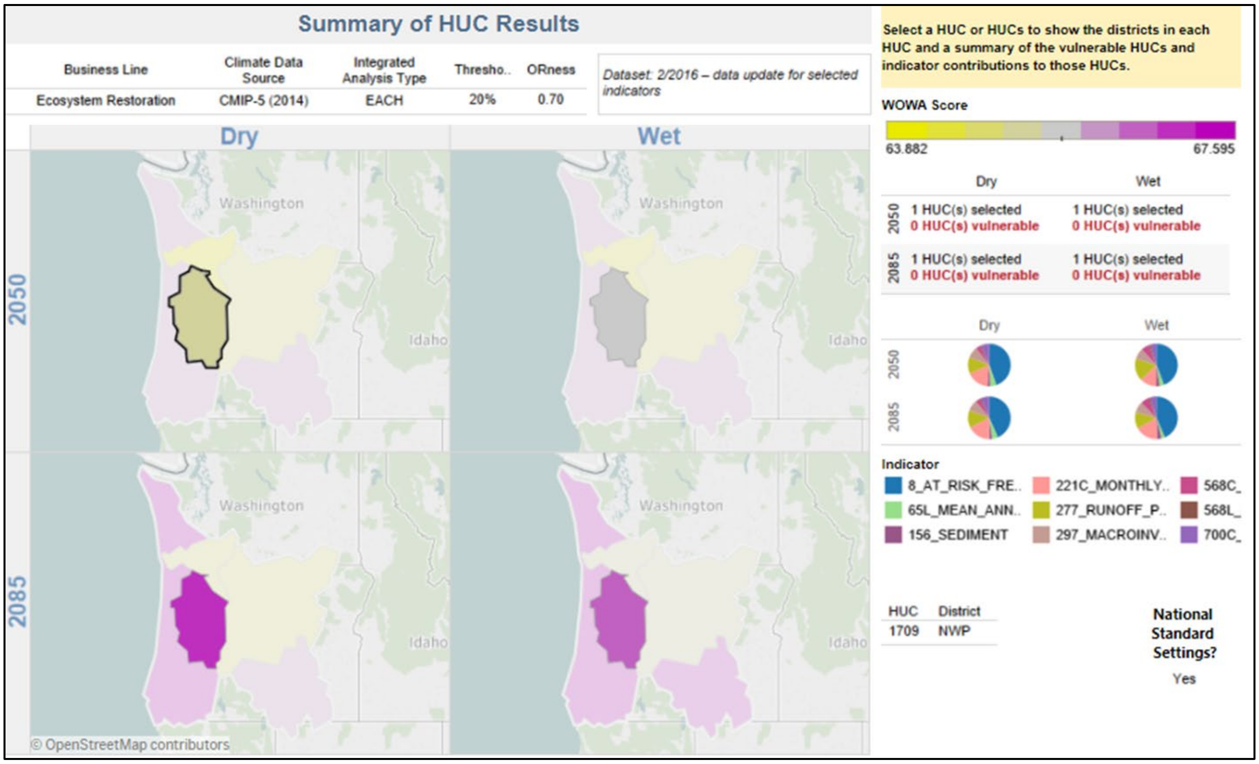


Figure 6-3. VA Tool Ecosystem Restoration business-line

Table 6-6. VA Ecosytem Restoration Indicators

Ecoystem Restoration		
Indicator Code	**Indicator Name**	**Description**
8	**8_AT_RISK_FRESHWATER_PLANT**	**% of freshwater plant communities at risk**
65L	65L_MEAN_ANNUAL_RUNOFF	Mean annual runoff (local)
156	156_SEDIMENT	Change in sediment load due to change in future precipitation
221C	**221C_MONTHLY_COV**	**Monthly CV of runoff (cumulative)**
277	**277_RUNOFF_PRECIP**	**% change in runoff divided by % change in precipitation**
297	297_MACROINVERTEBRATE	Macroinvertebrate index of biotic condition
568C	568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)
568L	568L_FLOOD_MAGNIFICATION	Flood magnification factor (local)
700C	700C_LOW_FLOW_REDUCTION	Low flow reduction factor (cumulative)

(Note: Red indicates the top vulnerability indicators)

Table 6-7. VA WOWA score for Ecosystem Restoration

WIL HUC 17094	**Flood Risk Reduction**	
Epoch:	**2050**	**2085**
Dry Scenarios	46.84	49.4
Wet Scenarios	48.38	51.5

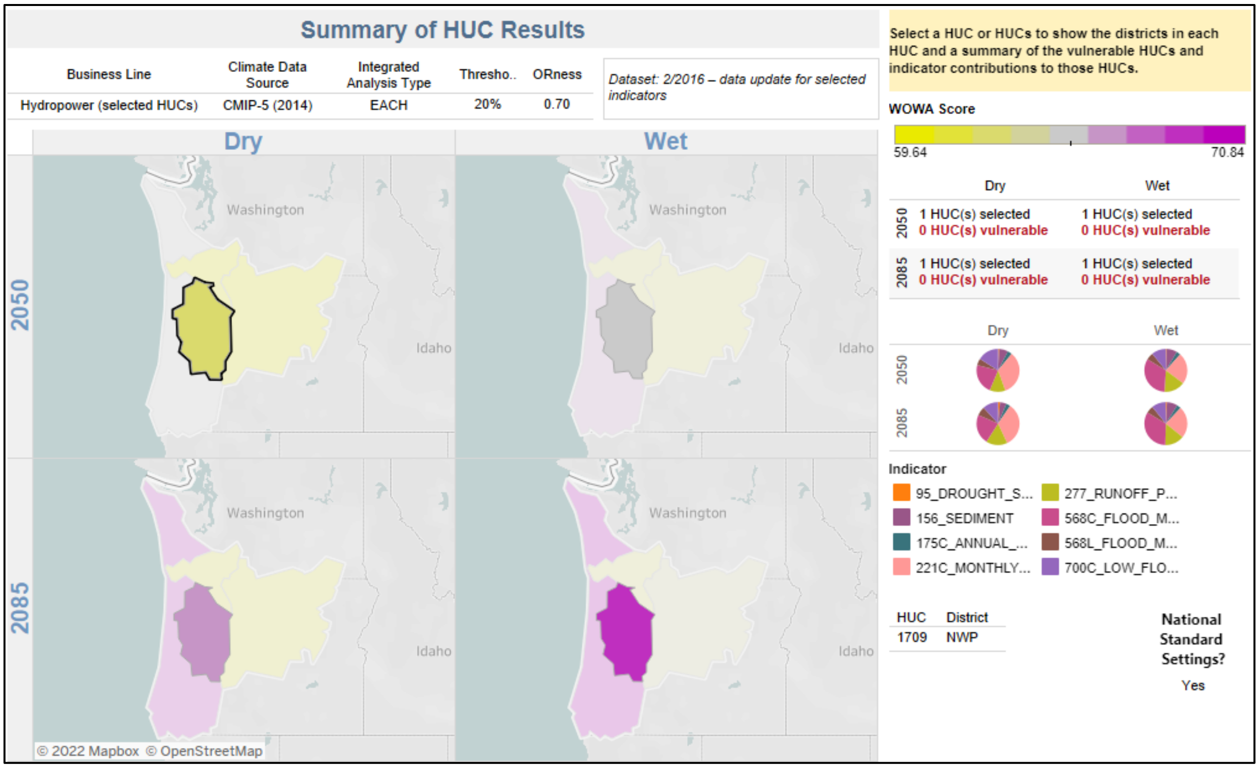


Figure 6-4. VA Tool Hydropower business-line

Table 6-8. VA Hydropower Indicators

Hydropower		
Indicator Code	**Indicator Name**	**Description**
95	95_DROUGHT_SEVERITY	Drought Severity Index
156	156_SEDIMENT	Change in sediment load due to change in future precipitation
175C	175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)
221C	**221C_MONTHLY_COV**	**Monthly CV of runoff (cumulative)**
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
568C	**568C_FLOOD_MAGNIFICATION**	**Flood magnification factor (cumulative)**
568L	568L_FLOOD_MAGNIFICATION	Flood magnification factor (local)
700C	700C_LOW_FLOW_REDUCTION	Low flow reduction factor (cumulative)

(Note: Red indicates the top vulnerability indicators)

Table 6-9. VA WOWA score for Hydropower

WIL HUC 17094	Hydropower	
Epoch:	**2050**	**2085**
Dry Scenarios	63.09	66.67
Wet Scenarios	65.72	69.21

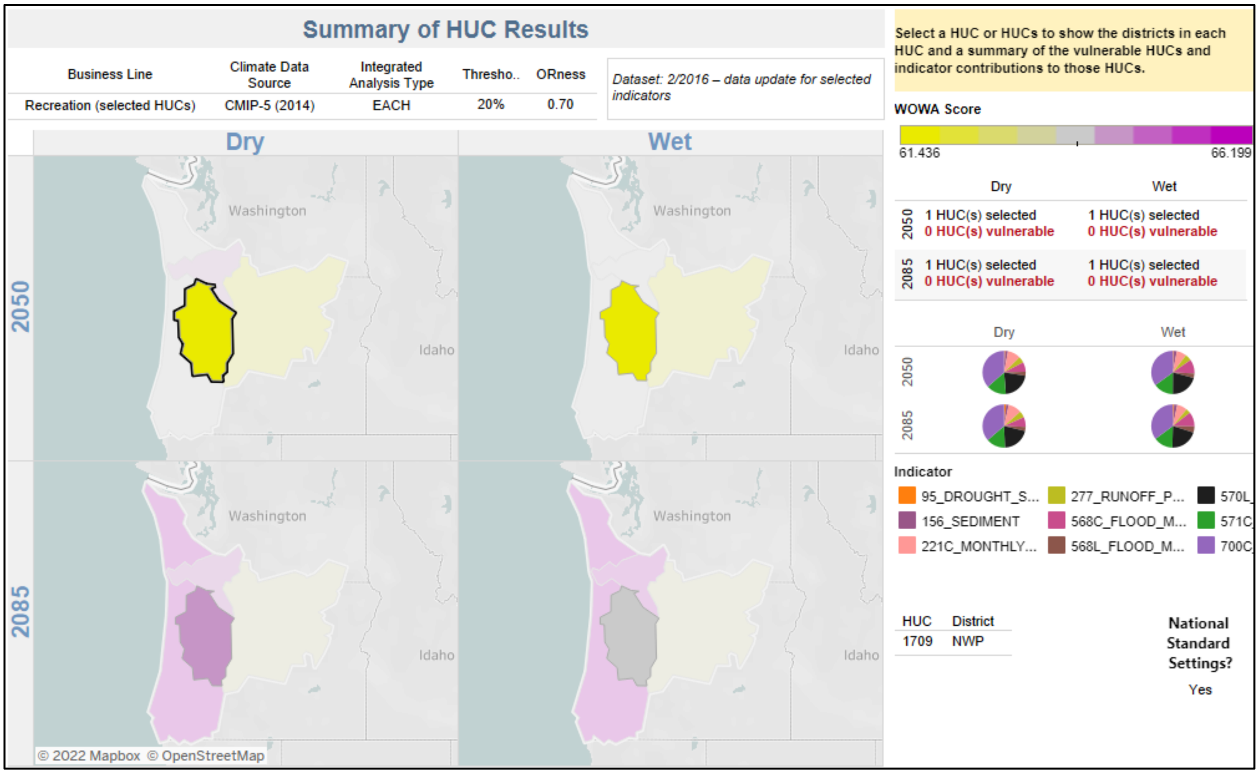


Figure 6-5. VA Tool Recreation business-line

Table 6-10. VA Recreation Indicators

Recreation		
Indicator Code	**Indicator Name**	**Description**
95	95_DROUGHT_SEVERITY	Drought Severity Index
156	**156_SEDIMENT**	**Change in sediment load due to change in future precipitation**
221C	221C_MONTHLY_COV	Monthly CV of runoff (cumulative)
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
568C	568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)
568L	568L_FLOOD_MAGNIFICATION	Flood magnification factor (local)
570L	**570L_90PERC_EXCEEDANCE**	**Low flow (monthly flow exceeded 90% of time; local)**
571C	571C_10PERC_EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; cumulative)
700C	700C_LOW_FLOW_REDUCTION	Low flow reduction factor (cumulative)

(Note: Red indicates the top vulnerability indicators)

Table 6-11. VA WOWA score for Recreation

WIL HUC 17094	**Recreation**	
Epoch:	**2050**	**2085**
Dry Scenarios	61.11	64.12
Wet Scenarios	61.44	63.61

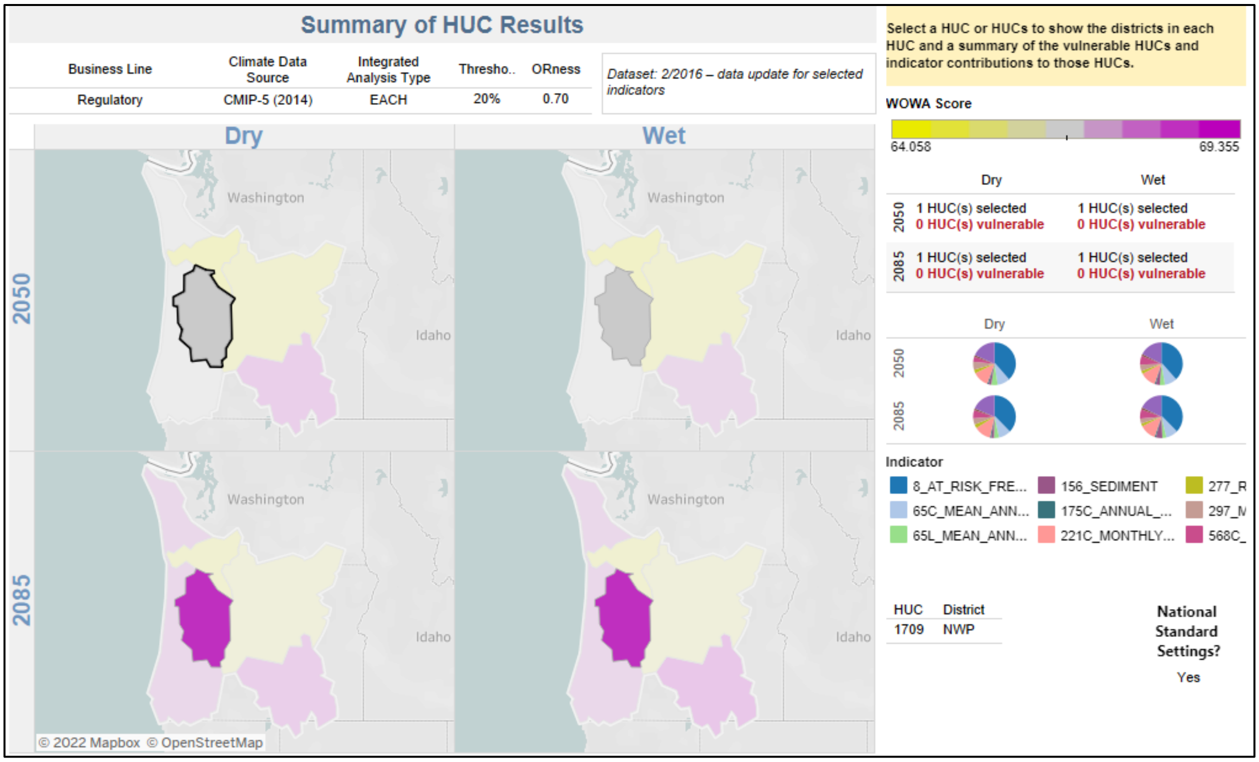


Figure 6-6. VA Tool Regulatory business-line

Table 6-12. RegulatoryIndicators

Regulatory		
Indicator Code	**Indicator Name**	**Description**
8	**8_AT_RISK_FRESHWATER_PLANT**	**% of freshwater plant communities at risk**
65C	65C_MEAN_ANNUAL_RUNOFF	Mean annual runoff (cumulative)
65L	65L_MEAN_ANNUAL_RUNOFF	Mean annual runoff (local)
156	156_SEDIMENT	Change in sediment load due to change in future precipitation
175C	175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)
221C	**221C_MONTHLY_COV**	**Monthly CV of runoff (cumulative)**
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
297	297_MACROINVERTEBRATE	Macroinvertebrate index of biotic condition
568C	568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)

(Note: Red indicates the top vulnerability indicators)

Table 6-13. VA WOWA score for Regulatory

WIL HUC 17094	**Regulatory**	
Epoch:	**2050**	**2085**
Dry Scenarios	66.93	68.41
Wet Scenarios	66.95	68.57

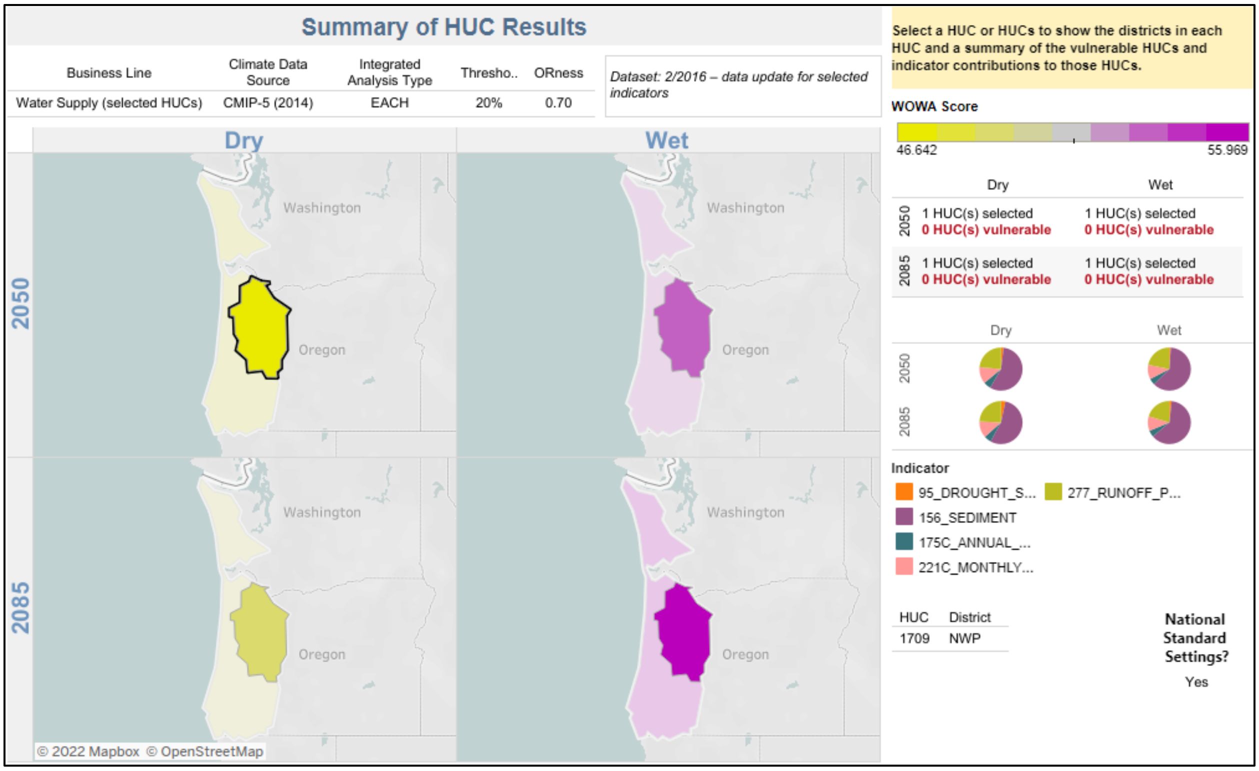


Figure 6-7. VA Tool Water Supply business-line

Table 6-14. Water Supply

Water Supply		
Indicator Code	**Indicator Name**	**Description**
95	95_DROUGHT_SEVERITY	Drought Severity Index
156	**156_SEDIMENT**	**Change in sediment load due to change in future precipitation**
175C	175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)
221C	221C_MONTHLY_COV	Monthly CV of runoff (cumulative)
277	**277_RUNOFF_PRECIP**	**% change in runoff divided by % change in precipitation**

(Note: Red indicates the top vulnerability indicators)

Table 6-15. VA WOWA score for Water Supply

WIL HUC 17094	Water Supply	
Epoch:	**2050**	**2085**
Dry Scenarios	46.64	49.66
Wet Scenarios	52.86	55.32

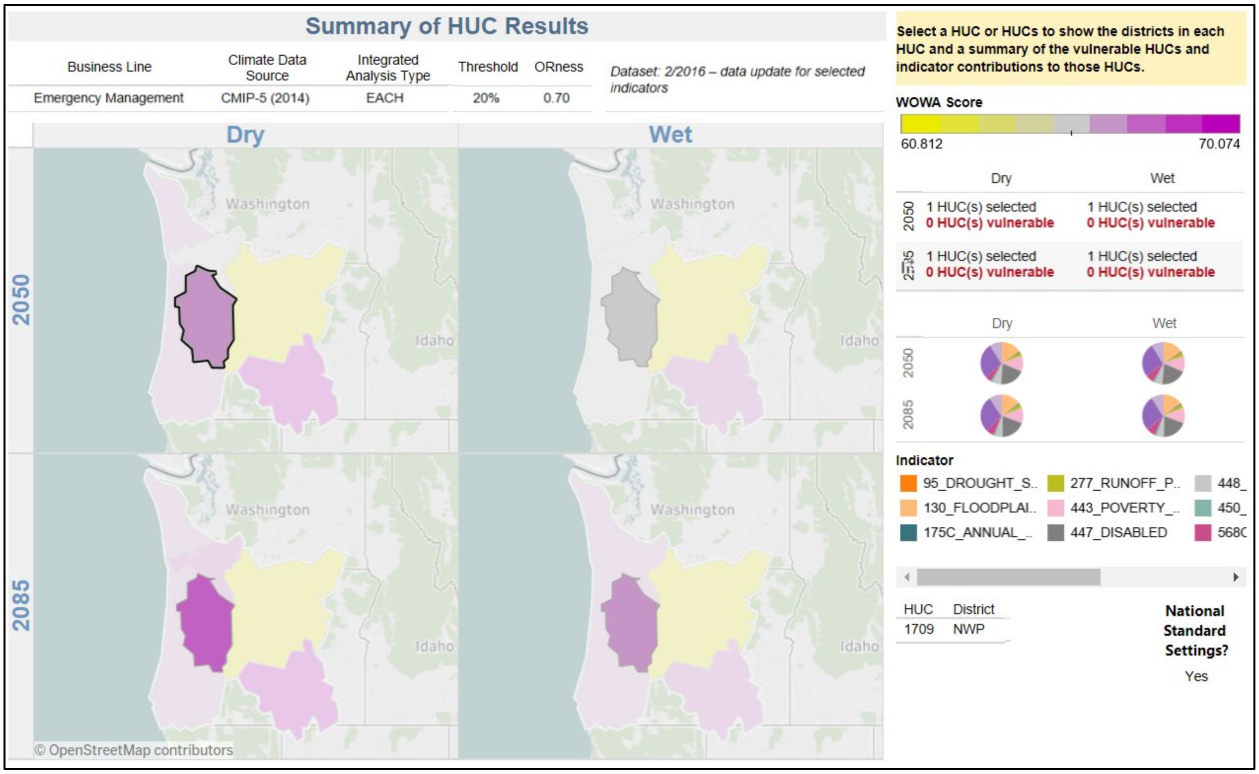


Figure 6-8. VA Tool Emergency Management business line

Table 6-16. Emergency Management

Emergency Management		
Indicator Code	**Indicator Name**	**Description**
95	95_DROUGHT_SEVERITY	Drought Severity Index
130	130_FLOODPLAIN_POPULATION	Population in 500-year floodplain
175C	175C_ANNUAL_COV	Annual CV of unregulated runoff (cumulative)
277	277_RUNOFF_PRECIP	% change in runoff divided by % change in precipitation
443	**443_POVERTY_POPULATION**	**Number of people below poverty line**
447	**447_DISABLED**	**% of people disabled**
448	448_PAST_EXPERIENCE	Disaster resilience due to experience
450	450_FLOOD_INSURANCE_COMMUNITIES	Number of communities with flood insurance
568C	568C_FLOOD_MAGNIFICATION	Flood magnification factor (cumulative)
700C	**700C_LOW_FLOW_REDUCTION**	**Low flow reduction factor (cumulative)**

Table 6-17. VA WOWA score for Emergency Management

WIL HUC 17094	**Emergency Management**	
Epoch:	**2050**	**2085**
Dry Scenarios	66.21	67.21
Wet Scenarios	65.57	66.53

6.3 VA IMPLICATIONS FOR RESOURCE AREAS

Consequential vulnerability indicators (aka, "metric drivers") that affected most of the resource areas, were VA metrics that tended to reflect high and low flow seasonal or annual changes. Flood risk reduction vulnerability was driven by flood magnification (local and cumulative) and flood event encroachments into 500-year urbanized floodplains. The VA Higher peak flows and flow volumes are likely to stress the WVS EIS NAA flood risk reduction objective and may increase future costs associated with flood damage, etc. This trend broadly agrees with conclusions drawn from the literature review and the CHAT results discussed above in sections 3.1 and 3.3.

Potential uptick in frequency of persistent low flows and decreased refill inflows and conservation season, baseflows, were more difficult to assess. VA driver 95 "drought severity", while occurring often as a driver, was not a primary one. Driver 95 was conspicuously absent for the Willamette, Ecosystem Restoration vulnerability business line. Another low flow metric driver, 700C, low flow reduction, was a driver for Ecosystem Restoration, Hydropower, Recreation, and Emergency Management, but not Water Supply. And for those VA business lines, 700C was not identified as a major driver for the vulnerability.

This underrepresentation of low flow driver metrics was unexpected for the WVS. VA drivers 221L and 221C, i.e., local, and cumulative coefficient of variation of monthly runoff, were shared by many of the VA business lines. VA driver metric 221 indicates degree of variability in monthly regulated flows, "…indicator [which] measures short-term variability in a region's hydrology. It is the 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff." A higher value for NWP, Willamette region, may indicate that the WVS NAA may experience"…high[er] variability in monthly runoff within a year. Flash floods may occur in areas that experience frequent variation between wet and dry conditions", compared to historical norms.

Although the VA tool does not provide directionality or variability for the indicator it may be reflect more intense winter and less summer base flows. The literature and future flow projections assessed above (CHAT), point to decrease of relative flow and volume in the summertime. Overall, VA hydrologic results support those climate change trend inferences.

SWE and wildfire driver metrics are not represented in the VA results. However, increasing Flood Risk Reduction for the Willamette, e.g., increasing WOWA scores out through 2085, and overall, increase prevalence of the "277_RUNOFF_PRECIP", "% change in runoff divided by % change in precipitation", may point to the transition from SWE/freshet influence to a wholly rain driven pattern. This would be consistent with other assessments of future hydro-climate change trends (e.g., literature review studies and CHAT analyses). Temperature increases, presented as having a high degree of confidence for occurring in the future, may be circumstantially corroborated by the VA business line analyses for the Ecosystem Restoration, and occurrence of the drought severity indicator. Wildfire risk drives potential increase in sediment transport. The change in the land cover is the primary mechanism for increasing potential sediment supply. Higher rainfall and runoff will act to mobilize the sediment. With the occurrence of increased sediment as indicated in the Navigation and Water Supply Vulnerability business lines, some degree of increasing likelihood of future wildfire may be suggested.

CHAPTER 7 – SUMMARY AND CONCLUSIONS

This climate change assessment was prepared to support the Willamette Valley System (WVS) Environmental Impact Statement (EIS). The Willamette Valley Project (WVP) operates 13 dams and reservoirs (projects) to meet multi-purpose objectives. These include operations to reduce the risk and associated damages of flooding throughout the basin; water conservation (water supply), power generation, fish and ecosystem function, and recreational purposes. The projects operate both collectively and individually, as mandated by their water control manuals, meet objectives, and provide various other project benefits such as water supply, environmental releases, and recreation. The EIS PDT identified relevant climate change factors early on. Factors such as ambient temperature change, evaporation at reservoirs, changing flow peaks and timing, more frequent and intense occurrence of wildfire and their effects, changing SWE and water temperate increased, were perceived likely impacting EIS resource areas. Refer to Appendix F2 for additional discussion and analysis of these climate factors.

Relevant climate change factors were consequential for the future climate vulnerability analyses and identification of residual risk. The Corps Climate Preparedness and Response (CPR) Community of Practice (CoP) views as the risk that remains after measures have been put into place targeted at reducing risk. The Corps' response to climate change is adaptation focused and formulates measures and alternatives to be as resilient as possible. A more resilient feature is one that is conceptually more resistant to likely future conditions, and/or possesses inherent flexibility to adapt successfully to projected changes.

The non-stationarity detection (NSD) analyses and attribution of observed annual peak streamflows in the basin, led to the determination that the is little evidence for changing hydroclimate effecting the observed peak streamflow hydrology in the Willamette Basin. This has implication primarily for the Corps' flood risk reduction business line. There is not an abundance of evidence pointing to hydrologic nonstationarity or peak streamflow trends for monthly or seasonal lows either. Low flow metric change is most impactful to ecosystem, water quality aspect for the WVS EIS.

While the assessment of streamflow data may not indicate a significant influence due to climate change factors, it is estimated that the WVP will experience wetter winter flood seasons with less snow and more rain, as well as warmer and drier summer conservation seasons in the future. These changes are supported by the literature, as well as the CHAT tool results. The directionality of projected changes highlights the need for flexibility in future flood risk, refill, BiOp, and conservation season operations. The future climate change factor trends will likely stress some authorized purposes of these reservoirs, such as water supply. Note that the uncertainty associated with future projections of hydrologic conditions is large.

Some residual risks will likely remain after EIS measures have been implemented. While the determinations presented in this assessment are qualitative, it should be noted that the residual risk could increase in the future as compared with present day residual risk.

It is likely that the WVP will be able to accommodate many future hydroclimatic and hydrologic changes. The EIS is operations focused, and its measures are designed to improve ecosystem function, facilitate downstream passage, and better regulate thermal flow regimes. A main objective is to provide optimal downstream flow conditions for fish passage and other environmental objectives. These measures are executed within the authorities and operational constraints identified in the water control manuals. Climate change has been identified as increasing the stress on many operational goals identified in the EIS. However, proposed EIS operations focused on ameliorating the stressors that are also climate change factors, will likely make any Preferred Alterative measures, more resilient to future climate factor changes.

There is significant hydro-regulation capacity and flexibility incorporated into existing water management plans. Therefore, the WVP is uniquely suited to be more resilient to future seasonal flows fluctuations such as more extreme high and low water events. Being operational in nature, the WVS EIS is more able to adapt to highly uncertain and extreme events. An adaptive response to climate change is inherently more resistant than a set piece approach design to a singular or small ensemble set of climate change projections.

Potential resilience measures which are best able to reduce future flood risk, maintain water supply levels, avoid water quality impacts, maintain reservoir levels for recreation, and maintain downstream flow and passage conditions for fish, may include structural modifications to individual reservoir projects. There improvements would be best if they increased the flexibility and range of the individual project and system operations. They could include acquisition of additional real estate to future infrastructure expansion, and changes to existing regulation outlets and spillways that provide more operational flexibility would also provide resilience to future climate effects. The goal would be to increase the range of operations that a project and/or the WVP could perform; to cope with more extreme conditions due to climate change.

Based on this assessment, it is recommended that potential, future effects of climate change be treated as having a high degree of future uncertainty. Therefore, measures should not be assessed for specific future climate change conditions. If this assumption proves to be inadequate when future observations or more refined projections become available, then a quantitative evaluation and revision of these results may be warranted. This could be part of the final adaptation plan as well. It is recommended that flow frequency and pool frequency be monitored, reevaluated periodically in the future to determine how projected trends manifest themselves in future observations.

Table 7-1, summarizes WVS EIS specific residual risks. ECB 2018-14 (rev1) states that in most cases, there will be risks to the project due to climate change that do not meet current evaluation criteria. The description of the Preferred Alternative should include a brief discussion of the residual risks resulting from changed climate conditions, and should include a table with rows for each major measure or feature (including nonstructural measures) and columns that describe the trigger event (climate variable that causes the risk), the hazard (resulting dangerous environmental condition), the harms (potential damage to the project or changed project output), and a qualitative assessment of the likelihood and uncertainty of this harm.

The intent of the residual risk table is to evaluate the without project/without change/No Action Alternative (NAA) condition relative to EIS actions being proposed and assign a risk rating (high/medium/Low). If an action alleviates/mitigates for a potential future impact/relevant climate change factor, this will lower residual risk. If an EIS action contains adaptative management features or has resilience capacity, the EIS action would lower/alleviate risk.

The EIS is operational in nature, with proposed structural appurtenances to allow more flexible future water management. EIS actions coincidentally will operate to offset some of the same hydrologic and hydraulic vulnerability drivers and relevant factors of concern for climate change. Therefore, the EIS actions may be viewed as inherently more resilient to compound/coincident impacts of the alternative and climate change over the project's 50 design period and 100-year operating life cycle. The EIS actions will not exacerbate climate change impact or adversely affect the WVS and its environment. If the potential for harm is absent, this would imply low risk too. Table 7-1, below summarizes the residual risks, hazards, and likelihood of effects from climate change. The NAA residual risks stand out as being rated highly likely. That reflects the idea that if nothing is done, climate change effects will progress, and maximum impacts be realized. If the measures are implemented considering the likely climate change effects (Table 7-1), the EIS can overall help ameliorate for climate change effects.

Table 7-1. Residual Risk Table for the WVS EIS

Proposed Change to Operations	Intended Effect on Current Performance	Trigger & Impact (Hazard)	Harm/Reduction	Likelihood of Occurring
No Action Alternative (Current)	NAA would not alter current performance, so NAA impact not considered applicable.	Hydroclimate and hydrologic trends below, are through the 2030s, (WY2020-2049) and 2070s (WY 2060-2089) Increasing annual and seasonal ambient **temperature**. Increasing wintertime (Nov-Mar) precipitation (**rainfall**) and **wintertime peak flow and streamflow volume**. Median decreases are expected for **summer/conservation season (Jun-Sep) precipitation and streamflows**. **SWE** is projected to decrease dramatically in the Cascade and Coastal ranges. **Freshet** timing will occur earlier (perhaps a week earlier by the 2030s) and diminish by the 2070s. **Spring (refill)** volumes are projected be more variable. However, projections differ on whether there will be a trend to less inflows during refill season. Increases are projected for the number of **high wildfire danger days**. Post fire condition is expected to drive increasing peak runoff, **sediment transport** including channel incision (upper basins) and deposition in the lower reaches.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	HIGHLY LIKELY
Flow Measures	**30a** Integrated temperature and habitat flow regime, integrated flow regime, adaptive flows, or adaptive fish flows **30b** Refined Integrated temperature and habitat flow regime, refined integrated flow regime, refined adaptive flows, or refined adaptive fish flows **304** Augment instream flows by using the power pool **718** Augment instream flows by using the inactive pool **723** Reduce minimum flows to Congressionally authorized minimum flow requirements	**30a Integrated temperature and habitat flow regime.** Projected higher temps and less summertime baseflow would likely complicate operations and could decrease the effectives of this measure. 30b Refined Integrated temperature and habitat flow regime. Higher projected summer temps could increase demand and reduce available volume for this operation. Projected higher temps and less summertime baseflow would likely complicate operations and could decrease the effectiveness of this measure. **304 Augment instream flows by using the power pool.** Higher projected summer temps could increase demand and reduce available volume for this operation. Lower projected conservation season baseflows could complicate the operation and could potentially decrease the measure's effectiveness. **718 Augment instream flows by using the inactive pool.** It's likely that there would need to be a very extreme low water event (or consecutive events) to seriously affect this measure. **723 Reduce minimum flows to Congressionally authorized minimum flow requirement.** Higher projected summer temps could increase demand and reduce available volume for this operation. Less SWE and changing freshet timing combined with variable spring refill, may complicate storage used for min flow releases. Lower projected conservation baseflows will likely stress and complicate this measure's operation.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY
Water Quality Measures (Thermal)	**105** Construct water temperature control tower **166** Use Regulating Outlets for Temperature Management **479** Foster Fish Ladder Temperature Improvement **721** Use spillway for surface spill in summer	**105 Construct water temperature control tower.** Higher projected summer temps could increase demand and reduce available volume for this operation. Less SWE and changing freshet timing combined with variable spring refill, may complicate storage used for min flow releases. Lower projected conservation baseflows will likely stress and complicate this measure's operation. **166 Use Regulating Outlets for Temperature Management.** This measure would be sensitive to future reservoir levels. Future refill may be more variable in the future, leading to unexpected water levels that may affect RO efficiency. Increasing temperatures may increase demand for thermal operations, reducing reservoir levels. Lake depth/temperatures may change. ROs would be more resilient, if they could be adapted (easily) to meet future (extreme) water levels and temperature requirements. **479 Foster Fish Ladder Temperature Improvement.** This measure would be triggered by climate change, like 166. The measure would be most resilient if it was designed to be adaptable (e.g., inverts were adjustable) to variable future reservoir levels. **721 Use spillway for surface spill in summer.** Changing/lower reservoir levels would likely affect this measure. The spillway would be most resilient if the crest was set to take advantage of times when the levels may be lower than current condition.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY
Water Quality Measures (TDG)	174 Structural improvements to reduce TDG (via TDG structures)	**174 Structural improvements to reduce TDG (via TDG structures).** Projections for warming air/water conditions and potential decreasing summer base flows, would stress this flow measure's effectiveness and ease to implement.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY

Proposed Change to Operations	Intended Effect on Current Performance	Trigger & Impact (Hazard)	Harm/Reduction	Likelihood of Occurring
Downstream Fish Passage Measures	**40** Deeper fall reservoir drawdown operation for downstream fish passage **392** Construct structural downstream fish passage, FSS/FSCs or Foster Fish Weir **714** Pass water over spillway in spring spill operation for downstream fish passage **720** Spring reservoir drawdown operation for downstream fish passage	**41 Deeper fall reservoir drawdown operation for downstream fish passage.** Future projections for more variable refill, less summer baseflow may affect available volume to conduct this measure. **392** Construct structural downstream fish passage, FSS/FSCs or Foster Fish Weir. Future change reservoir levels may affect this measure's implementation. Especially if measure depends on certain elevations to operate. Adding functionality to adjust operate at different elevations, would make this measure more resilient to climate change. **714 Pass water over spillway in spring spill operation for downstream fish passage.** This measure is elevation specific. Future WSE fluctuation (lower elevations) would stress effectiveness and implementation. **720** Spring reservoir drawdown operation for downstream fish passage. Projected refill season variability (both HW and LW events) would likely impact measure effectiveness and implementation.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY
Upstream Fish Passage Measures	**52** Provide improved Pacific lamprey passage and infrastructure **639** Restore/improve upstream and downstream passage at drop structures **722** Construct adult fish facility	**52 Provide improved Pacific lamprey passage and infrastructure.** Future reductions in headwater flows may adversely affect benefits to Lamprey. **639 Restore/improve upstream and downstream passage at drop structures.** Measures that depend on certain WSE's to operate effectively, are vulnerable to future reservoir pool level fluctuation (e.g., lower elevations than expected) will stress measure effectiveness and implementation. Projected increase of future sediment transport in the basin, would likely increase O&M and could hinder effective operations at the drop structures. **722 Construct adult fish facility.** Warming of the basin may offset the effectiveness of providing new fish facilities, especially if released at a "hotspot" location (e.g., lower elevation, little vegetation canopy, etc.). More extreme summer low flow periods would also stress effectiveness and operability for this measure. The measure 's resilience would increase if future warmer temperatures are considered during implementation. Lower downstream flows in the flow should also be considered. Generally, adding ability to change (adaptability) to the measure details for future contingencies would increase the measure's resilience.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY
Common Measures	**384** Gravel Augmentation **719** Adapt Hatchery Program **9** Maintain Revetments using nature-based engineering or alter revetments for aquatic ecosystem restoration **726** Maintain adult fish release locations (out planting sites) above dams **NTOM** Near Term Operations Measure (Common to Alternatives 2a, 2b, 3a, 3b, 4, and 5)	**385 Gravel Augmentation.** Projected increased sediment transport in the basins (because of projected increasing wildfire danger) could increase the vulnerability for this measure. Higher wintertime flow peaks and durations could negatively impact intended gravel augmentation locations and effectiveness. **719 Adapt Hatchery Program.** Adaptation is a resiliency feature in terms of responding to climate change. Therefore, this measure would be less susceptible to climate change triggers and impacts (hazards). **9 Maintain Revetments using nature-based engineering** or alter revetments for aquatic ecosystem restoration. Projected increasing temperature and changing precipitation patterns may stress the 'nature ' based implementation measures. Higher sustained wintertime flows may increase erosive stresses than anticipated during implementation of this measure. Considering these potential climate change triggers during implementation would increase the measure's resiliency. **726 Maintain adult fish release locations (out planting sites) above dams.** Projected higher summertime (annual) temperatures and less baseflow during conservation season, would likely stress this measure. **NTOM** Near Term Operations Measure (Common to Alternatives 2a, 2b, 3a, 3b, 4, and 5). Near term hydrology changes (reduced SWE and increasing wintertime precipitation, etc.) would trigger impacts, but the impacts (hazards) would be like that experienced over the historical POR.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY
Existing operations continued	Fall Creek Drawdown for Fish Passage Continued Operation of Existing Adult Fish Facilities Operation, Maintenance, Repair, Replacement and Rehabilitation	**Fall Creek Drawdown for Fish Passage.** This is like other drawdown measures. Projected refill season variability (both High Water and Low Water events) would likely impact measure effectiveness and implementation. **Continued Operation of Existing Adult Fish Facilities**. Generally, all hydrology/hydroclimate trends mentioned previously would trigger impacts to this measure. Adding features to compensate for warming downstream flow conditions and less summer baseflow would make this continued operation more resilient to climate change, etc. **Operation, Maintenance, Repair, Replacement and Rehabilitation.** Generally, all hydrology/hydroclimate trends mentioned previously would trigger impacts to this measure. Adding features to compensate for warming downstream flow conditions and less summer baseflow would make this continued operation more resilient to climate change, etc.	Broadly, future projected hydroclimate and hydrologic trends will create **adverse** water management framework to operate within.	LIKELY

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SYSTEM OPERATIONS AND MAINTENANCE
Willamette Valley
ENVIRONMENTAL IMPACT STATEMENT

WILLAMETTE VALLEY SYSTEM OPERATIONS AND MAINTENANCE

DRAFT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

APPENDIX F2: SUPPLEMENTAL CLIMATE CHANGE INFORMATION

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CHAPTER 1 – INTRODUCTION

This sub appendix outlines additional climate change information used in the Willamette Valley System (WVS) Operations and Maintenance Environmental Impact Study (EIS). The information contained in this supplemental appendix provides additional details that the qualitative climate change assessment may lack. The supplemental information was used by the EIS Project Delivery Team (PDT) as they qualitatively assessed how changes in future hydroclimate may affect their resource areas, and other likely impacts of concern.

Engineering and Construction Bulletin (ECB) 2018-14 (revision 1, September 2019) , Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects states “It is important to conduct a qualitative analysis at a scale appropriate for the study…a successful qualitative analysis will combine the most useful information from a range. of sources, noting the differences in information types, such as observed and projected data and the differences in uncertainty or confidence in the data and information deployed for the analysis.”

USACE NWD and NWP have proactively conducted and been involved in regional climate change studies in the Pacific Northwest and Columbia River Basin (CRB). The result of these efforts has yielded comprehensive collections of highly useful reports and databases. In particular, the River Joint Operating Committee, RMJOC II climate projection information was used as basis for much of the discussions found below. The RMJOC II climate change planning studies and data have been used for recent efforts such as the Columbia River Treaty (CRT), Columbia River System Operations (CRSO) EIS and Columbia Basin Water Management Hydrology. The “Climate toolbox, a regional suite of assessment tools, was also used for EIS purposes to demonstrate comparative climate trend changes between different Valley sites and projects, over the historical as well projected future years.

CHAPTER 2 – RELEVANT CLIMATE CHANGE FACTORS

The WVS EIS PDT identified early on which climate factors were likely most relevant to the NEPA, EIS, analysis. Their importance and relevance were evaluated with respect to EIS affected areas and focused on the most consequential resource areas and impacts to alternatives of the EIS. The relevant climate change factors are listed below. USACE PDT refined the list of relevant climate factors that were relevant to the WVS EIS climate change analysis. Each resource topic analysis used the climate change assessment as the basis of a qualitative analysis of relevant climate change factors as shown in Table 2-1.

Table 2-1. Relevant climate factors analyzed by resource area

Resource Topic	Ambient temp	Water temp	Precipitation	Flow peak and timing	Summer low flow	Spring snow melt	Evapotranspiration	Wildfire	Wildfire effects
Hydrologic Processes			X	X	X	X	X		
River Mechanics and Geomorphology				X		X		X	
Geology and Soils									
Water Quality	X	X	X	X	X	X	X	X	X
Vegetation (ESA/sensitive species and critical habitat)	X	X	X	X	X	X	X	X	X
Wetlands	X		X	X	X	X	X		X
Fish, Aquatic Invertebrates, and Aquatic Habitat (ESA/sensitive species and critical habitat)	X	X	X	X	X	X	X	X	X
Wildlife, Birds, and Terrestrial Habitat (ESA/sensitive species and critical habitat)	X	X	X	X	X	X	X	X	X
Air Quality	X							X	
Socioeconomics	X	X	X	X	X	X	X	X	X
Power and Transmission	X		X	X	X	X	X		
Water Supply (Irrigation, Municipal, and Industrial)			X	X	X				
Recreation	X	X	X	X	X	X	X	X	X
Land Use					X			X	
Hazardous Materials	X		X		X			X	
Public Health and Safety – Hazardous Algal Blooms		X	X	X	X		X		X
Public Health and Safety – Hazardous Materials			X					X	
Public Health and Safety – Drinking Water			X	X	X	X	X		X
Environmental Justice	X	X	X	X	X	X	X	X	X
Tribal Resources									
Cultural Resources				X	X			X	
Visual Resources		X	X	X	X	X	X	X	X
Noise								X	

The list of relevant climate factors are as follows:

- Ambient air temperature change;
- Water temperature change;
- Precipitation changes;
- Seasonal timing of flow peaks and volumes;
- Low summer flow- shortage/volume/frequency;
- Change in snowpack accumulation and spring freshet timing;
- Reservoir evaporation/ reach evapotranspiration effects;
- Wildfire intensity/frequency change; and
- Wildfire impacts to water quality.

The relevant hydroclimate variables, with exception of wildfire intensity, reflect the O&M centric metrics of the EIS. The wildfire element of the list below is indicative of likely impacts on future post fire runoff response and water quality related issues that will likely be experienced in the future.

CHAPTER 3 – SUPPLEMENTAL DATA SOURCES

The RMJOC II and derivative Columbia River basin climate studies were very useful for characterizing current period as well as expected future climate trends in the Pacific Northwest including the Willamette Valley. The RMJOC II information discussed below is a planning level product. That is, while suitable for relative difference analyses, e.g., ensemble median change between baseline historical period and future epochs, etc., it was not "designed" for reservoir routing modeling in the watersheds like the Willamette River. The RMJOC data was "designed" to be most accurate and relevant and actionable on the large Columbia River Basin Federal Columbia River Power System, FCRPS scale. Future projections (streamflow) results at Salem, OR in the Willamette Valley, for example, are likely to contain higher levels of modeling uncertainty and variability due to the relative shorter travel times and smaller spatial areas. For this and other technical reasons, it is not appropriate to use RMJOC II generated future period of record (POR) streamflow for quantitative (e.g., hydro-regulation) modeling or as a definitive way to assess final climate projection impacts to EIS Alternatives. The RMJOC II reports are on the following website:

https://usace.contentdm.oclc.org/utils/getfile/collection/p266001coll1/id/10562

https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/9936/rec/1

The Climate Toolbox data visualization tools (https://climatetoolbox.org/climate) are also useful and compelling for making qualitative determinations about how relevant climate factors are likely to change. The Climate Change Toolbox consists of a collection of web tools for visualizing past and projected climate and hydrology of the contiguous United States. The tool provides the user with extensive options for site selection (includes all sites of interest for the WVS EIS) as well as a robust range of climate change hydroclimate and hydrology variables that can be statistically summarized. The user can easily generate an extensive climate report, contrasting historical baselines to future year climate change scenarios of interest.

For these reasons, the tool and its results were found very useful for supplementing PDT understanding of likely climate change trends in the Valley. There are important considerations to keep in mind when using the Climate Toolbox. First, the tool utilizes 9 global circulation models (GCMs) as basis for the future change projections synthesized by the tool. In comparison, the RMJOC II streamflow ensemble dataset is composed of 160 GCM scenarios. "It is USACE policy to use the hydrologic projections from the full ensemble CMIP5 model outputs to capture the range of potential future hydrologic conditions within a basin, as at this time there is no justification for selecting only a subset of models." (RMJOC 2018). While the Toolbox can be useful for qualitative comparisons, in would be erroneous to explicitly compare RMJOC II and the Climate Toolbox results.

3.1 Overview of RMJOC II Climate Change projections

The primary basis for climate change projections discussed in the following sections of this appendix are derived from the RMJOC II study reports 1 and 2 (RMJOC 2018, RMJOC 2020). RMJOC II hydroclimate change trends have been used in follow-on climate change studies in the Columbia River Basin (CRB) such as Columbia River Treaty studies (CRT, 2021) and the Columbia River System Operations Environmental Impact Statement, CRSO EIS (CRSO, 2020). These synthesized qualitative determinations and interpretations included trends in projected temperature, precipitation, snowpack, and naturalized streamflow. These unregulated drivers and flow metrics are documented in the RMJOC report Part 1. This study represents the most recent and best available technical information for future climate change in the Columbia River basin, including the Willamette Valley.

Report 2 of the RMJOC II studies focused on hydro-regulation modeling results in the major subbasin of the Columbia River basin. A notable exception for not performing hydro-regulation with climate change streamflows was the Willamette River basin. Details reasoning for the decision, are contained in Report 2 (RMJOC 2020). The Willamette River routing model networks were found to be too coarse to accurately represent some critical computation points and operations in Willamette Valley Project. It was determined that for RMJOC II purposes, that the end results of hydro regulating future projection flows could lead to high uncertainty in the modeling results.

3.1.1 Temperature

The region is warming, and projections indicate that this trend will likely accelerate. Over the historical period (1990-1999), temperatures have increased and are expected to increase (U.S. Global Change Research Program [USGCPR] 2017; River Management Joint Operating Committee [RMJOC] 2018). Temperatures in the region have warmed about 1.5 degrees

Fahrenheit (F) since the 1970s. They are expected to warm relative to the historic period 1970-1999 by another 1.5° to 3° F by the 2030s (WYs 2020 thru 2049) and 2° to 5° by the 2070s (WYs 2060 thru 2089). Warming is projected to be greatest in the Willamette Valley floor, lowland areas (e.g., I-5 corridor), during the summer. Higher elevation areas such as the Cascades and Coast ranges could experience somewhat lower warming rates. Figure 3-1 displays Willamette Valley ambient (air) temperature projections from RMJOC II, Report 1. GCM scenario projections (numbers in the bar plot), relative to the historical baseline period, 1970 thru 1999.

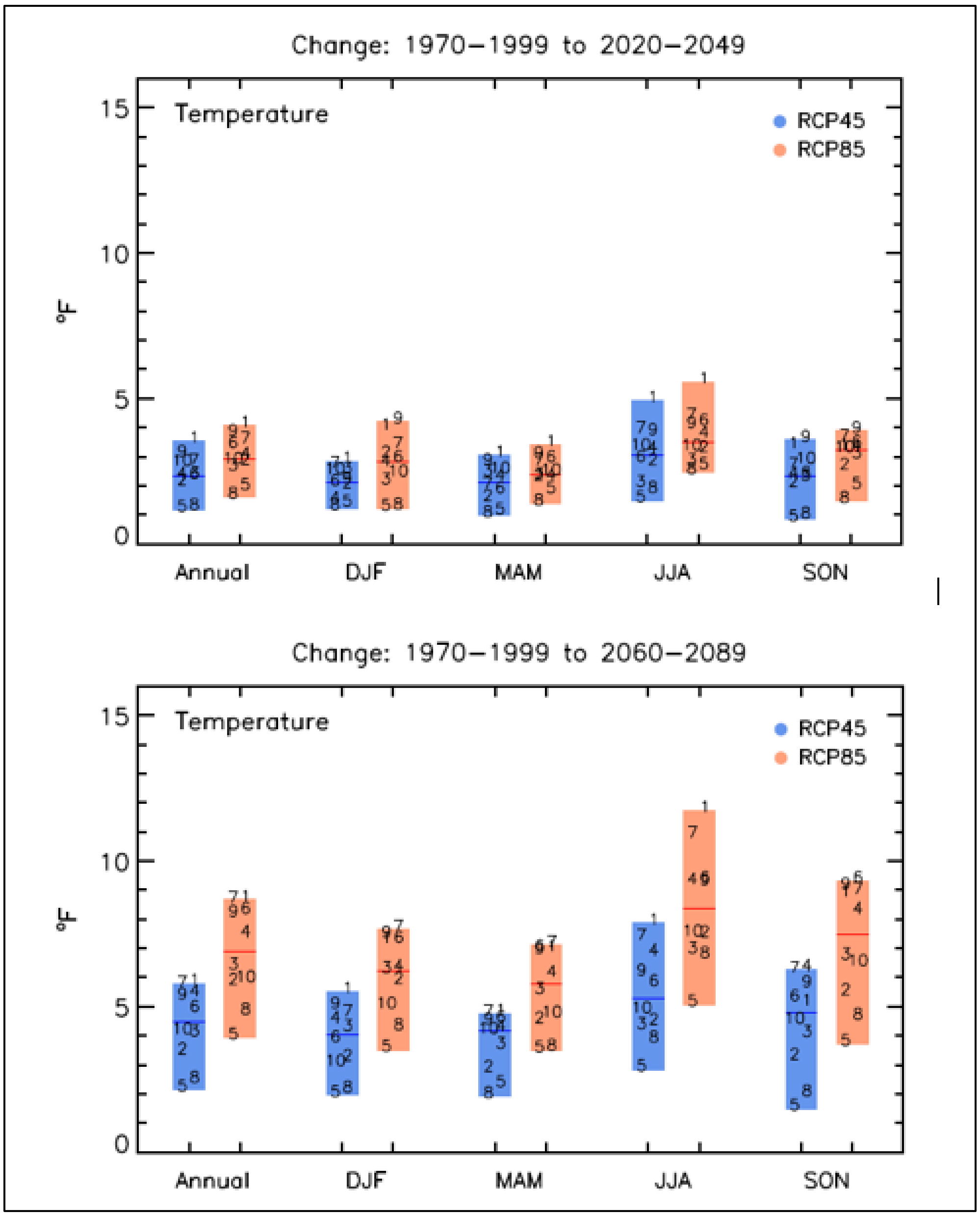


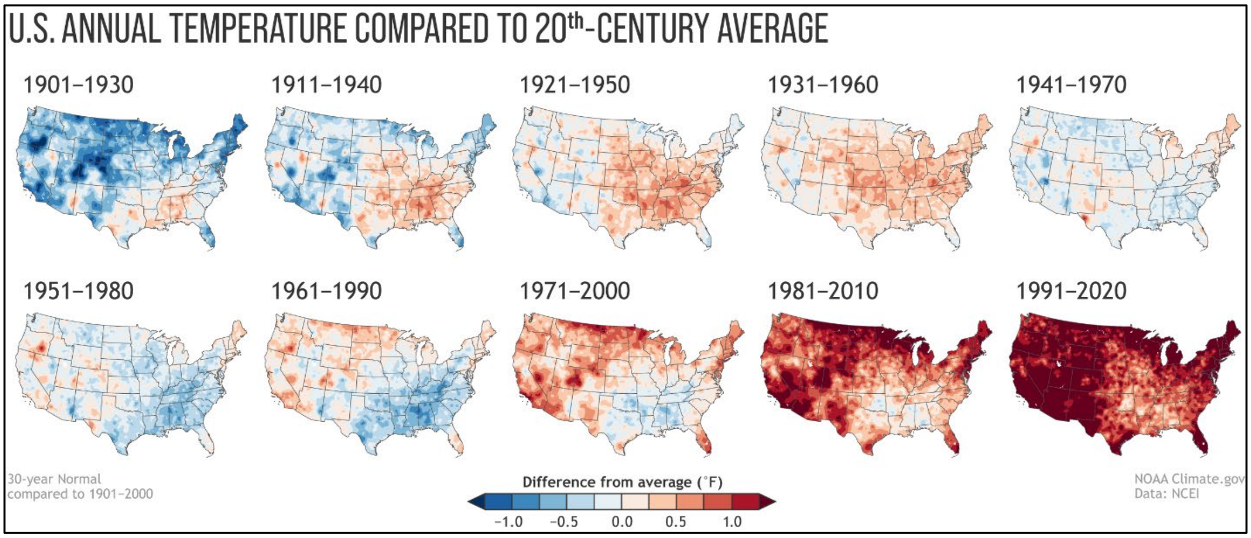
Figure 3-1. Projected basin average temperature change (RMJOC 2018)

Recent years, 2000 thru present, are on average warmer compared to 1970 thru 1999. National Oceanic and Atmospheric Administration, NOAA published revised "climate normals".

https://www.climate.gov/news-features/understanding-climate/climate-change-and-1991-2020-us-climate-normals (current as of April 2022).

If the more recent revisions were used as baseline, the relative differences would be less, than shown above. For reference, Source: https://www.climate.gov/media/13467

Figure 3-2 displays NOAA annual observed temperature changes (NOAA 2021) are shown below.



Source: https://www.climate.gov/media/13467

Figure 3-2. NOAA annual observed temperatures

Regionwide warming is expected to increase into the future, continuing the trends seen above. Although ambient temperature increase, is a primary driver of other hydroclimate variables, corresponding changes in temperature are not linearly translated.

For example, an increase of annual temperatures may not translate to streamflow change in similar directions or percent magnitudes. The hydrologic system is too complex to make highly predictable and certain forecasts. Forecast uncertainty increases dramatically further out into the century. The precise degree to which temperatures will increase is clouded and specific determinations are highly uncertain at this time. Although it is desirable to have quantifiable future temperature data for EIS determinations, it is cautioned that the climate change information available at this time, does not support that that precision for Willamette Valley.

3.1.2 Precipitation

RMJOC II (Report 1) found that observed precipitation trends are less certain than observed temperature trends. However, across both Representative Concentration Pathways, (RCP), RCP 4.5 and 8.5, the majority of GCMs project marginal increases in annual precipitation, with most changes occurring seasonally; the largest increases in the winter December thru February months (DJF) and decreases in the summer months, June thru August (JJA). Trends in the

RMJOC II are for the entire Columbia River basin (CRB), but were determined at The Dalles, OR. The general trends are similar for the Willamette Valley. The precise future precipitation trends are still uncertain, but reflective of overall CRB forecast; a general upward annual precipitation trend is likely for the rest of the twenty-first century, particularly in the winter months. Already dry summers could become drier in the Willamette basin.

Caution interpreting future projection trends is warranted. The study (RMJOC 2018) identified high interannual variability in the observed datasets. Further, the warmest or driest GCMs at The Dalles, may not be the same in all subbasins. Therefore, importance is reinforced for using a large ensemble set to assess likely climate change trends.

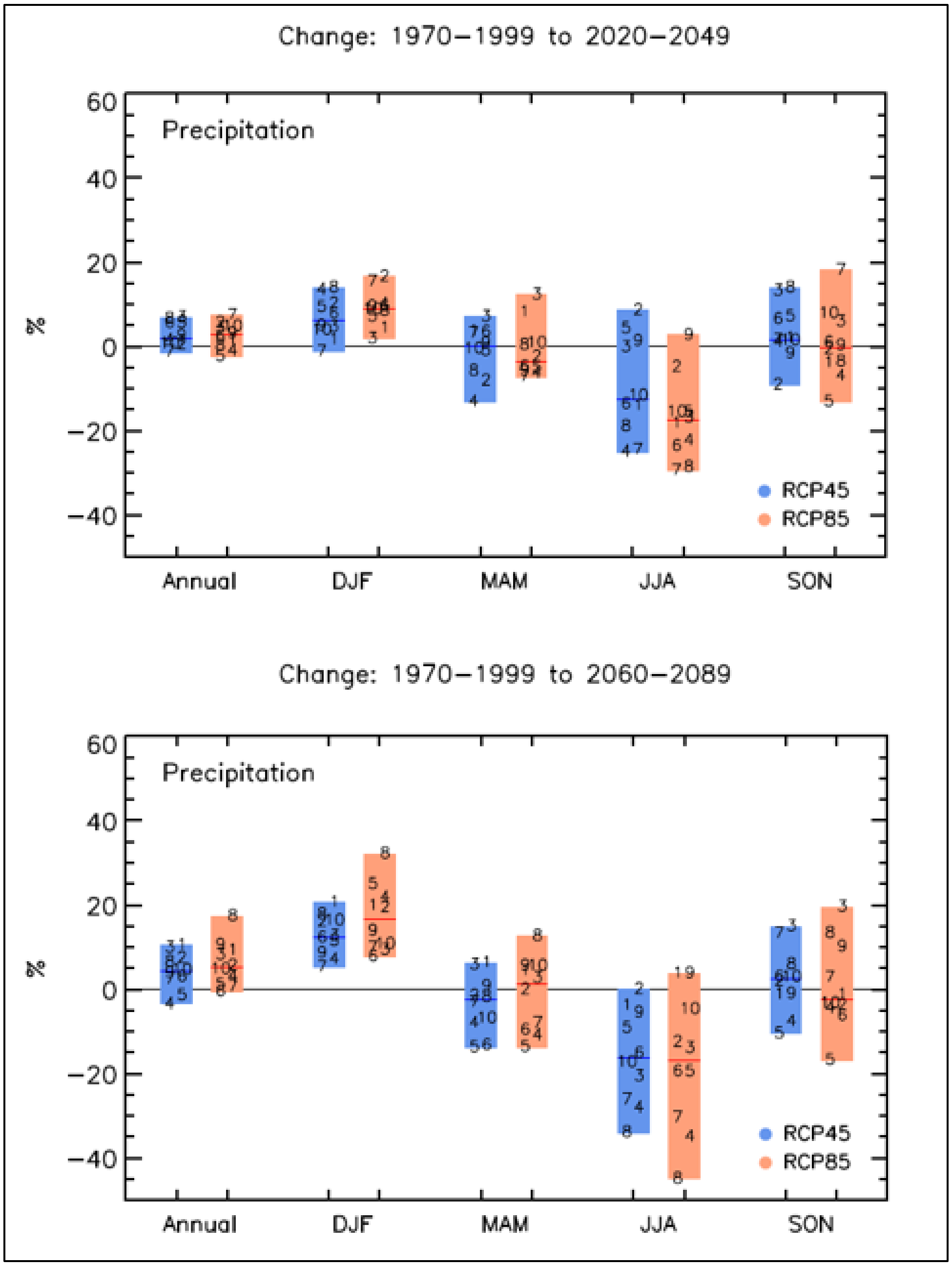


Figure 3-3. Projected basin average precipitation change (RMJOC 2018)

3.1.3 Snow Water Equivalent (SWE)

Winter snowpack is very likely to decline over time as more winter precipitation falls as rain instead of snow. The general trend across the basin is for decrease in most medium to low elevation subbasins. In the Willamette, the forecast is for near total reduction of annual snowpack towards the end of century (RMJOC 2018). Figure 3-4 depicts Columbia Basin Snow Water Equivalent (SWE) in the 1980s, and average SWE changes by the 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099) on April 1, for the 10 GCMs using RCP8.5 and downscaled via BCSD. Areas in tan historically have less than 10 mm of snow-water equivalent (RMJOC 2018).

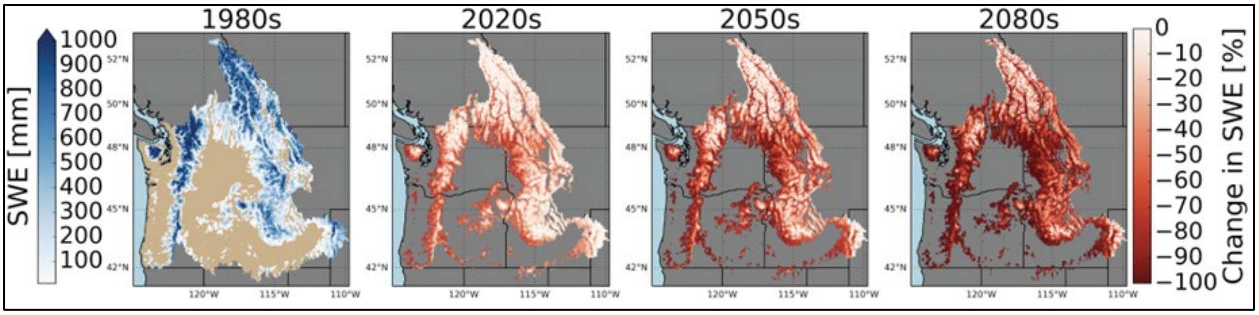


Figure 3-4. Projected basin average SWE (RMJOC 2018)

SWE conceptually drives runoff patterns as well as streamflows temperatures. However, the complexity of correlating the water temperature response to the flow changes driven by snow melt runoff is very complex. Caution should be exercised when attempting to extrapolate SWE projections to forecasts of future water temperatures. For this reason, the EIS climate change assessment primarily focuses on SWE as a major component driving the historical spring freshet. In the near term, it is likely that the spring freshet will occur earlier but will decrease to near 100 percent reduction by end of century.

3.1.4 Naturalized Streamflow

The most downstream portion of the Willamette River considered in the WVS EIS is at Willamette Falls, which is situated adjacent to Oregon City, OR. The Cascade Range basins are tributary to the Willamette River. The basin is rain driven, with the annual maximum runoff occurring in the winter months (DJF). Historically, there has been a small spring freshet as snowmelt swells streams, starting April 1st to May 1st. Future projections point to near elimination of the snow driven freshets, as higher ambient temperatures take hold in the Valley (RMJOC 2018). The overall projection is for median increases of wintertime flows and volumes with decreasing later spring and summertime flows, Figure 3-5.

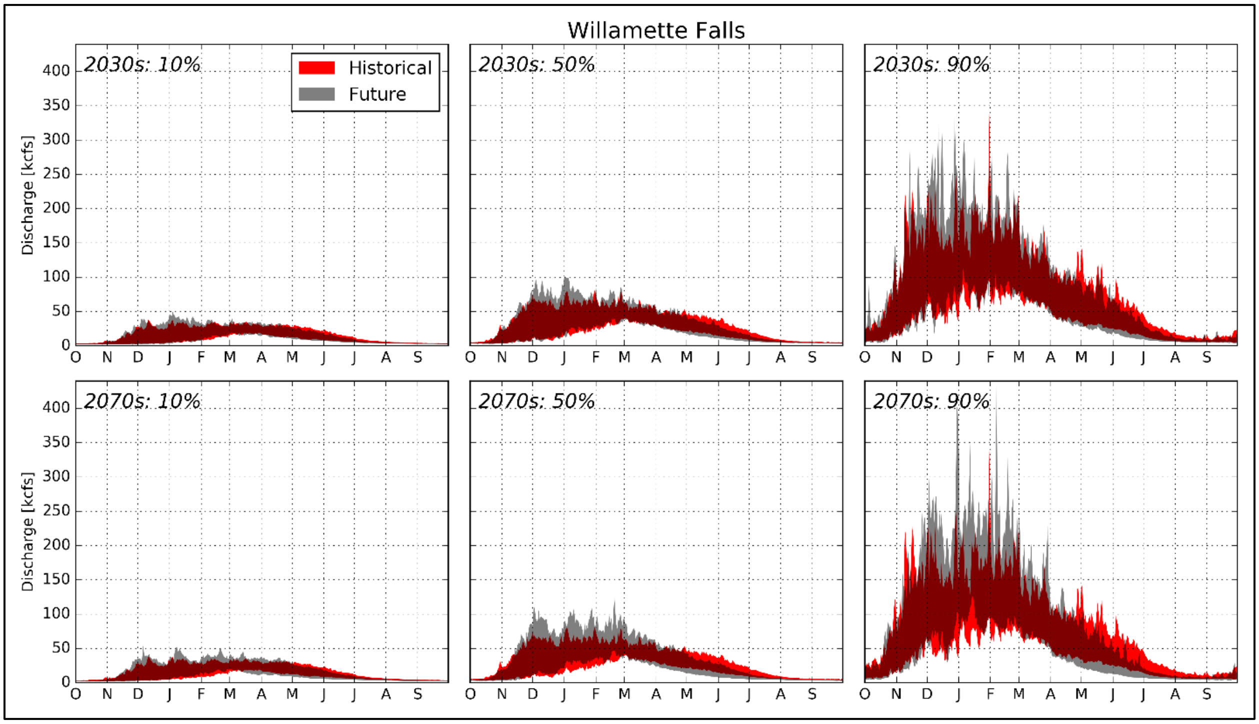


Figure 3-5. Projected basin average naturalized streamflows (RMJOC 2018)

3.1.5 Wildfire Danger

The Willamette basin experienced historic wildfires in September 2020 (Abatzoglou, et al, 2021). The fires reached the suburbs of Portland, OR and air quality was greatly diminished by smoke and burn particulates. Health impacts to the residents of the Portland and adjacent communities were very severe. The wildfire event itself was driven by an unusual concurrence of dry and windy weather conditions. A large blocking low pressure front over Idaho and southern Canada drove unusually high and sustained winds into the Willamette Valley. This occurred on the hills of a hotter and drier summer, than usual (Abatzoglou, et al, 2021). There is question whether these conditions were accentuated by near term climate change factor trends, and whether this pattern could become more frequent in the future.

The resulting fire intensity, damages, and loss of life added urgency to consideration of changes in future hydroclimate conditions, that may in turn drive future wildfire intensity and destructiveness. There are other post-fire impacts that are relevant to the WVS. Changing runoff, on terrain denuded and glazed to higher imperviousness, could conceivably create higher peak flow events and increase sediment transport. These changes could have an unpredictable and high degree of impact to water quality and aquatic health. Re-deposition of sediment, could increase O&M costs and alter the effectiveness of current water supply infrastructure (e.g., intakes) etc. Overall, the future projections for wildfire risk, is exemplified in the following from the change.

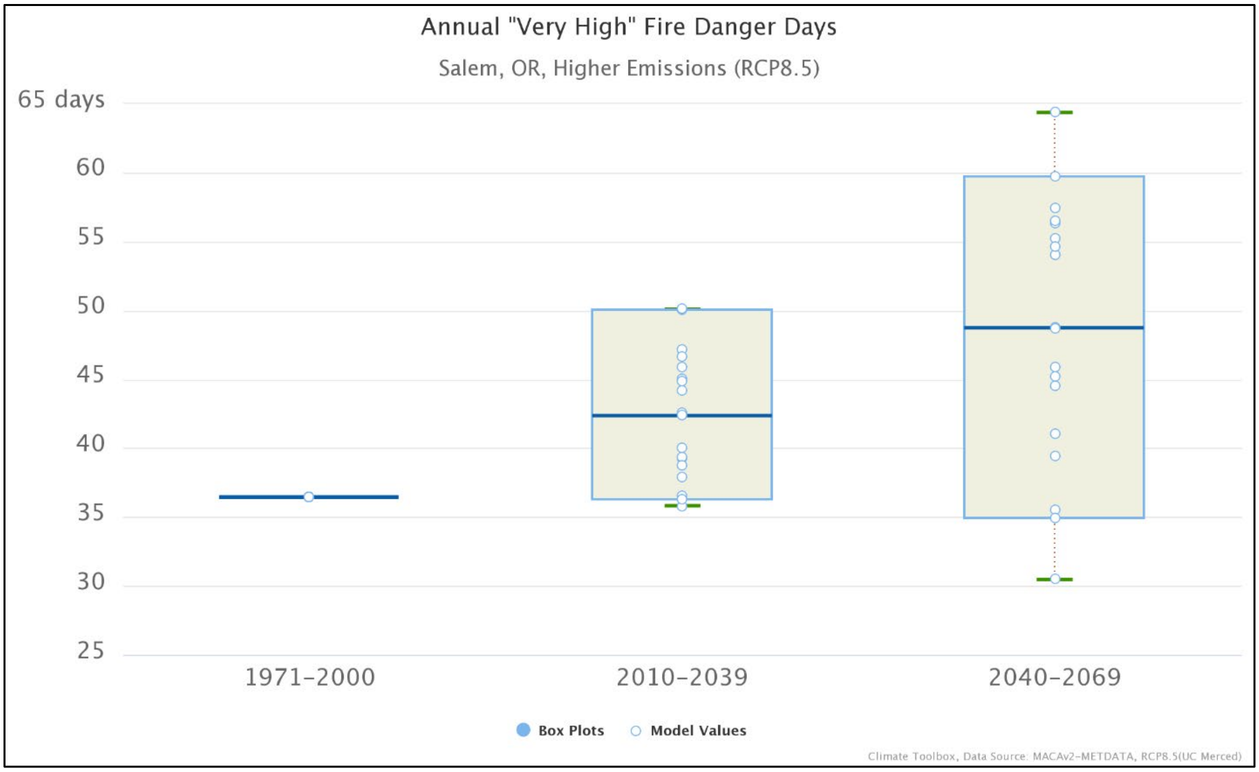


Figure 3-6. Salem, OR Annual Very High Fire Danger Days

While Salem is not a historic location of high fire danger, the graphic shown above does provide the direction of wildfire danger thru end of century. The figure shows increase in median change and the variability between GCM scenario projections shown.

3.2 Climate Change in the Willamette Subbasins

Climate change is regional in scope and extent. Therefore, this EIS assesses the climate change affected environment in terms of the whole Willamette River basin. The study extents with subbasin delineation are shown below in Figure 3-7. The WVS EIS spatial focus were at the 13 Corps projects shown.

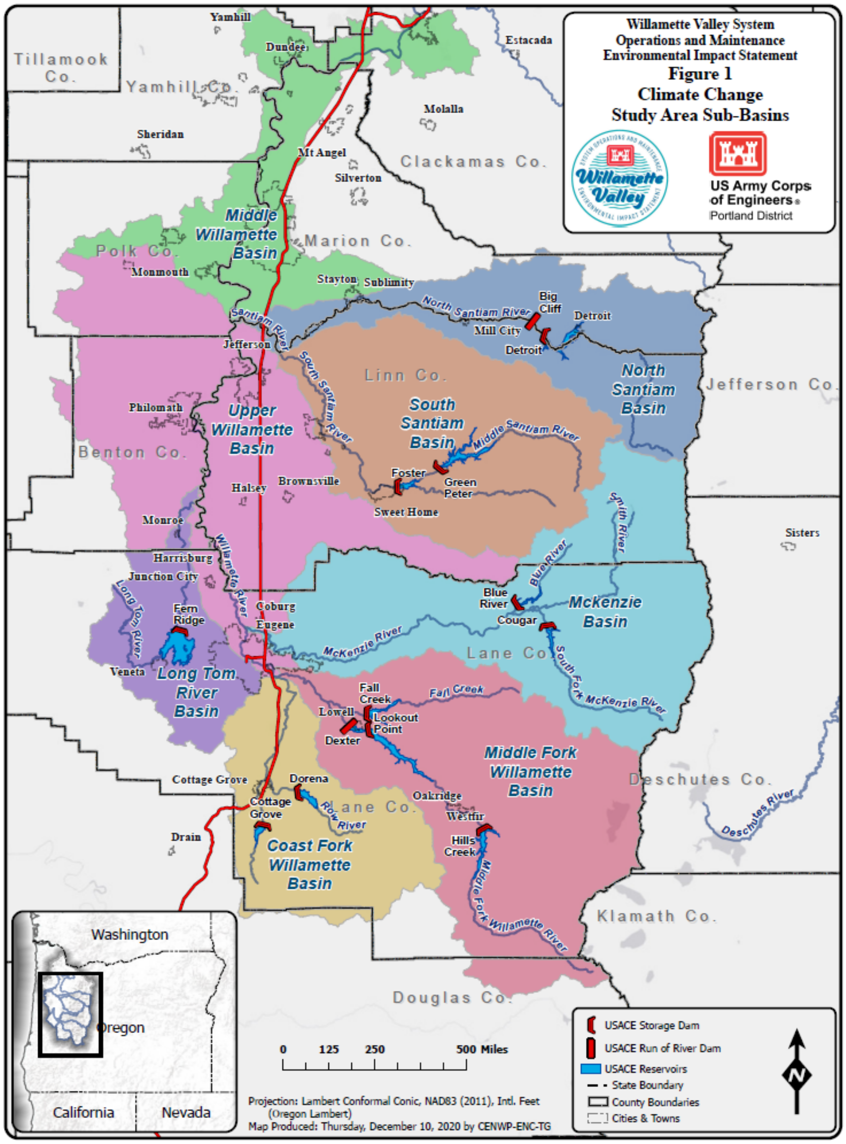


Figure 3-7. Willamette River subbasins

The WVP is divided into two primary areas, the Middle and Upper Willamette basins (MF and UW respectively). The Middle Willamette includes the mainstem Willamette from Willamette Falls at Oregon City, OR (RM 26.6) to the confluence with the Santiam River (RM 108). The Upper Willamette (UW) begins above RM 108, Santiam River confluence, and includes the following tributary basins:

- North and South Fork Santiam River
- McKenzie River
- Middle Fork Willamette
- Coast Fork
- Long Tom River basins.

3.2.1 Current regulation

Operationally the system is defined by regulating to Willamette Valley system target flows, such as flooding flow rates and water levels at Salem and Albany. Wintertime (e.g., November thru March) Columbia River flood risk management (FRM) also includes adjusting flows in the Willamette to ameliorate flood conditions at Portland, OR and Vancouver, WA (USACE 1997). When downstream control points reach bankfull flow, USACE project outflows are reduced to conservation minimums, to reduce downstream flood impacts. Flood peak reduction is constrained by the large unregulated area below Salem as well as limited flood space in the tributary reservoirs themselves. Willamette Valley reservoirs are lowered each winter to create maximum flood space (i.e., reservoir pool volume). At the local scale, USACE operates dams in the tributaries to minimize downstream flooding at local points.

USACE Willamette Valley Project storage projects are operated at or below a flood control rule curve unless regulating a highwater event. The rule curve provides guidance to reservoir regulators on how to manage the storage in the reservoir to meet the multi-purpose needs. The storage projects are typically drawn down (i.e., storage is evacuated) in the fall to provide space to store high runoff from winter rain events. Historically, rain events cause the reservoirs to rise and then stored water is evacuated once the flood threat has passed. In the early spring, the reservoirs begin to capture some of the runoff to store water for use in the summer months. Some stored water may also be used in the late spring for fish flow augmentation during drier years.

The Willamette Basin conservation season occurs from approximately May through November and is a time when water stored in the system is governed by multipurpose uses taking into consideration biological resources, water quality, power generation, irrigation, municipal and industrial (M&I) uses, and recreation. USACE, together with its partners and customers, determine the order of use for stored water among the various projects and often address environmental variables and other constraints to project operation using real-time adaptive management.

In the fall, the storage projects are drafted down to their minimum pool level in preparation for operating to reduce flood damages, which occurs primarily in December and January. The dams are operated as a system with flood risk management being their primary purpose (Figure 3-8). In total, the dams control flows on six major tributaries affecting approximately 27% of the upstream watershed of Portland, OR.

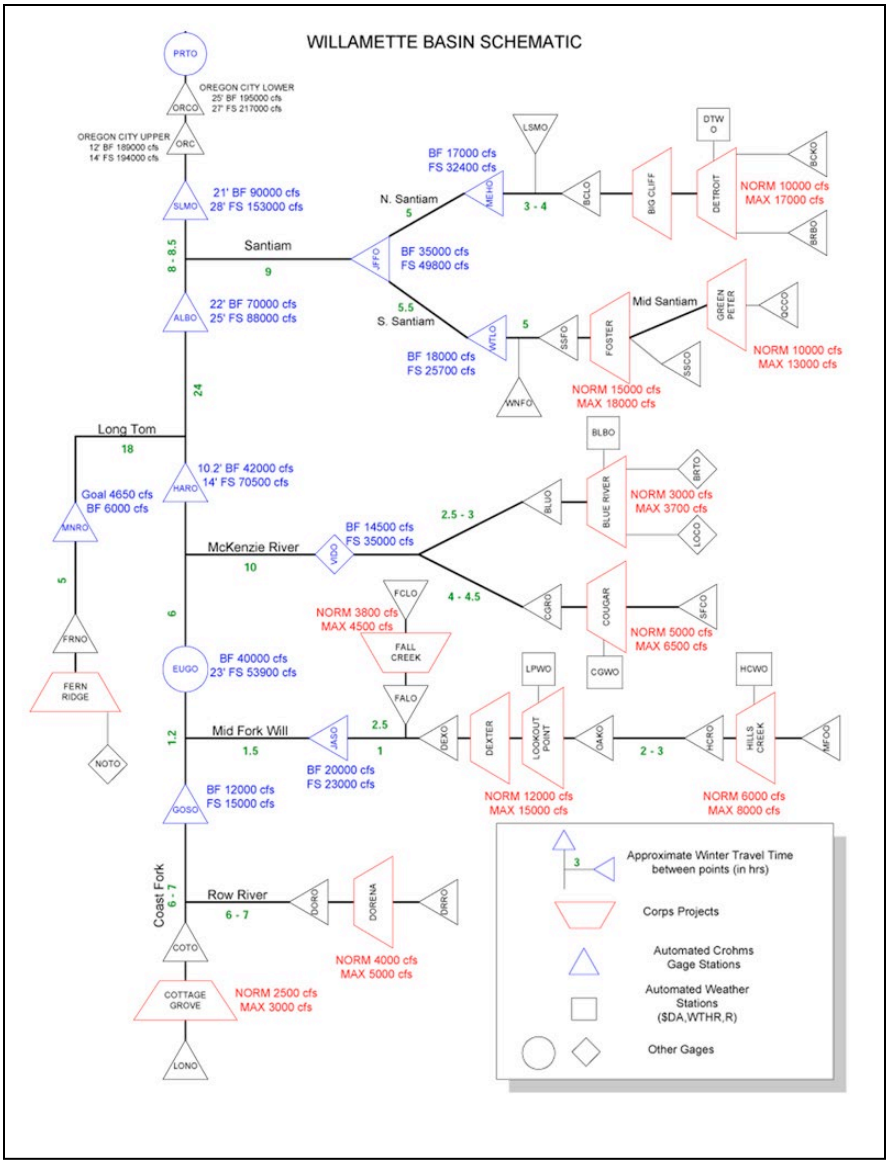


Figure 3-8. WVP regulation schematic

3.2.2 Climate change projections

Future year climate change projections used are derived from the latest global climate model projections from the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment report, AR5 (IPCC 2022a).

This EIS study frames future scenarios in terms of two Representative Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5, These two represent future scenarios for emissions of greenhouse gases (GHGs). Figure 3-9 below graphically summarizes the RCP scenarios. RCP 8.5 trends more extreme by 2100. The figure source is, https://ar5-syr.ipcc.ch/topic_futurechanges.php.

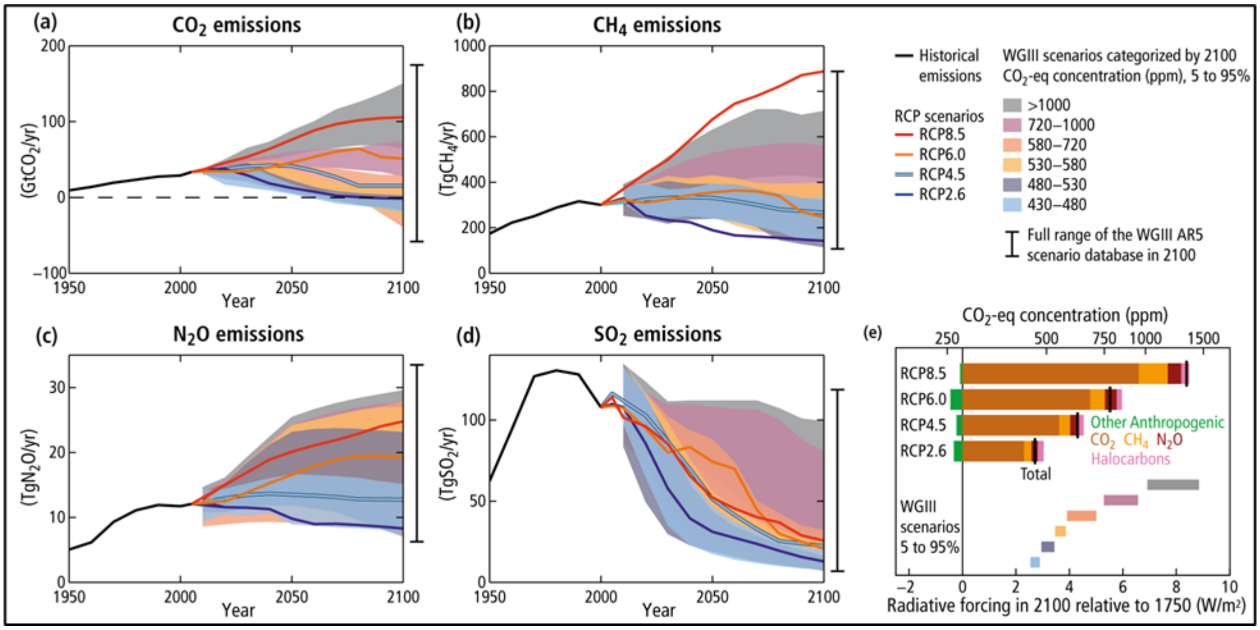


Figure 3-9. IPCC Representative Concentration Pathways (RCPs)

Under current USACE guidance (e.g., ECB 2018-14 [USACE 2018]), the climate for which a project is designed can change over the full lifetime of that project and may affect its performance, or impact operation and maintenance activities. USACE climate change assessment period is recommended to extend up to 100 years. Often the GCM datasets do not extend a 100-years from a project completion date. This is the case here, and for the purposes of this EIS, the climate change evaluation is thru end of 21st century, year 2100.

3.2.3 Key to summary hydrograph figures

Several summary flow hydrographs are presented below. They are derived from the RMJOC II study analyses. The summary plots draw on disparate streamflow datasets and present the statistical distribution as box plots, defined by median, and quartile ranges. Figure 3-10 graphically depicts the summary hydrographs displayed below.

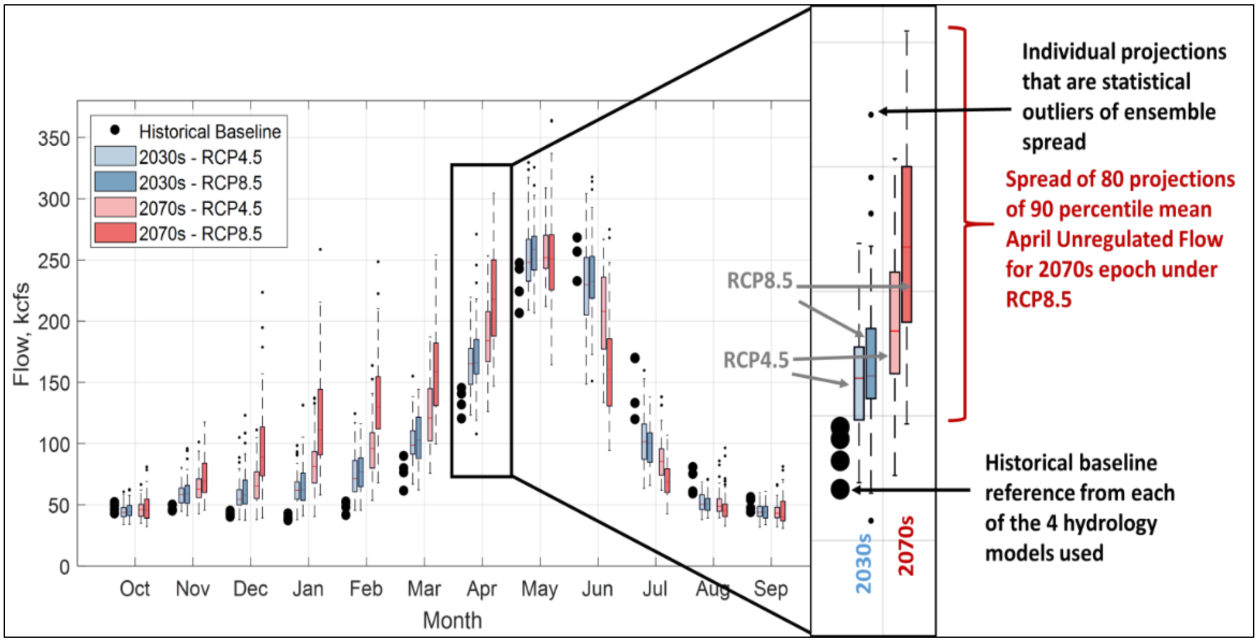


Figure 3-10. Example visual of historic and future predictions graph

3.2.4 Middle Willamette River

The Middle Willamette (MW) includes the mainstem Willamette River from Willamette Falls at Oregon City, OR (RM 26.6) to the confluence with the Santiam River (RM 108). Figure 3-11 below graphically shows the basin delineation and major features including land cover, as of 2016. It is provided as context for the overall climate change impacts to the affected environment. Note that the following subbasin section maps, show the land cover as well.

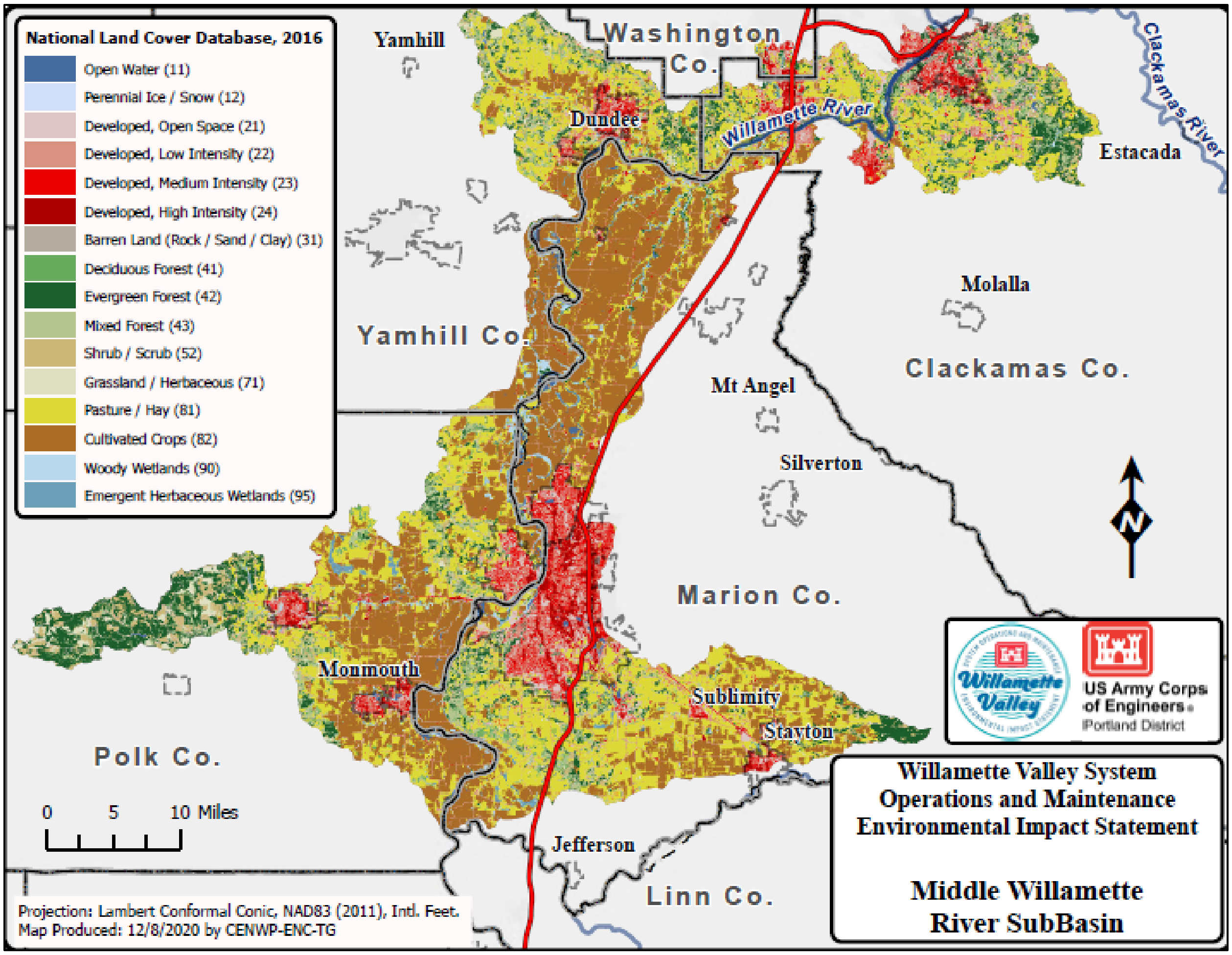


Figure 3-11. Middle Willamette Sub-basin

This portion of the basin contains largest population centers outside of Portland, OR. The Salem/Keizer metro area is larger than the Eugene/Springfield metro area. The basin is primarily low-lying valley floor. The Willamette River annual hydrograph is highly impacted by upstream water management operations. Below Salem, local flows are primarily unregulated. Regulation has reduced flood peaks significantly while moderating low flow conditions during the summertime. Figure 3-12 below shows the effect of regulation over 12 months of the water year, with data from water years (WYs) 1934 to 2019. Unregulated flows are shown as gray shaded areas, with regulated flows shown as colored lines.

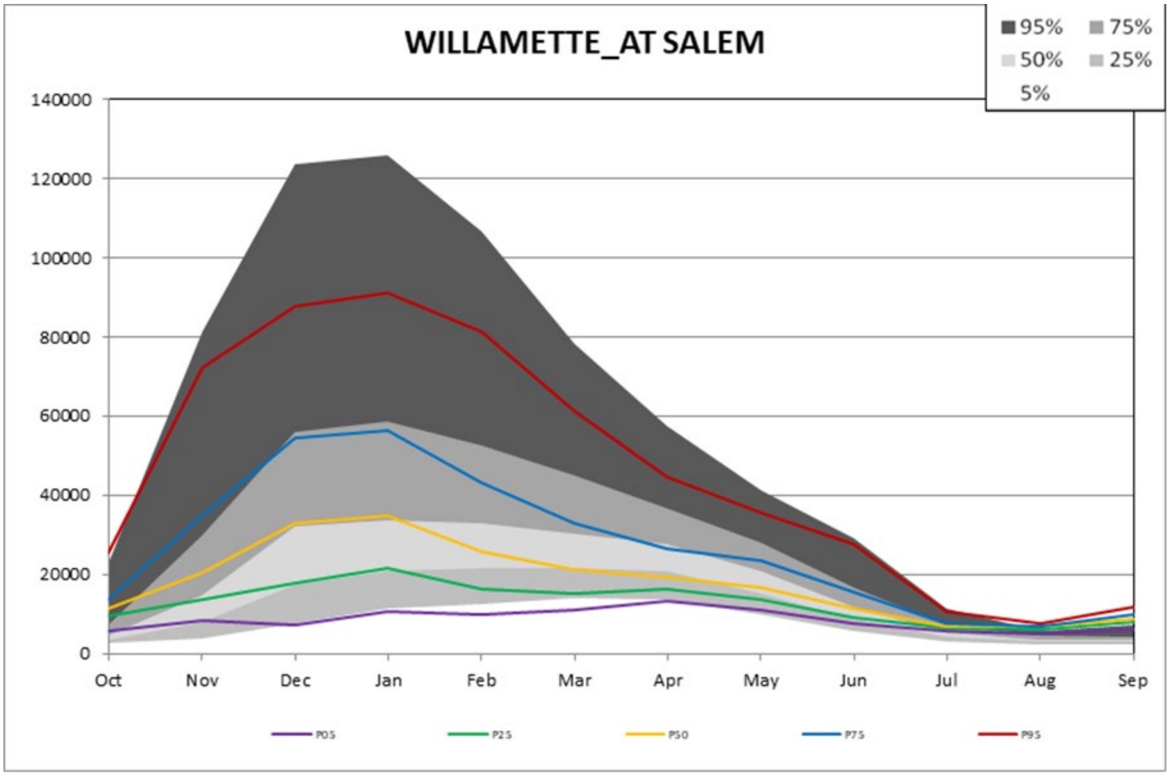


Figure 3-12. Willamette River at Salem, OR, Reg vs UnReg flows

Relative to pre-dam conditions, Willamette Valley project regulation reduce peak high water during the wintertime flood season, November thru March, and increase low summer flows. The 13 Corps projects also make possible thermal regulation, through release of cooler reservoir outflows. Given that many climate change projections are for warmer conditions, increased wintertime volumes and less baseflow in the summer, WVS project storage and regulation operations tend to ameliorate climate change hydrology and hydro-climate trends of concern.

Figure 3-13 below, is derived from the Northwest Climate Toolbox. https://climatetoolbox.org/. The figure graphically shows average annual temperatures trending upward, with an increasing rapidity, into the 21st Century. At Salem, OR in the Middle Willamette sub-basin, the annual median temperature is projected to increase about +7.5° F compared to the 1971-2000 baseline. Caution should be taken in applying these projections. *The climate toolbox graphics below can be used with confidence to identify the direction and relative scope of climate factor trends, but individual values should not be used as a threshold or design values.*

It is expected that the Valley floor (roughly along axis of the I-5 corridor) will experience the greatest relative warming. End of century mean summertime temperatures are projected to be 10.4° greater than end of century, as shown in Figure 3-14.

The likelihood of higher temperatures in the future, may be the greatest concern for the WVS EIS resource areas' qualitative climate change impact determinations. This trend will likely increase future consumptive water demand and could make future water scarcity and drought like conditions more severe and frequent. Increasing water temperature will likely pose a significant stressor of concern, for the fish and wildlife operations at Corps projects. Although, formulating a specific metric value for projected water temperatures, has been elusive, ambient air temperature changes in the future is a proxy for the likely trend of the relevant climate change factor.

Precipitation in the Middle Willamette is projected to increase in the winter months, some of the most pronounced being the months of December through February (DJF). Figure 3-15 graphically shows expected precipitation change over box plots of wintertime (DJF) precipitation change. The plots graphically show the historic and three 30-year future epochs. Seen below, wintertime precipitation is projected to increase by approximately 2.2 inches. This change would likely stress Corps flood space and wintertime flood operations.

Average summertime precipitation (already low) is expected to decline by 0.2 inches by end of century. See Figure 3-16. Lower summertime precipitation could stress sustaining of regulated conservation flows and with increasing air temperatures, increase need for downstream thermal regulation.

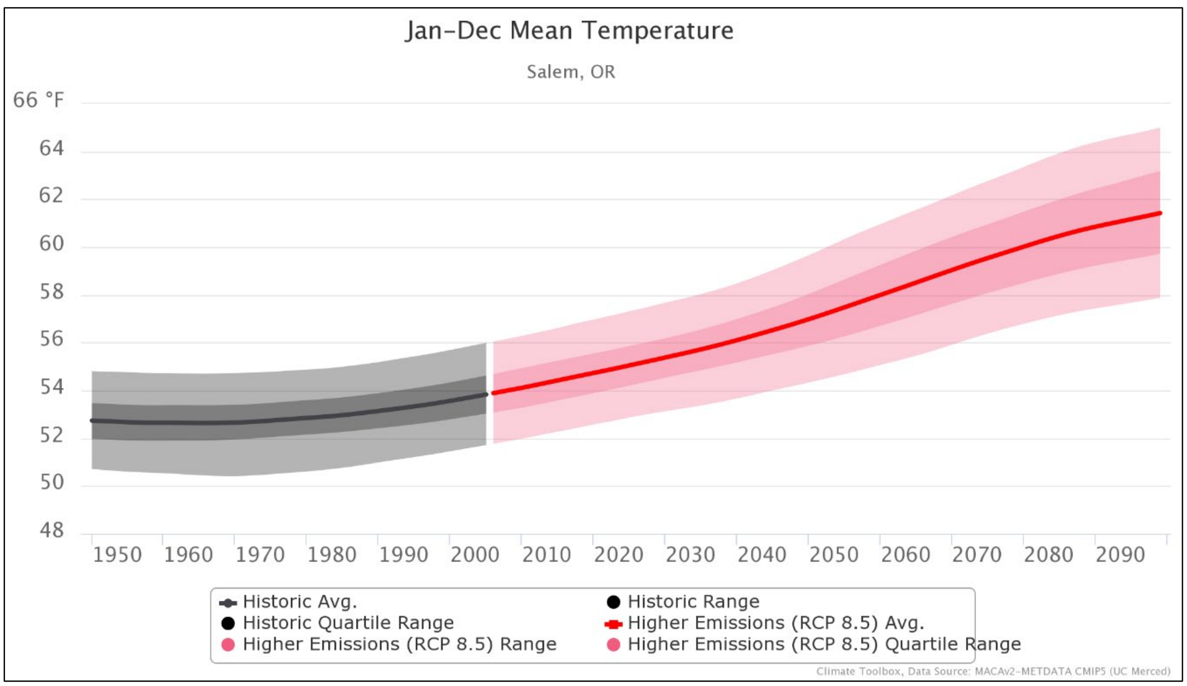


Figure 3-13. Average annual temperature trends at Salem, OR. (1950-2100)

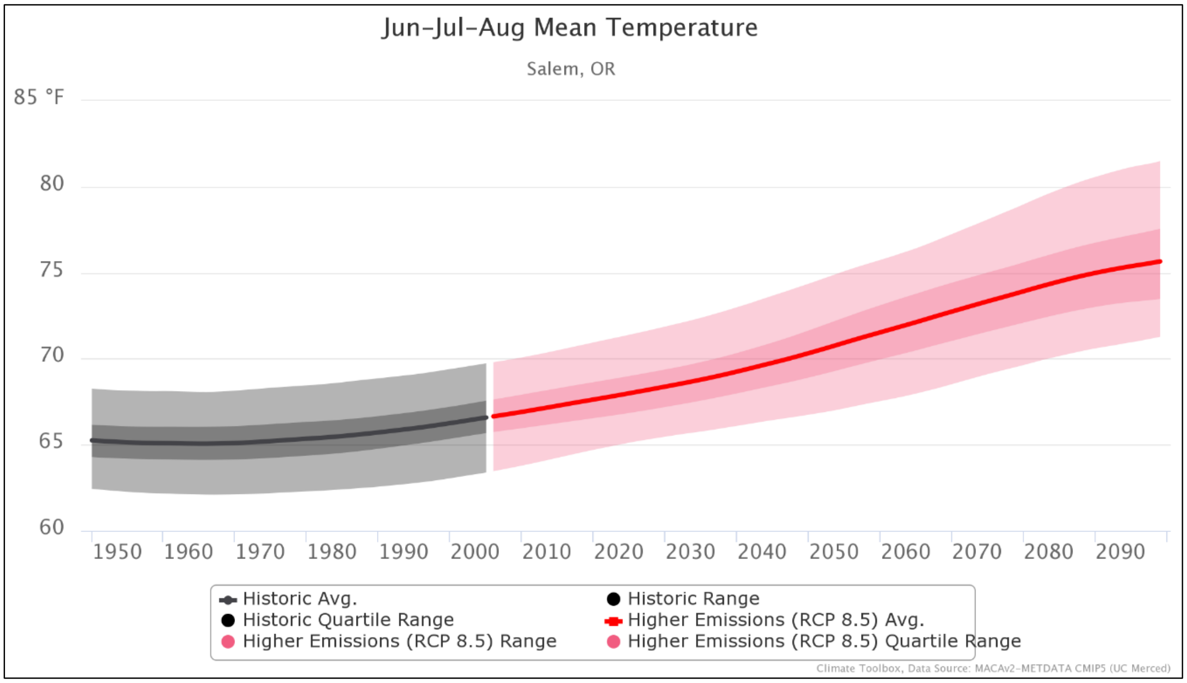


Figure 3-14. Average annual summer temperature trends at Salem, OR. (1950-2100)

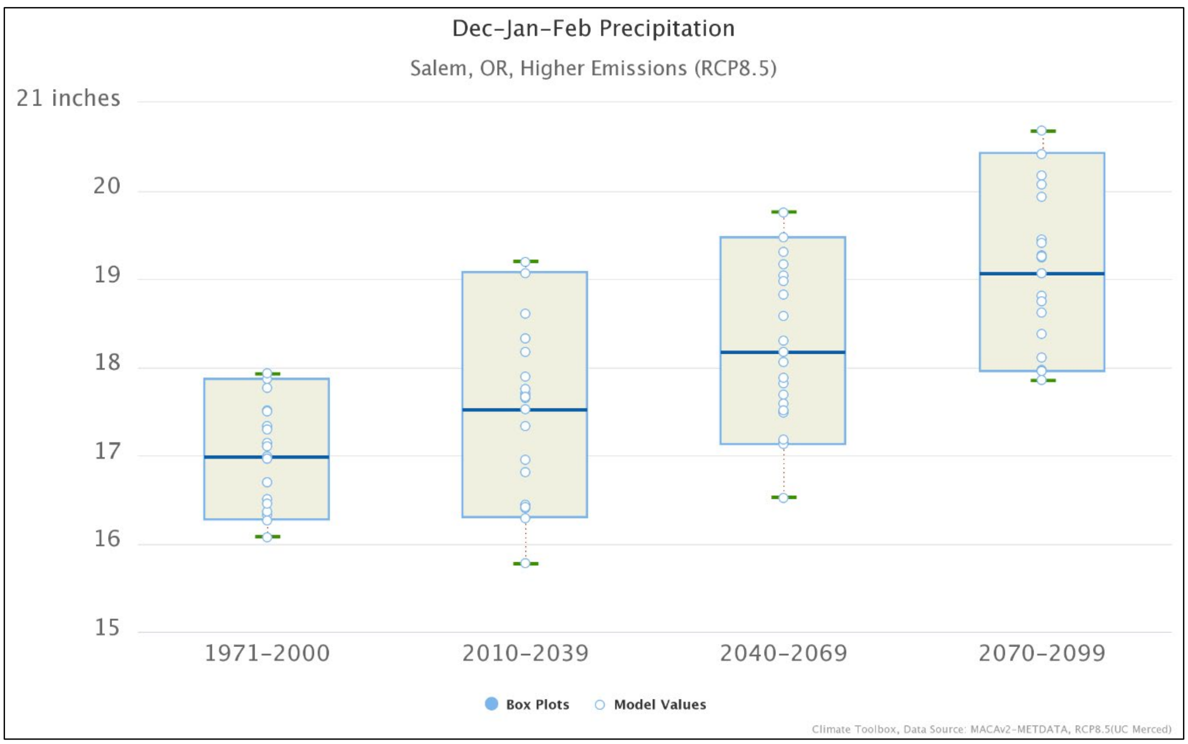


Figure 3-15. Median winter precipitation trend at Salem, OR. (1950-2100)

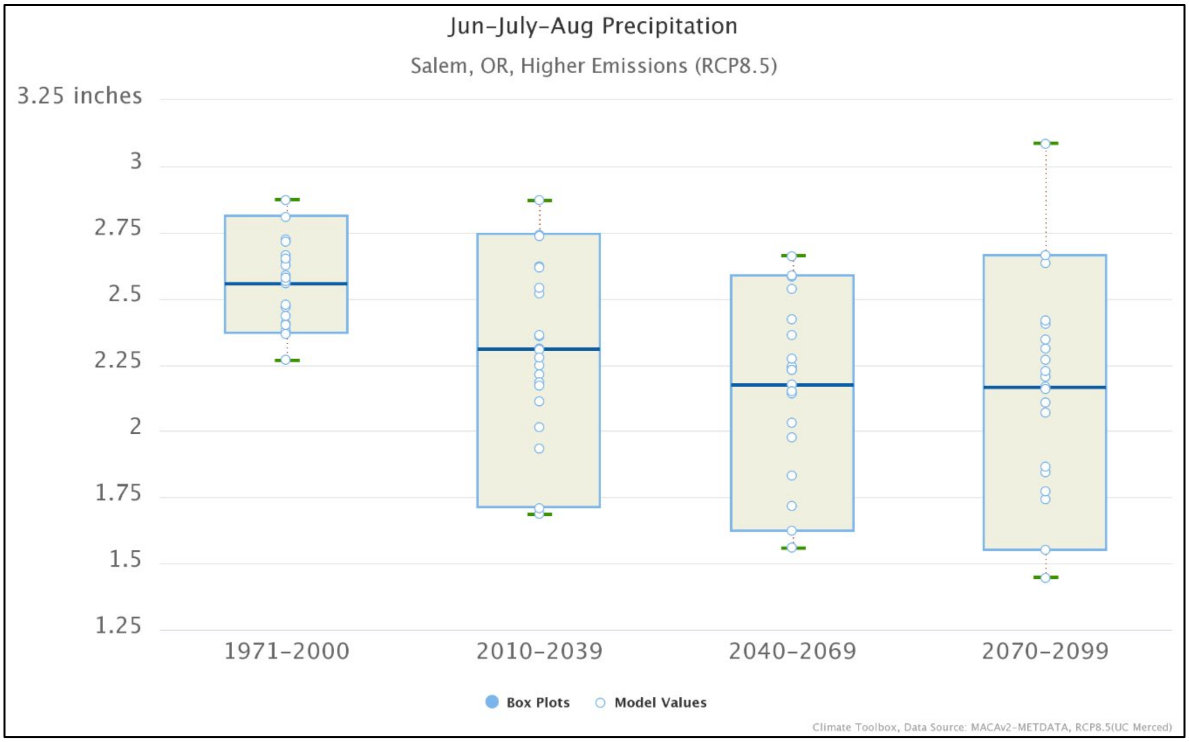
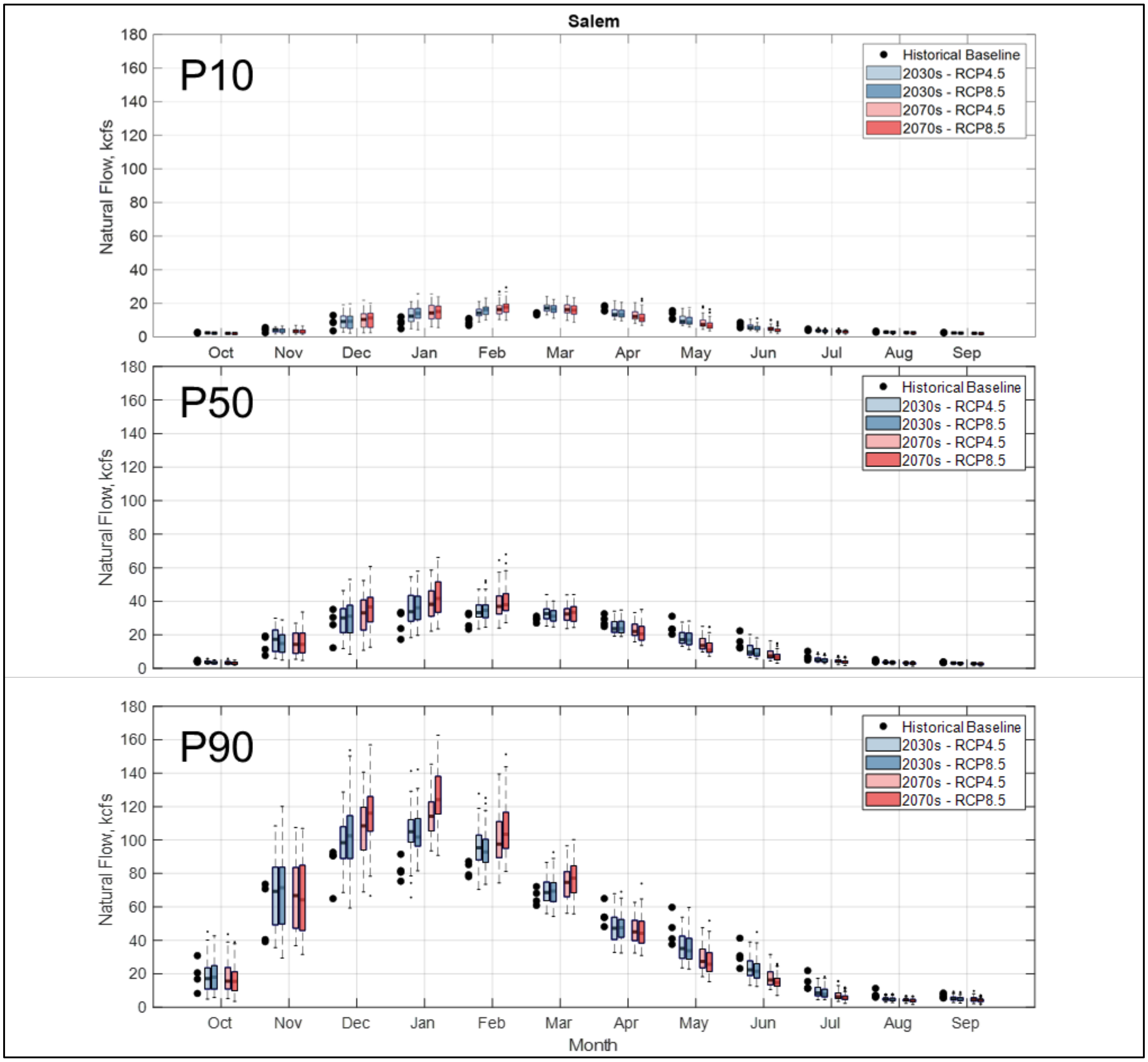


Figure 3-16. Median summer precipitation trend at Salem, OR. (1950-2100)

The warming temperatures and tendency for increased precipitation, particularly in the already wet winter months, result in higher winter volumes. In the summer, there is a tendency for lower flows or a longer period of low flows. The Willamette River Basin area has a tendency toward lower spring and summer flows (RMJOC 2018).

Source: RMJOC II, 2018

Figure 3-17 graphically depicts the projected changes in seasonal unregulated (naturalized) streamflow at Salem, representing the prevalent future trends the Middle Willamette sub-basin. Figure 16 graphically summarize Willamette River at Salem, OR - 10, 50 and 90% Percentile summary hydrographs for Historical Period (1975-2005), 2030s (2020-2049) and 2070s (2060-2089) (RMJOC 2018). Refer to Figure 9 for a legend and explanation of the summary hydrograph presentations.



Source: RMJOC II, 2018

Figure 3-17. Willamette River at Salem, OR summary hydrographs

Table 3-1 below summarizes the percent of normal relative to historical baseline. It exemplifies the relative degree of monthly and seasonal change. Positive flows tend to increase in December thru March while shoulder seasons, spring and fall, with summers, tend to decrease, relative to modeled baseline flows.

Table 3-1. SLM flow change

SLM Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	-0.3	-0.5	-0.2	-0.5	0	-0.5
Nov	0	-1.4	0.1	0.1	12	1
Dec	1	3	6	12	20	37
Jan	6	7	10	13	19.5	40.5
Feb	7	8.5	6	9	9	20
Mar	3	2	2	4	7	15
Apr	-4	-6	-6	-8.5	-15	-16
May	-4.5	-6.5	-7	-14.5	-6	-21
Jun	-2	-3	-8.5	-11	-9.5	-12
Jul	-1	-1.2	-2.5	-3.5	-10	-14
Aug	-0.3	-0.5	-1	-1.5	-4	-5
Sep	-0.1	-0.2	-0.2	-0.6	-4	-5

Higher winter (DJF) inflows and increasing frequency of systemwide winter flood events will likely complicate system flood risk management, especially during winter (e.g., at Salem and Portland, OR), when future flow volumes are likely to increase relative to historical norms.

During the spring, summer, and fall; decreased precipitation and warmer conditions will likely reduce inflows to reservoirs and could stress seasonal refill and conservation operational objectives. Lower inflows for the refill, will likely complicate follow-on conservation season minimum flow operations. For example, the so called “measure 30” and “near term low flow” measures are dependent and driven by concurrent refill inflows and demands in the conservation season, respectively.

An additional climate change stressor variable of concern is the projection of increased likelihood of higher fire danger days. Increasing risk is driven primarily by higher ambient temperatures and low precipitation. One contributing variable that is not well understood, is how high winds may contribute ignition and the fire intensity. Off season occurrence of and higher duration of sustained wind and gusts have been a catalyst for recent mega-conflagrations in the PacNW (Abatzoglou et al., 2021). This metric is not modeled in most climate change studies. This dynamic will likely need to be better understood to address future higher fire danger. Figure 3-18 below graphically shows the trend of high fire danger days in the future.

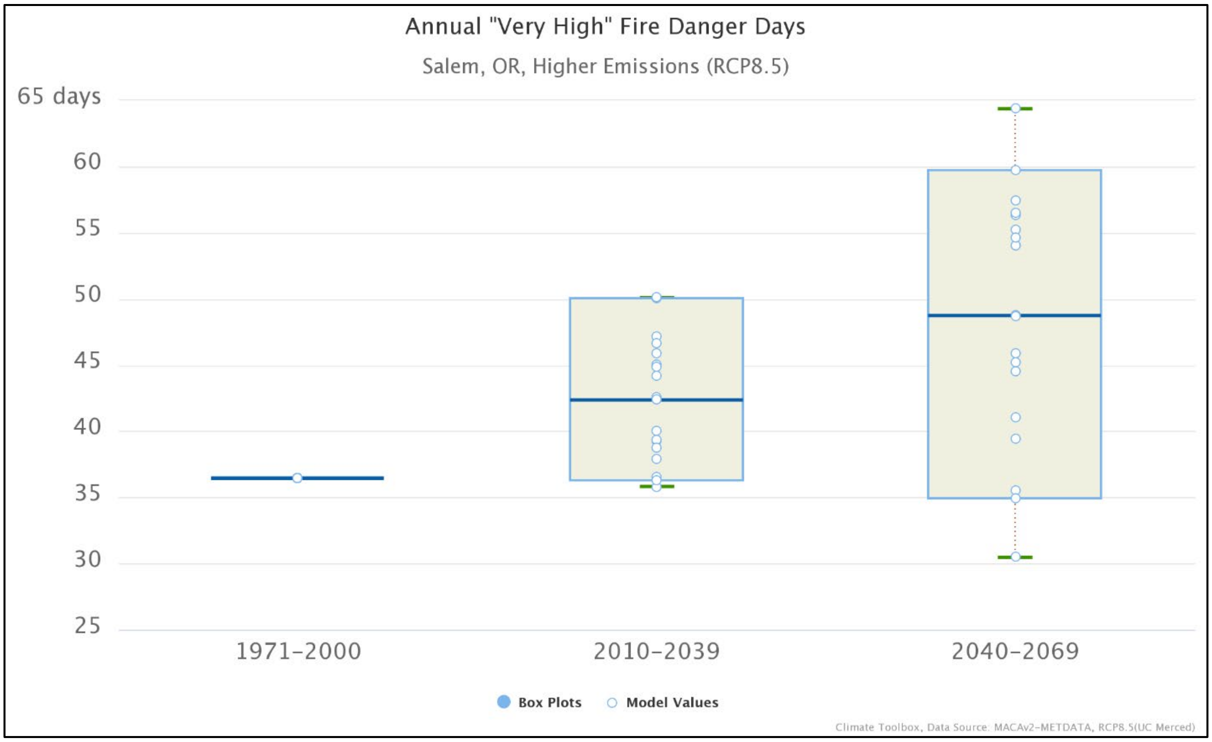


Figure 3-18. Salem, OR Annual Very High Fire Danger Days

3.2.5 Upper Willamette River

The Upper Willamette basin is shown Figure 3-19 below. The basin straddles the Interstate 5 (I-5) corridor and stretches between two major metropolitan areas, Albany, OR at the north end to the Eugen/Springfield metro area to the south. The principal Corps dam in this basin is Fern Ridge on the Long Tom River.

Warming is projected in the Upper Willamette sub-basin. Figure 3-20 shows that average annual temperatures at Eugene OR are projected to increase by 8° F compared to the 1971-2000 baseline, by end of century. End of century mean summertime temperatures are projected to be +10.3° warmer as shown in Figure 3-21.

Like the rest of the low-lying Willamette Valley, precipitation in the Upper Willamette basin is projected to increase in the winter months, December through February. Figure 3-22 graphically shows expected wintertime precipitation change at Eugene, OR with box plots of wintertime (DJF) precipitation change for historical and three future 30-year epochs. As seen below winter precipitation is projected to increase by approximately 2.2 inches, the same as projected for Salem, OR. Summer precipitation, Figure 3-23, already very low, will decrease in a similar was as seen at Salem, OR as well.

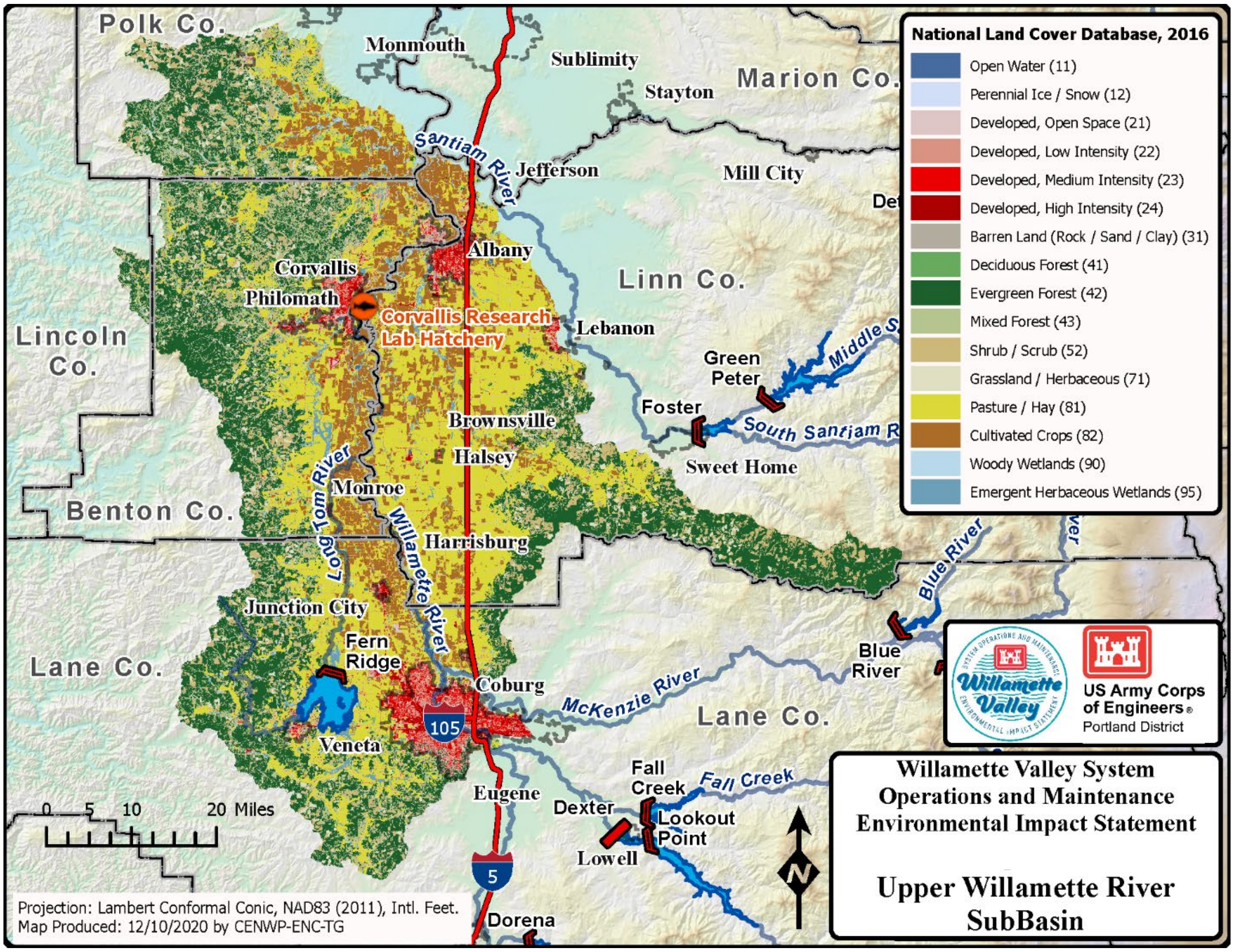


Figure 3-19. Upper Willamette Sub-basin

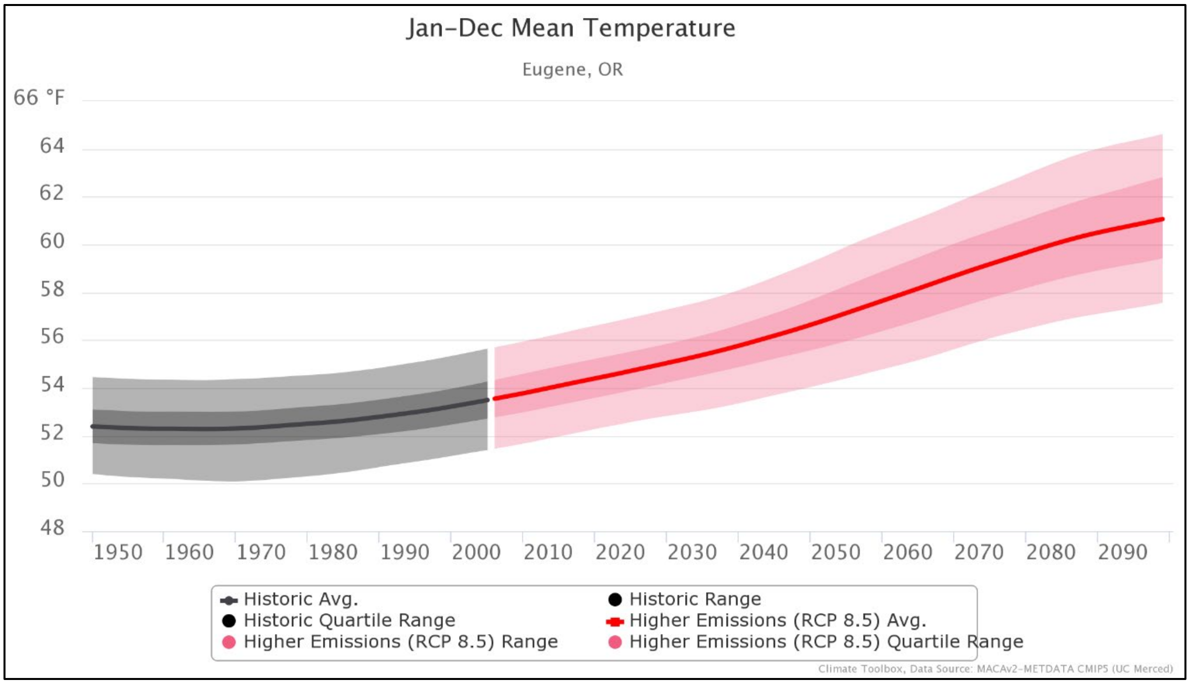


Figure 3-20. Average annual temperature trends at Eugene, OR. (1950-2100)

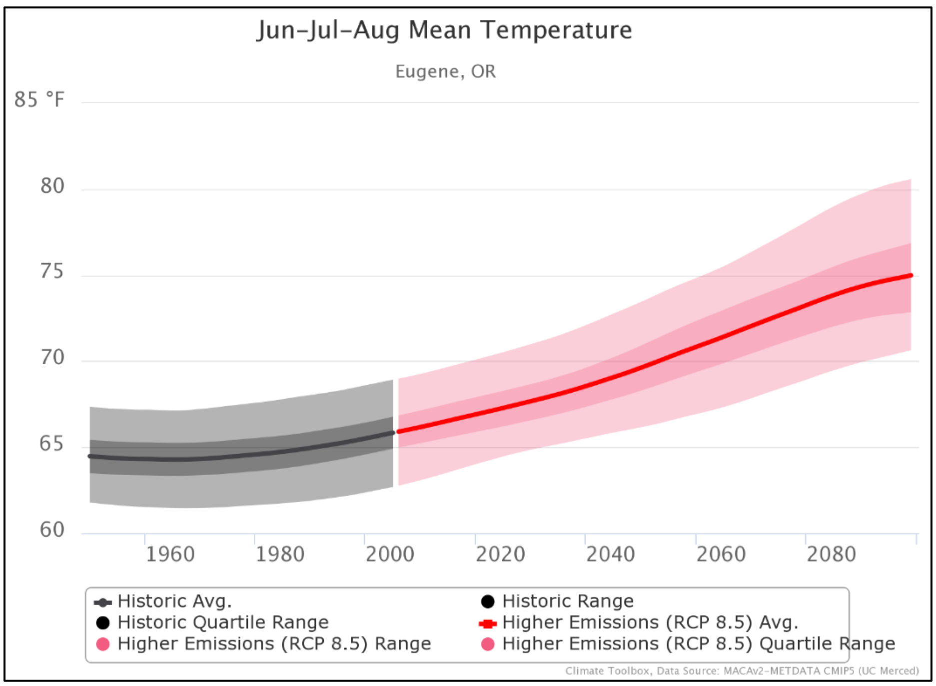


Figure 3-21. Average annual summer temperature trends at Eugene, OR. (1950-2100)

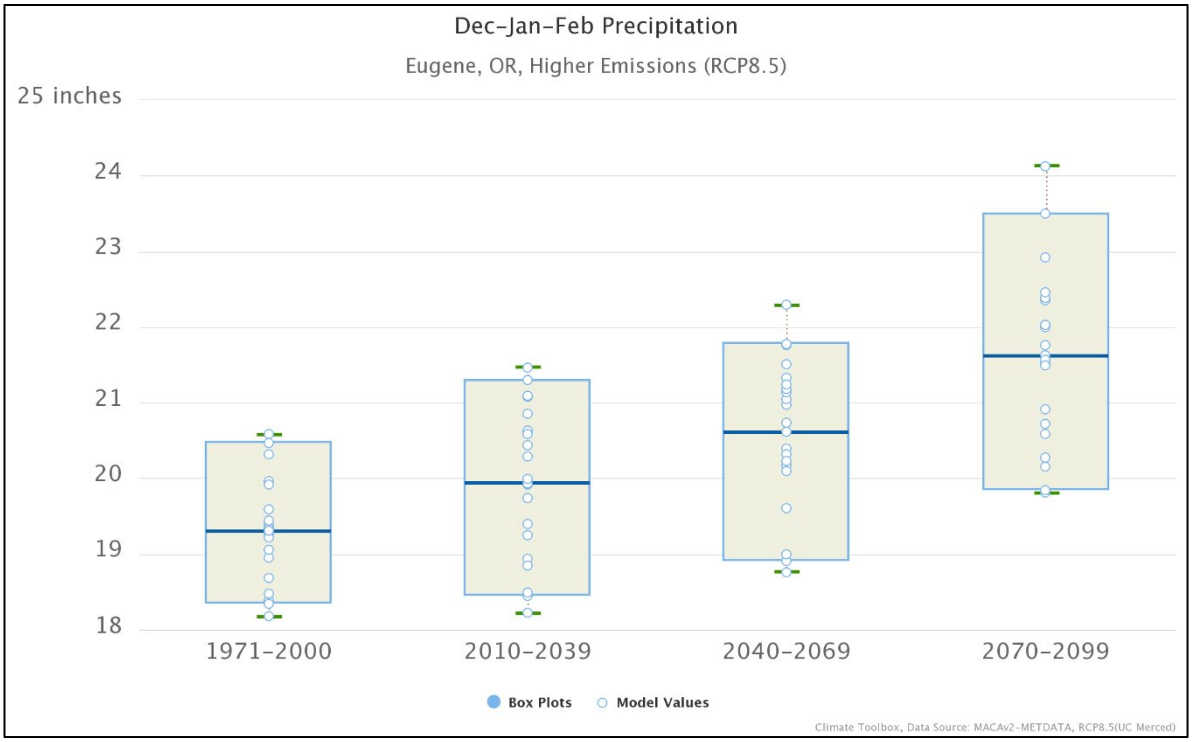


Figure 3-22. Median winter precipitation trend at Eugene, OR. (1950-2100)

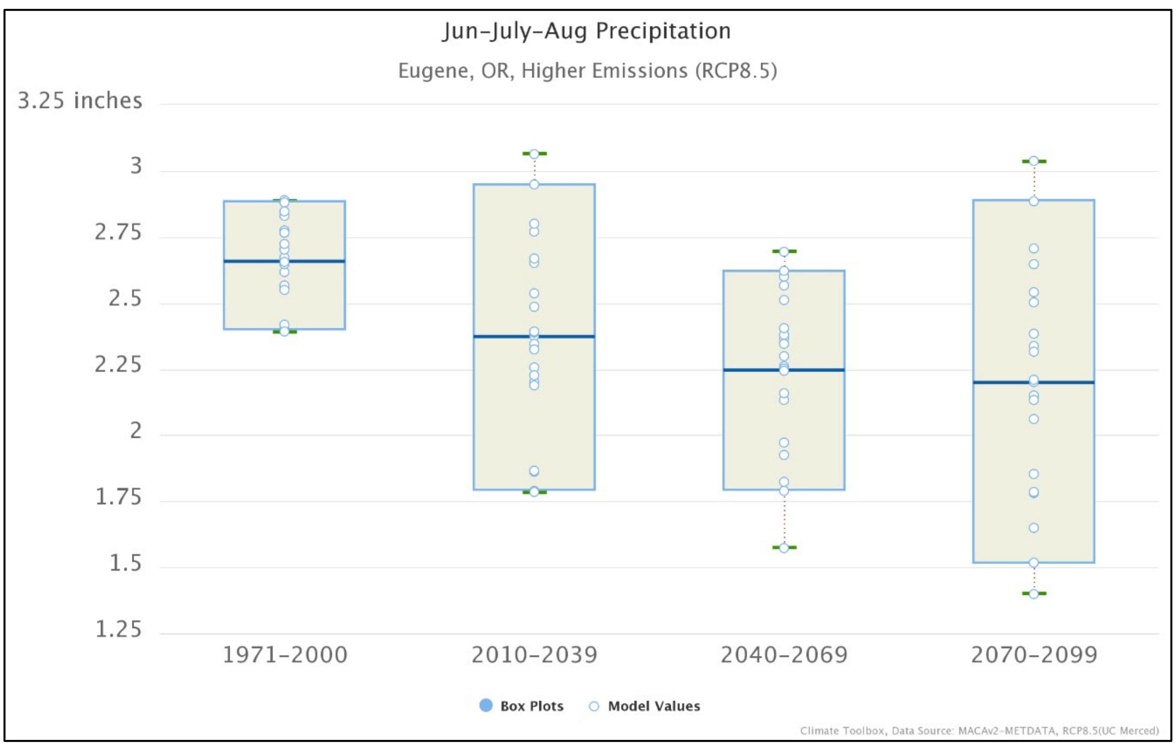
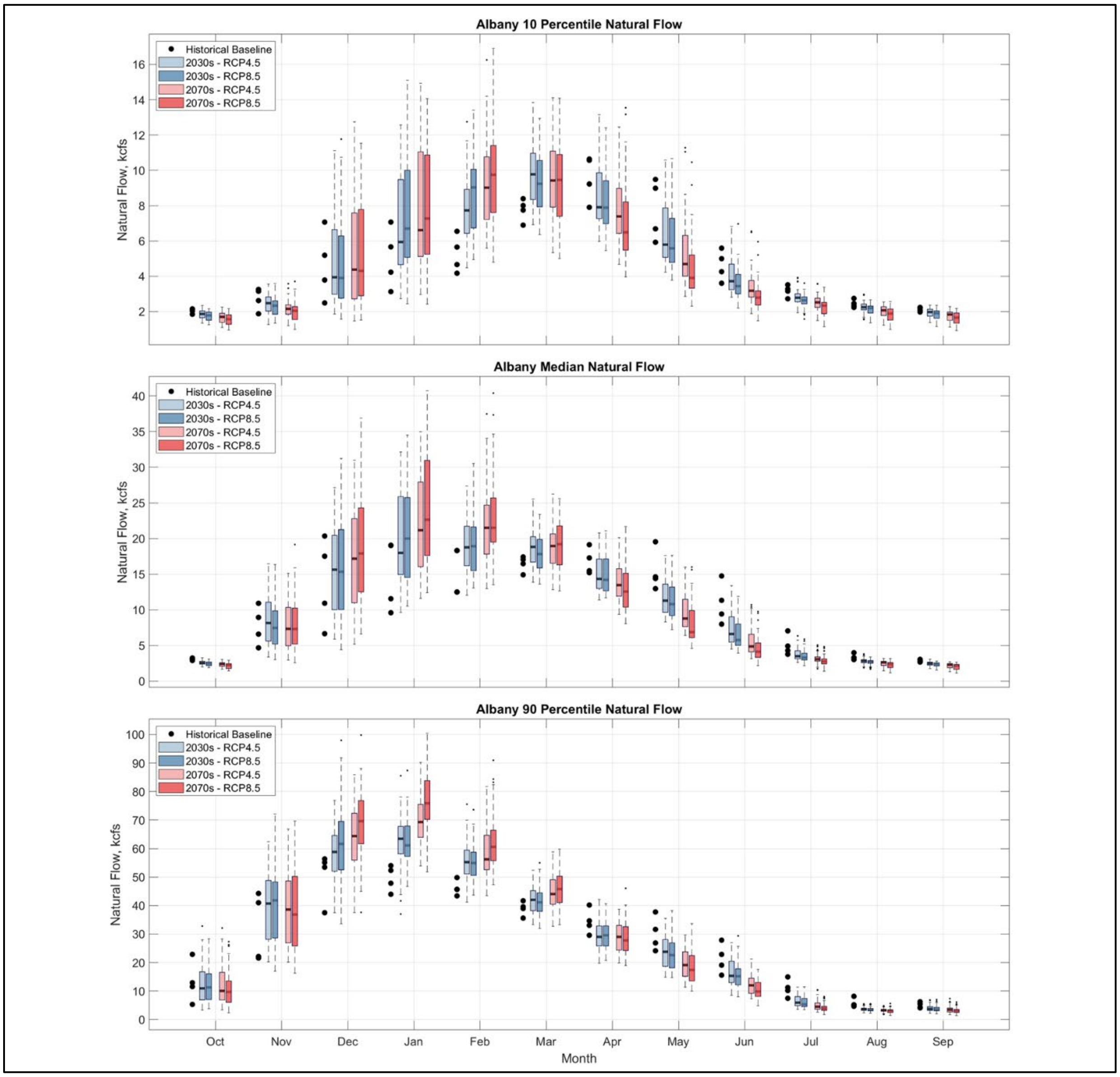


Figure 3-23. Median summer precipitation trend at Eugene, OR. (1950-2100)

The warming temperatures and overall increased precipitation, especially in the winter will result in higher winter volumes in the Willamette River. In the summer, there is a tendency for lower flows or a longer period of low flows. The Willamette River Basin area has a tendency toward lower spring and summer flows (RMJOC 2018). The natural (unregulated) streamflow trends for the Upper Willamette sub-basin as reported at Albany are below in Source: RMJOC II, 2018

Figure 3-24. They reflect the same overall trends as the exceedance plots at Salem. OR, shown in the previous section.



Source: RMJOC II, 2018

Figure 3-24. Willamette River at Albany, OR summary hydrographs

Table 3-2 below summarizes the percent of normal relative to historical baseline. It exemplifies the relative degree of monthly and seasonal change. Positive flows tend to increase in

November, December, and March while shoulder seasons, spring and fall, with summers, tend to decrease, relative to modeled baseline flows.

Table 3-2. ALB flow change

ALB Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	-0.1	-0.2	-0.8	-1	-1.5	-2
Nov	-0.1	-0.2	-0.1	-0.1	6	3
Dec	-0.3	-0.1	0.6	3.3	9	17.8
Jan	1.8	2.3	5	2.5	12	27
Feb	3.8	4.4	3.4	6.9	7	12.5
Mar	1.3	1.5	1.8	3	2	6.5
Apr	-1.4	-3.1	-3	-4.5	-4.5	-5
May	-2.1	-3.9	-4	-8	-8	-11
Jun	-0.4	-1.5	-5.5	-7	-3	-10
Jul	-0.9	-1	-1.2	-2.5	-5.5	-7.5
Aug	-0.2	-0.4	-1.3	-1.7	-3.5	-3.7
Sep	-0.2	-0.25	-0.1	-0.5	-0.5	-0.7

Climate change effects in the Upper Willamette basin are very similar to the Middle Willamette basin. Higher winter (DJF) inflows and increasing frequency of systemwide winter flood events will likely complicate system and local flood risk management. During wintertime, increased flow project inflow volumes, and back-to-back high-water events, could lead to increased severity of flooding. Back-to-back flood events tax available flood space. Projects may not completely empty with short periods between events. With projected higher precipitation in the winter, the likelihood of back-to-back events, is likely to increase.

High water events that occur during refill may reduce available water year conservation storage and hinder summer minimum flow releases and thermal regulation operations (10 May through 15 November). The Willamette River, April 2019 highwater event (USACE 2019) was a flood that occurred as reservoirs were refilling. Higher pools at the time of the event complicated the flood reduction operations and subsequent emptying of the pools post event, was by water management regulators (USACE 2019). Occurrence of late high-water events could become more common in the future and emphasize the importance of highly flexible flood season regulation. Measures with more operational flexibility, e.g., latitude of decision making, and availability in a broader range of release and storage options, would be more resilient to projected climate change trends.

Overall, decreased precipitation and warmer conditions could reduce inflows to reservoirs and reduce normal baseflows in tributaries and downstream mainstream reaches. Lower inflows during refill, will likely complicate follow-on conservation season low flow fish operations, recreation, and other conservation objectives. Warming downstream flows during the summer and fall months will likely impact how temperature operations are performed. An additional climate change stressor variable of concern is the projection of increased likelihood of higher fire danger days. Figure 3-25 below graphically shows the trend of high fire danger days in the future.

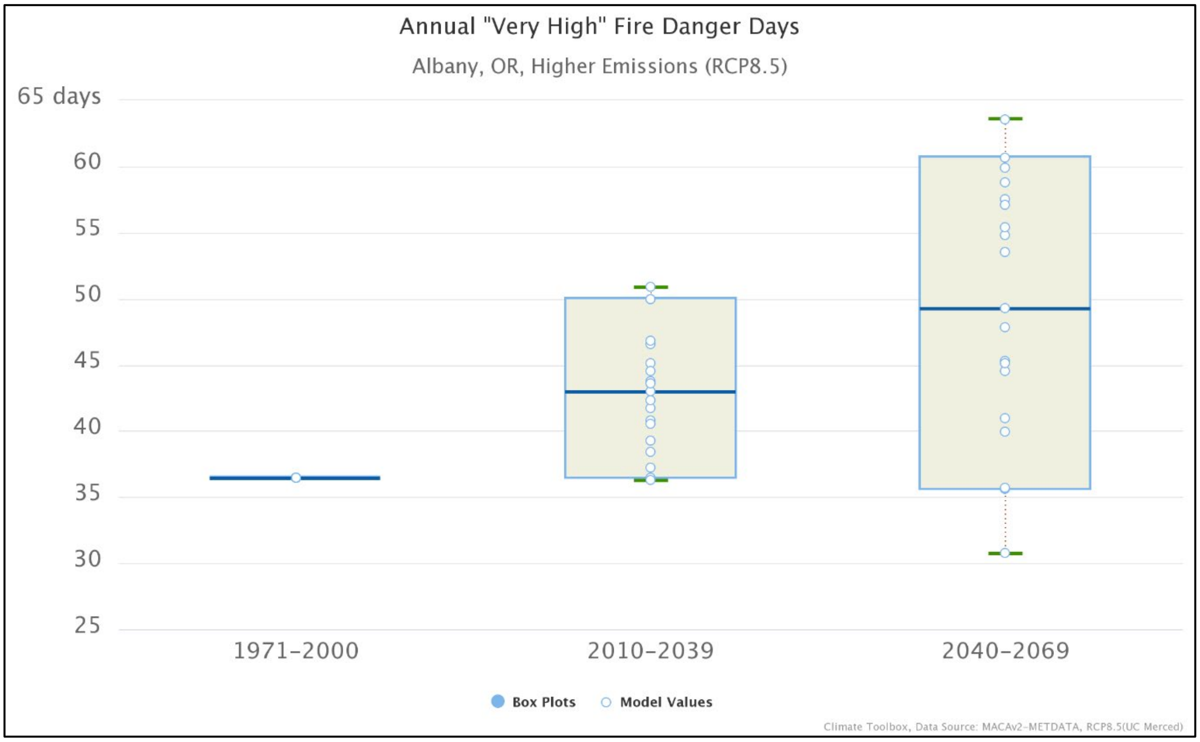


Figure 3-25. Albany, OR Annual Very High Fire Danger Days

3.2.6 North Santiam River sub-basin

Figure 3-26 graphically shows the North Santiam basin. The North Santiam sub-basin is approximately 766 square miles. The North Santiam fork combines with mainstem Santiam River at Jefferson, OR. The basin is defined by steep and mountainous terrain until Gates, OR, where the slopes become gentler, and the river bottom lands expands to the valley floor. Towards the lower end of the basin at Stayton, OR, there is extensive agriculture and residential properties. Overall. The North Santiam average elevation is 2,900 feet while the high elevation is 10,457 feet on Mount Jefferson. The low spot in the basin is at approximately elevation 160 feet (NAVD88).

The North Santiam River headwater project (project refers to dams and their associated reservoirs), is Detroit Dam. It is multipurpose in nature and is operated for power generation (100 MW), flood risk reduction and water conservation. Big Cliff Dam is located about 3 miles downstream of Detroit dam. It acts as re-regulation, “rereg”, project. It serves to attenuate and mitigate power peaking flows from Detroit Dam. Big Cliff also has power generation capacity at 18 MW from one turbine. ESA listed species are present in the basin as well. There is a fish hatchery at Marion Forks on the North Santiam above Detroit. ESA listed species in the North Santiam River sub-basin, include, Winter steelhead and Spring Chinook.

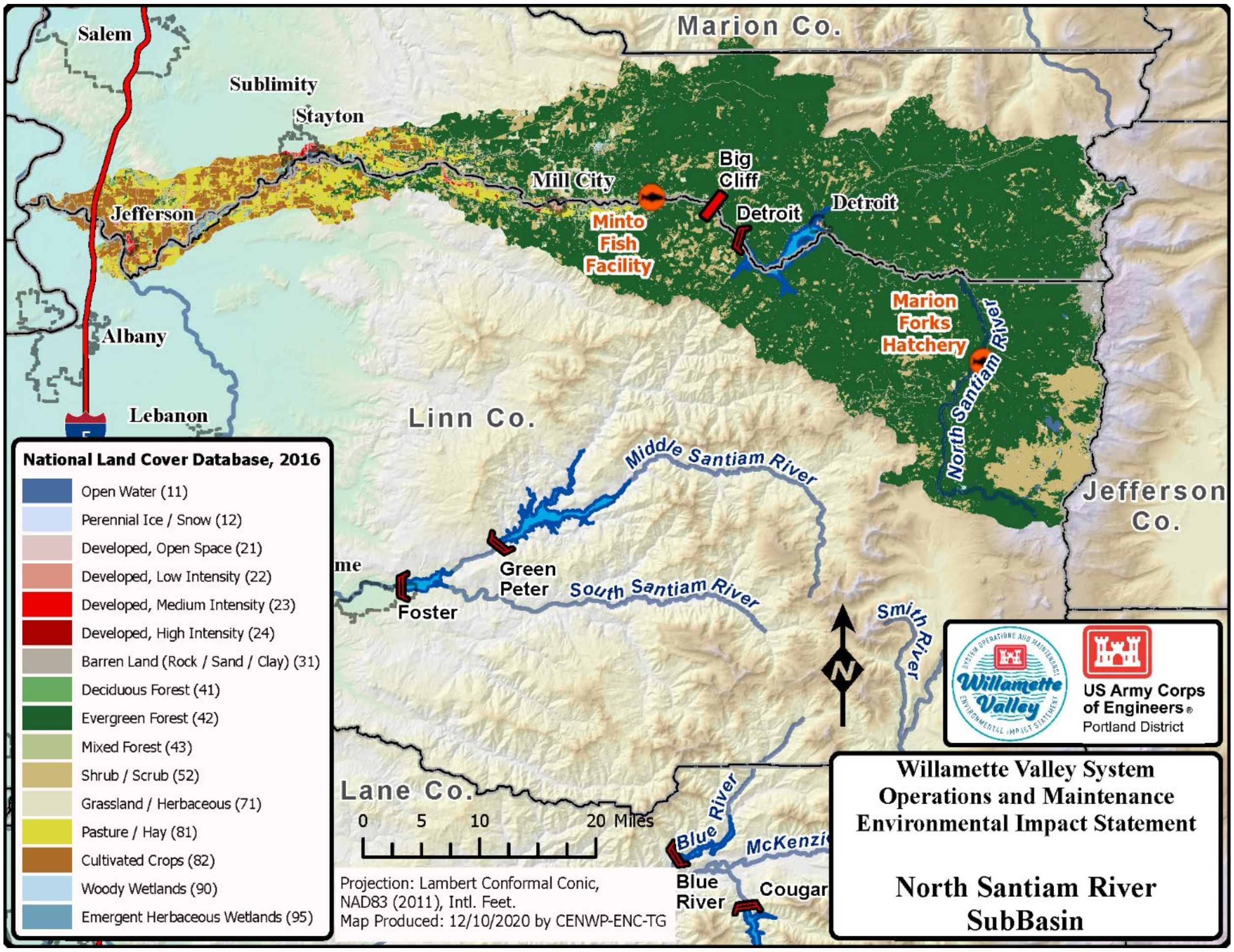


Figure 3-26. North Santiam River Sub-basin

The topography in the majority of the North Santiam is generally mountainous. The primary land cover is upland forest. Snowpack is also often present during the wintertime in the higher elevations. Santiam snowpack melt historically produces a significant proportion of spring freshet volume at Salem, OR.

Future (ambient) temperature projections in the sub-basin, have potential implications for the Detroit's proposed large water temperature downstream control tower as well as fish collection project. The temperatures at Detroit are projected to increase as shown in Figure 3-27 (annual change) and Figure 3-28 below, depicting summertime projections at the site, respectively.

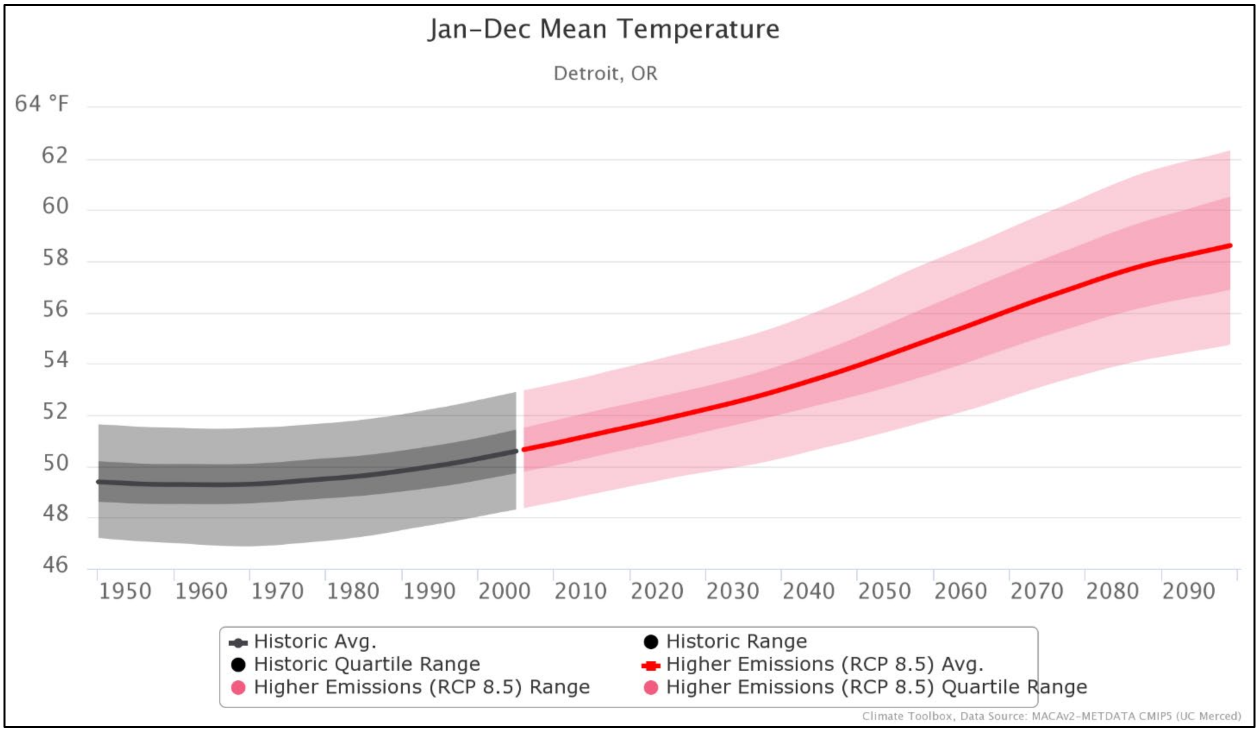


Figure 3-27. Average annual temperature trends at Detroit, OR. (1950-2100)

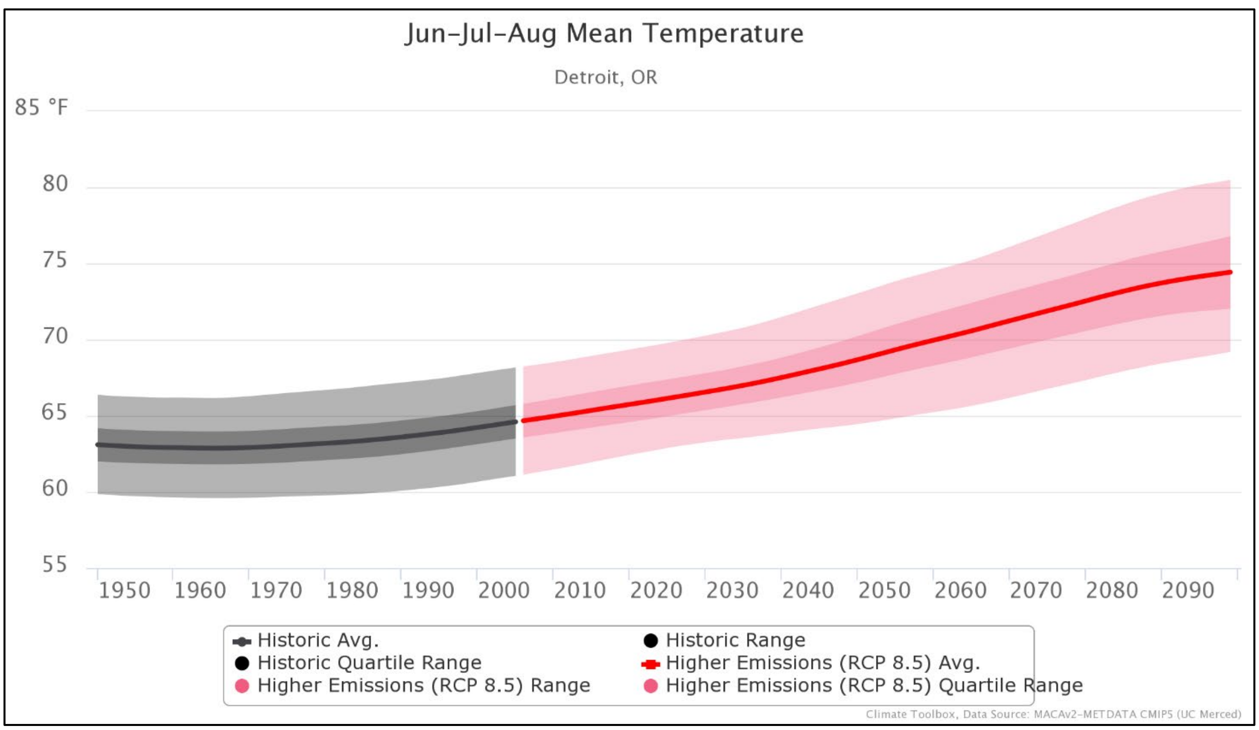


Figure 3-28. Average annual summer temperature trends at Detroit, OR. (1950-2100)

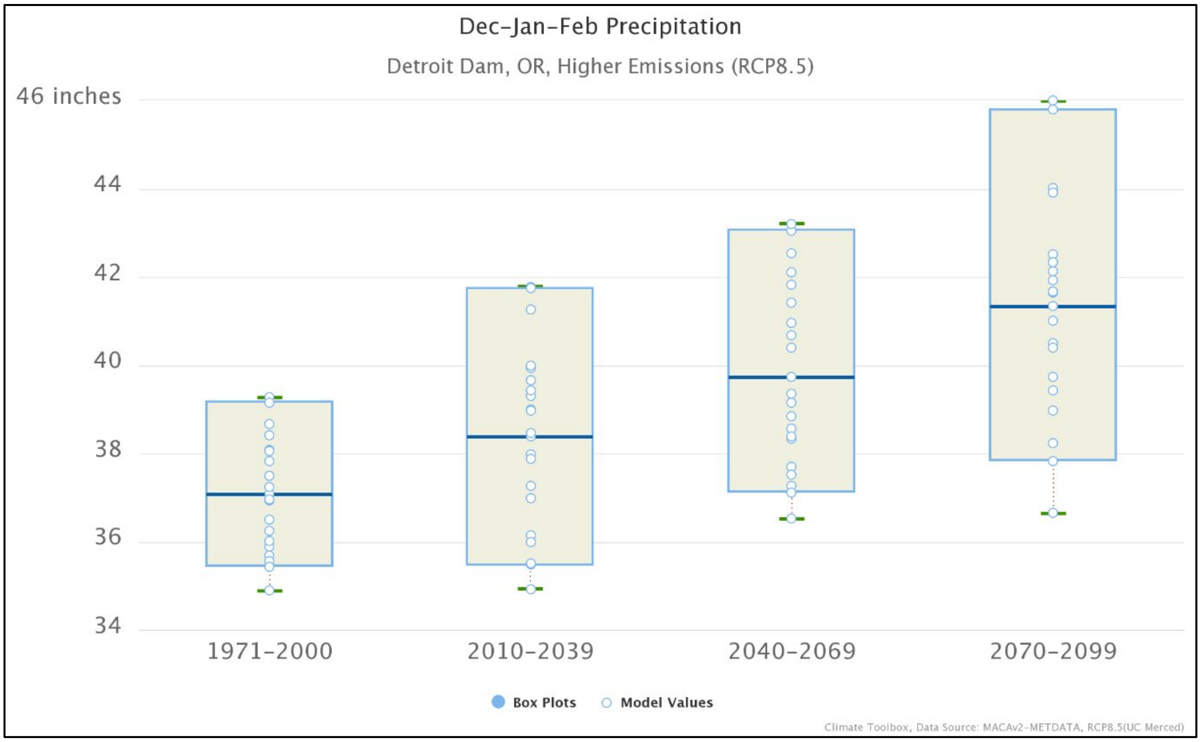


Figure 3-29. Median winter precipitation trend at Detroit, OR. (1950-2100)

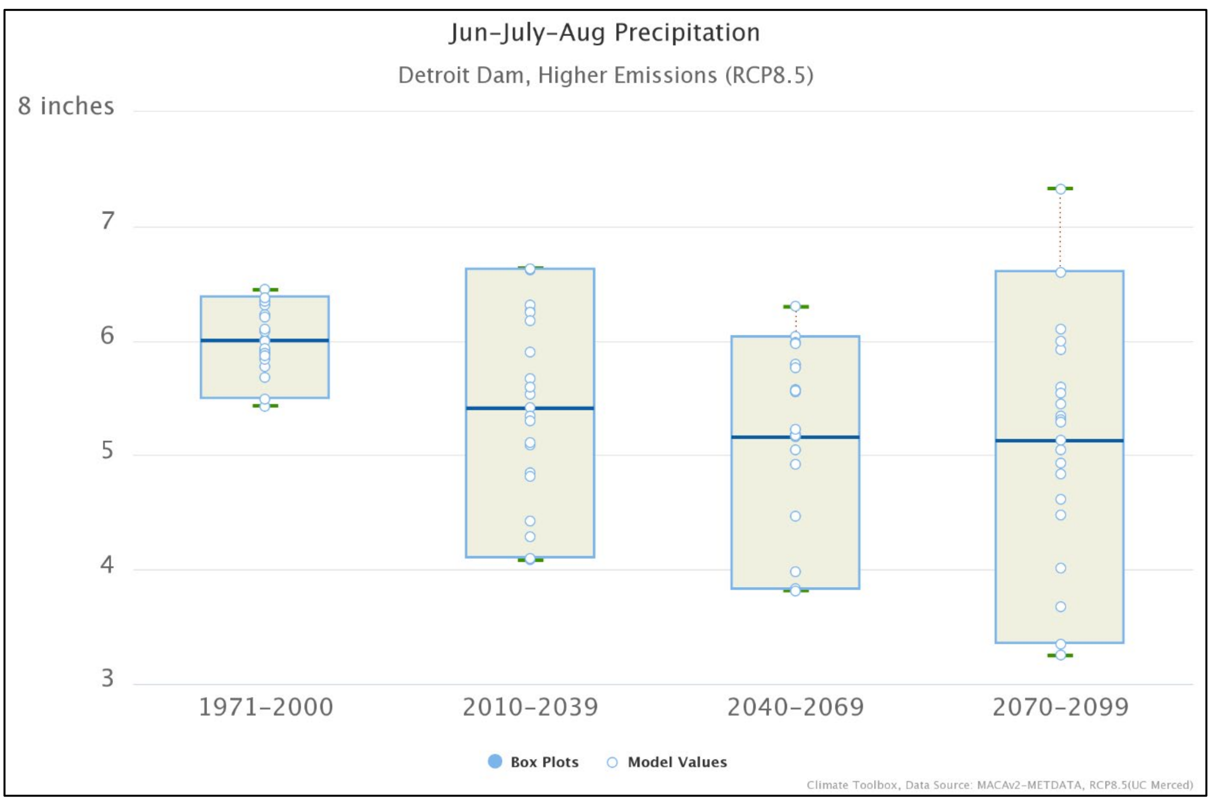


Figure 3-30. Median summer precipitation trend at Detroit, OR. (1950-2100)

Future change of projected air and water temperatures are relevant climate change factors for the EIS. The impacts of warmer temperatures are most consequential for impacts on aquatic species. However, overall ecosystem function and habitat health are also very sensitive to and projected air temperature and water temperature increases. The graphics above summarize projections indicating increasing temperature trends are likely through the end of century. For the North Santiam basin, the relative change is a projected to be somewhat greater than in the Middle and Upper Willamette sub-basins. Figure 3-27 indicates that average annual temperatures at Detroit OR are projected to increase by about 9.5° F compared to the 1971-2000 baseline years, by end of century. End of century temperature means for the critical summer season (JJA) are projected to rise +11.5° as shown in Figure 3-28.

The projected precipitation changes at Detroit Dam shown to trend upwards in the winter and decline in the summer. Streamflow projections mirror the future precipitation trends. SWE, already declining, is likely to become extremely marginal to non-existent by end of century. The Detroit unregulated summary hydrographs, highlighting the 10 (more frequent, low flows), 50 (median) and 90^{th} (less frequent, high flows) exceedance percentiles, is shown below as Figure 3-31. Hydrographs at Big Cliff, a reregulating dam would follow a similar trend to Detroit.

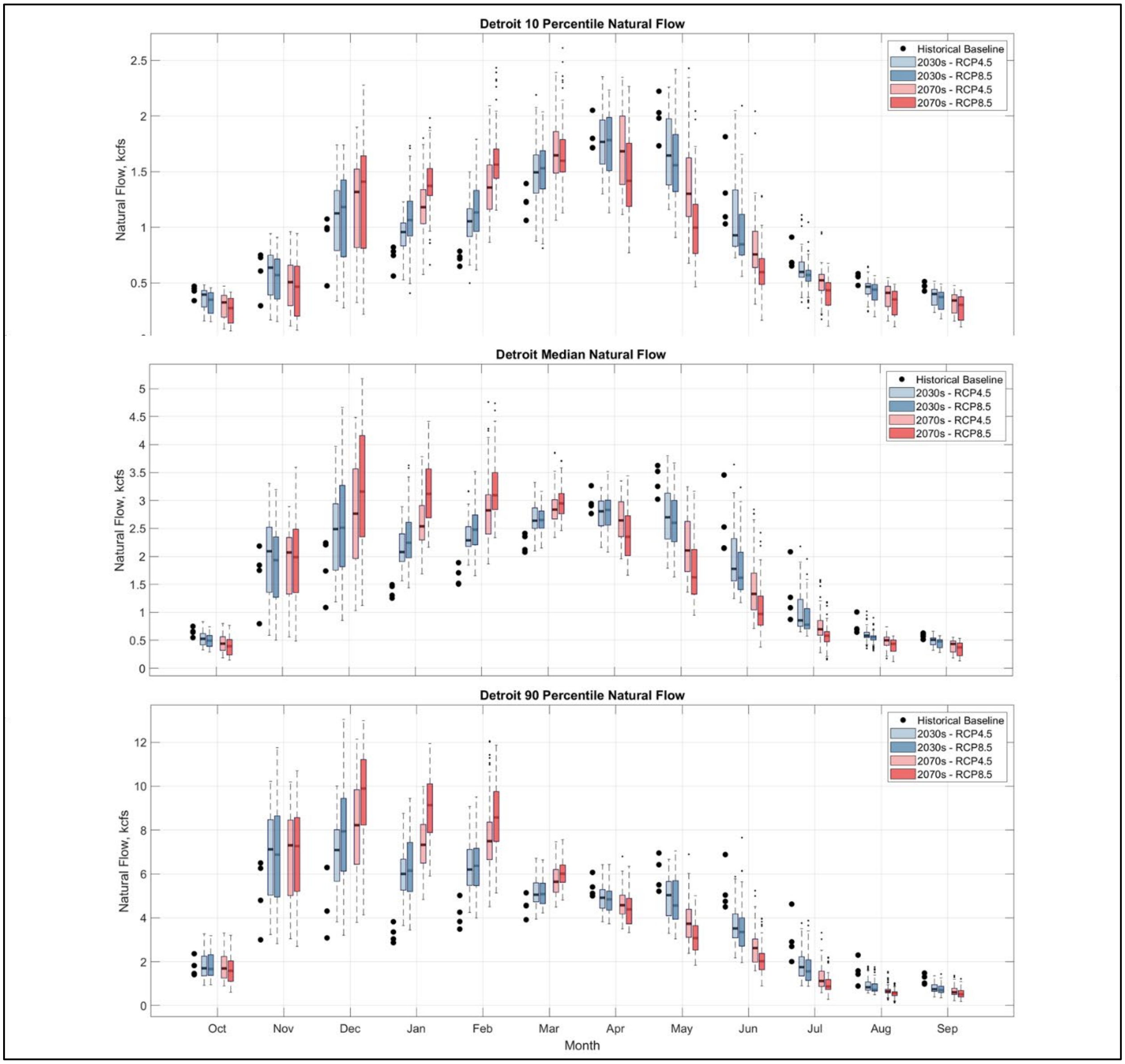


Figure 3-31. North Santiam River at Detroit, OR summary hydrographs

Table 3-3 below reflects Figure 3-31 above.

Table 3-3. DET flow change

DET Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	**2030s**	**2070s**	**2030s**	**2070s**	**2030s**	**2070s**
Oct	-0.15	-0.2	-0.1	-0.12	-0.05	-0.1
Nov	0	-0.02	0.3	0.4	1.9	2.2
Dec	0.4	0.65	0.7	1.4	3	4.9
Jan	0.35	0.65	0.85	1.75	2.6	5.7
Feb	0.45	0.8	0.75	1.35	2.2	4.5
Mar	0.3	0.35	0.35	0.65	0.7	1.7
Apr	0	-0.35	-0.1	-0.5	-0.7	-2.4
May	-0.2	-0.8	-0.85	-1.8	-1.7	-3
Jun	-0.45	-0.65	-0.95	-1.5	-2.4	-3.8
Jul	-0.15	-0.3	-0.5	-0.69	-0.95	-1.9
Aug	-0.02	-0.03	-0.25	-0.31	-0.9	-1.4
Sep	-0.02	-0.19	-0.05	-0.15	-0.1	-0.6

The increase in wintertime flows is indicated by the November thru March, relative increases in median flows. Contrasting with the pattern seen in the valley floor, Detroit, OR summary hydrographs portray the different streamflow patterns of a snowpack affected basin. The historical pattern is for an annual peak in the wintertime (DJF) followed by a lesser annual rise, from the snow melt pulse peaking in May.

The future pattern will reflect higher wintertime volume and a diminished (or eliminated) spring runoff. This change in timing and quantity will complicate traditional hydro-regulation practices in the Valley. Operational approaches should consider potential effects from these projected changes to effectively navigate likely changes in the future.

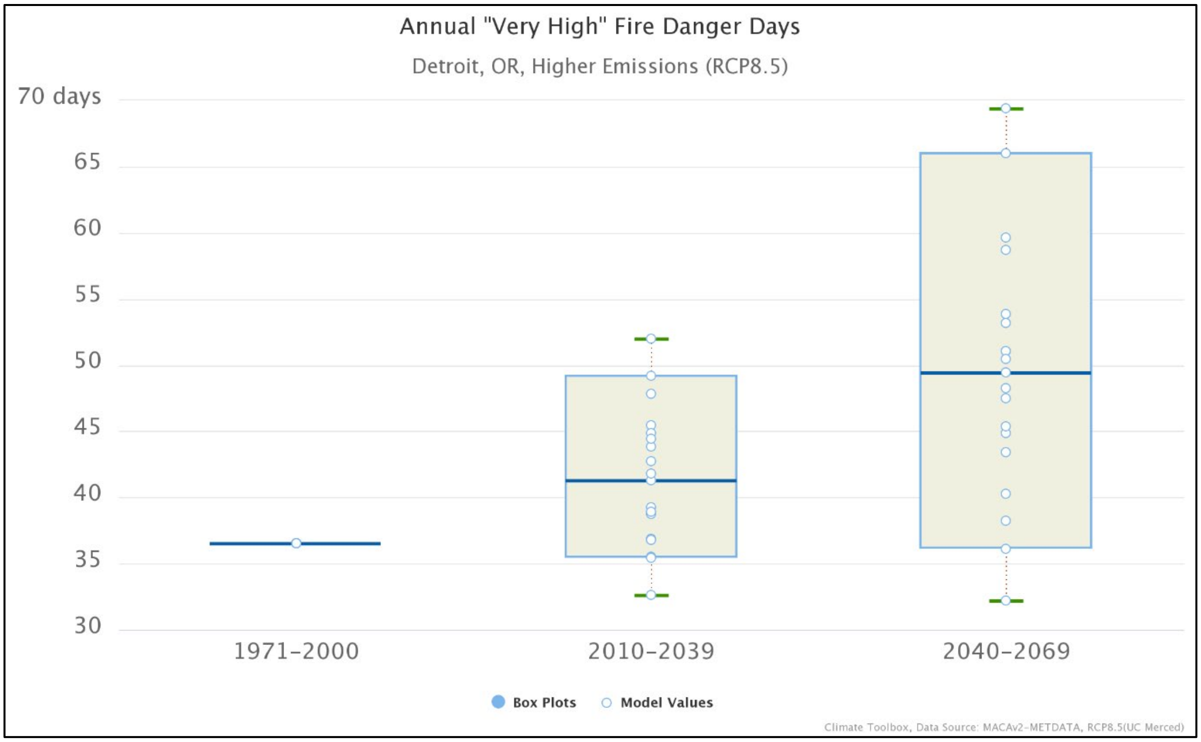


Figure 3-32. Detroit, OR Annual Very High Fire Danger Days

As seen in Figure 3-32, the Detroit area is likely to experience higher fire danger in the future. Median change is upward for both future epochs. The variability of the fire danger days (between GCM models) is greater in the upland basins, in contrast to the valley floor sites, such as Salem and Albany. Detroit, OR suffered heavily from the 2020 fires.

3.2.7 South Santiam River sub-basin

The South Santiam drainage area is approximately 1,040 square miles and is about a third larger than the North Santiam basin (740 square miles). The majority (about 2/3) of the basin is steep and mountainous. The South Santiam average elevation is comparable to the North Santiam sub-basin, being approximately 2,000 feet (NAVD88). The South Santiam sub-basin's high point is about 5,800 feet (NAVD88) while the low elevation is approximately 215 feet (NAVD88). Green Peter dam and reservoir straddle the Middle Santiam River. Foster dam located about 7 miles downstream and moderates Green Peter, power peaks. The so-called Cascadia dam was planned for construction as part of the Willamette Valley Project, but never started. It would have been built on the upper South Santiam River.

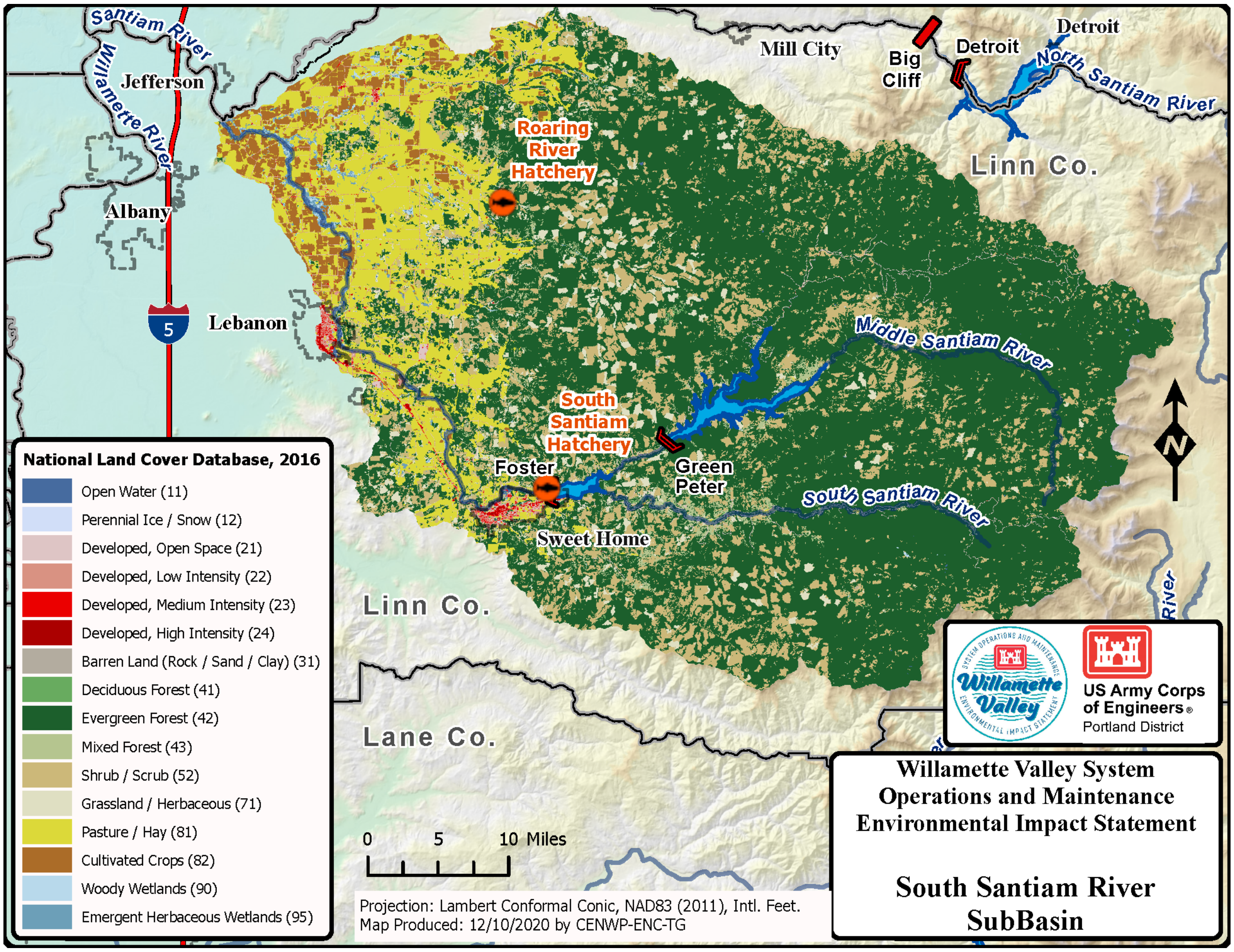


Figure 3-33. South Santiam River Sub-basin

Similar to North Fork Santiam, temperatures in the South Santiam are projected to increase as shown in Figure 3-34 (annual change) and Figure 3-35 below, and summertime (JJA) averaged projections at the site, respectively.

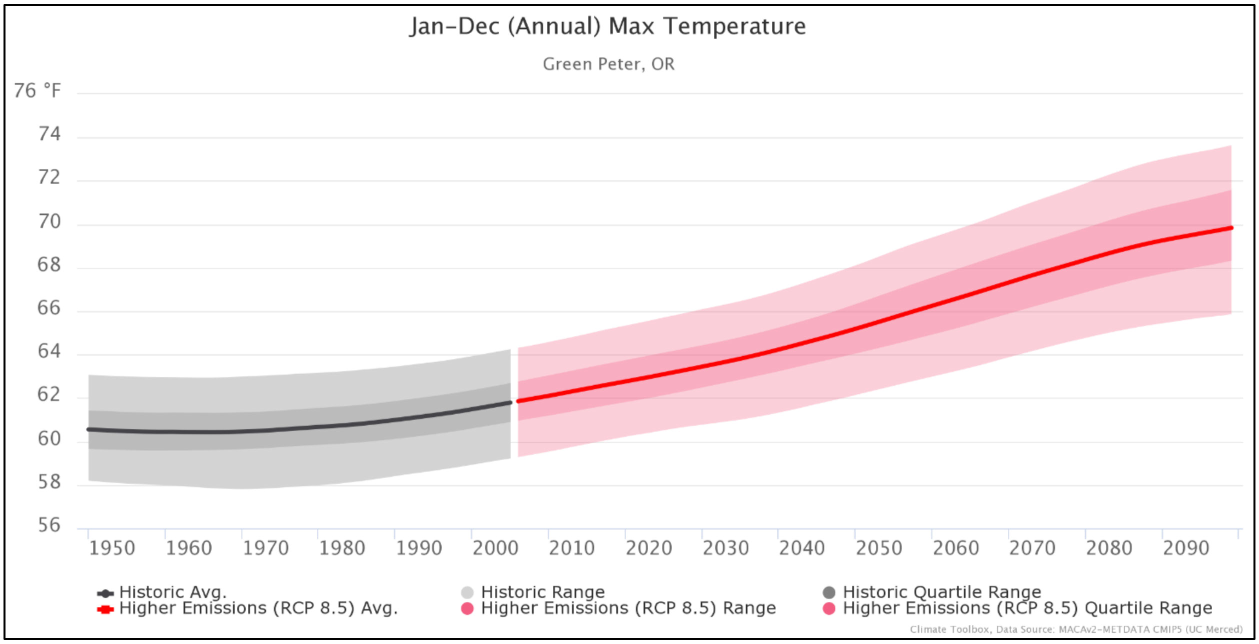


Figure 3-34. Average annual temperature trends at GreenPeter, OR. (1950-2100)

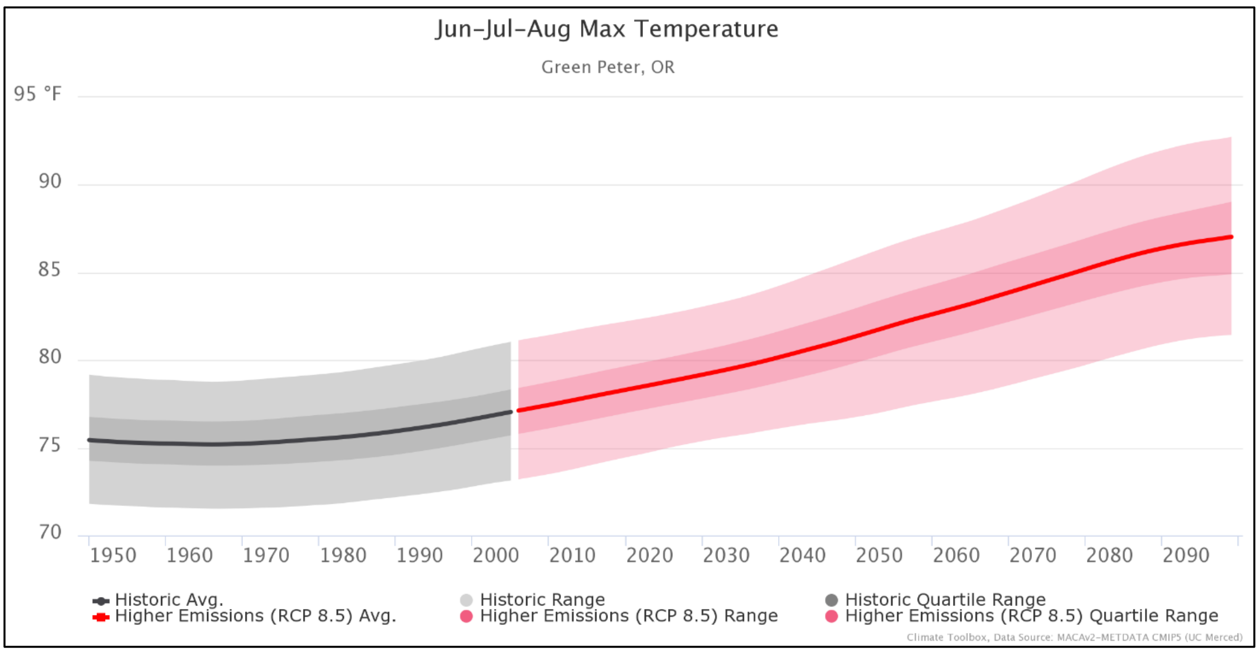


Figure 3-35. Average annual summer temperature trends at Green Peter, OR. (1950-2100)

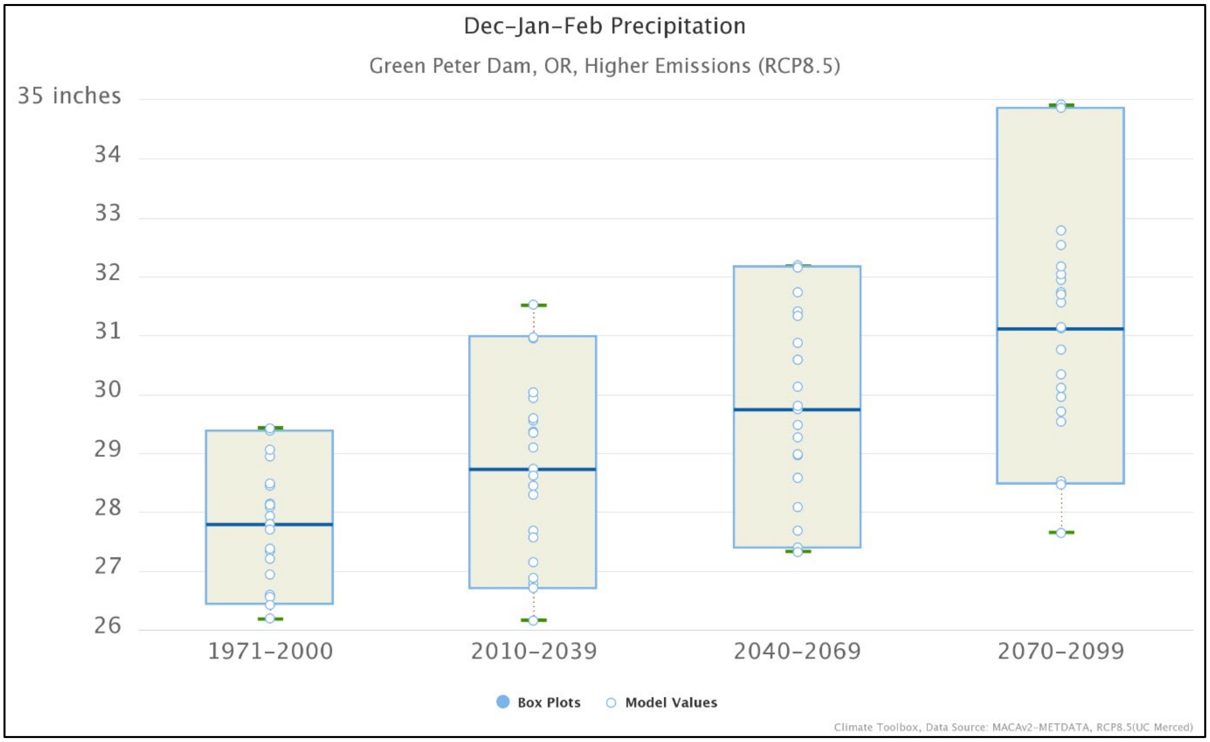


Figure 3-36. Median winter precipitation trend at Green Peter, OR. (1950-2100)

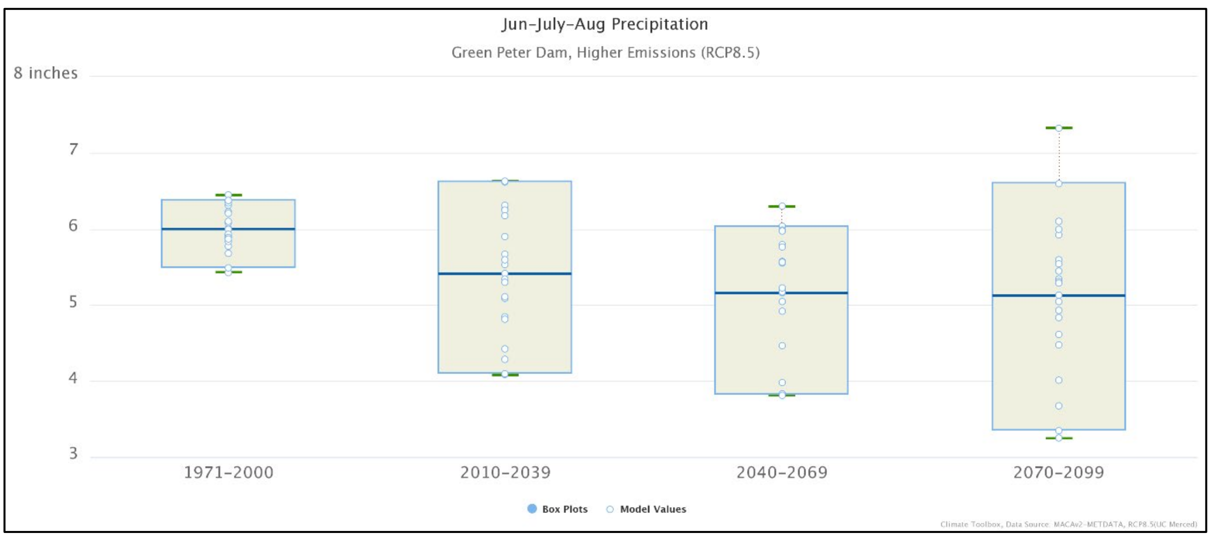


Figure 3-37. Median summer precipitation trend at Green Peter, OR. (1950-2100)

The South Santiam sub-basin (headwater site) pattern is very similar to the adjoining North Santiam sub-basin. Green Peter unregulated, naturalized hydrographs shows the effect of warming temperatures; transitioning a snow impacted basin to an entirely rainfall dominated basin, by the middle and end of century. The dominant signal is streamflow volume shifting from a winter and spring distribution to one almost entirely occurring in wintertime. This has significant implications for hydro-regulation operations in the future. For example, an operational shift to an earlier refill date may work in the short term, but it may be rendered ineffectual considering climate change, projected further. WVS operational response to climate change will need to be adaptative, and future regulation would benefit from enhanced forecast and operational flexibility.

The projected precipitation changes in the South Santiam point to higher expected rainfall in the winter with declines in the summer. Streamflow projections track the future precipitation trends. SWE, already declining, is likely to become non-existent by end of century. The Green Peter, unregulated summary hydrographs, highlighting the 10 (more frequent, low flows), 50 (median) and 90th (less frequent, high flows) exceedance percentiles, Figure 3-38 is shown below for Green Peter. Foster dam downstream, follows a similar trend to Green Peter.

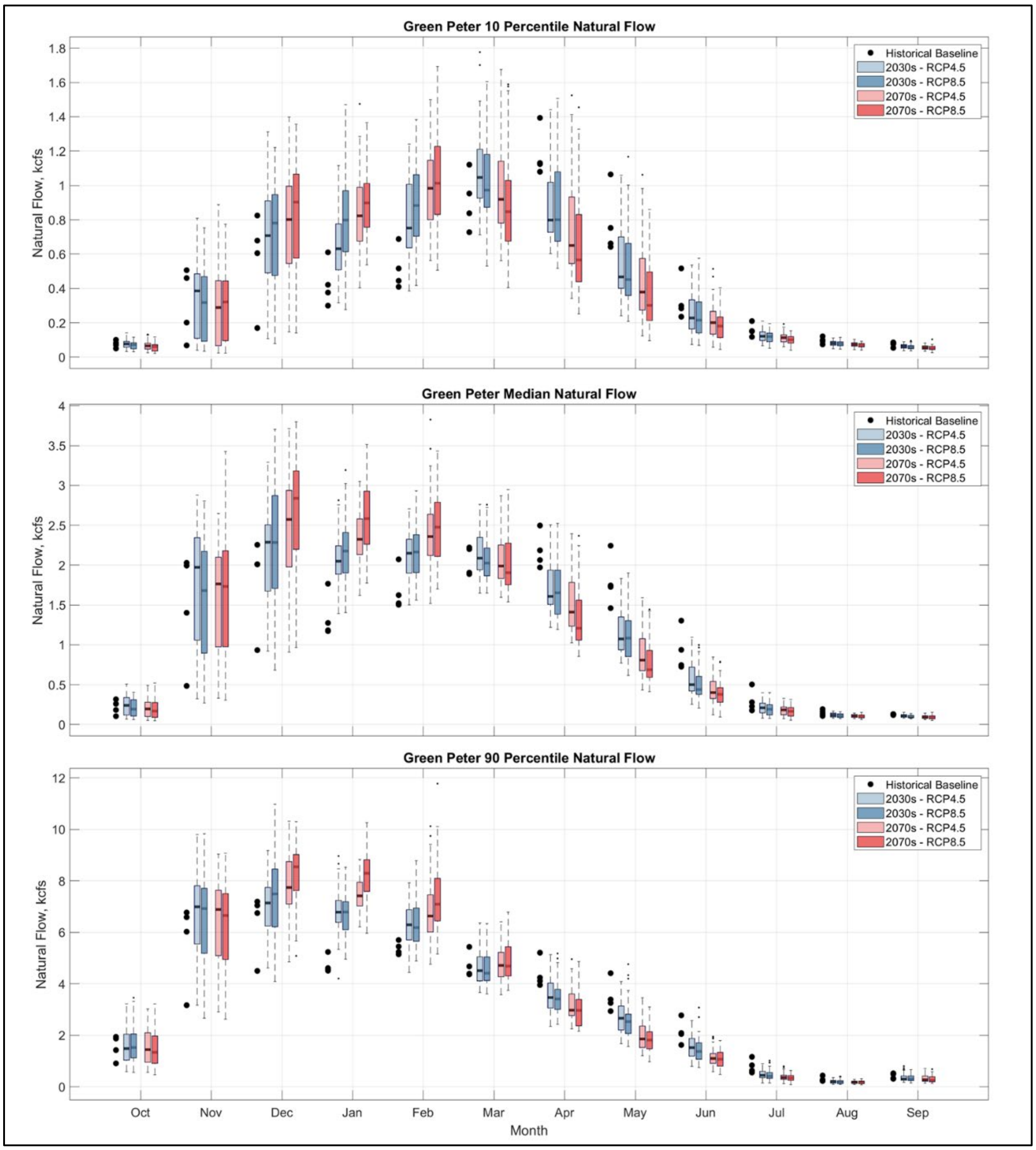


Figure 3-38. South Santiam River at Green Peter, OR summary hydrographs

Table 3-4. GPR flow change

GPR Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	-0.005	-0.01	-0.05	-0.05	0	-0.1
Nov	0.01	0.01	0.3	0.45	1	1
Dec	0.19	0.3	0.8	1.3	1.5	3.3
Jan	0.39	0.49	0.55	1.05	1.8	3.1
Feb	0.29	0.41	0.35	0.74	0.5	1.4
Mar	0.05	-0.09	-0.1	-0.25	-0.8	-0.5
Apr	-0.4	-0.61	-0.65	-1.05	-0.7	-1.2
May	-0.33	-0.45	-0.65	-1.15	-1.3	-1.6
Jun	-0.1	-0.11	-0.5	-0.55	-0.5	-1
Jul	-0.03	-0.04	-0.05	-0.1	-0.6	-0.62
Aug	-0.05	-0.05	-0.1	-0.1	-0.05	-0.05
Sep	-0.02	-0.02	-0.05	-0.07	-0.02	-0.02

The increase in wintertime flows is indicated by the November thru March, relative increases in median flows. Contrasting with the pattern seen in the valley floor, Detroit, OR summary hydrographs portray the different streamflow patterns of a snowpack affected basin. The historical pattern is for an annual peak in the wintertime (DJF) followed by a lesser annual rise, from the snow melt pulse peaking in May.

The future pattern will reflect higher wintertime volume and a diminished (or eliminated) spring runoff. This change in timing and quantity will complicate traditional hydro-regulation practices in the Valley. As one looks to enact new operational approaches, responsible parties should consider potential effects from these projected changes, to effectively navigate like changes in the future.

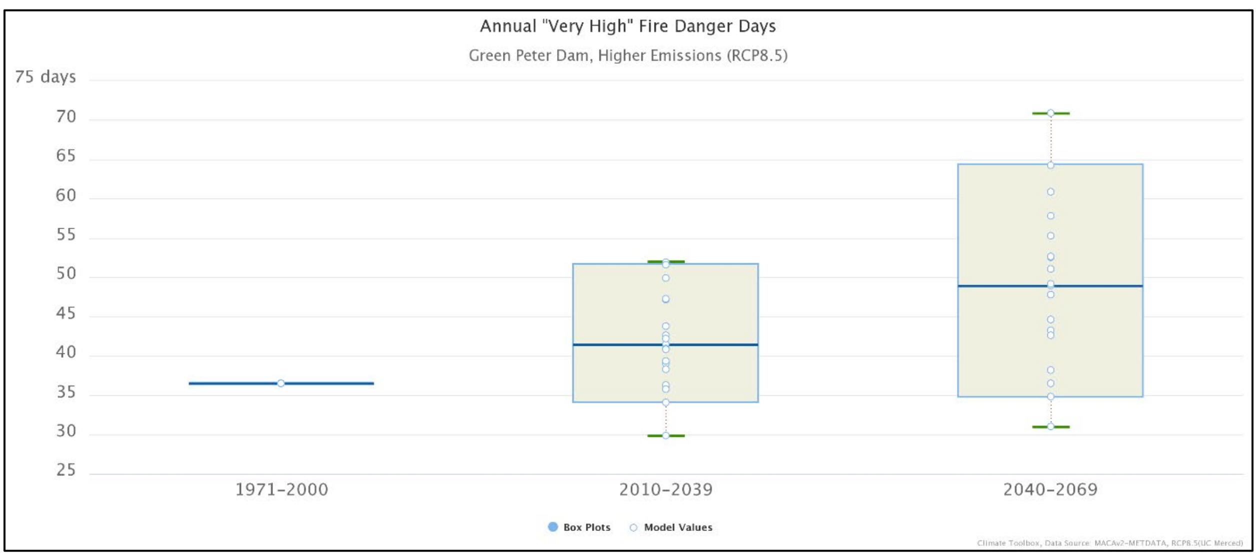


Figure 3-39. Green Peter, OR Annual Very High Fire Danger Days

As seen in Figure 3-39, Green Peter dam and surrounding areas are likely to experience higher fire danger in the future. Median change is upward for both future epochs. The variability of the fire danger days (between GCM models) is greater in the upland basins, in contrast to the valley floor sites, such as Salem and Albany.

3.2.8 McKenzie River sub-basin

The McKenzie sub-basin is approximately 1,345 square miles. Over three quarters of the basin is steep, mountainous, and forested. The sub-basin's average elevation is approximately 3,140 feet (NAVD88). The sub-basin's high point adjacent to McKenzie Pass, is about 10,309 feet (NAVD88). The minimum elevation is 316 feet (NAVD88), close to the basin terminus, at Springfield, OR.

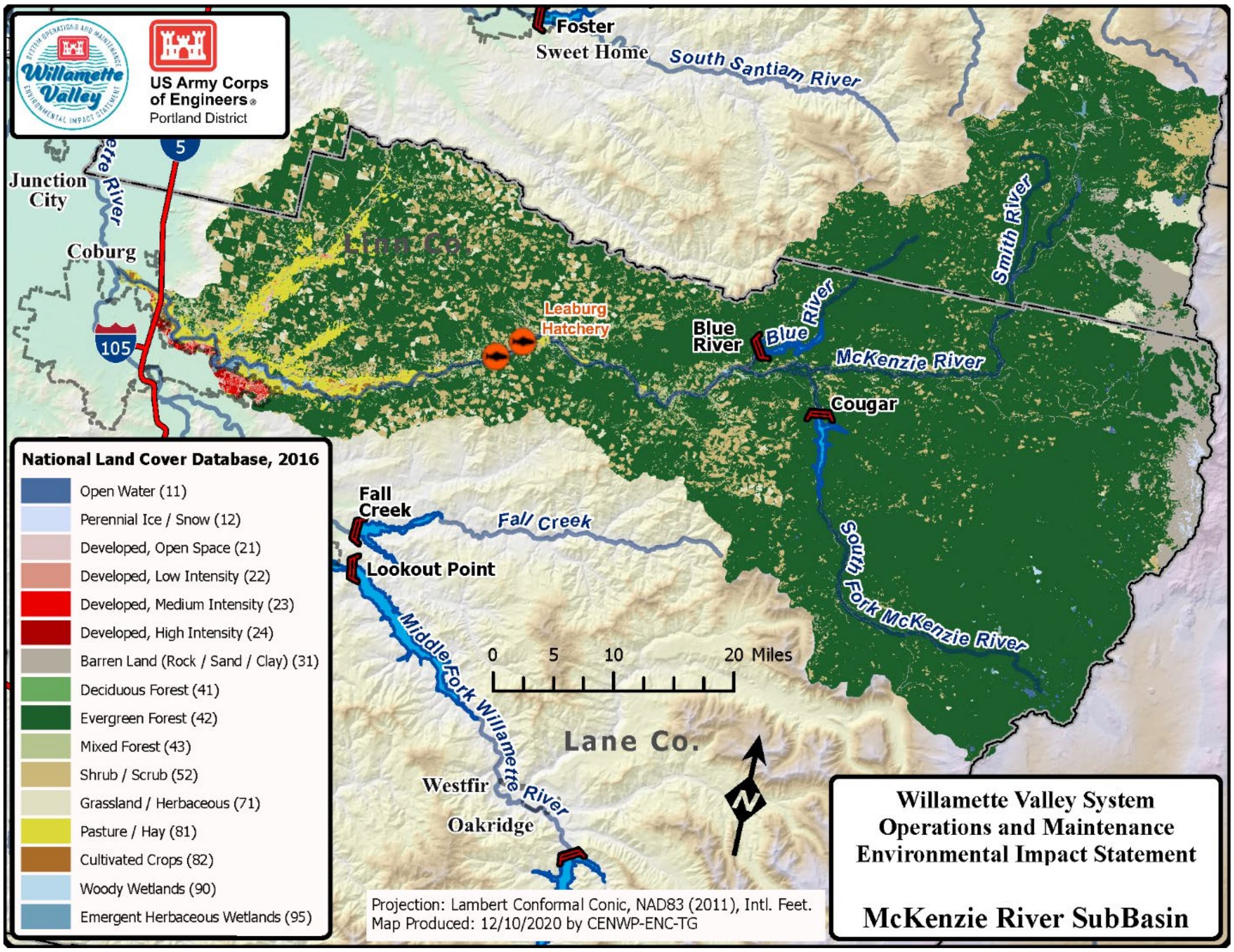


Figure 3-40. McKenzie River Sub-basin

The two USACE projects in the McKenzie Basin are Cougar Dam on the South Fork McKenzie River and Blue River Dam on the Blue River, tributary to McKenzie River. Cougar is a multi-use project; primarily power (i.e., 25 MW), recreation and flood risk reduction. ESA-listed spring Chinook, Oregon chub, and bull trout are present in the subbasin. A water temperature control structure at Cougar began operation in May 2005 and provides cooler downstream flows to improve spring Chinook salmon production.

Figure 3-41 and Figure 3-42 depict the average annual and summertime (JJA) air temperature changes at Cougar. As the basin experiences increased warming, there will likely be impacts to future temperature operations at Cougar. Blue River is operated with Cougar to facilitate flood risk management locally to Springfield/Eugene, and downstream system control points. Water temperature control measures at Blue River have been determined to be not feasible. There are two hatcheries in the basin. The hatcheries are located at Leaburg, OR and another is located downstream on the McKenzie mainstem.

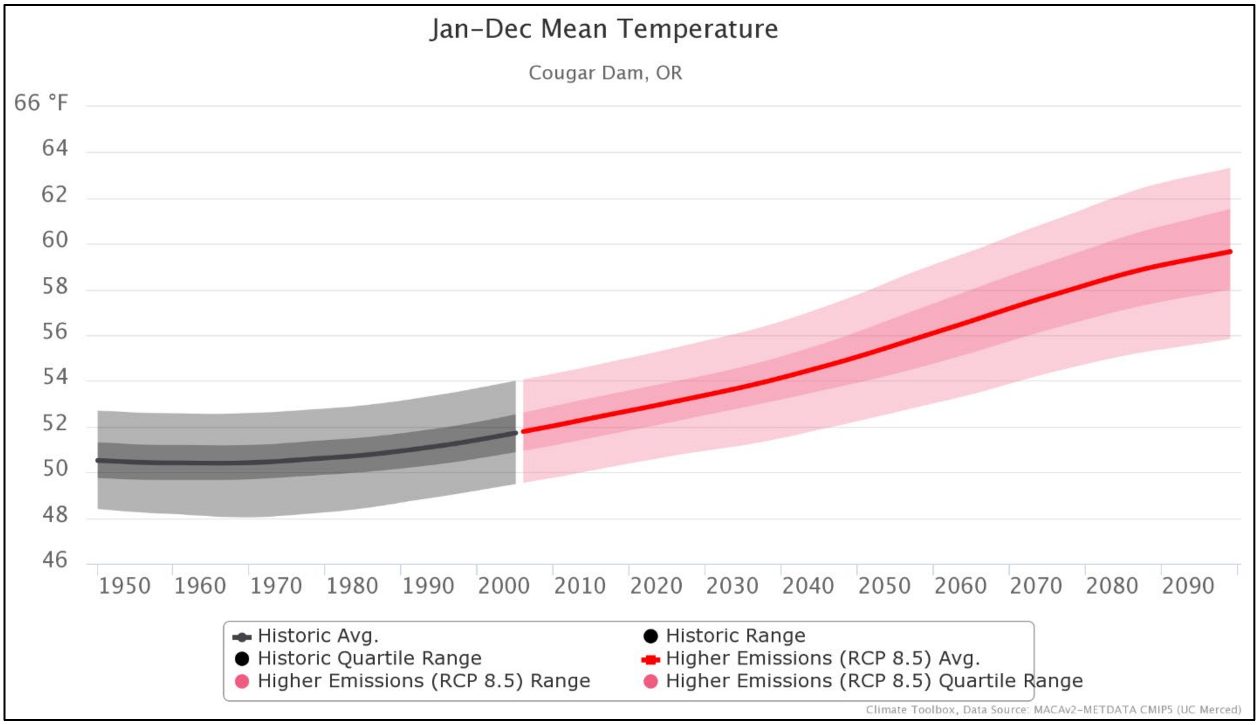


Figure 3-41. Average annual temperature trends at Cougar, OR. (1950-2100)

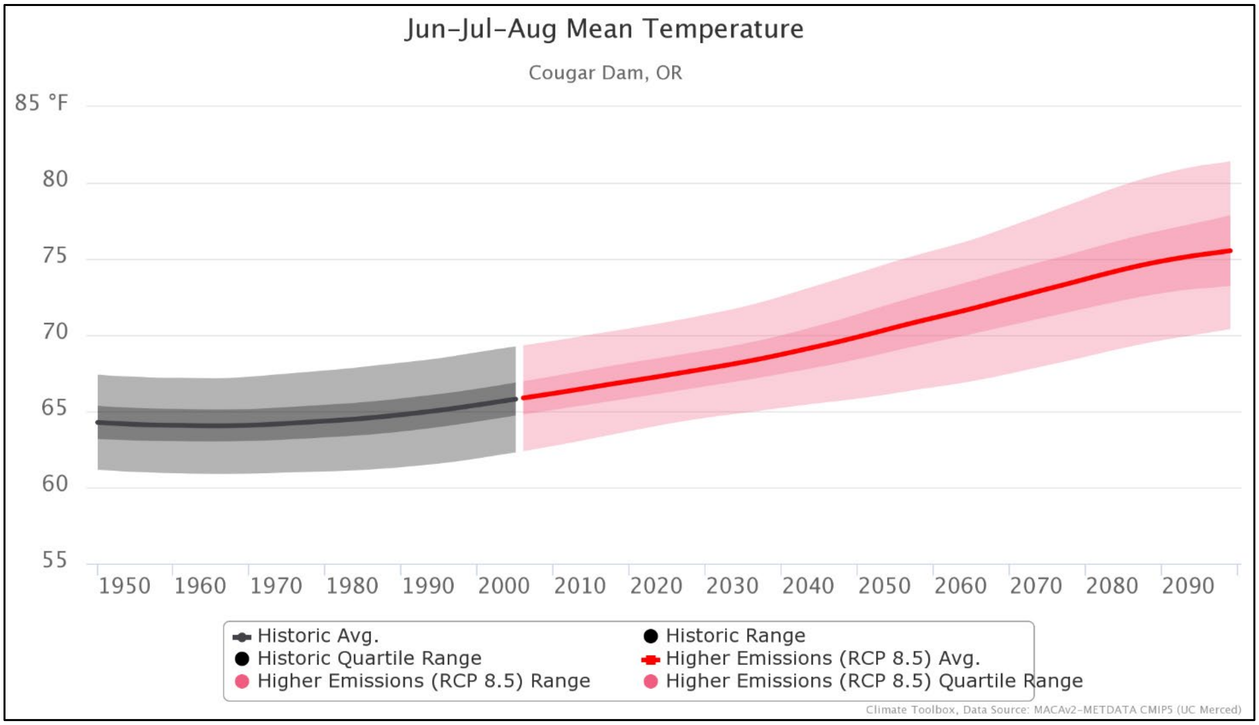


Figure 3-42. Average annual summer temperature trends at Cougar, OR. (1950-2100)

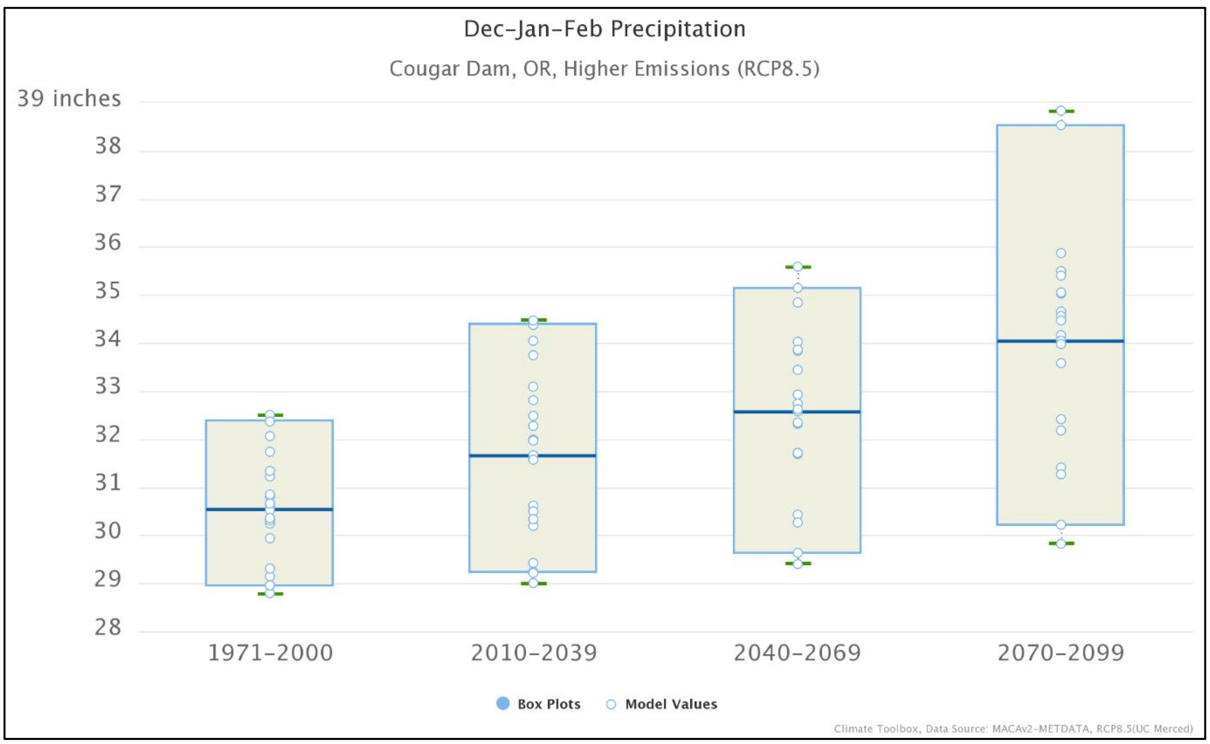


Figure 3-43. Median winter precipitation trend at Cougar Dam, OR. (1950-2100)

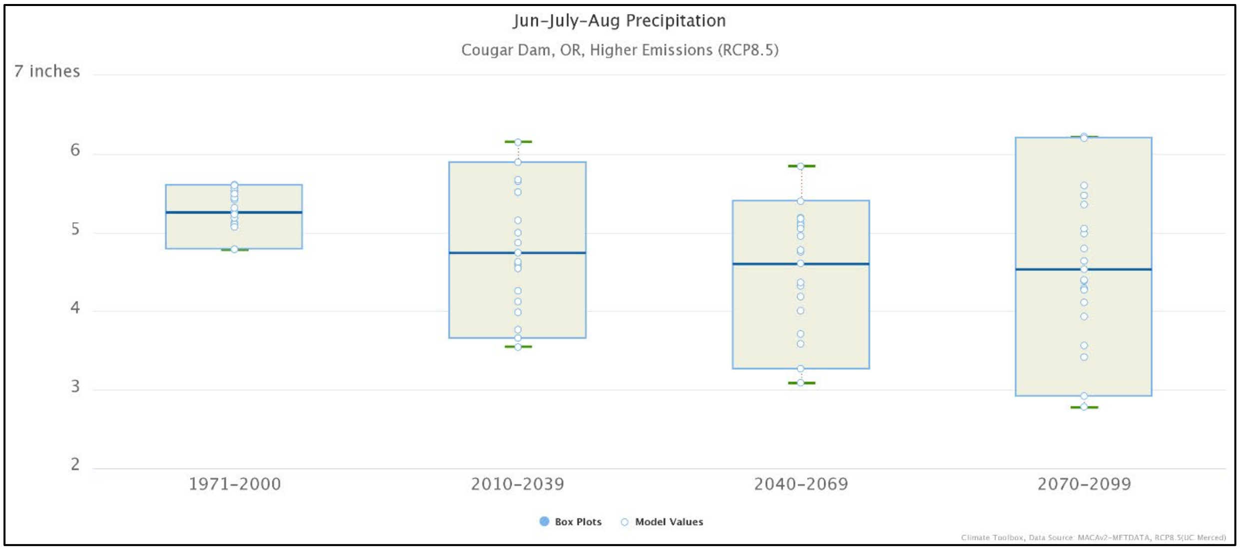


Figure 3-44. Median summer precipitation trend at Cougar Dam, OR. (1950-2100)

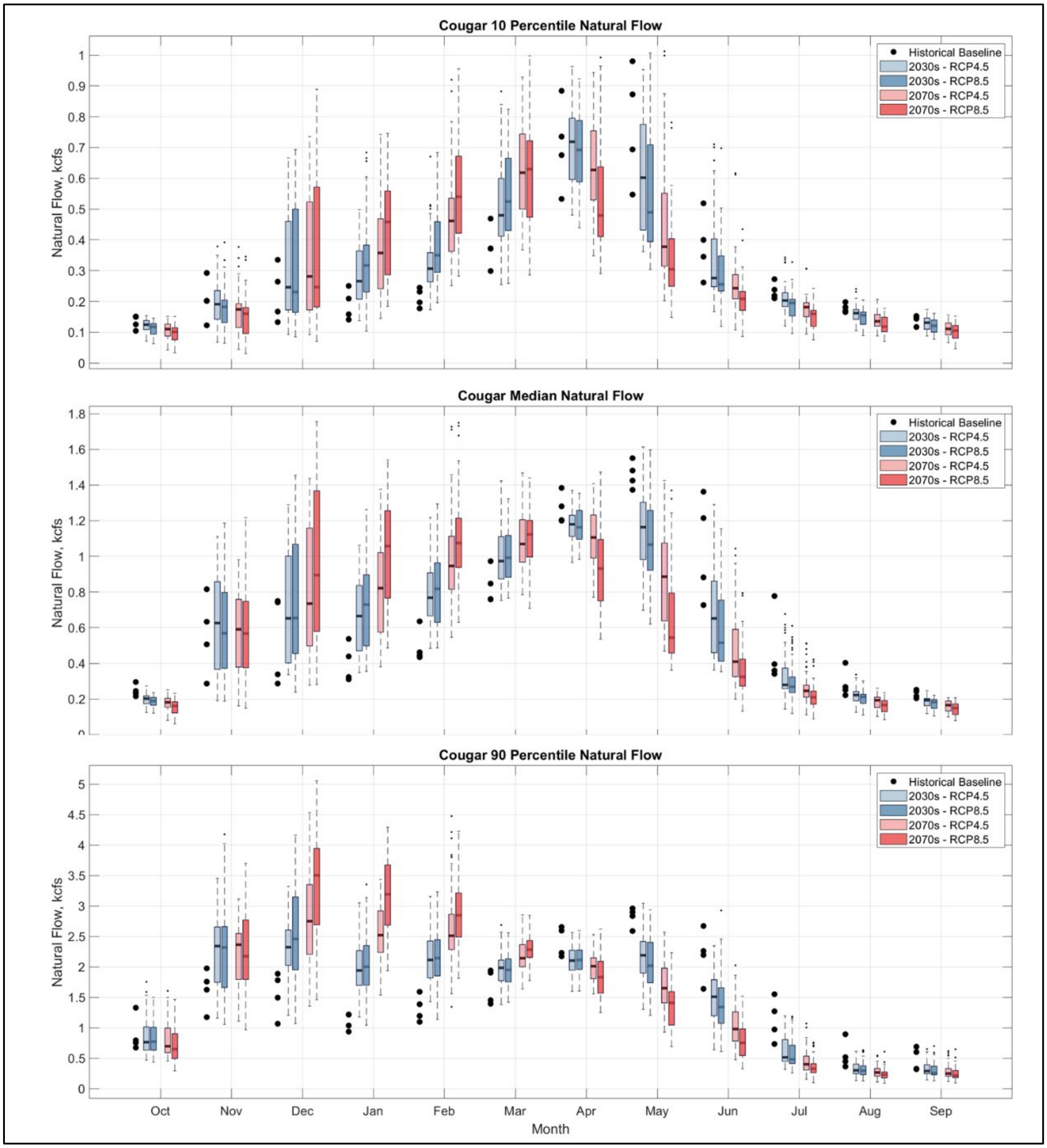


Figure 3-45. McKenzie River at Cougar, OR summary hydrographs

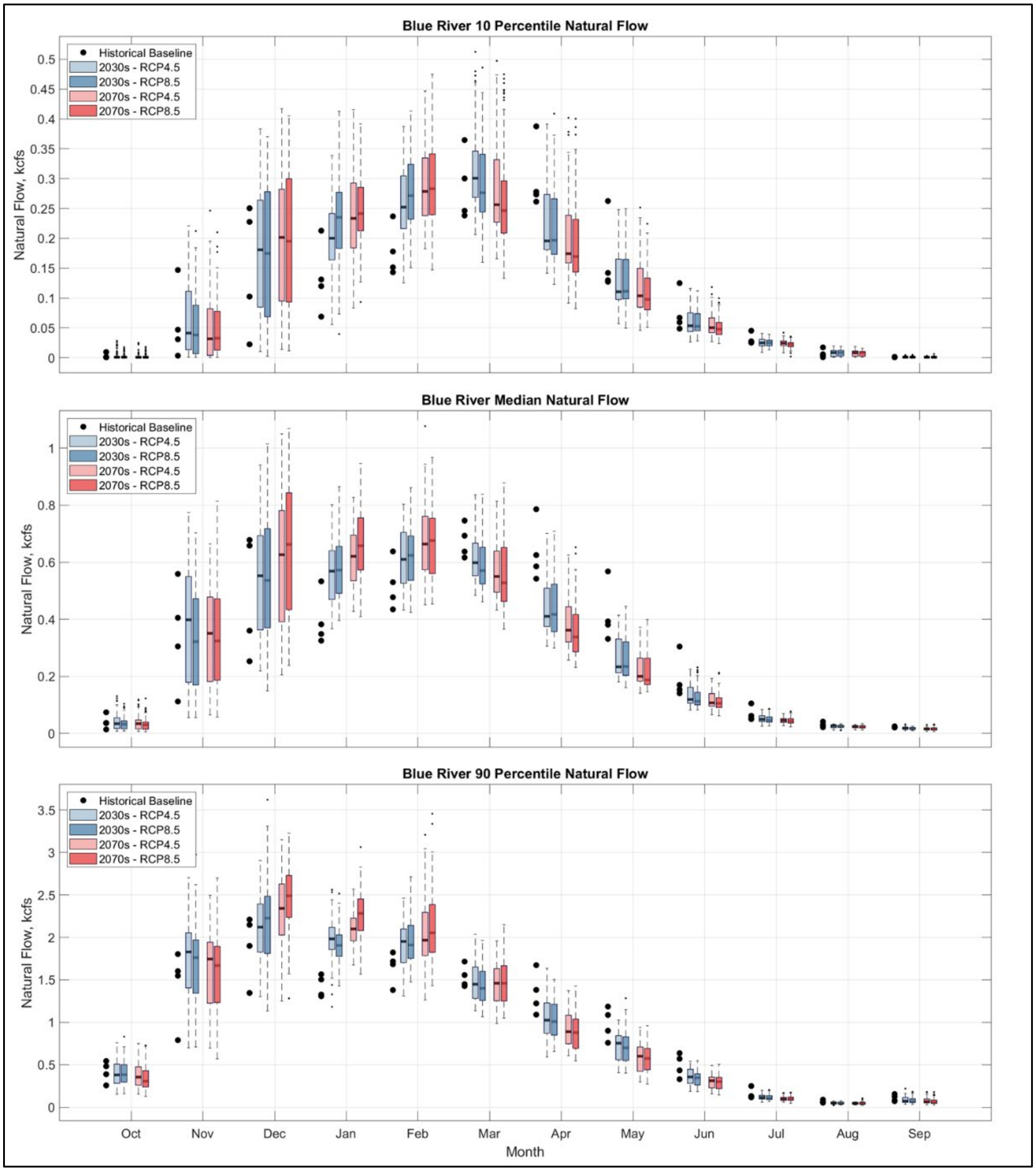


Figure 3-46. Blue River, OR summary hydrographs

Overall, the McKenzie River (at Cougar Dam) and Blue River Dam sub-basins (headwater site) future hydroclimate and hydrology trends are similar to that seen in the Santiam sub-basins – headwater projects. Both Cougar and Blue River hydrographs shows the effect from warming temperatures, transitioning from a snow impacted basin to a rainfall dominated basin. The dominant signal is streamflow volume shifting from a winter and spring distribution to almost one almost entirely occurring in wintertime.

Table 3-5 below reflects Figure 3-45 above.

Table 3-5. CGR flow change

CGR Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	**2030s**	**2070s**	**2030s**	**2070s**	**2030s**	**2070s**
Oct	0.01	0.05	0.02	0.04	-0.25	-0.4
Nov	0.01	0.02	0	0	0.85	0.5
Dec	0.01	0.02	0.06	0.34	0.89	1.9
Jan	0.08	0.28	0.38	0.68	0.9	2.25
Feb	0.14	0.33	0.35	0.62	0.8	1.5
Mar	0.14	0.24	0.39	0.37	0.25	0.55
Apr	0.01	0.21	0.08	-0.3	-0.3	-0.6
May	0.29	0.48	0.34	0.84	-0.8	-1.35
Jun	0.14	0.19	0.51	0.71	-0.7	-1.45
Jul	0.05	0.07	-0.2	0.27	-0.6	-0.75
Aug	0.02	0.06	0.06	0.09	-0.25	-0.35
Sep	0.02	0.03	0.02	0.03	-0.25	-0.3

Table 3-6 below reflects Figure 3-46 above.

Table 3-6. BLU flow change

BLU Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	**2030s**	**2070s**	**2030s**	**2070s**	**2030s**	**2070s**
Oct	0.004	0.004	-0.04	-0.04	-0.08	-0.18
Nov	-0.02	0.025	-0.06	-0.06	0.33	0.23
Dec	0.03	0.05	0.07	0.14	0.74	0.99
Jan	0.09	0.1	0.18	0.23	0.42	0.77
Feb	0.07	0.1	0.1	0.17	0.27	0.47
Mar	-0.01	-0.04	-0.09	-0.11	-0.16	-0.07
Apr	-0.1	-0.13	-0.21	-0.25	-0.35	-0.55
May	-0.07	-0.07	-0.21	-0.23	-0.3	-0.49
Jun	-0.03	0.035	-0.06	-0.11	-0.08	-0.03
Jul	-0.02	-0.02	-0.3	-0.3	-0.15	-0.15
Aug	0.006	0.006	-0.05	-0.05	-0.05	-0.05
Sep	0.002	0.002	-0.03	-0.03	-0.1	-0.1

The increase in wintertime high flows (P90) is indicated by the November thru March, relative increases in P90 median flows. Contrasting with the pattern seen in the valley floor, Cougar, OR and Blue River summary hydrographs portray the different streamflow patterns of a snowpack affected basin. The historical pattern is for an annual peak in the wintertime (DJF) followed by a lesser annual rise, from the snow melt pulse peaking in May.

The future pattern will reflect higher wintertime volume and a diminished (or eliminated) spring runoff. This change in timing and quantity will complicate traditional hydro-regulation practices in the Valley. Operational approaches should consider potential effects from these projected changes to effectively navigate likely changes in the future

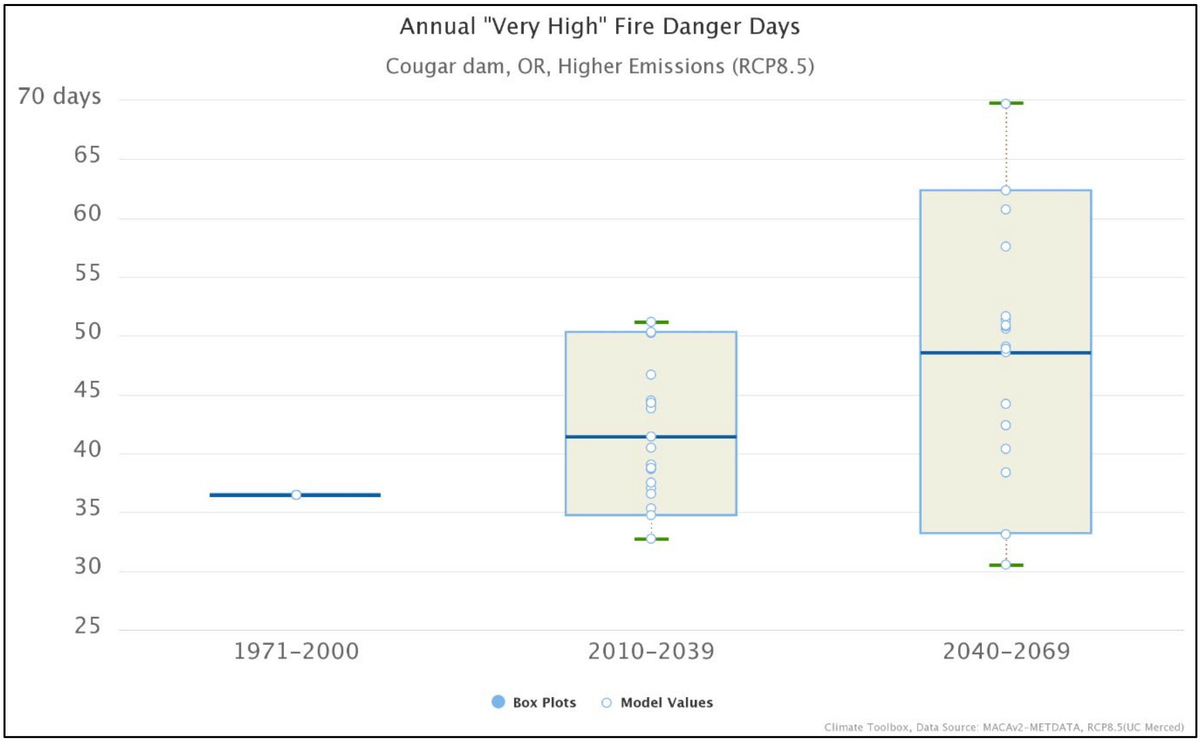


Figure 3-47. Cougar, OR Annual Very High Fire Danger Days

The fire danger at Cougar dam, OR, is chosen as representative for the basin. Blue River high fire danger day trends would be similar in magnitude and variability. Again, there is a distinct median increase, suggesting an increasing fire hazard in the future.

3.2.9 Middle Fork Willamette River sub-basin

The Middle Fork (MF) Willamette sub-basin is approximately the same size as the McKenzie sub-basin at, 1,366 square miles. Similarly, the majority (over 3/4) of the basin's topography is steep, mountainous and the land-use/cover is forested. However, the Middle Fork sub-basin is at a lower average elevation, at approximately 3,270 feet (NAVD88). The sub-basin's high point is about 8,710 feet (NAVD88) while the minimum elevation is 152 feet (NAVD88). The basin outlets at I-5, just upstream (south) of Eugene, OR. The basin contains very little urban area.

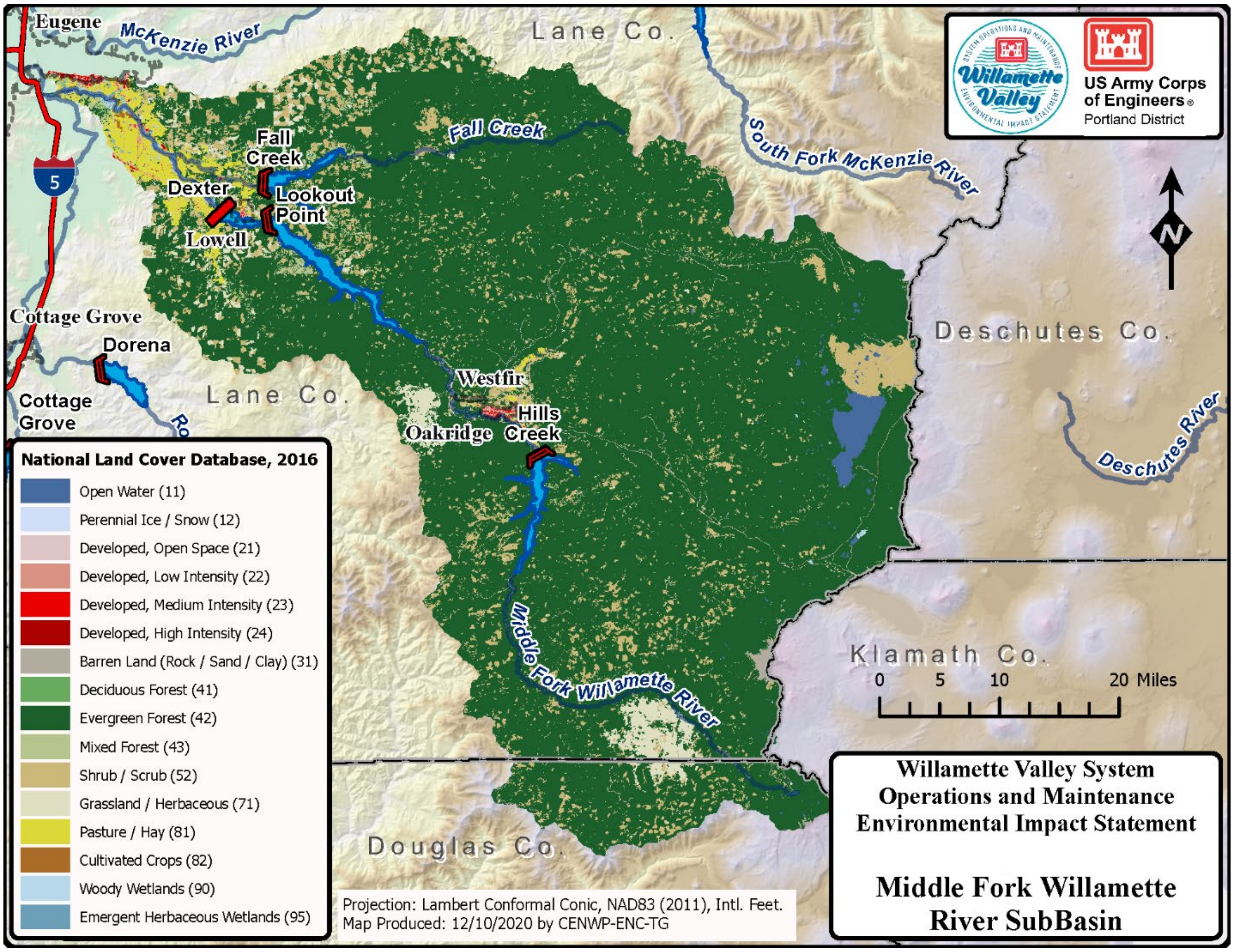


Figure 3-48. Middle Fork Willamette River Sub-basin

The basin contains no fewer than four USACE projects. Hills Creek, Lookout Point and Dexter dams are located on the Middle Fork (MF) Willamette River. Hills Creek Dam is the most upstream project on the MF Willamette. Fall Creek Dam is on Fall Creek tributary to MF Willamette River. Currently, ESA-listed spring Chinook, and bull trout are present in the subbasin. Hills Creek and Lookout Point are multi-purpose projects operated in tandem and storage between the two projects is generally balanced to capture floodwater during the winter and spring months. In summer, storage from these projects is used extensively to meet minimum flow requirements on the mainstem Willamette River. Hills Creek has two turbines capable of producing 15 MW each and Lookout Point has three turbines capable of producing 40 MW each. Dexter is a re-regulation project located downstream of Lookout Point and is used to control water levels created by peak hydropower generation at Lookout Point. There is one turbine unit at Dexter that produces 15 MW of power. Dexter reservoir is heavily used for recreation in summer. Fall Creek is a multi-purpose project and currently does not have a powerhouse. Fall Creek reservoir also is heavily used for recreation in summer.

Hydro-climate changes are similar across the basin. Hills Creek precipitation and temperature trends are presented below as representative of Middle Fork climate change projections for annual, seasonal, and high fire danger days, risk trends. Together, they are considered representative of the greater Middle Fork Willamette, sub-basin expected future patterns. Overall, the climate change projections for the future indicate substantial warming in the sub-basin. Figure 3-49 and Figure 3-50 portray upwards trends annually and summer. Summertime temperature changes are expected to have greatest relative increases. Figure 3-51 through Figure 3-54, graphically summarize, via statistical box plots, the projected changes of the relevant hydroclimate variables, precipitation, and ambient temperatures, for the critical winter and summer months.

Projected streamflow changes are shown at Lookout Peak and Fall Creek Dams respectively. Together, they are considered representative of the greater Middle Fork Willamette, sub-basin expected future patterns.

Hills Creek is also shown and represents the more upstream somewhat higher elevation and more pristine natural conditions subbasin. Fall Creek represents the lower elevation and more downstream rural land-use site. The unregulated naturalized streamflow changes at Hills Creek, Lookout Point and Fall Creek Dams are shown in Figure 3-55, Figure 3-56, and Figure 3-57, below. Dexter was not included because of its regulation status to and proximity to Lookout point.

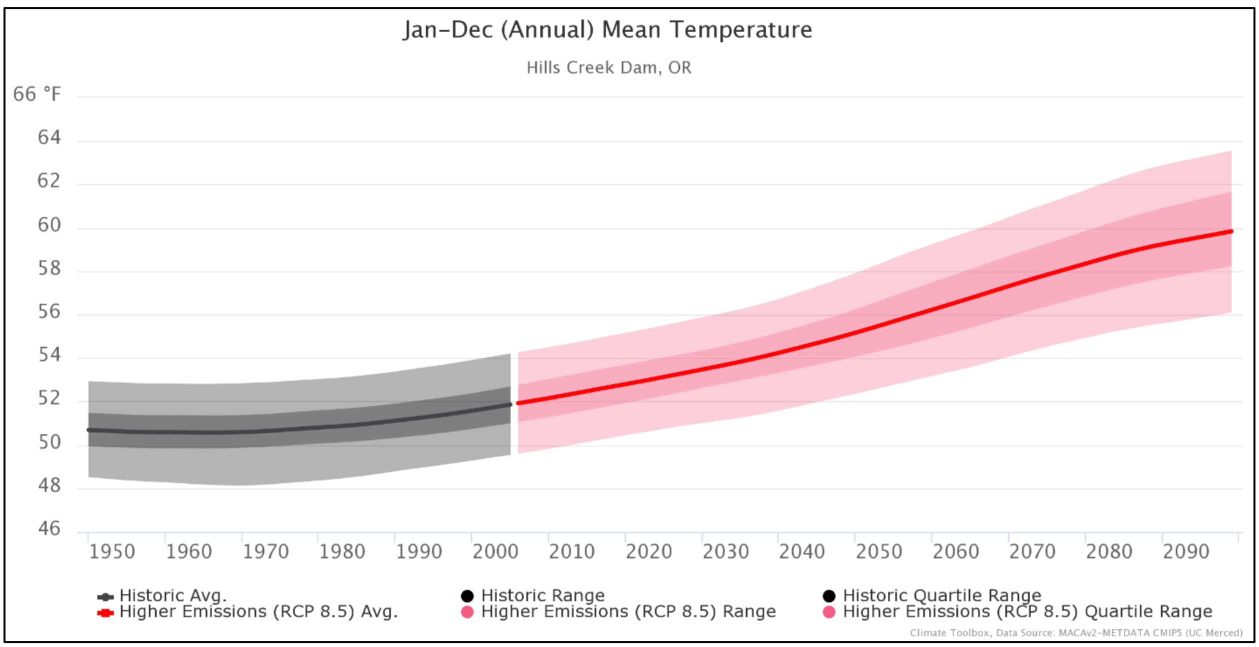


Figure 3-49. Average annual temperature trends at Hills Creek, OR. (1950-2100)

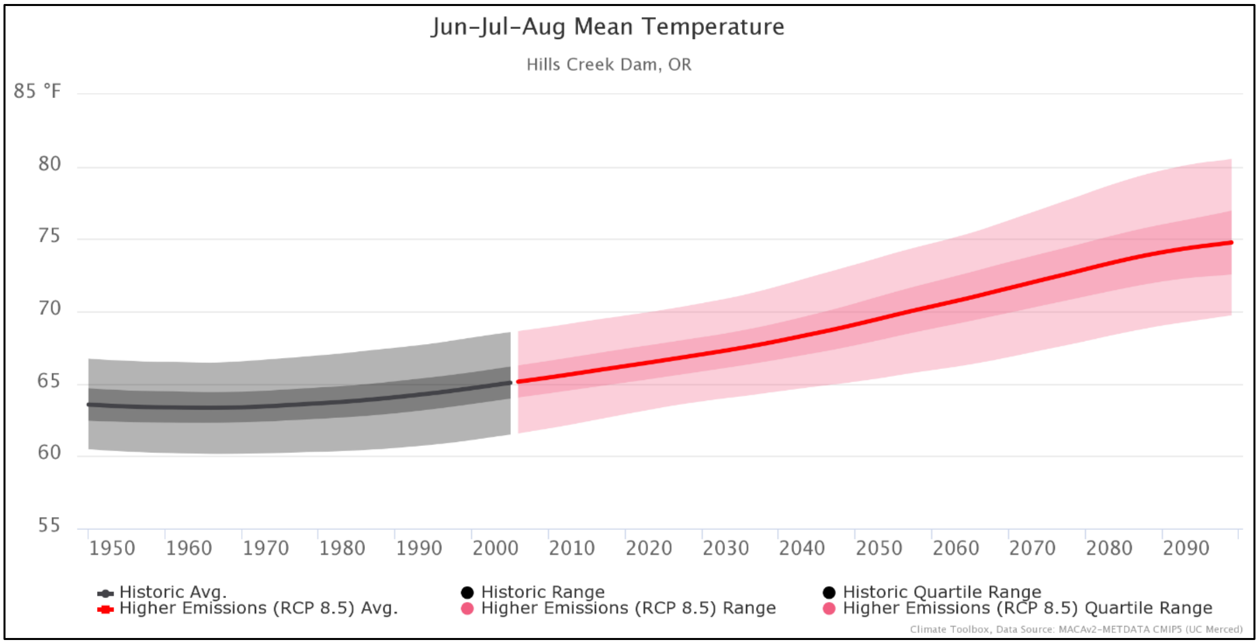


Figure 3-50. Average annual summer temperature trends at Hills Creek, OR. (1950-2100)

For contrast, Lookout Point projected temperatures are presented as well. The trends are very similar between Hills Creek and Lookout Point. However, temperature changes presented herein should not be used quantitatively, only to inform a qualitative determination.

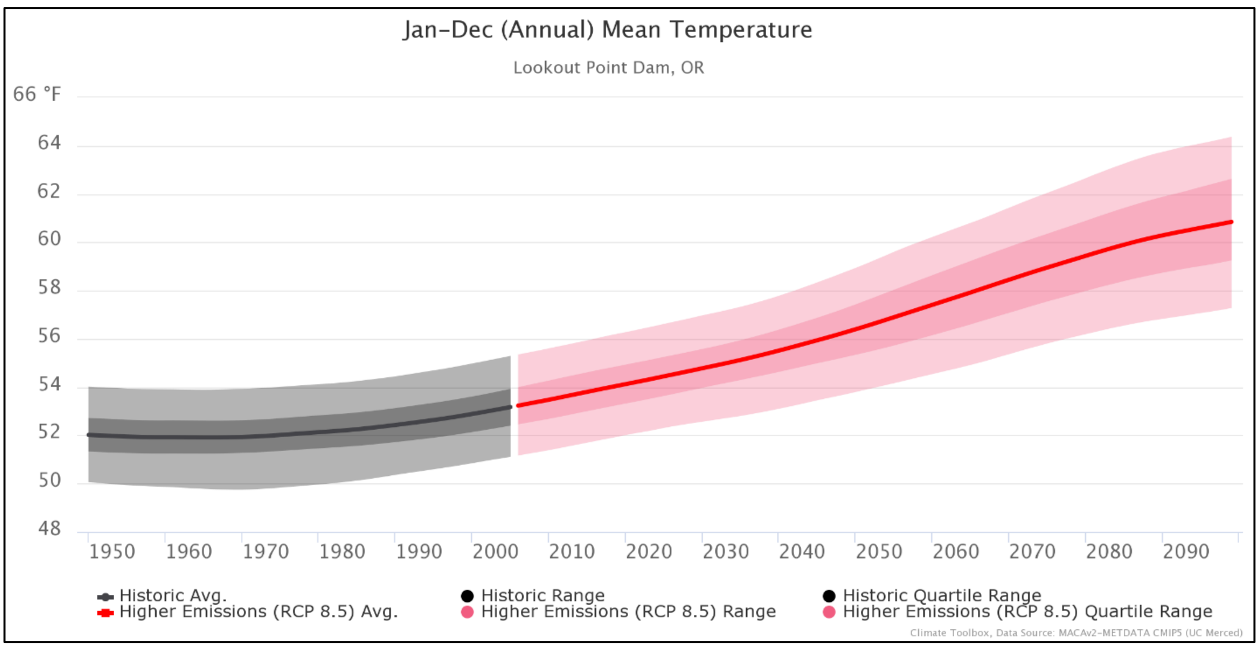


Figure 3-51. Average annual temperature trends at Lookout Point, OR. (1950-2100)

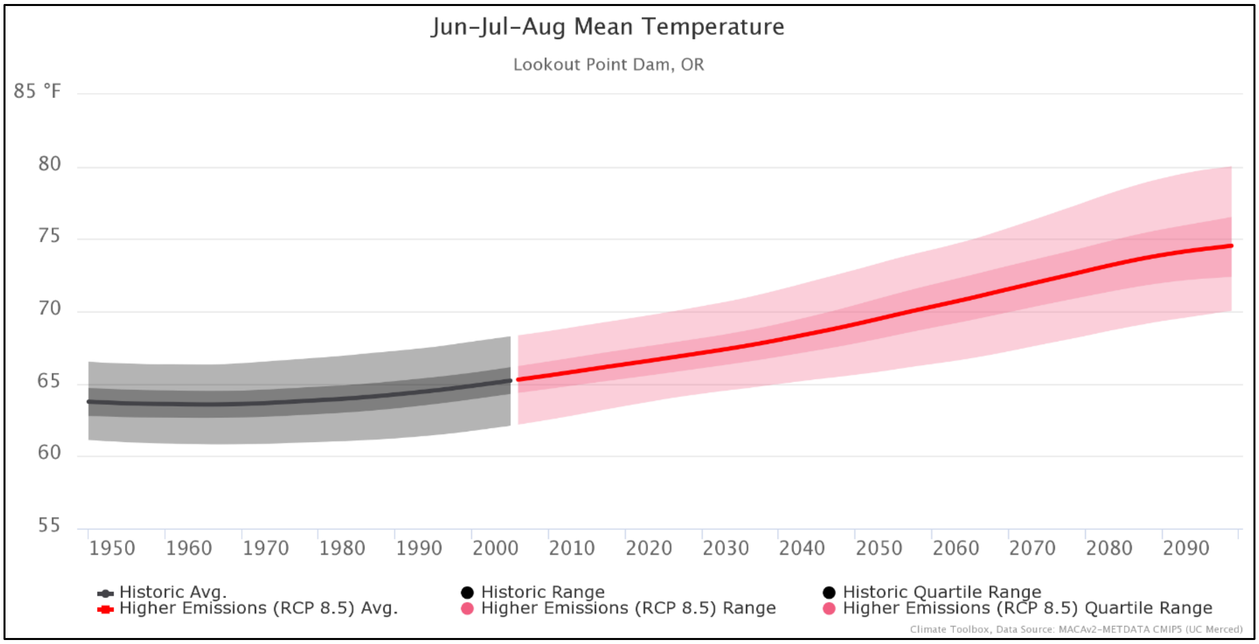
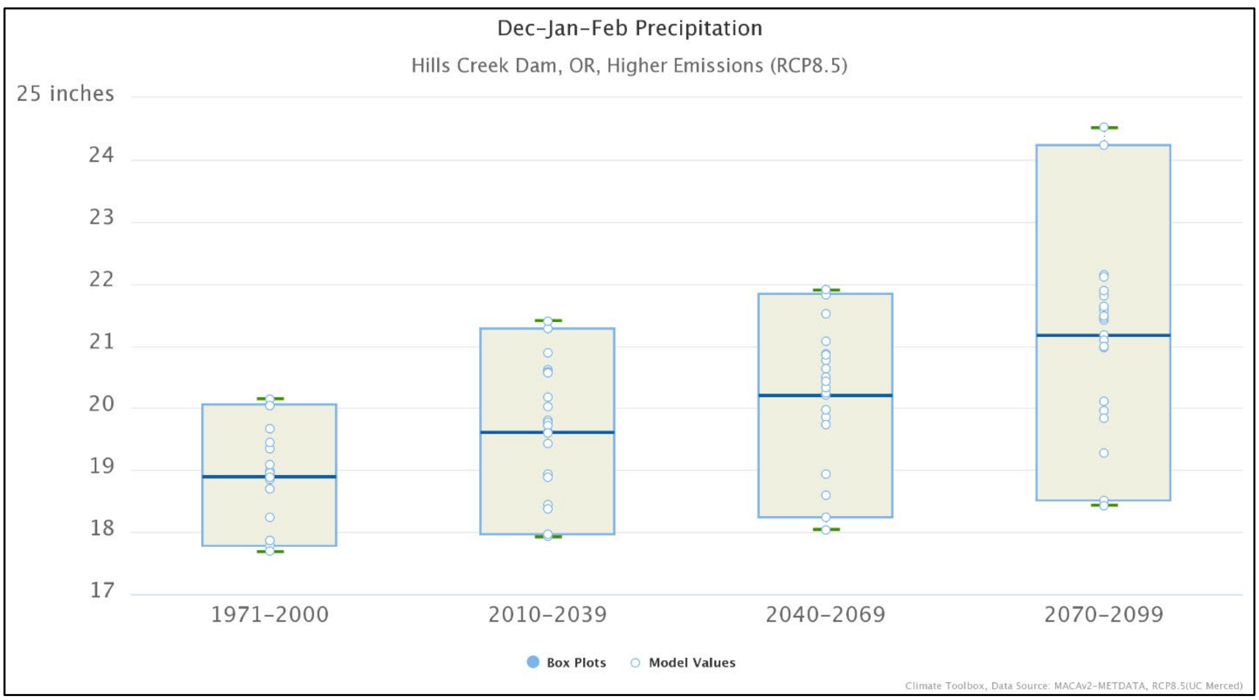


Figure 3-52. Average annual summer temperature trends at Lookout Point, OR. (1950-2100)



Source: Northwest Climate Toolbox

Figure 3-53. Median winter precipitation trend at Hills Creek, OR. (1950-2100)

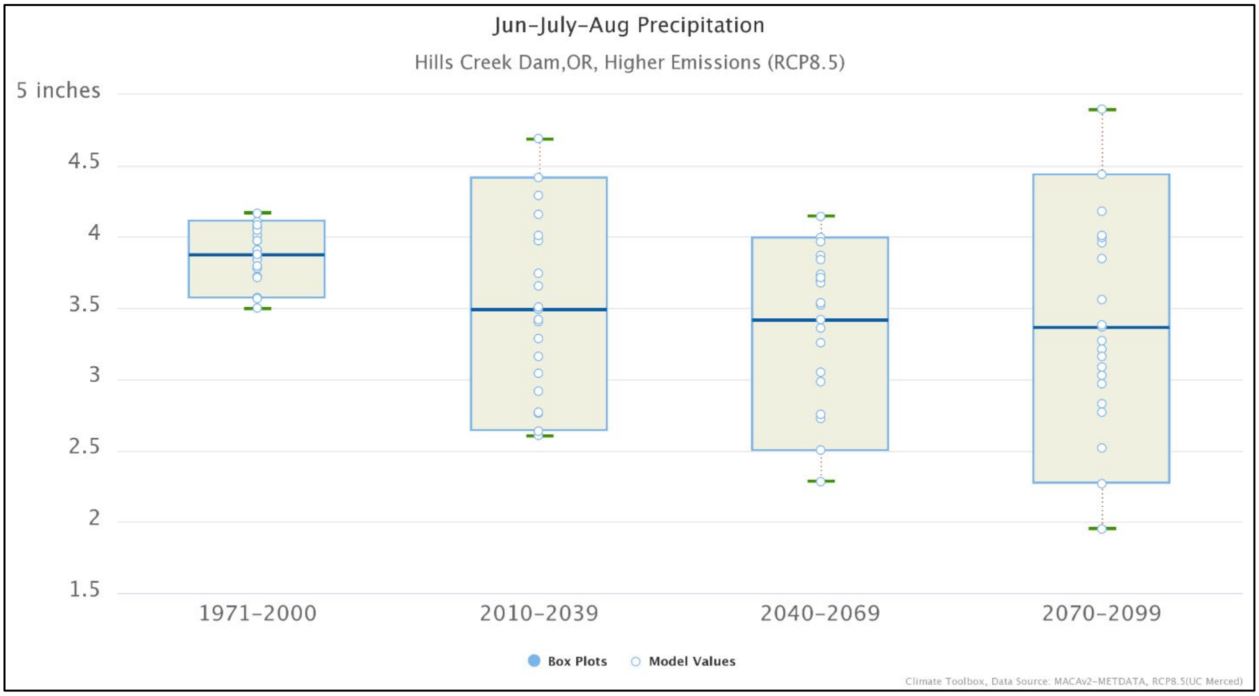


Figure 3-54. Median summer precipitation trend at Hills Creek, OR. (1950-2100)

Overall MF Willamette sub-basin projected climate change patterns correspond to the trends projected for the rest of the Willamette Valley basin. The summary hydrograph plots bellow, exemplify the effect from warming temperatures, transitioning from a snow impacted basin to a fully rainfall dominated basin. The dominant signal is streamflow volume shifting from a winter and spring distribution to one almost entirely occurring in wintertime. As shown below, this has implications for hydro-regulation operations in the future.

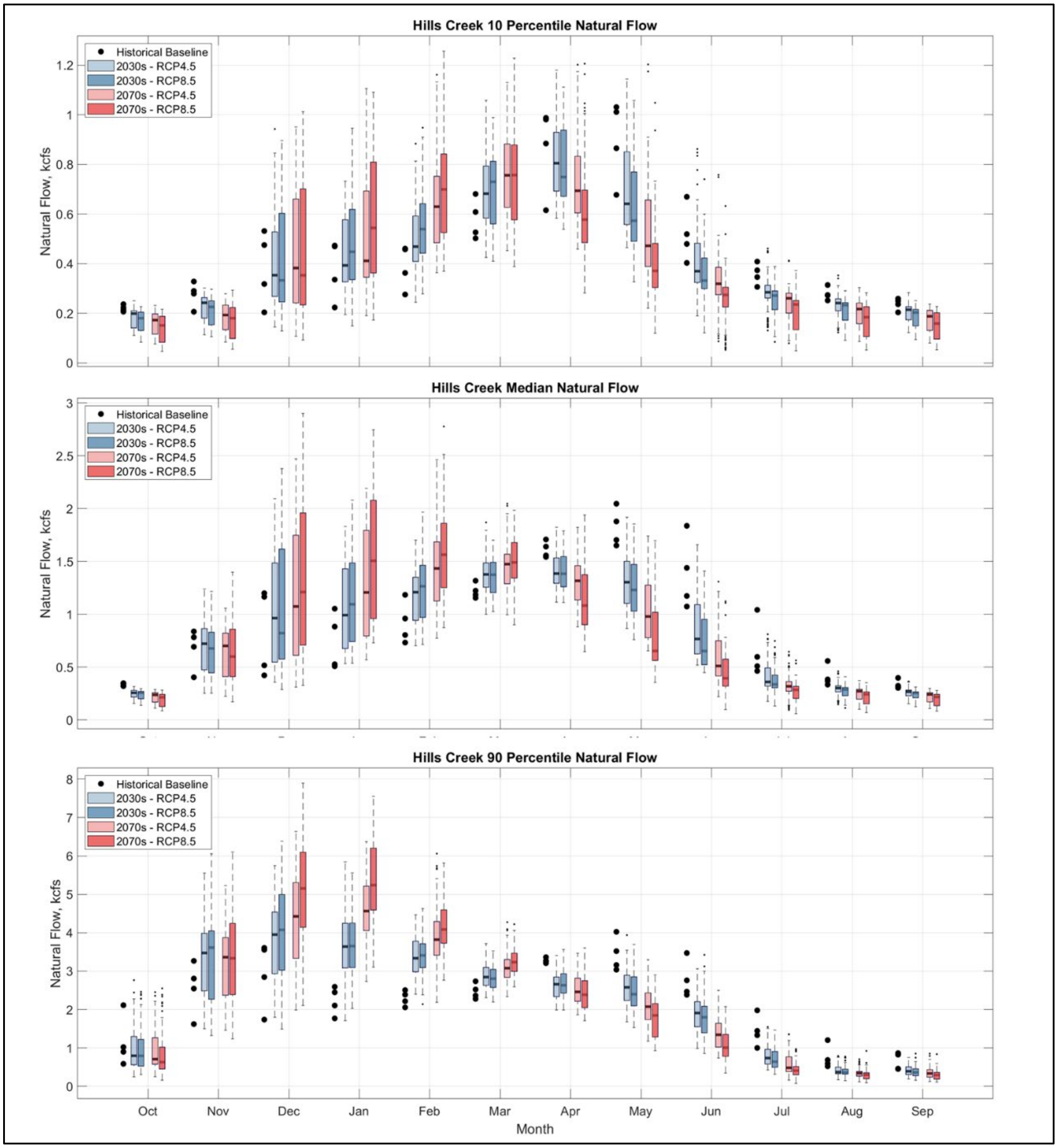


Figure 3-55. MF WillametteRiver at Hills Creek, OR summary hydrographs

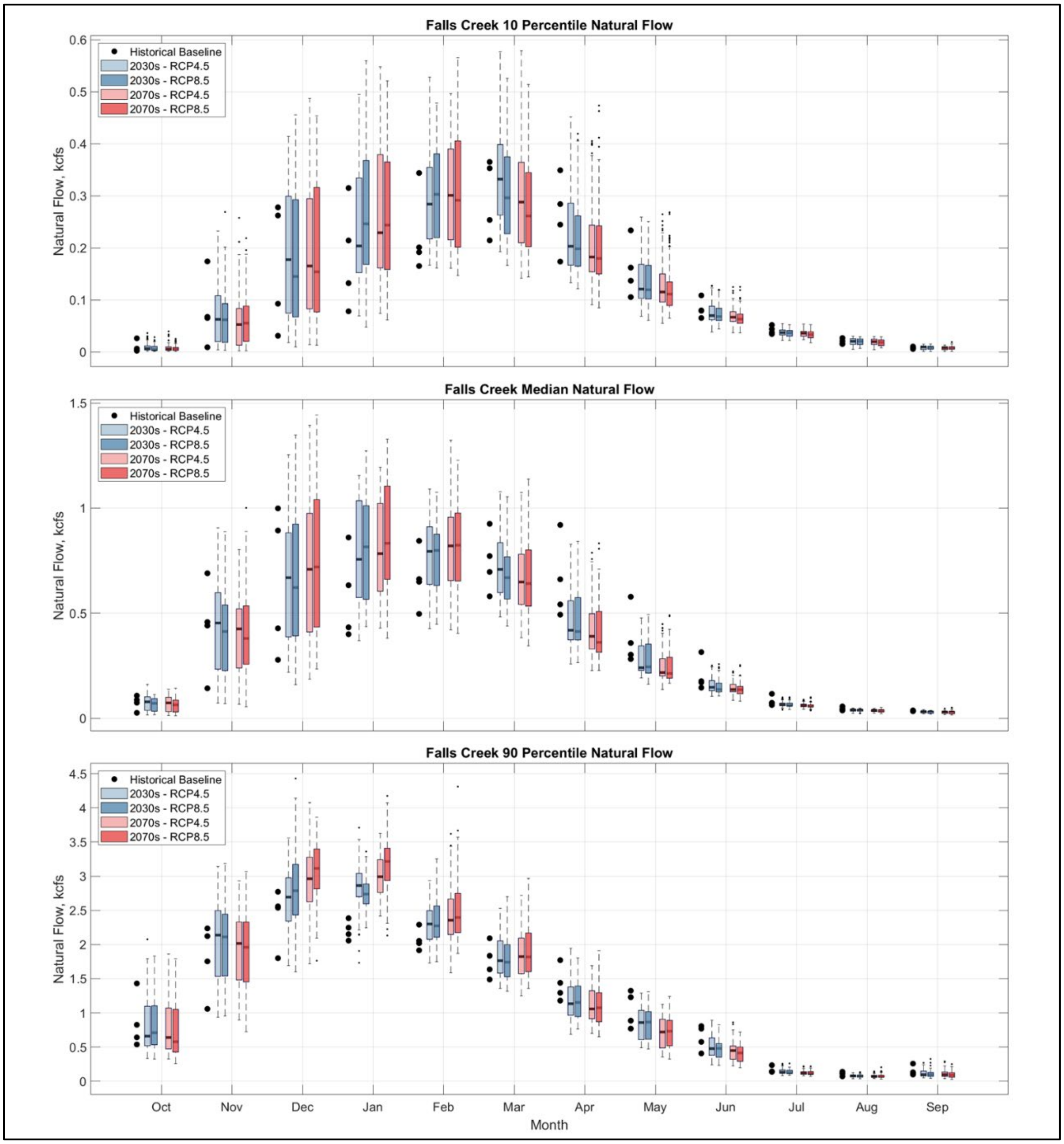


Figure 3-56. Fall Creek, OR summary hydrographs

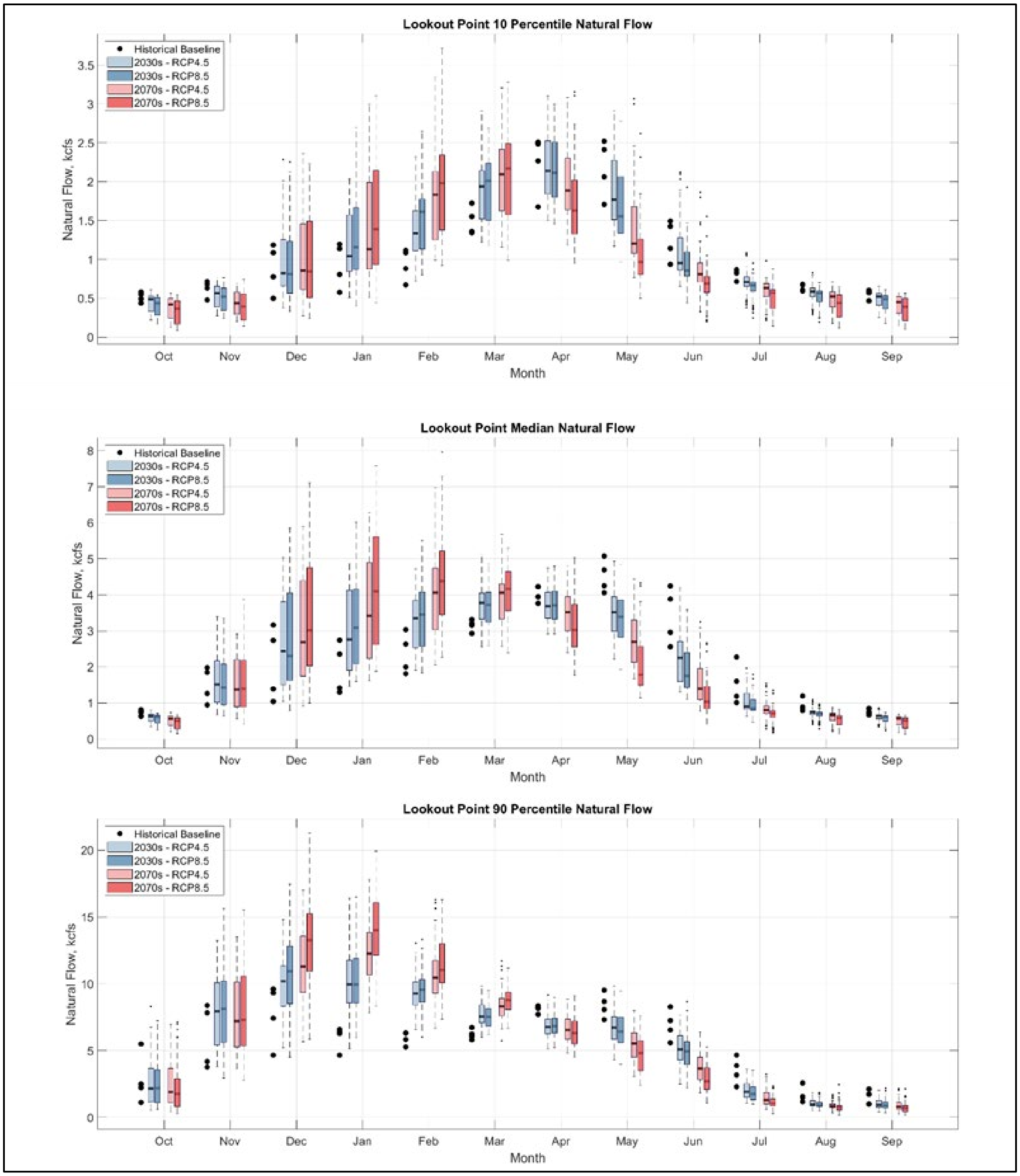


Figure 3-57. MF Willamette River at Lookout Point, OR summary hydrographs

The following three tables below reflects the summary hydrographs above.

Table 3-7. HCR flow change

HCR Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	-0.02	-0.03	-0.1	-0.05	-0.5	-0.7
Nov	-0.08	-0.11	0.025	0.125	1	0.75
Dec	-0.02	-0.01	0.05	0.45	1.35	2.4
Jan	0.03	0.19	0.37	0.77	1.7	3.1
Feb	0.16	0.31	0.25	0.55	1.35	2
Mar	0.1	0.185	0.2	0.25	-0.3	0.1
Apr	-0.05	-0.24	-0.2	-0.5	-0.5	-0.8
May	-0.28	-0.48	-0.5	-1.15	-1.2	-1.7
Jun	-0.19	-0.26	-0.8	-0.91	-1	-1.9
Jul	-0.12	-0.17	0.495	-0.5	-0.95	-1.2
Aug	-0.06	-0.09	-0.24	-0.29	-1.1	-1.2
Sep	-0.02	-0.04	-0.1	-0.1	-0.3	-0.4

Table 3-8. FAL flow change

FAL Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	-0.01	-0.01	0	-0.01	-0.24	-0.33
Nov	-0.04	-0.05	-0.02	-0.07	0.5	0.4
Dec	-0.14	-0.02	0.3	0.4	0.35	0.7
Jan	0.06	0.06	0.18	0.2	0.5	0.95
Feb	0.06	0.05	0.11	0.13	0.2	0.35
Mar	0.03	-0.01	-0.13	-0.16	0	0.05
Apr	-0.06	-0.08	-0.25	-0.615	-0.3	-0.35
May	-0.04	-0.05	-0.15	-0.17	-0.25	-0.35
Jun	-0.01	-0.02	-0.05	-0.05	-0.1	-0.15
Jul	-0.01	-0.01	-0.05	-0.06	-0.05	-0.05
Aug	0.005	0	-0.02	-0.02	0	0
Sep	0	0	-0.01	-0.01	-0.05	-0.05

Table 3-9. LOP flow change

LOP Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	-0.01	-0.02	-0.2	-0.3	-0.5	-1.5
Nov	-0.1	-0.12	-0.15	-0.2	2.6	1.8
Dec	-0.18	-0.08	0.05	0.9	3	5.5
Jan	0.2	0.5	1	2	4.5	9
Feb	0.74	1.09	1.3	2.1	4.35	4.9
Mar	0.45	0.65	0.7	1	1.5	2
Apr	-0.05	-0.55	-0.3	-1	-1.55	-1.8
May	-0.64	-1.29	-1	-2.6	-2	-3.05
Jun	-0.35	-0.55	-1.4	-2.2	-2	-4.5
Jul	-0.15	-0.2	-0.6	-0.8	-2.25	-3
Aug	-0.05	-0.11	-0.3	-0.4	-2	-2.05
Sep	0	-0.02	-0.2	-0.3	-1.05	-1.05

Middle Fork projections present the same broad hydrologic trends as forecast for the rest of the Valley's sub-basins, the increase in wintertime high flows (P90) is indicated by the November thru March, relative increases in P90 median flows. Projected reduction of SWE will drive the transition to a fully rain dominated basin, driving the annual maximum flow. The historical spring pulse in April and May is projected to disappear in the future, under both emission scenarios (RCP 4.5/8.5).

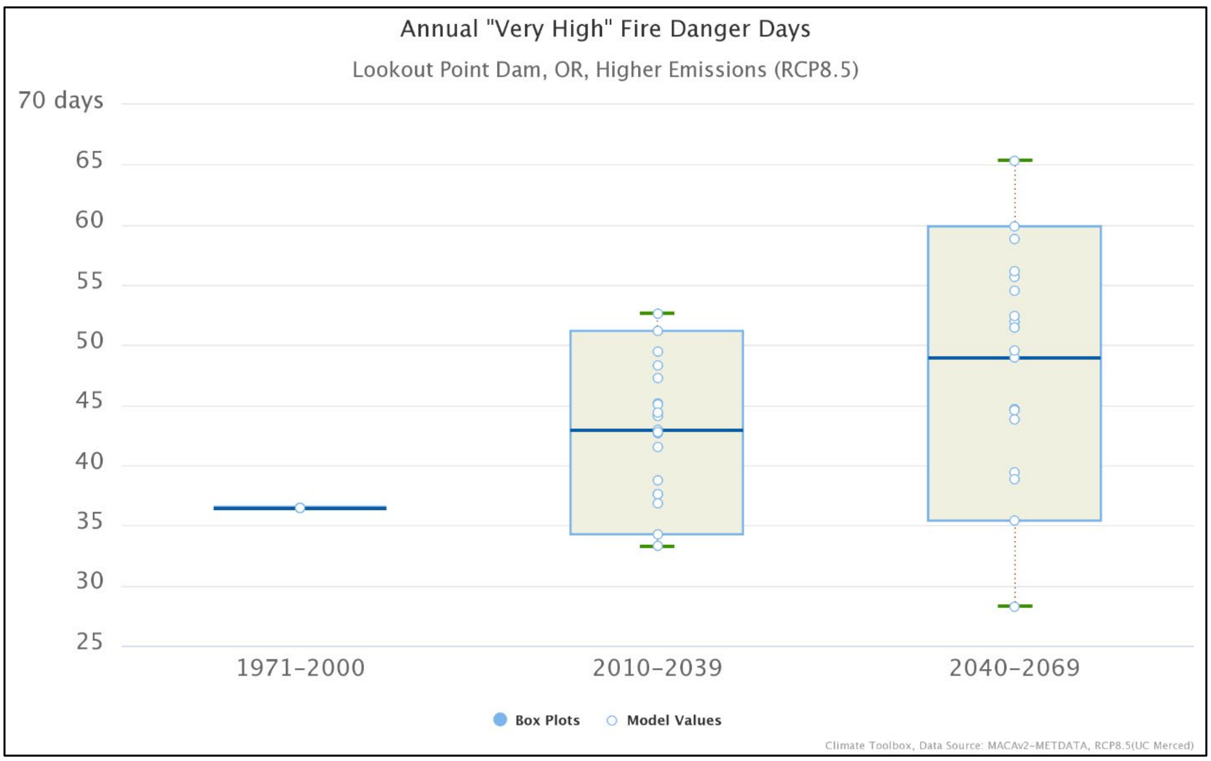


Figure 3-58. Lookout Point, OR Annual Very High Fire Danger Days

Lookout Point dam is used as the proxy site for changing fire danger in the broader Middle Fork Willamette subbasin. It was chosen as the example site, due to its central location in the MF Willamette basin. Conjecturally, Hills Creek, being the headwater of the basin and composed of pristine and sensitive habitat may be more vulnerable to future fires, because of reduced accessibility, more rugged terrain and denser vegetative cover and understory. Fall Creek is similar in trending magnitude and variability, relative to Lookout Point.

3.2.10 Coast Fork Willamette River sub-basin

The Coast Fork (CF) Willamette sub-basin 667 square miles. The basin's topography is steep, mountainous and the land-use/cover is forested. However, the Coast Fork sub-basin is at an average elevation, at approximately 1,916 feet (NAVD88). The sub-basin's high point is about 5,950 feet (NAVD88) while the minimum elevation is 439 feet (NAVD88). The sub-basin terminates at Creswell OR.

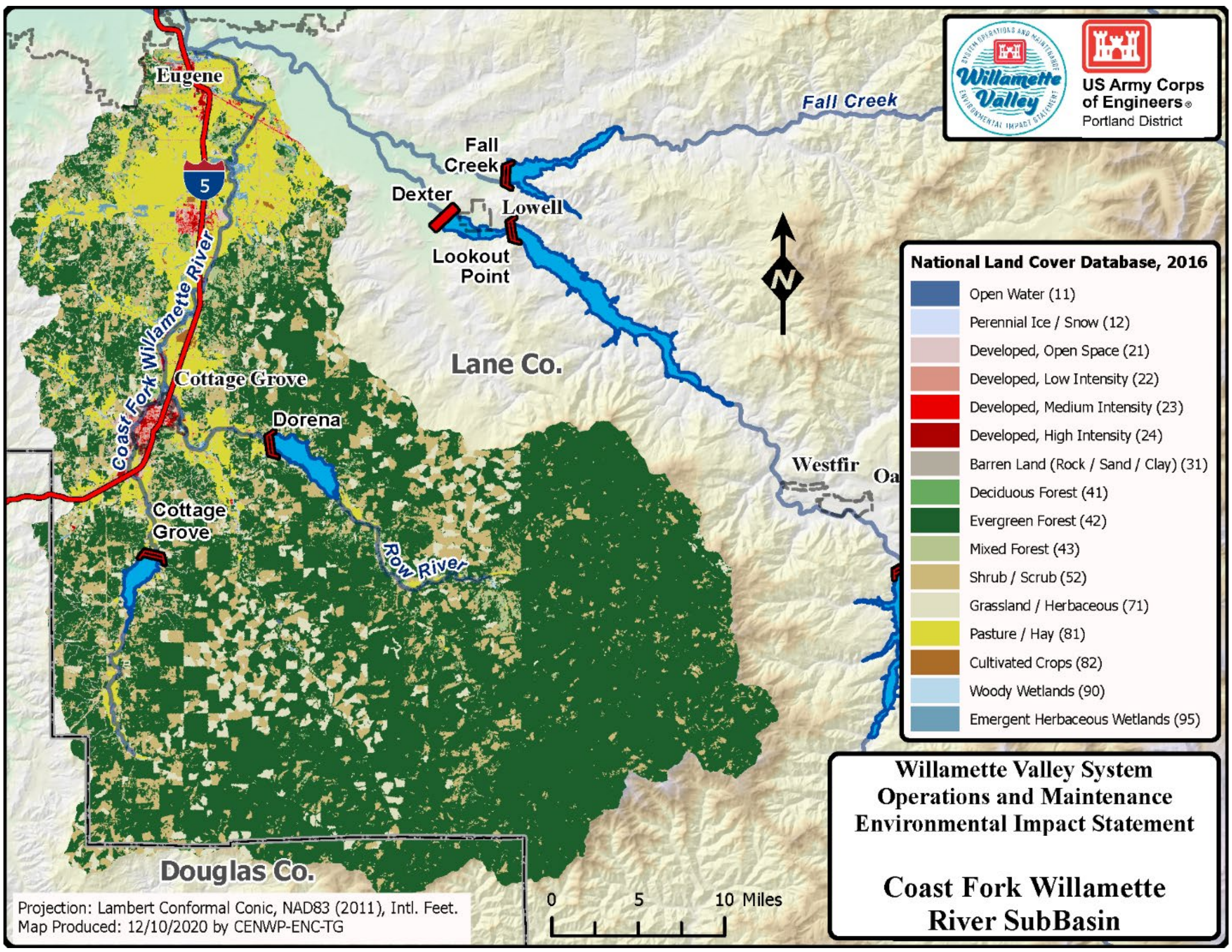


Figure 3-59. Coast Fork Willamette River Sub-basin

Cottage Grove Dam is a multipurpose (headwater) project on the Coast Fork (CF) Willamette River. Dorena Dam is also a multipurpose project on the Row River, tributary to the CF Willamette River. Dorena is an earthfill structure with a concrete spillway and works in coordination with Cottage Grove Dam to provide flood risk management, water quality improvement, irrigation, recreation and habitat for fish and wildlife (USACE 2020). This area has historically been habitat for a very small population of ESA listed salmonids.

Projected hydroclimate changes in temperature and precipitation are comparable to trends expected across the Willamette Valley. Figure 3-60 and Figure 3-61 show that 1) annual warming is likely in the future and 2) the greatest degree of seasonal warming will be in the summer. Precipitation is projected to increase in the wintertime and decrease in the summer (Figure 3-62 and Figure 3-63). Summer precipitation is already very low in the summer months normally.

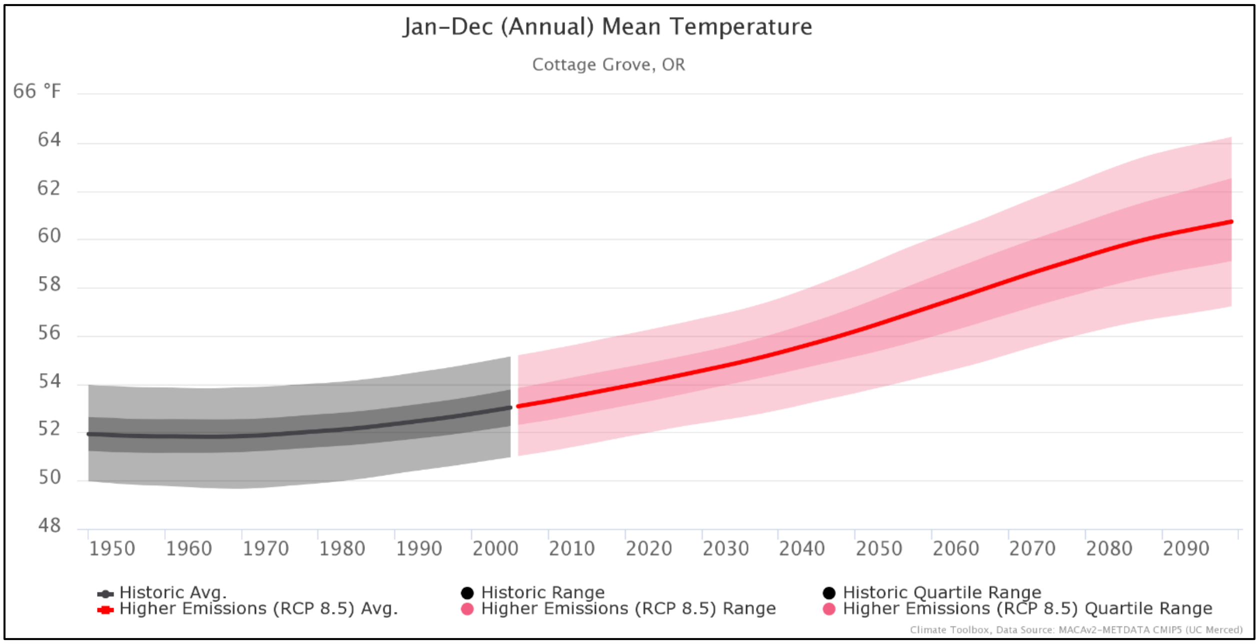


Figure 3-60. Average annual temperature trends at Cottage Grove, OR

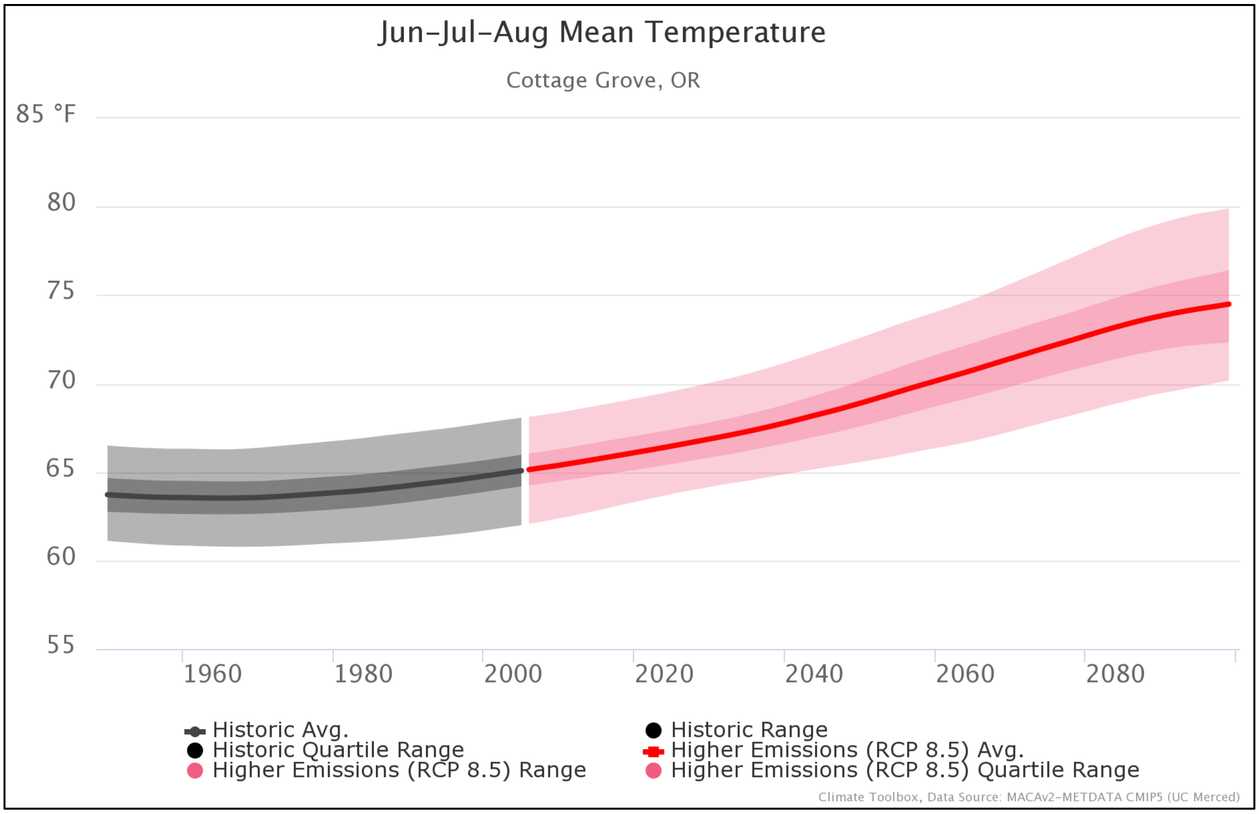


Figure 3-61. Average annual summer temperature trends at Cottage Grove, OR

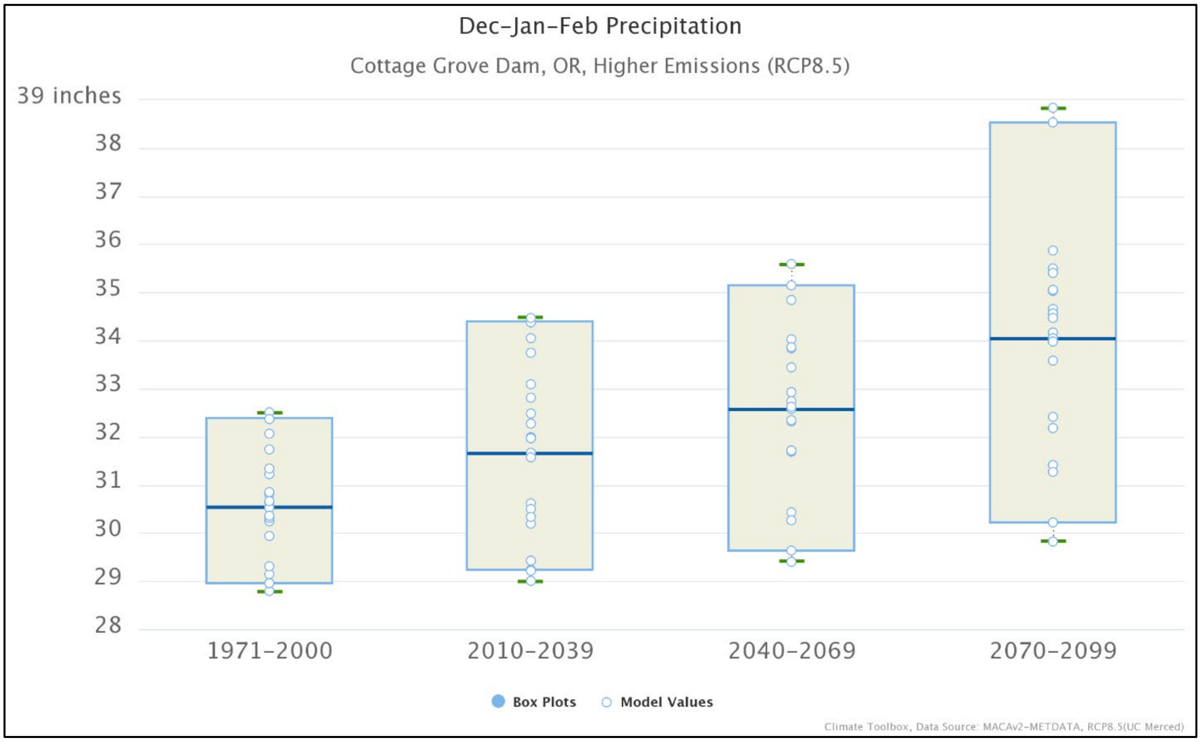


Figure 3-62. Median winter precipitation trend at Cottage Gorve, OR

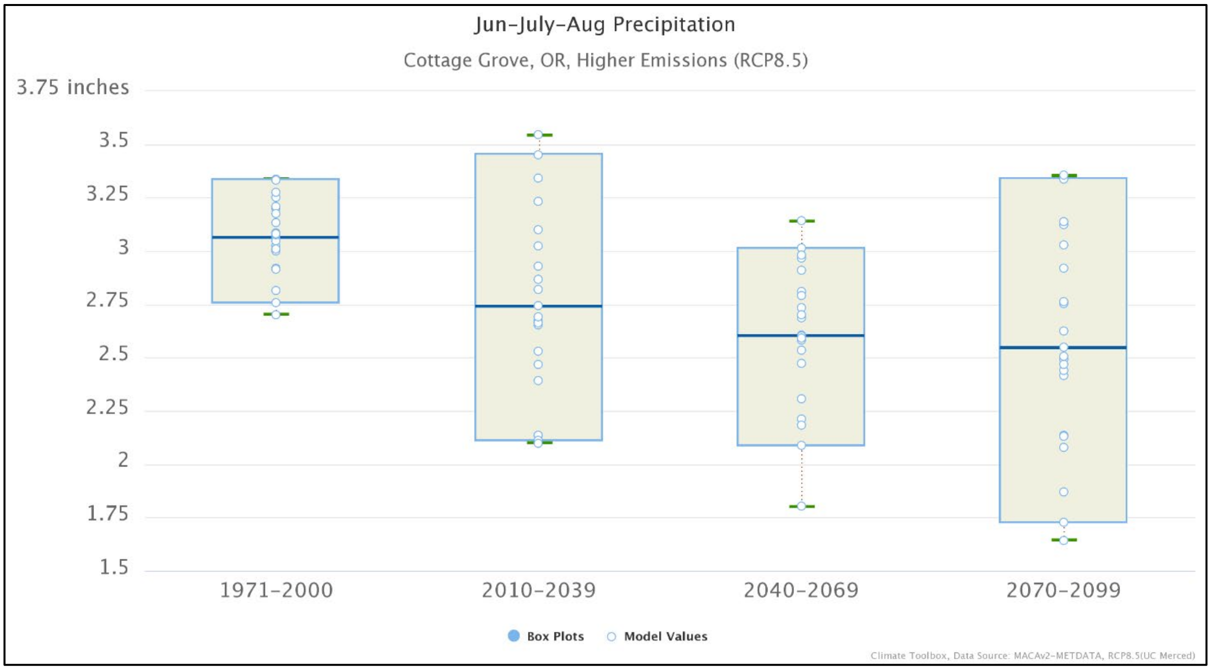


Figure 3-63. Median summer precipitation trend at Cottage Grove, OR

The contributing area to the Coast Fork Willamette River at Cottage Grove OR is a lower elevation rain dominated basin. Therefore, the projected changes are not as dramatic as shown in other sub-basins discussed above. The primary change in the future decades is towards greater wintertime volume and flow duration with some increase of peak flows during high water events. The peak month remains January.

During the summer, median streamflow volume is projected to decrease. Likely increased ambient temperatures could translate to increased need for water temperature regulation. Higher temperatures will most likely stress resident (and listed) fish species. Lower base flow during the summer and fall months will likely complicate maintaining of conservation pool as demand rises and additional variability in the late winter and early spring could complicate refill. Mean Row River streamflows at Dorena are projected to be higher than historical averages in winter months (starting October through March). Higher runoff would be due to increased duration and intensity of wintertime rainfall events and higher winter baseflow in the hills that feed into the subbasin. Winter outflows and storage fluctuations could become more variable as reservoirs store and evacuate water for downstream FRM.

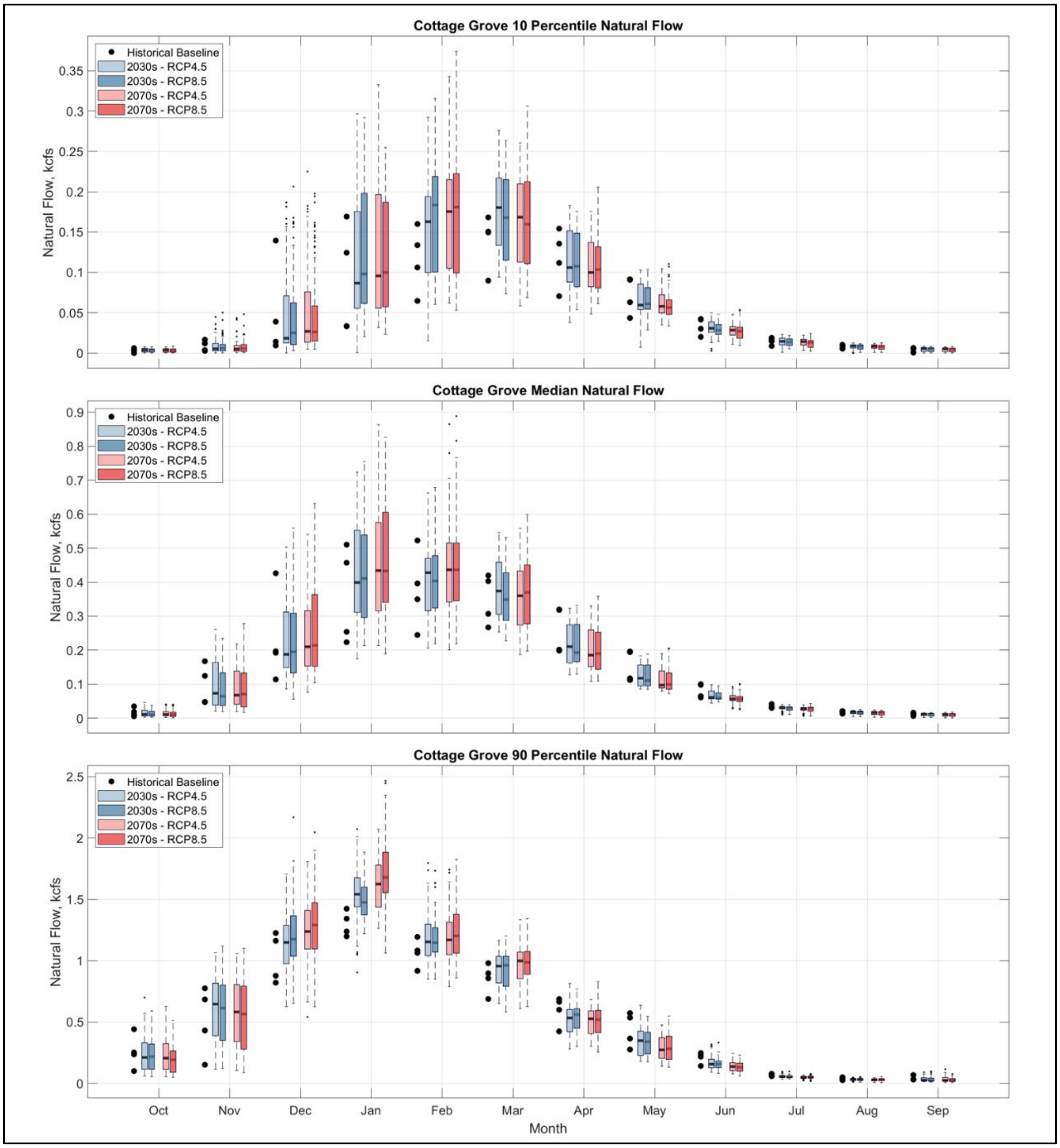


Figure 3-64. CF Willamette River at Cottage Grove, OR summary hydrographs

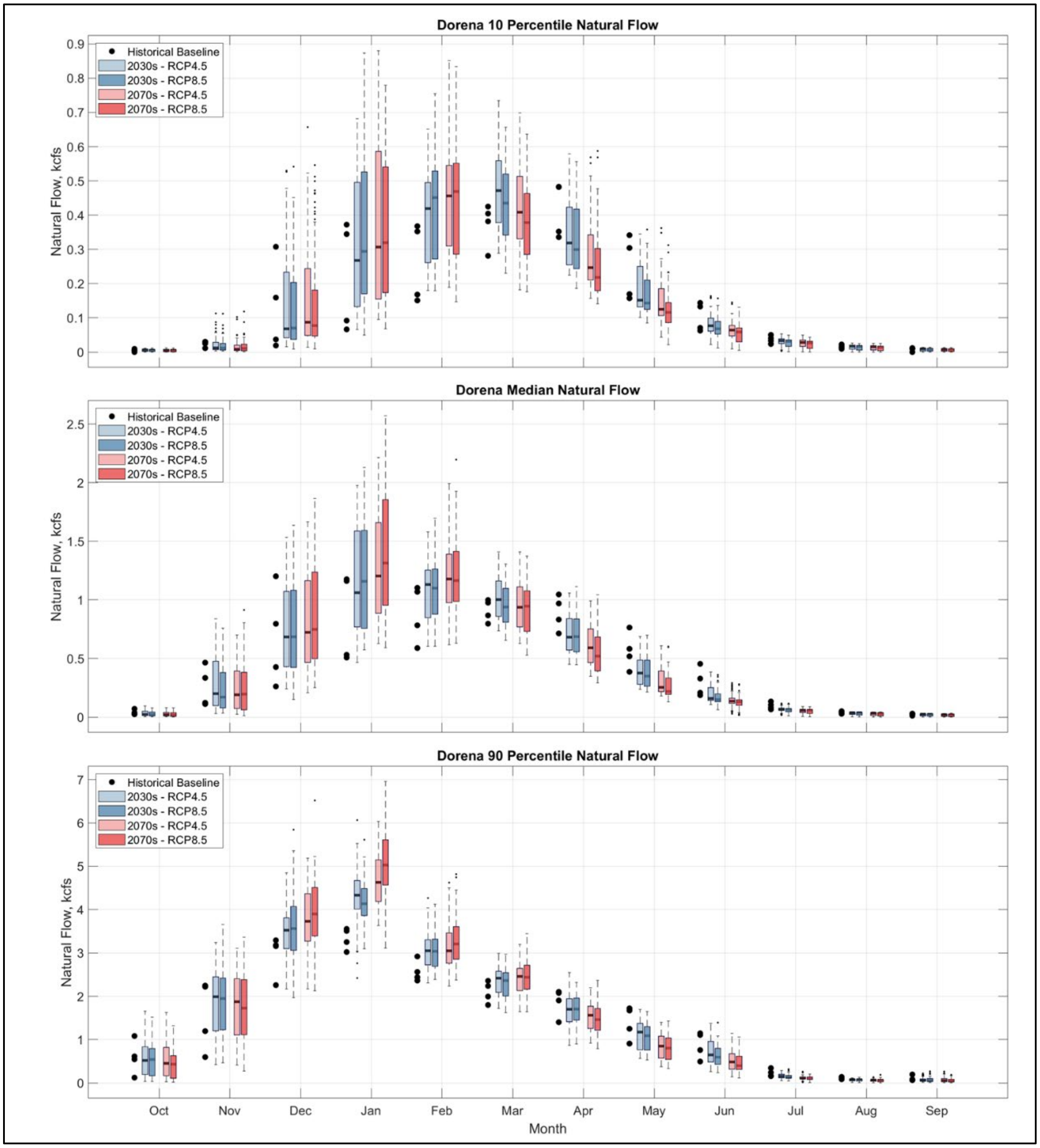


Figure 3-65. Row River at Dorena, OR summary hydrographs

The tables below correspond to the above summary hydrograph figures. The future pattern of increased runoff beginning in in November thru March (slight relative increase) to substantial decreases in the summer months. The overall annual changes are slightly upward in this and other sub-basins of the WVS.

Table 3-10. COT flow change

COT Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	0	0	0	0	-0.05	-0.07
Nov	-0.001	-0.001	-0.06	-0.06	0.14	0.09
Dec	-0.025	-0.025	-0.055	-0.035	0.2	0.3
Jan	0.033	0.033	0.025	0.035	0.24	0.4
Feb	0.07	0.065	0.04	0.07	0.05	0.1
Mar	0.025	0.02	0	0.01	0.1	0.15
Apr	-0.015	-0.016	-0.055	-0.055	0	-0.01
May	-0.015	-0.02	-0.045	-0.05	-0.1	-0.15
Jun	0	-0.002	-0.01	-0.02	-0.05	-0.1
Jul	0	0	-0.005	-0.005	-0.01	-0.01
Aug	0	0	0	0	-0.01	-0.01
Sep	0	0	0	0	-0.01	-0.01

Table 3-11. DOR flow change

DOR Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	0	0	-0.03	-0.03	0	-0.2
Nov	-0.005	-0.005	-0.05	-0.04	0.65	0.55
Dec	0.015	0.015	-0.09	0.06	0.97	1.32
Jan	0.035	0.05	0.4	0.55	0.9	1.8
Feb	0.17	0.2	0.28	0.4	0.2	0.3
Mar	0.05	0.02	0.05	0.05	0.05	0.1
Apr	-0.12	-0.21	-0.15	-0.29	0	-0.3
May	-0.11	-0.14	-0.15	-0.31	-0.2	-0.4
Jun	-0.04	-0.04	-0.15	-0.15	-0.2	-0.5
Jul	-0.01	-0.01	-0.05	-0.05	-0.1	-0.1
Aug	0	0	-0.01	-0.01	-0.05	-0.05
Sep	0	0	-0.01	-0.01	-0.05	-0.05

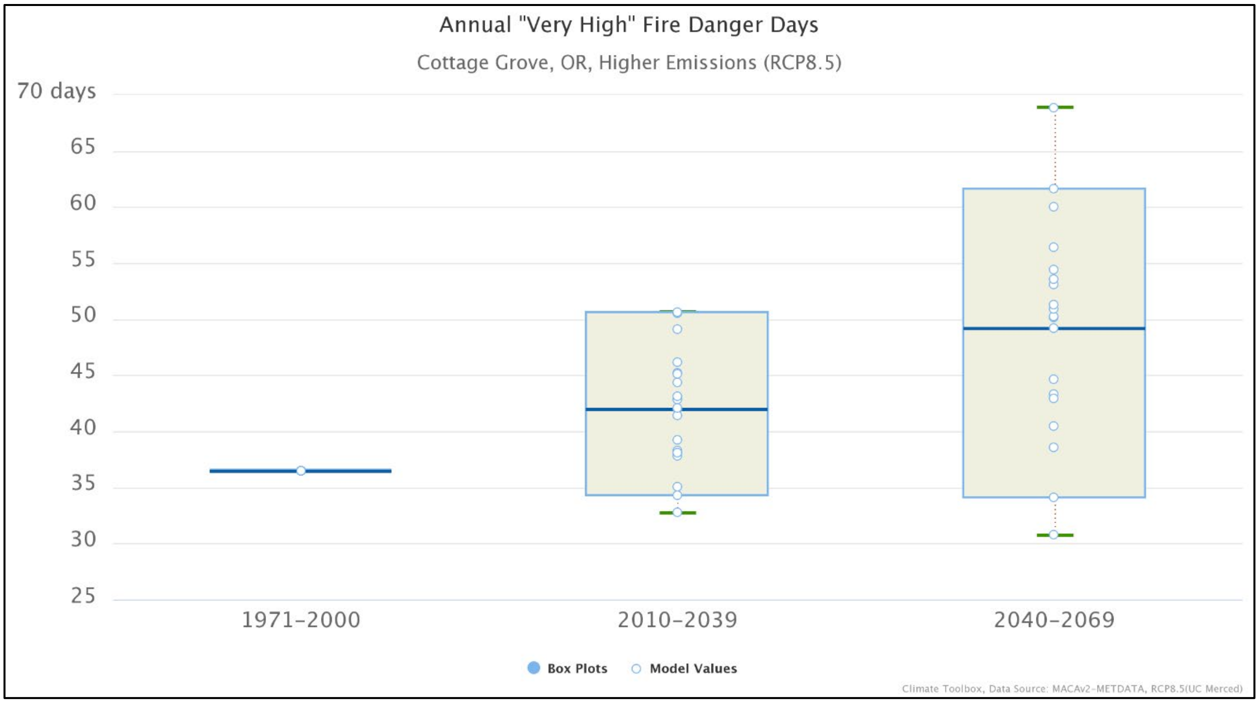


Figure 3-66. Dorena, OR Annual Very High Fire Danger Days

Fire danger at Dorena dam is representative for the Coast Fork basin. The overall trends are the same as for the rest of the subbasins in the Willamette Valley.

3.2.11 Long Tom River sub-basin

The Long Tom River sub-basin is the smallest described basin at 392 square miles. The basin's topography is milder compared to the others as well. Average elevation is approximately 636 feet (NAVD88). The sub-basin's high point is about 2095 feet (NAVD88) while the minimum elevation is 275 feet (NAVD88). The sub-basin terminates at approximately Monroe, OR. The primary USACE project, is Fern Ridge.

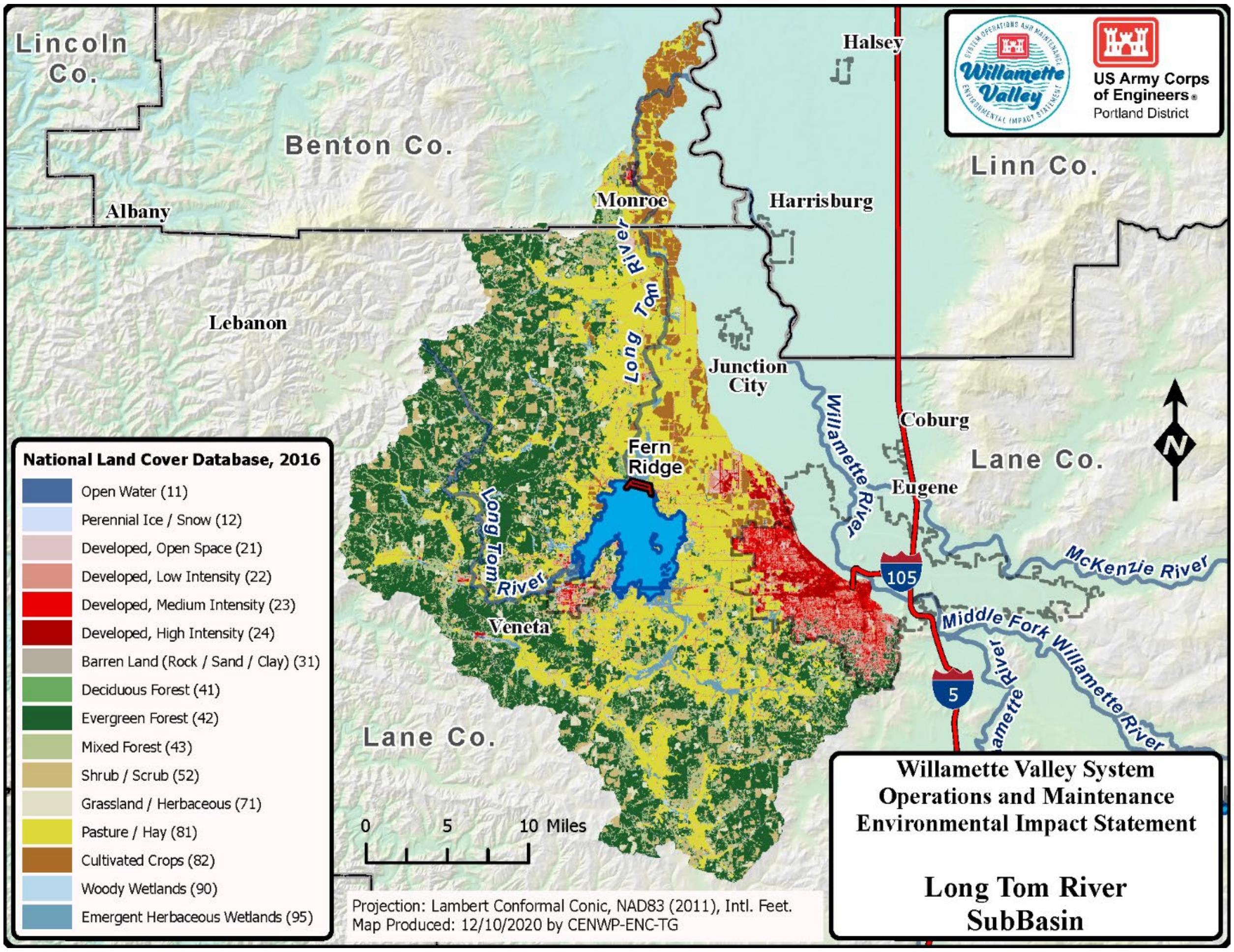


Figure 3-67. Long Tom River Sub-basin

The reservoir surface area is large (9,400 acres), and it is a popular site for recreation (sailing, power boating, etc.). The project is authorized for flood risk management, recreation, irrigation, and water quality. This sub-basin, like the Coast Fork has a very small populations of salmonids, therefore, there is not a dedicated fish operation at this project. Downstream reaches are surrounded by extensive farm fields. The project is a primary source of irrigation flows to these areas.

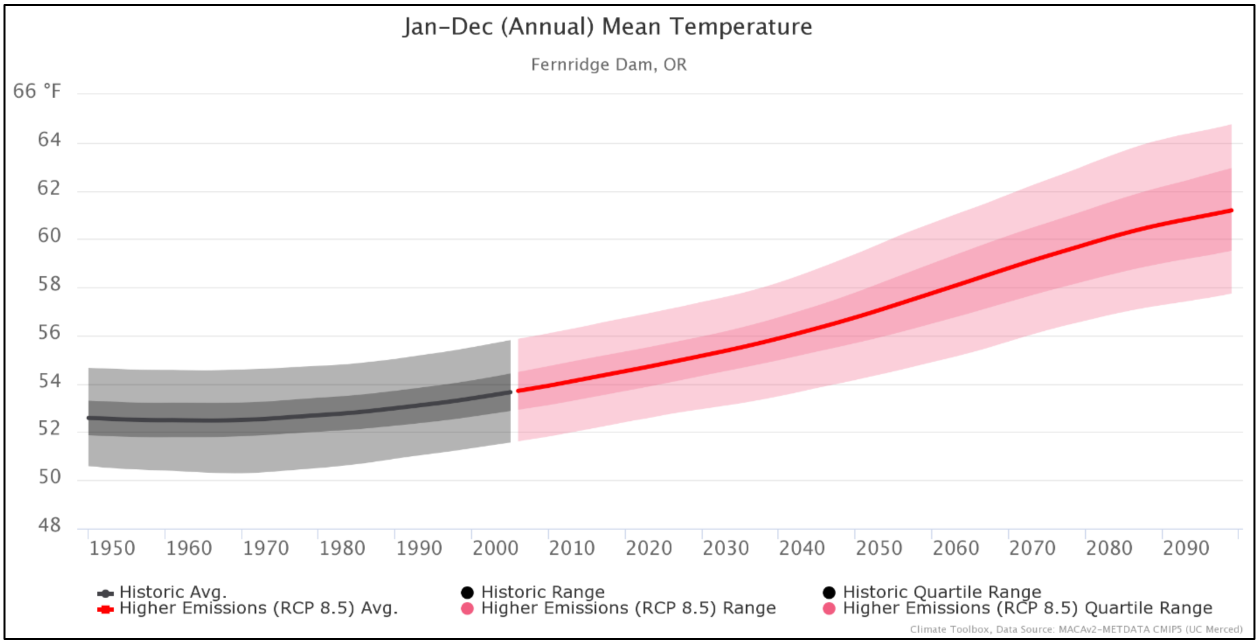


Figure 3-68. Average annual temperature trends at Fernridge, OR

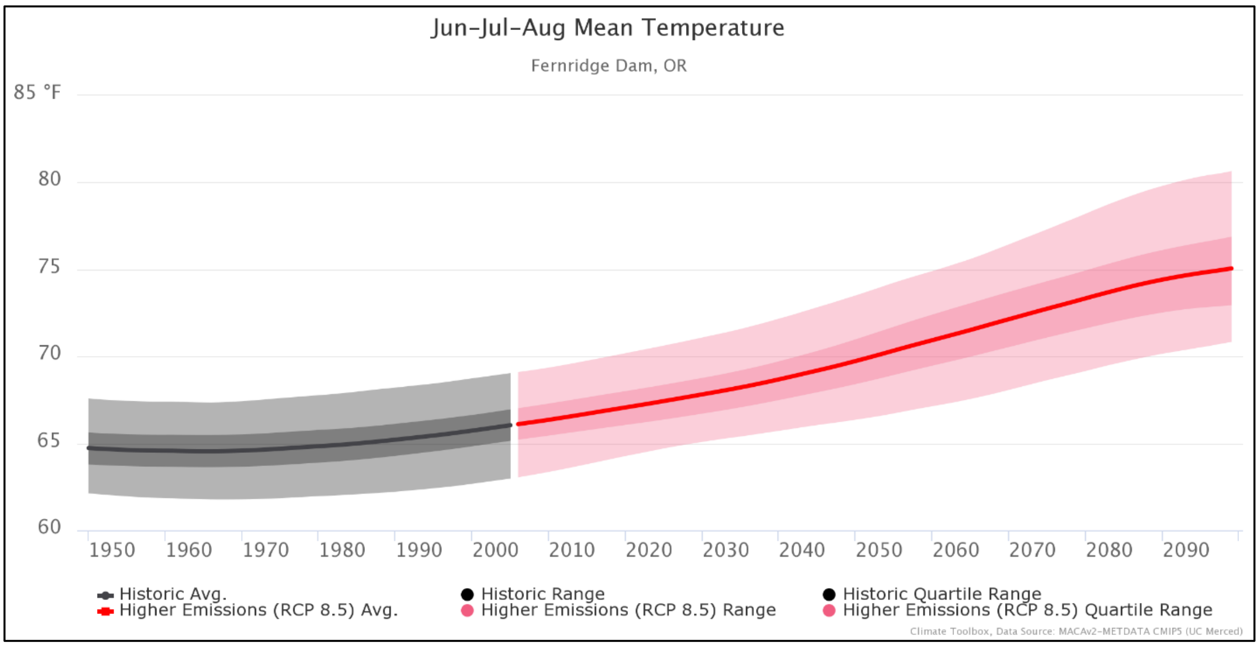


Figure 3-69. Average annual summer temperature trends at Fernridge, OR

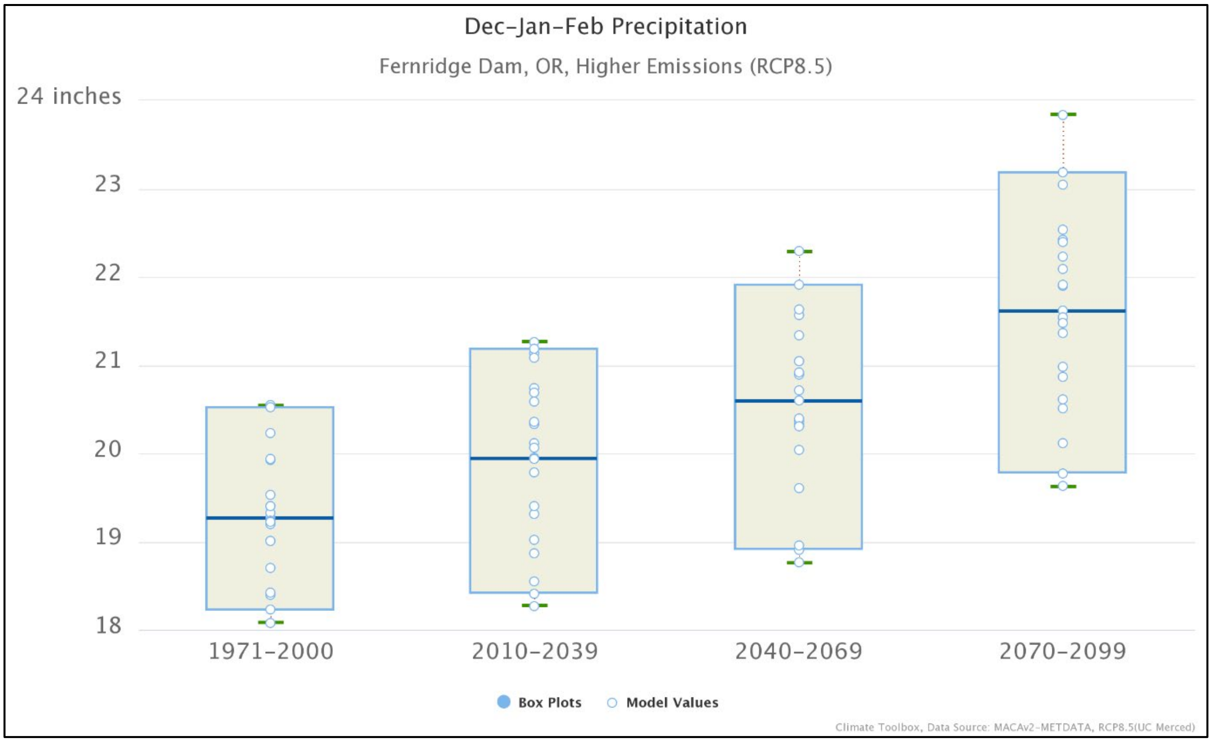


Figure 3-70. Median winter precipitation trend at Fernridge, OR

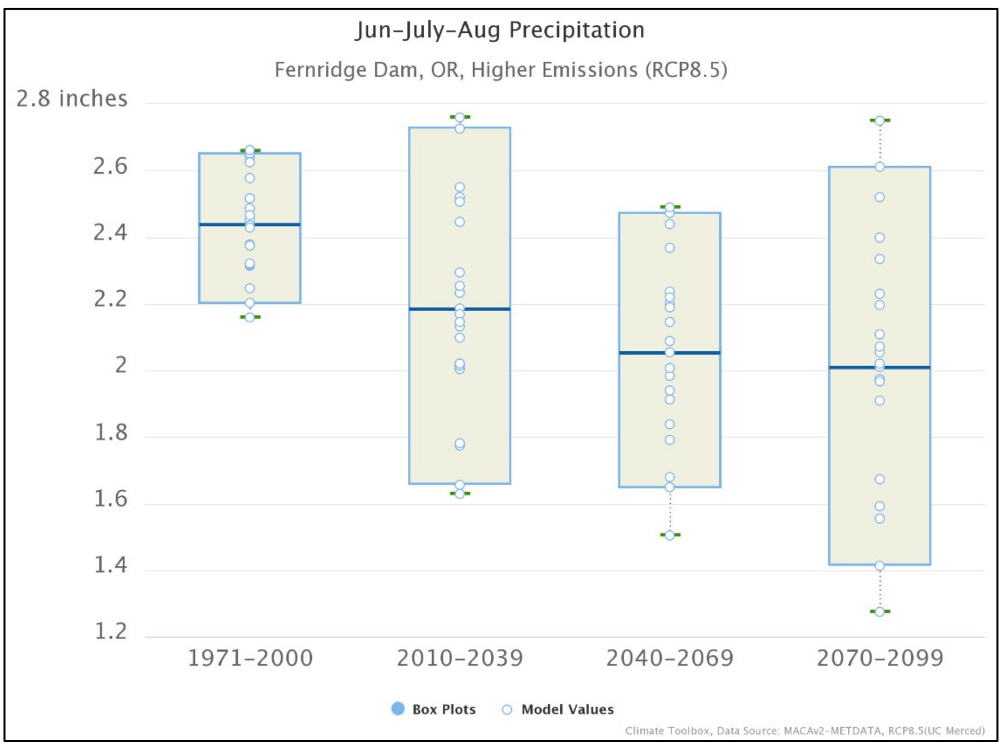


Figure 3-71. Median summer precipitation trend at Fernridge, OR

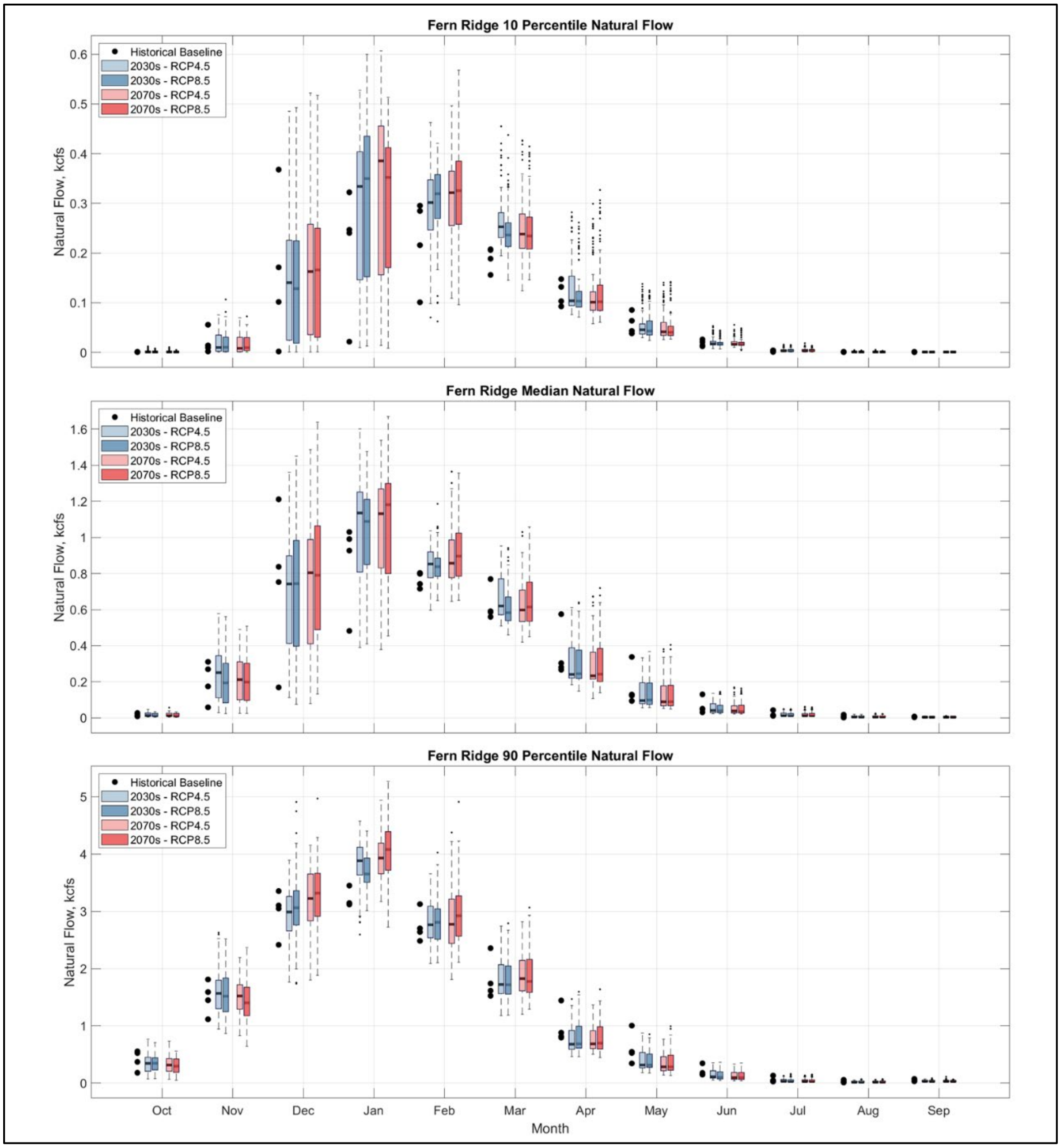
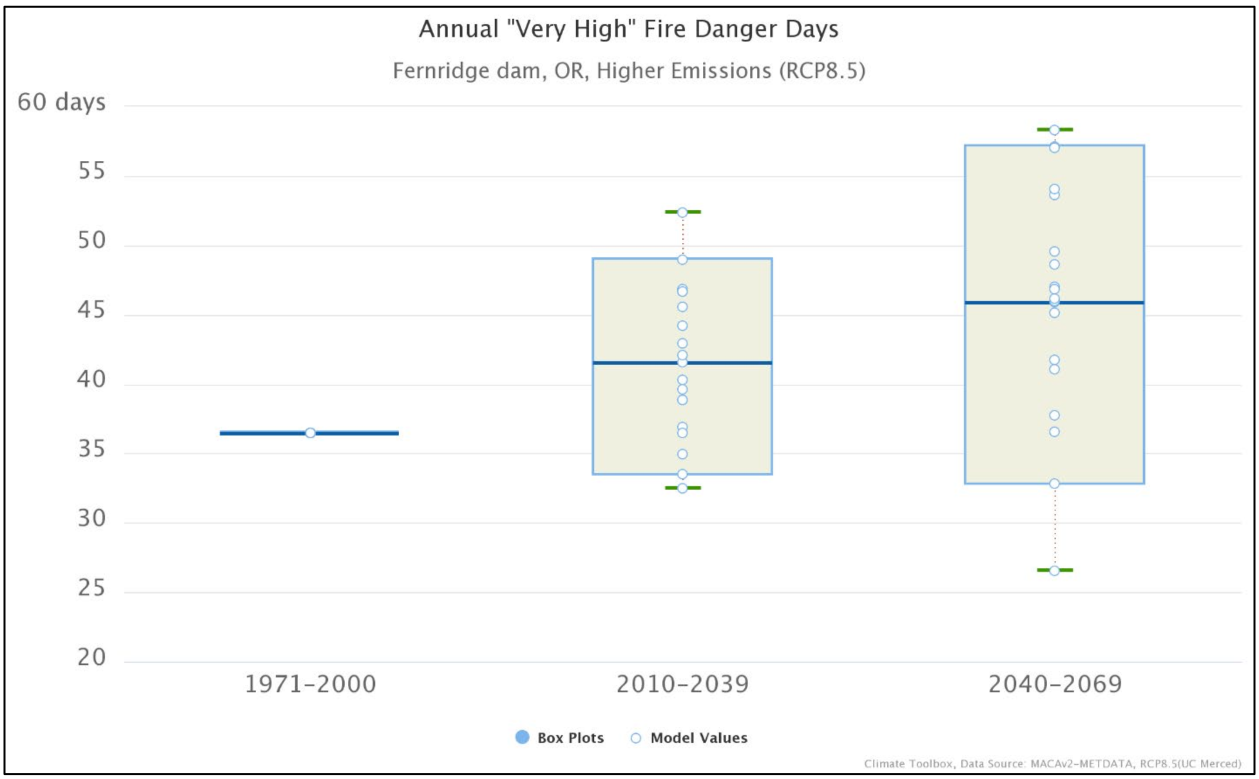


Figure 3-72. Long Tom River at Fernride dam, OR, summary hydrographs

Table 3-12. FRN Median flow change

FRN Median change - RCP 8.5 2030s and 2070s vs Historical baseline (1976-2005)						
	10th Percentile kcfs		Median kcfs		90th Percentile kcfs	
Month	2030s	2070s	2030s	2070s	2030s	2070s
Oct	0	0	0	0	-0.1	-0.15
Nov	-0.005	-0.005	-0.01	-0.01	0	-0.1
Dec	-0.03	0.02	0.04	0.05	0.2	0.4
Jan	0.17	0.17	0.28	0.37	0.3	0.8
Feb	0.11	0.14	0.02	0.11	-0.1	0
Mar	0.05	0.05	-0.11	-0.09	-0.1	0
Apr	-0.02	-0.02	-0.16	-0.16	0.7	0.7
May	-0.01	-0.01	-0.06	-0.06	-0.3	-0.35
Jun	0	0	-0.07	-0.07	-0.2	-0.2
Jul	0	0	-0.005	-0.005	-0.18	-0.18
Aug	0	0	0	0	-0.09	-0.09
Sep	0	0	0	0	-0.09	-0.09

As shown in Figure 3-72 and corresponding Table 3-12 , Long Tom streamflows are likely to be more variable, with ensemble projections showing some negative (albeit, minimal) median shifts in March. Still, the future WVS pattern of wetter winters and lower baseflows in the summer, still holds.



Source: climatetoolbox.org, 2021

Figure 3-73. Fernridge, OR Annual Very High Fire Danger Days

Fire danger in the Long Tom, at Fern Ridge, OR is reflective of the similar fire risk in the Upper Willamette at Salem and Albany, OR for example. These valley floor locations show median changes that are relatively lower as compared to higher elevation, wilder subbasins (North and South Santiam subbasins, for example. The overall trend is towards higher fire danger in the future.

CHAPTER 4 – REFERENCES

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