US Army Corps of Engineers®
Portland District

WILLAMETTE VALLEY SYSTEM OPERATIONS AND MAINTENANCE

FINAL ENVIRONMENTAL IMPACT STATEMENT

APPENDIX F1: QUALITATIVE ASSESSMENT OF CLIMATE CHANGE IMPACTS

APPENDIX F1 HAS BEEN MODIFIED FROM THE DEIS
INSERTION OF LARGE TEXT IS IDENTIFIED; MINOR EDITS ARE NOT DENOTED

Summary of changes from the DEIS:

- **Additional USACE Time Series Tool (TST) runs and graphics were added. The three types of monotonic ("up or down") trend tests and nonstationary tests to the temperature timeseries of interest and to the precipitation timeseries of interest were presented via new TST run output. Additional timeseries analyses were performed and added to the text.**

- **Updated information has been provided to include USACE climate hydrology tool displays of the Climate Hydrology Assessment Tool (CHAT) output related to temperature and precipitation. CHAT plots of projected changes in monthly and seasonal changes of precipitation and ambient temperature were included. The link between increasing summer temperatures and its impact on habitat, hydropower demand, and the need to meet minimum flow requirements were highlighted and discussed throughout the assessment.**

- **Additional information was added to clarify the determination to truncate versus not to truncate the 80+ year period of record (i.e., the record length adopted for trends analysis, based on statistical significance test; Mann-Kendall, Spearman Rank Order Test; t-test, nonstationarity detection (NSD) analysis (as executed via the TST)).**

- **Additional information on wildfires has been added to describe more fully the links between wildfire and hydrologic response both in terms of water quantity and quality impacts.**

- **DEIS Table 7 1, Residual Risk Table for the WVS EIS, was updated. The title has been modified to Residual Risk Table for the WVS EIS Alternatives Analyses.**

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1. INTRODUCTION AND BACKGROUND

This appendix supports the Willamette Valley System (operations) Final Environmental Impact Statement (WVS FEIS). This climate change assessment 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) 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" (USACE 2018a) This document supports the Willamette Valley System Operations Environmental Impact Statement (WVS EIS) effort. There are no sea level rise impacts within the analysis area.

This assessment documents the qualitative effects of climate change on hydrology in the region and informs the climate change assessment being performed by USACE for the Willamette Valley System Environmental Impact Statement (EIS). The original assessment was performed for USACE Risk Management Center (RMC) to assess the potential impacts and risk drivers that 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 natural climate variability occurs and may also be changing the range of that variability.

This is relevant to USACE because the assumptions of stationary climatic baselines and a fixed range of natural variability as captured in the historical 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 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 Snow Water Equivalent (SWE) and seasonal/monthly/regional/elevation snowpack
- Water temperature change (warming)

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Potential climate change shifts will complicate decision making for water managers. Critical linkages exist between rising temperatures and changing rainfall and snowmelt on the projected shifts of seasonal and annual, average, and extreme flow quantity and timing.

The Willamette Valley System (WVS) project design and current water management is predicated on past years of record. WVS flood and conservation space were provided based on estimates of observed record winter and spring volumes as well as the time of year the inflows would occur.

Changing average ambient temperatures and reduced baseflows are changes that will directly stress thermal regulation necessary for ESA-listed fish and other critical and endangered species survival in the Willamette River Basin. These climate change impacts are emphasized under each resource analysis in Chapter 3.0, Affected Environment and Environmental Consequences, and in Chapter 4.0, Cumulative Effects.

END NEW TEXT

The above factors were seen as driving the impacts to future flood risk management and fish operations as well as likely effects to recreation, operations, and maintenance 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 Resilience (CPR) Community of Practice (CoP) (USACE 2023) 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 analysis area encompasses the Willamette River Basin to Willamette Falls at Oregon City. The overall Willamette River Basin is Oregon's largest river basin, containing nearly 70 percent 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 Basin is bounded by the Oregon Coast Mountain Range to the west and the Cascade Mountain Range to the east and is approximately 160 miles long and 100 miles wide. Elevations within the Basin range from approximately 20 feet above sea level at upper Willamette Falls to well beyond 10,000 feet in the Cascade Mountain Range. Tidal influence is up to the face of Willamette Falls.

USACE operates 13 dams and reservoir projects within the Willamette Basin as part of the Willamette Valley System (WVS).

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

Construction of the first of the individual dams that constitute the WVS was completed in 1941 and the last was completed in 1968, with filling complete in 1970. Collectively, the WVS provides nearly 1.7 million acre-feet of flood control storage. In addition to the 13 USACE flood risk management projects within the Willamette River 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, meaning they contribute very little flood storage (i.e., flood space). Figure 1-1 displays the location of these projects within the WVS.

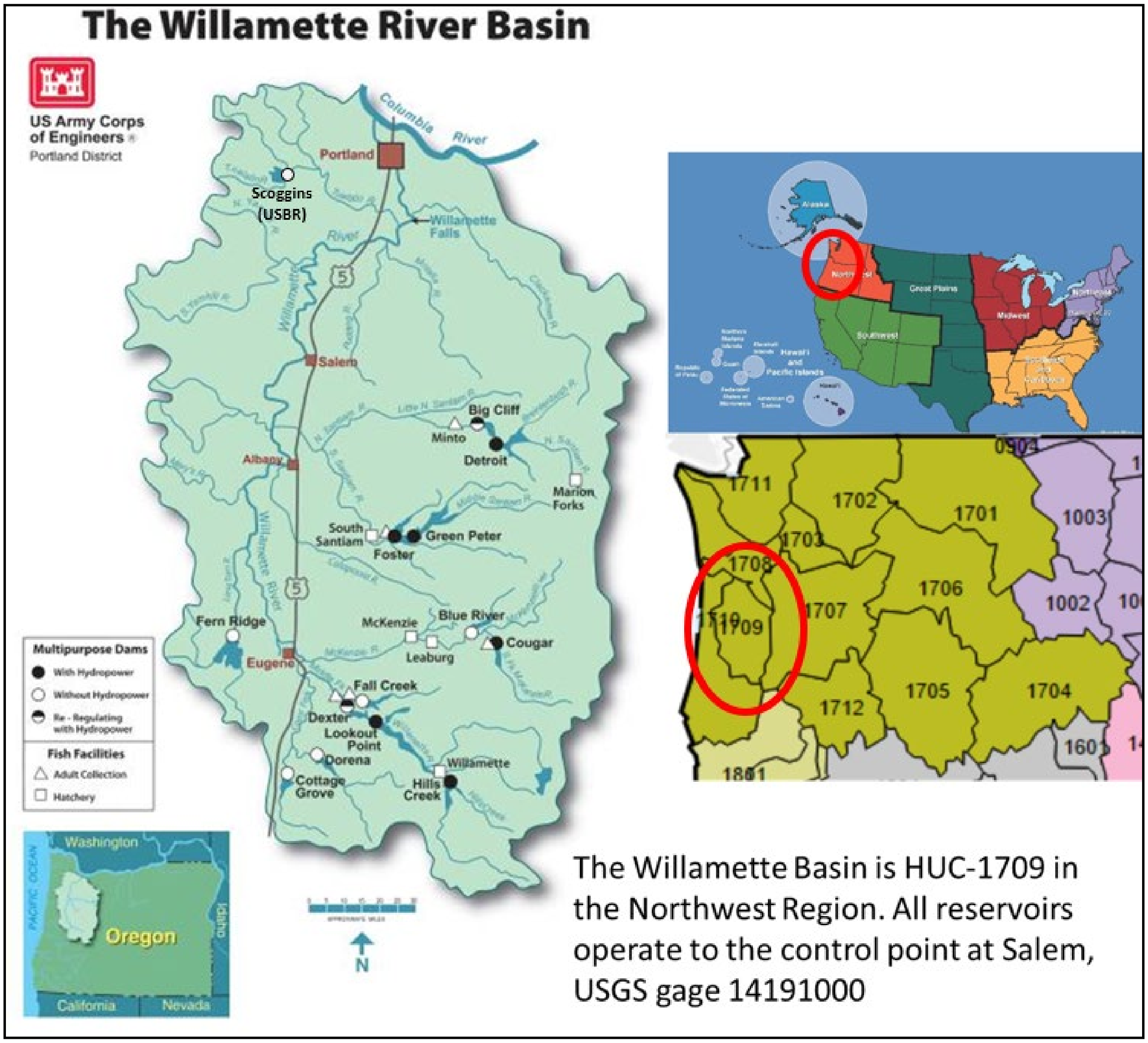

Figure 1-1. Map of the Willamette River Basin.

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 River Basin as well as USBR's Scoggins Dam. Scoggins Dam is not part of the WVS EIS but will be kept in this document as legacy information.

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 five hydrologic groups based on 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. 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 in the Projected Trends in Future Climate and Climate Change section.

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

Eighty-five active stream gages are distributed throughout the Willamette River Basin and there are approximately 94 additional inactive gages. Many of these gages are affected by WVS regulation and even more are impacted by upstream impoundment of another sort. To separate 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 that are largely free of the effects of basin modification. These gages represent natural run-of-the-river morphologic conditions, allowing for greater insight into the impacts potentially caused by climate change. While the pristine gages chosen for analysis were selected primarily because of the lack of regulation within their upstream basins, preference was also given to sites with lengthy annual peak streamflow periods 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 non-stationarity (the assumption that the statistical characteristics of a time-series dataset are constant over the period of record) analysis.

In addition to analyzing the relatively pristine gages, various other gages of interest were selected as hydrologically representative of the Willamette River Basin. These gages are dispersed spatially throughout the Basin as well as through a range of elevations because 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, and nearby WVS locations, are shown in Table 1-2. For gages marked as “regulated” in the far-right 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 13 WVS 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 percent of the 11,200 square miles that comprise 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 WVS total drainage areas (areas above all reservoirs) represent 42 percent of the total Salem drainage area, and about half (51 percent) of the annual water volume passing through Salem has passed through at least one WVS dam.

Table 1-2. Relevant Gages Used in Qualitative Analysis.

USGS Gage Num.	USGS Site Name	Reservoir Group	Peak Streamflow Period of Record	Peak Streamflow Observations	Drainage Area	WVS 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

Flow data available at the USGS Salem gage has been influenced by reservoir operations since 1970. Scoggins Dam was constructed in 1975 but is located downstream of the Salem gage and is not located 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 Willamette River Basin work together to provide flood damage reduction at Salem along with other local control points, and all the projects provide supplemental storage during the summer months to help maintain the Biological Opinion required minimum flow targets, including at Salem.

2. HISTORICAL CLIMATE WITHIN THE WILLAMETTE RIVER BASIN

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

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 River Basin (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, USACE 2017a).

Precipitation. Relatively high precipitation occurs in the Cascade Range, the eastern boundary of the Willamette River Basin, reaching 140 inches or more per year. Precipitation in the Basin is considerably less, varying from 35 to 50 inches per year with 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 historical 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 percent confidence level ($p\text{-value} < 0.05$). Neither of the precipitation datasets analyzed presented a statistically significant trend. Because Salem is only one specific location in the Willamette River Basin, regional temperature and precipitation trends are discussed in more detail within the literature review below.

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Linear regression for observed temperature and precipitation is limited. However, the older time-series datasets were not available as input for other analysis tools, such as USACE Time Series Tool (TST) (Figure 2-1 and Figure 2-2). Therefore, analysis options were limited and the analyses were not extended. However, longer period-of-record streamflow information was available for Salem, OR via the TST.

Temperature and precipitation change trends are important to the alternatives analyses because they are conceptual drivers for runoff and streamflow metrics flow can be a proxy for overall synergistic impact from temperature and precipitation changes. Annual and seasonal flow non-stationarity detection (NSD) and statistically relevant trend tests of observed flows at Salem, OR are summarized in Section 3.5.

Overall, the apparent effect from precipitation and temperature (linear) trends shown in Figure 2-1 and Figure 2-2 was minimal. Conclusive evidence of increasing observed temperatures and a relatively slight increase in annual maximum 1-day maximum precipitation was assumed for the alternatives analyses.

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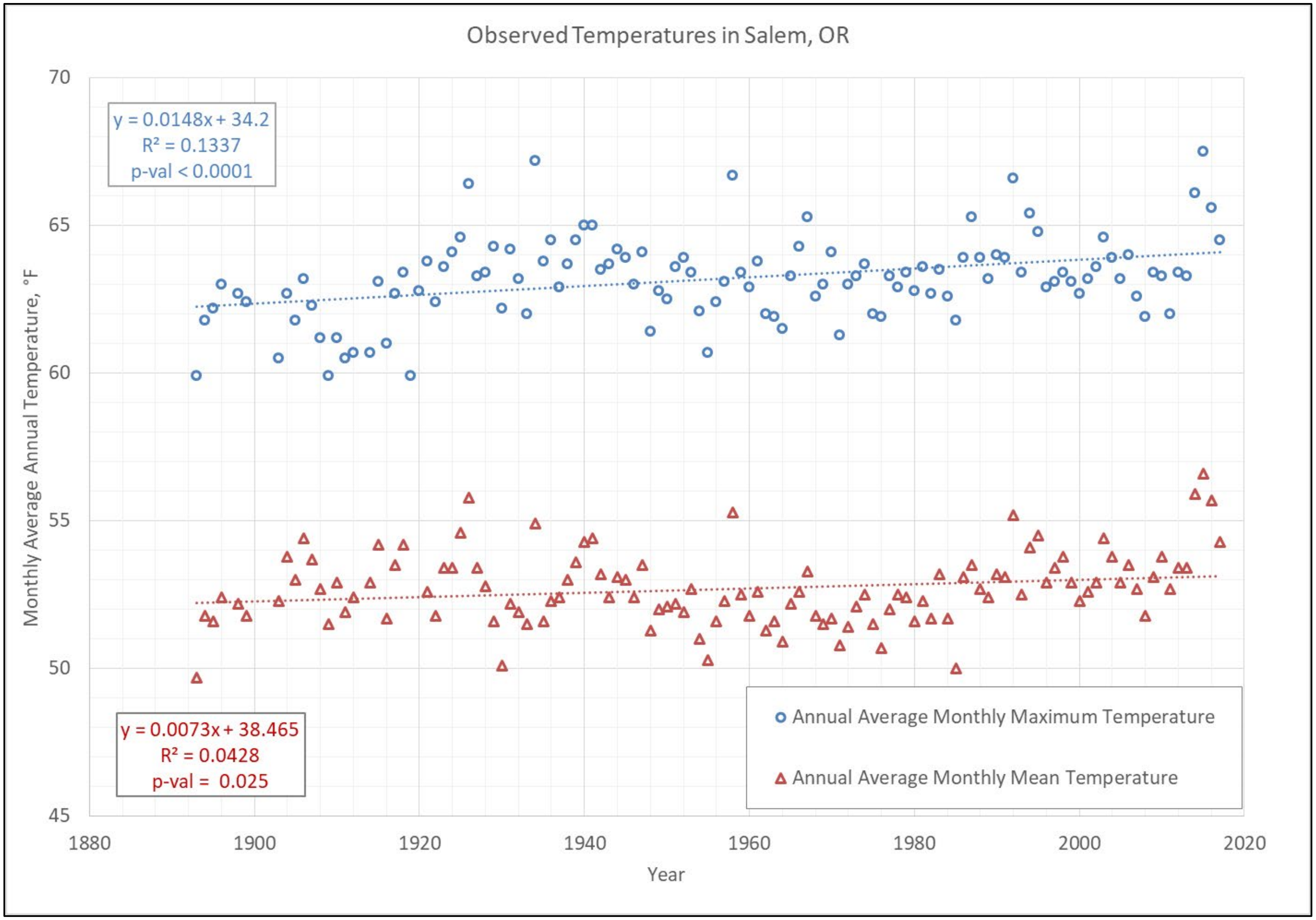

Figure 2-1. Trends in Observed Temperature at Salem, Oregon.

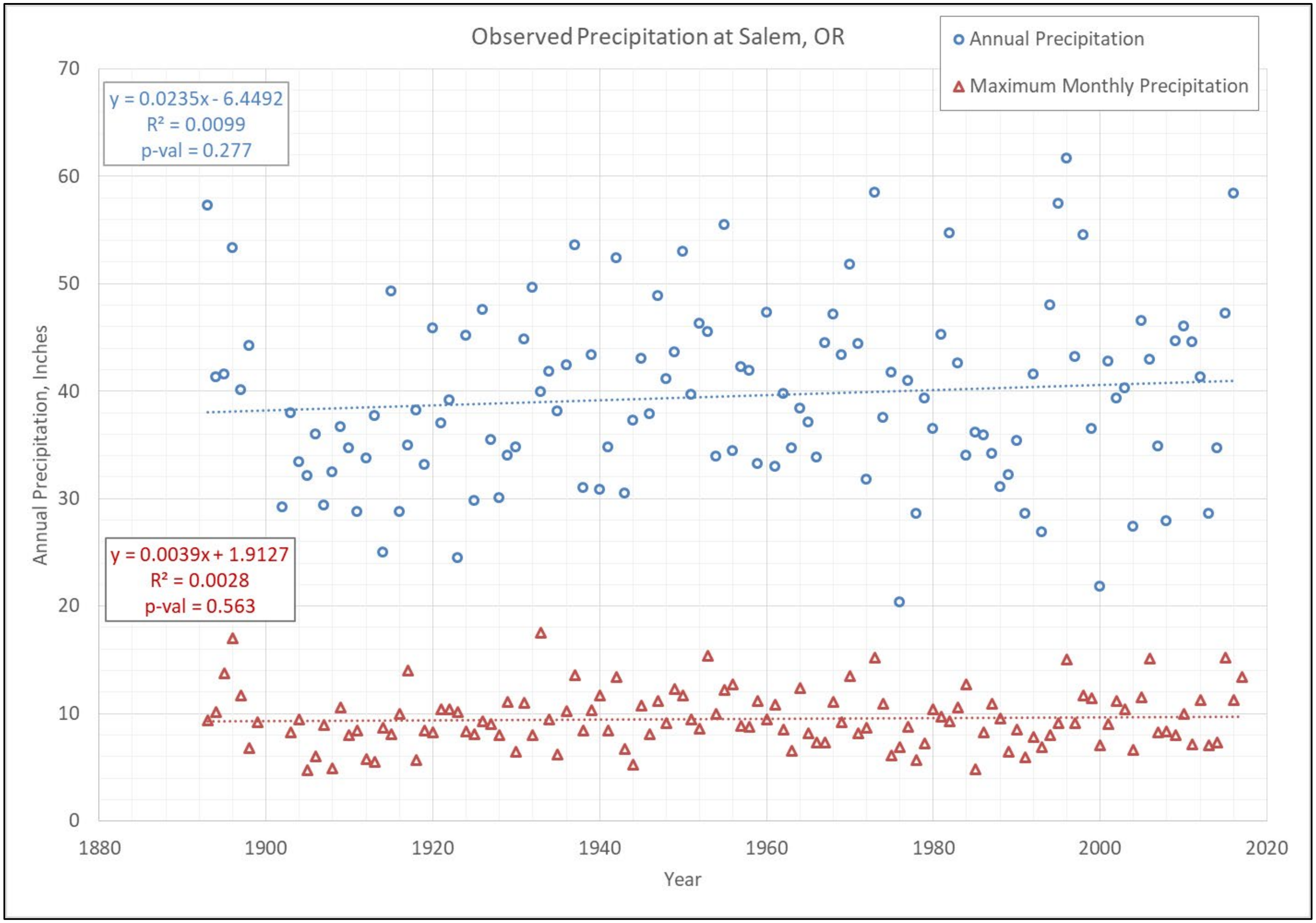

Figure 2-2. Trends in Annual and Maximum Monthly Precipitation.

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Temperature and precipitation trends could not be reproduced by the TST because the original time series datasets were not relocated. However, the Climate Hydrology Assessment Tool (CHAT; developed by USACE) analyses can be utilized as a potential supplemental and/or a surrogate update assessment for the above temperature and precipitation information. The CHAT analyses provide added value by comparing the historical modeled to the projected future trend patterns. Figure 2-3 shows the CHAT analyses hydrologic subbasin and reach around Salem. Note, that CHAT is not used to address OBSERVED value time series trends, but does present synthetic, modeling result during the historical period (1950-2006).

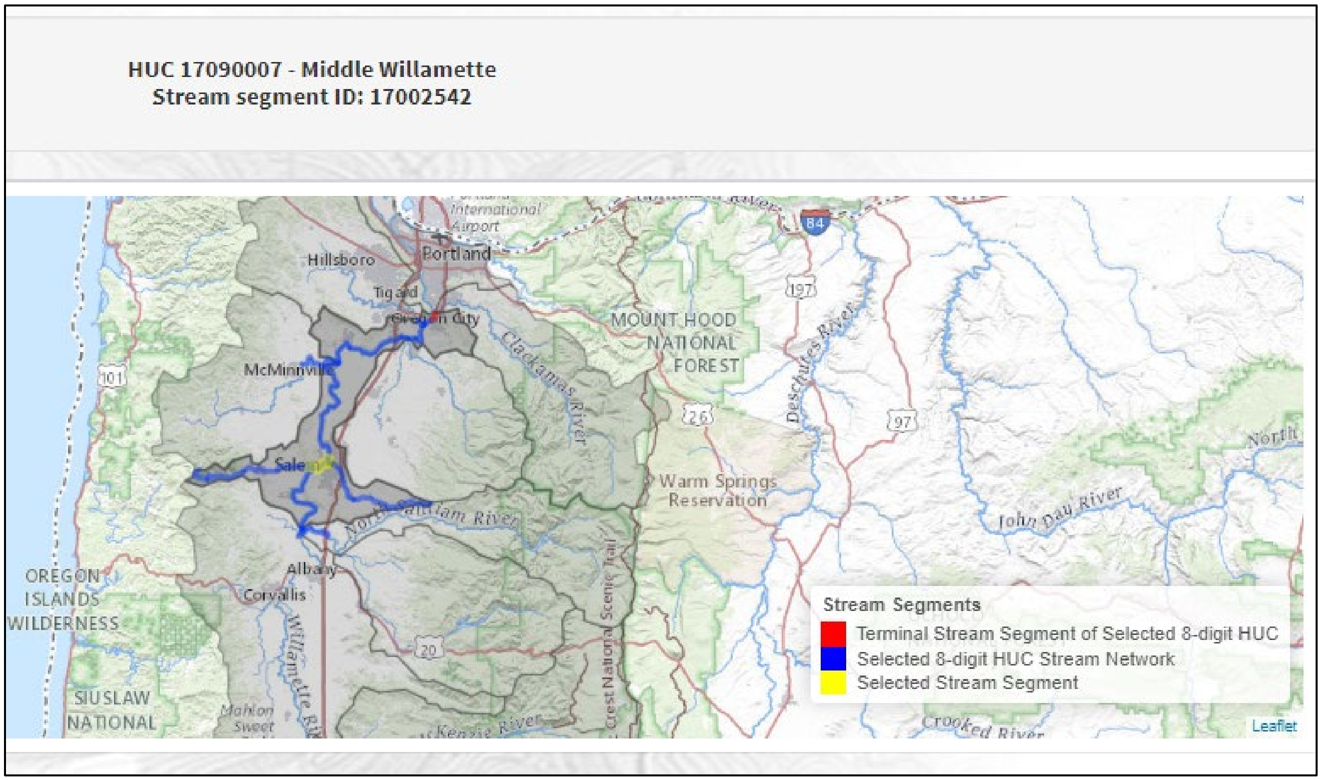


Figure 2-3. Salem, Oregon Assessment Point.

CHAT results are shown in Figure 2-4 and Figure 2-5. Median shifts in November to March precipitation (maximum and average) are increasing in the historical modeled record and the future projected periods. April to September precipitation median change is relatively flat, with some below average drops in precipitation between the historical period and the future projected years. Temperatures are projected to increase for all months and future years (through 2100). The boxplots reflect the trends. It is instructive to note that while median precipitation change is relatively small, there is more pronounced change in the projected streamflow median change. Temperature remains higher overall across all months and future periods.

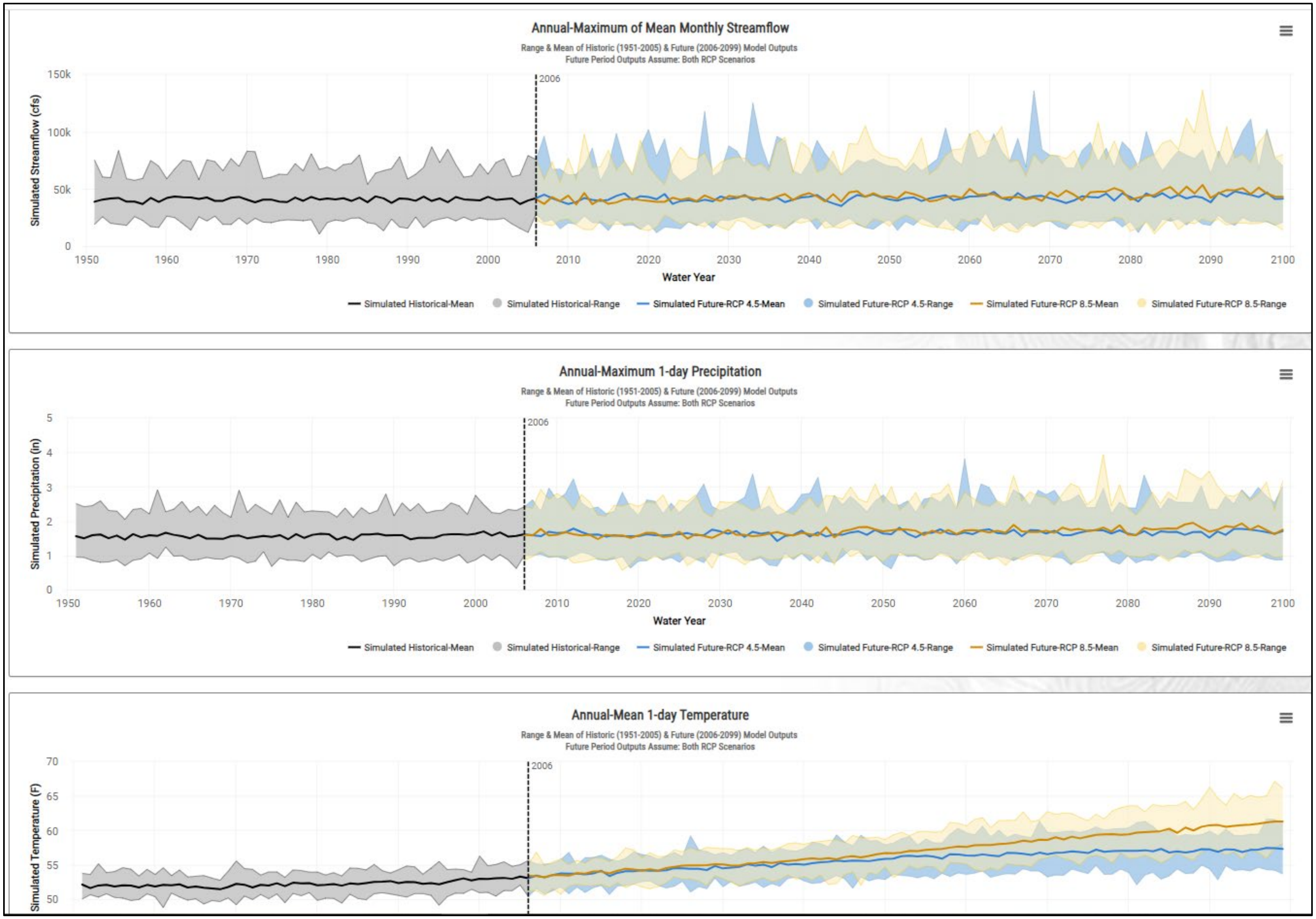
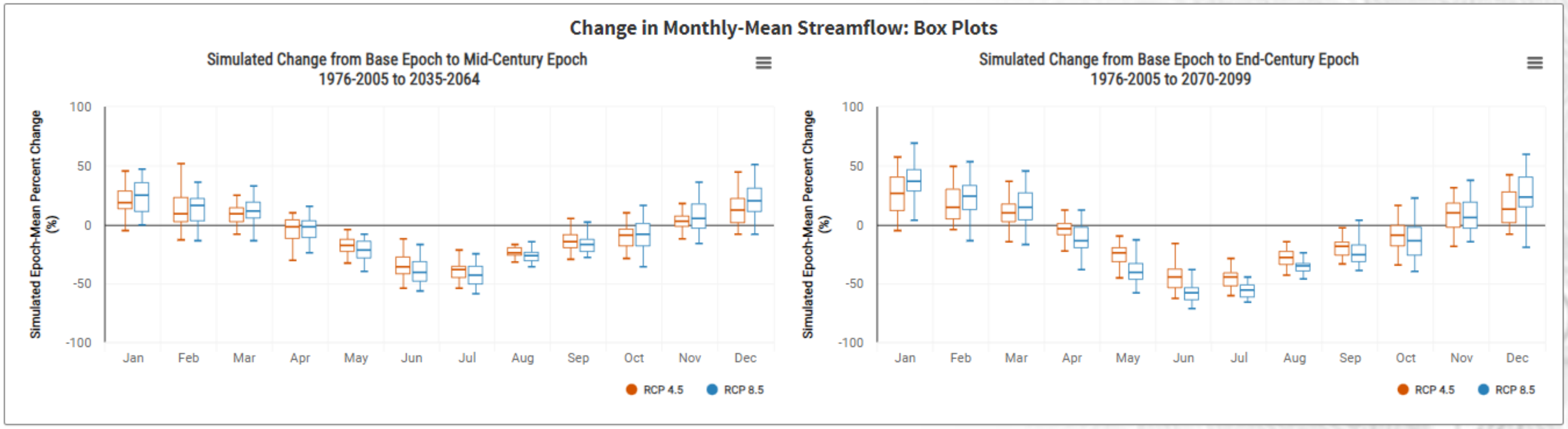
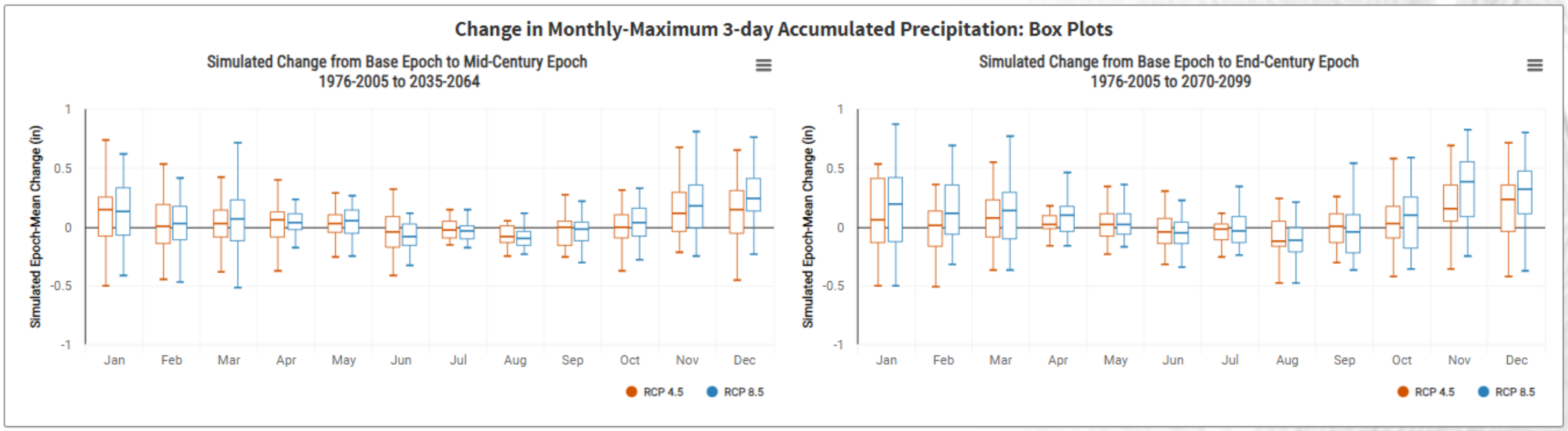


Figure 2-4. Salem, Oregon Observed and Projected Mean Monthly Flow, Precipitation, and Temperature Trends.


Change in Monthly-Mean Streamflow: Box Plots
Simulated Change from Base Epoch to Mid-Century Epoch
1976-2005 to 2035-2064
Simulated Change from Base Epoch to End-Century Epoch
1976-2005 to 2070-2099
Simulated Epoch-Mean Percent Change (%)
100
50
0
-50
-100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
RCP 4.5
RCP 8.5


Change in Monthly-Maximum 3-day Accumulated Precipitation: Box Plots
Simulated Change from Base Epoch to Mid-Century Epoch
1976-2005 to 2035-2064
Simulated Change from Base Epoch to End-Century Epoch
1976-2005 to 2070-2099
Simulated Epoch-Mean Change (in)
1
0.5
0
-0.5
-1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
RCP 4.5
RCP 8.5

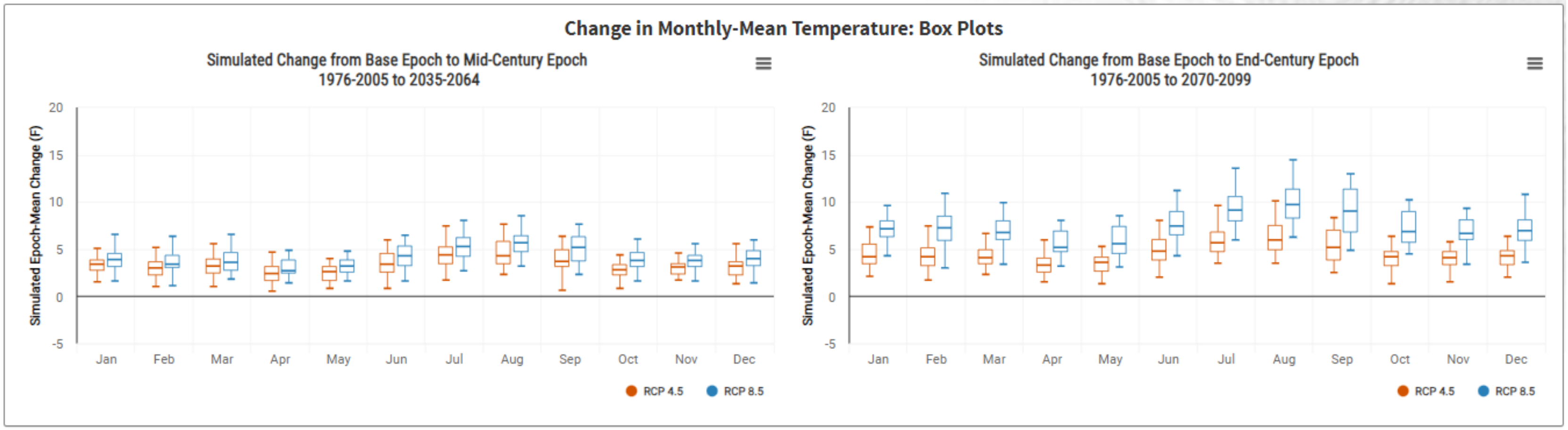


Figure 2-5. Salem, Oregon Mean Monthly Flow, Precipitation, and Temperature Trend Box Plots.

END NEW TEXT

3. OBSERVED TRENDS IN CURRENT CLIMATE LITERATURE REVIEW

3.1 Climate Change Literature Syntheses

The September 2015 Literature Synthesis (known hereafter as the Literature Synthesis) conducted by the USACE Institute of Water Resources summarizes the available peer-reviewed literature related to trends in both observed and projected hydrometeorological variables for the Pacific Northwest Region (HUC 1709), which includes the Willamette River Basin. Figure 3-1 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. The number of relevant literature studies reviewed would likely increase for all hydrologic variables should this figure be updated. The literature review focuses on trends in observed, historical temperature, precipitation, and hydrology/streamflow changes.

Temperature. The 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 River Basin.

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Precipitation. According to the 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.” There is a high level of consensus across the studies that more intense and extreme precipitation (high intensity) events are likely in the future. There is less literature consensus for observed extreme precipitation events.

Extreme precipitation trends may be tied closer to future changes to atmospheric rivers, but this is still being studied. Lower precipitation extremes are correlated to drought cycle trends that are harder to understand. The episodic changes can progress over decades and it’s difficult to determine if an observed trend is the result of long-term but natural variability or due to a real shift in weather patterns due to climate change. Given this uncertainty, resilience can be increased through measures that make available and/or increase additional system storage capacity.

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Hydrology / Streamflow. The 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 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.

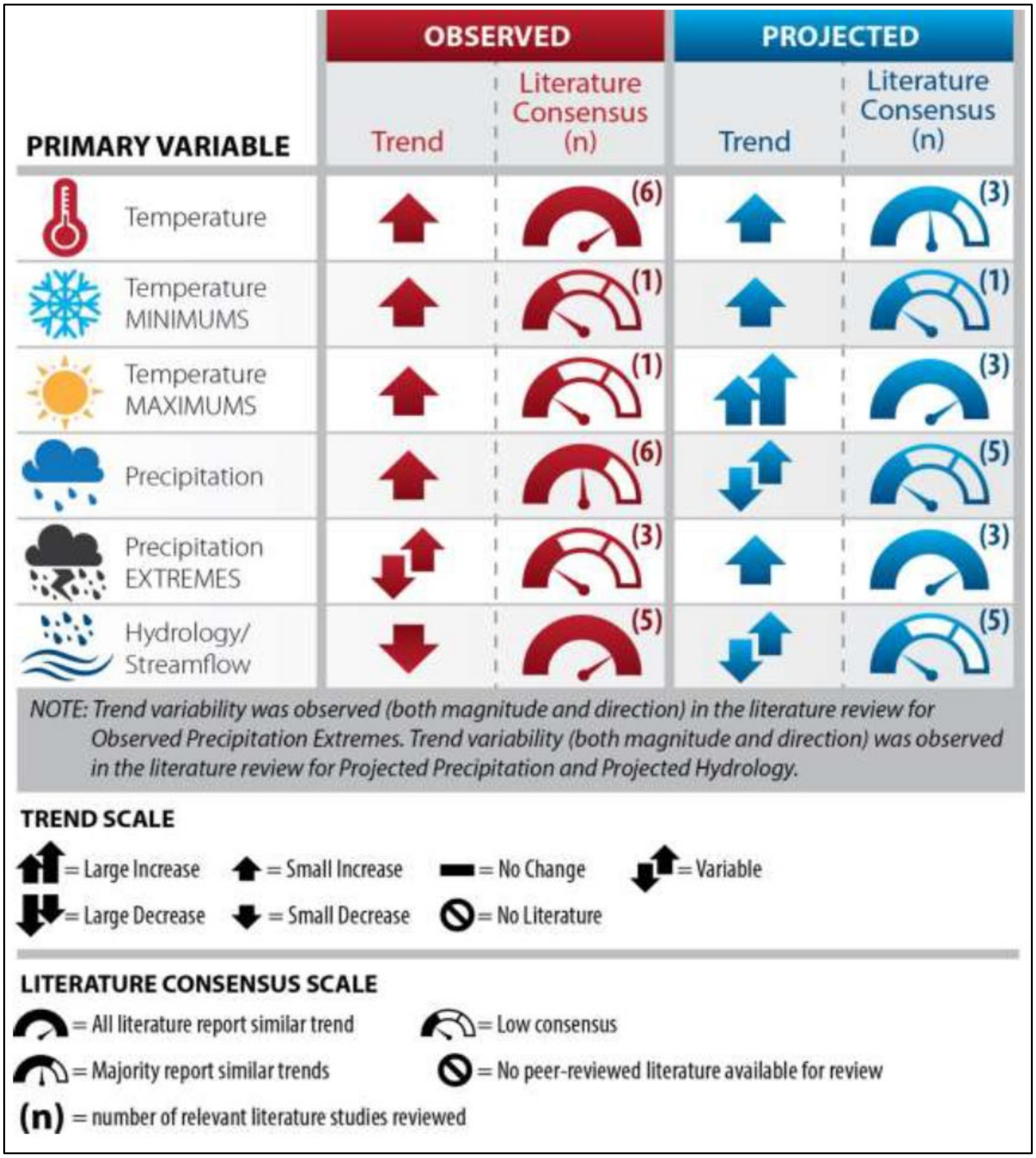

Figure 3-1. Summary of Literature Review Findings.

3.2 Fourth National Climate Assessment

The Fourth National Climate Assessment (NCA4) Volume II, released in 2018 (USGCRP 2018a, 2018b, 2018c), 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 in this qualitative analysis are the chapters regarding changing climate, water, and the Pacific Northwest Region (hereafter the Pacific Northwest), 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 through 2016 as compared with the historical average from the period 1901 through 1960 (for the continental U.S.). Note that virtually the entire Pacific Northwest, and much of the western U.S., has experienced warming of 1 to 2 degrees Fahrenheit. The approximate analysis area is circled in red in the following figures.

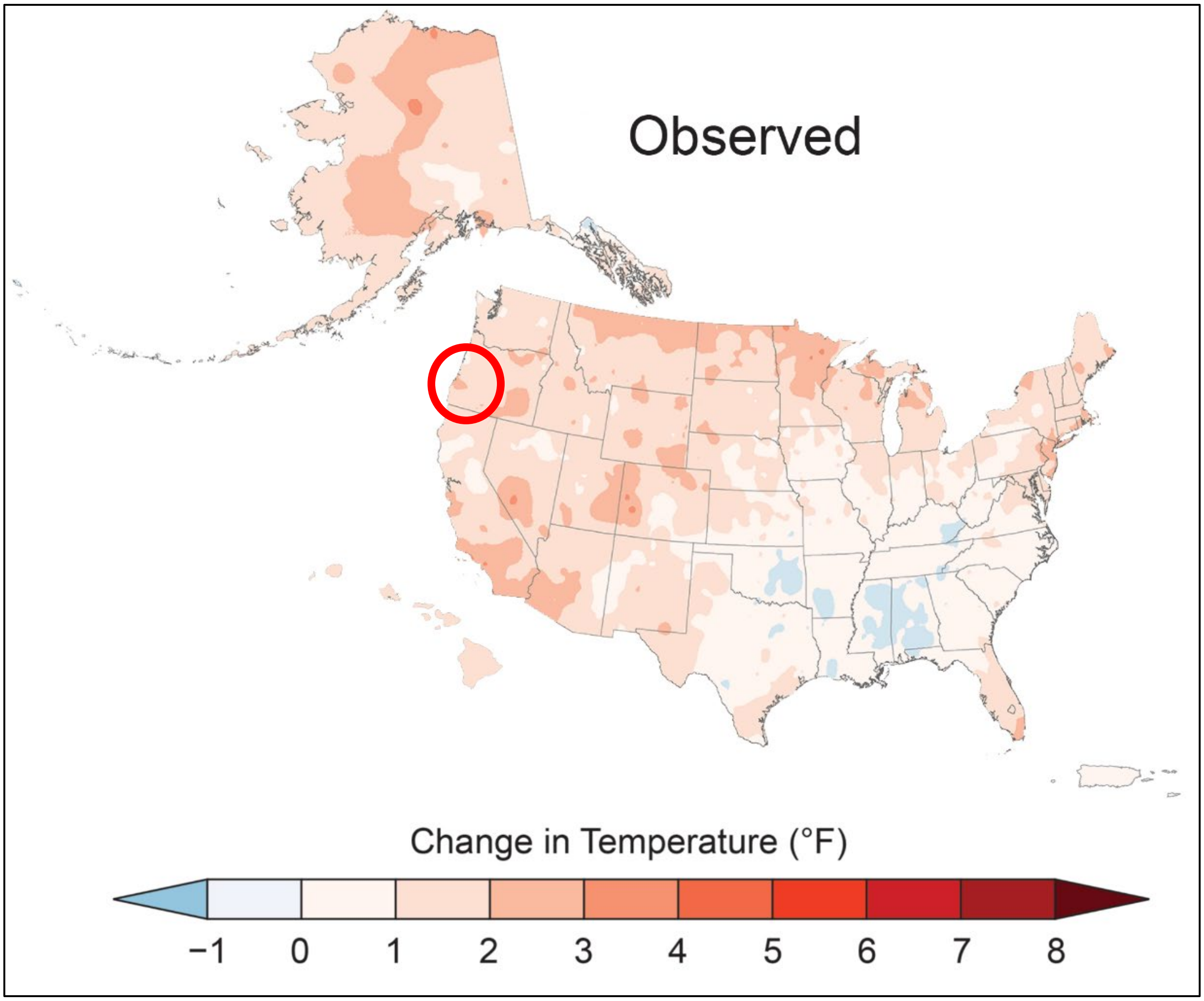

Figure 3-2. Observed Changes in Temperature.

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. Regional variation in observed precipitation change is much greater than in 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 1986 through 2015 as compared with the historical baseline of 1901 through 1960. Looking more closely at the Pacific Northwest, most of the state of Oregon in the vicinity of the Willamette River Basin has observed an increase in annual precipitation between 0 percent and 5 percent, with some isolated areas experiencing a change between 5 percent and 10 percent.

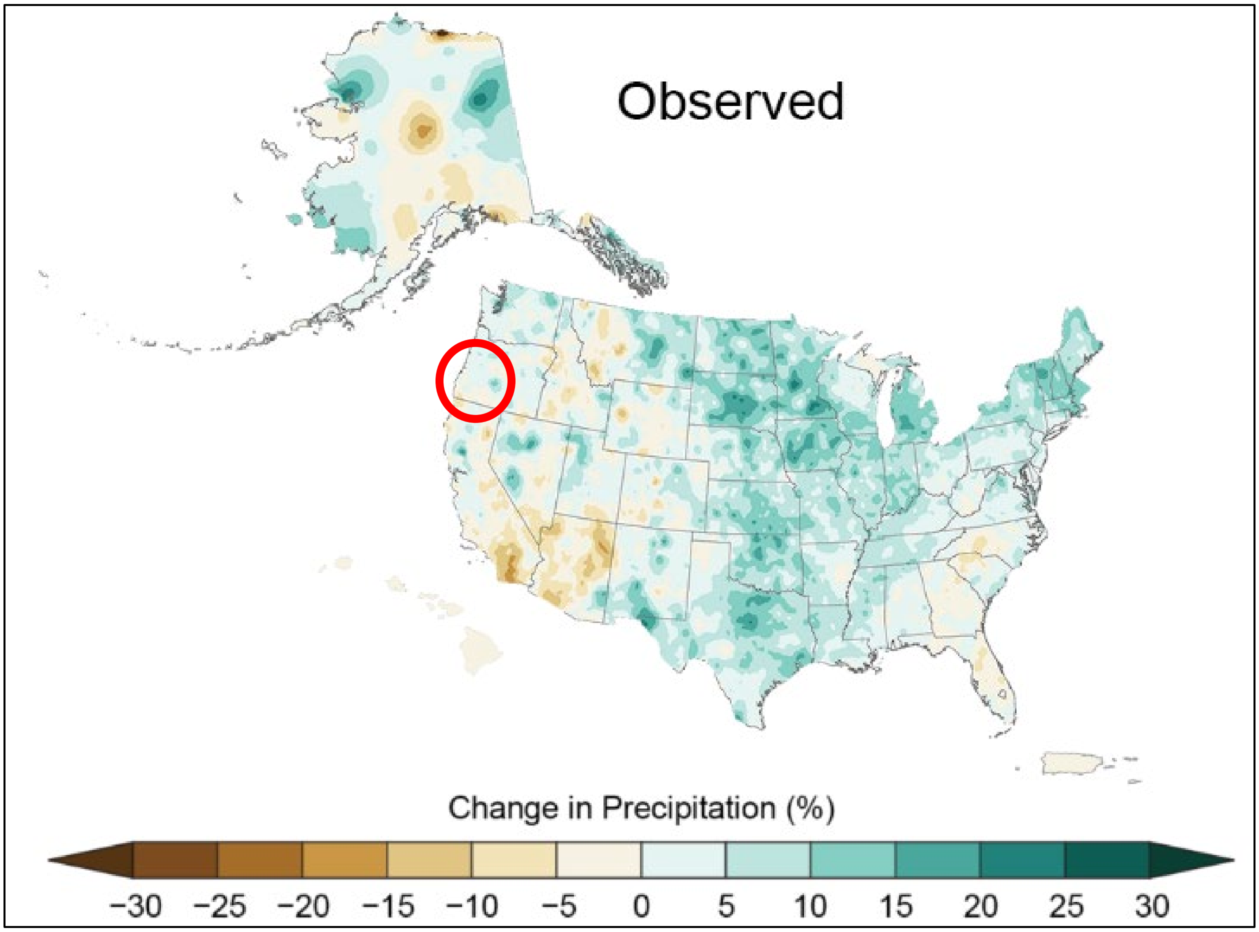

Figure 3-3. Observed Changes in Precipitation.

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 percent of events (99th percentile of the distribution). The left map within Figure 3-4 displays the percent difference between the 1901 and 1960 historical baseline versus the 1986 to 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 sides of the figure, the Pacific Northwest has experienced a moderate increase in the precipitation falling during extreme events. This indicates that extreme events have become 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.

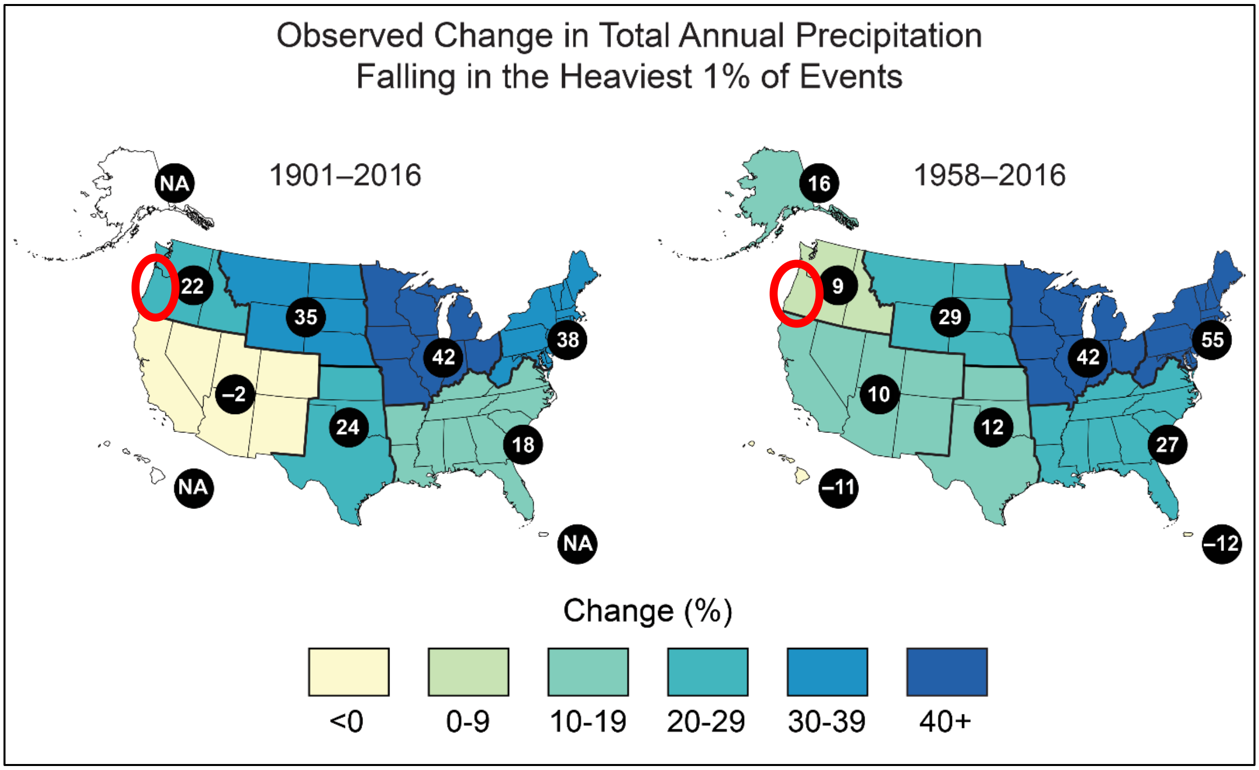

Figure 3-4. Observed Precipitation Change during the Heaviest 1% of Events.

3.3 Climate Hydrology Assessment

Statistical trend analyses, as executed via the Time Series Tool, TST, was used to examine trends in observed annual peak streamflow for the various gage locations shown in Table 1-2. TST 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 results presented in this section are focused on flood peaks. For discussion of other streamflow metrics of interest to the analysis, such as low flow periods and conservation season runoff volume, refer to Section 3.5.

Many of the flow gages selected for trend analysis have been heavily impacted by regulation over different periods of time. For gages where the observed period of record includes regulation effects, the annual peak streamflow dataset cannot be considered homogenous, and it is difficult to draw conclusions based on 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 TST. The annual peak data from 1893 through 1940 represents a pre-regulation dataset because no reservoirs were constructed upstream of the gage until 1941. The time period of 1941 through 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 the period of record can thus roughly be considered homogenous in terms of reservoir operation. For these reasons, the period of record for the Willamette River at Salem was analyzed over three time periods: 1) complete heterogenous 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 a 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 because 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 minor. Nonstationarity detection results, discussed below, offer further insight into the homogeneity of the peak streamflow dataset.

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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 TST. Verification was made such that the subsets of data analyzed for trends and nonstationarity detections (NSDs) are consistent with what is recommended by the guidance. It is likely that "strong" nonstationarities are associated with the year when the dam was constructed. However, NSD is also driven by irrigation changes associated with farming and land clearing occurring as the region developed. NSDs are not automatically due to a "climate change signal" but are likely due to changes in normal water management operations and irrigation. Further NSDs at Salem, OR, described in Section 3.5, point to very low record sensitivity.

END NEW TEXT

A summary of the regression trends and their statistical significance is shown in Figure 3-5. Individual graphical output for each gage and period of record analyzed is shown in Figure 3-5 through Figure 3-22. Note that only five strongly statistically significant trends ($p\text{-value} < 0.05$) were detected, four of which 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.

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

Gage Number	Gage Name and Location	POR Used	Period of Record Note	Regression Slope	P-value	Trend Direction	Trend Significance	Trend?
14191000	Willamette at Salem	1892-2014	Complete, minus gaps	**-824.S**	**<0.0001**	**Downward**	**Strong**	Yes
14191000	Willamette at Salem	1892-1941	Reregulation	-1026.3	0.142	Downward	Weak	No
14191000	Willamette at Salem	1970-2014	Post-regulation	-493.5	0.306	Downward	Insignificant	No
14191000	Willamette at Salem	1928-2008	No Regulation, No Irrigation	198.5	0.589	Downward	Insignificant	N/A
14190500	Luckiamute at Suver	1941-2014	Complete, minus gaps, pristine	-15.6	0.66	Downward	Insignificant	No
14178000	North Santiam blw Boulder	1929-2014	Complete, pristine	2.6	0.896	Neutral	Insignificant	No
14181500	North Santiam at Niagara	1939-2014	Complete, minus gaps	**-138.4**	**<0.0001**	**Downward**	**Strong**	Yes
14181500	North Santiam at Niagara	1955-2014	Post-regulation	-34	0.143	Downward	Weak	No
14181500	North Santiam at Niagara	1928-2008	No Regulation, No Irrigation	41.6	0.344	Upward	Insignificant	N/A
14153500	Coast Fork nr Cottage Grove	1939-2014	Complete	**-12.8**	**0.002**	**Downward**	**Strong**	Yes
14153500	Coast Fork nr Cottage Grove	1943-2014	Post-regulation	**-12.1**	**0.009**	**Downward**	**Strong**	Yes
14153500	Coast Fork nr Cottage Grove	1928-2008	No Regulation, No Irrigation	-11.4	0.178	Downward	Very Weak	N/A
14154500	Row River near Dorena	1936-2014	Complete, pristine	-15.5	0.578	Downward	Insignificant	No
14154500	Middle Fork Willamette nr Dexter	1947-2014	Complete	**-263.1**	**<0.0001**	**Downward**	**Strong**	Yes
14150000	Middle Fork Willamette nr Dexter	1967-2014	Post-regulation	18.6	0.552	Upward	Insignificant	No
14150001	Middle Fork Willamette nr Dexter	1928-2008	No Regulation, No Irrigation	-22	0.761	Downward	Insignificant	N/A
14187200	South Santiam nr Foster	1974-2014	Complete/Post-regulation	-17.6	0.705	Downward	Insignificant	No
14187200	South Santiam nr Foster	1928-2008	No Regulation, No Irrigation	23.2	0.725	Upward	Insignificant	N/A

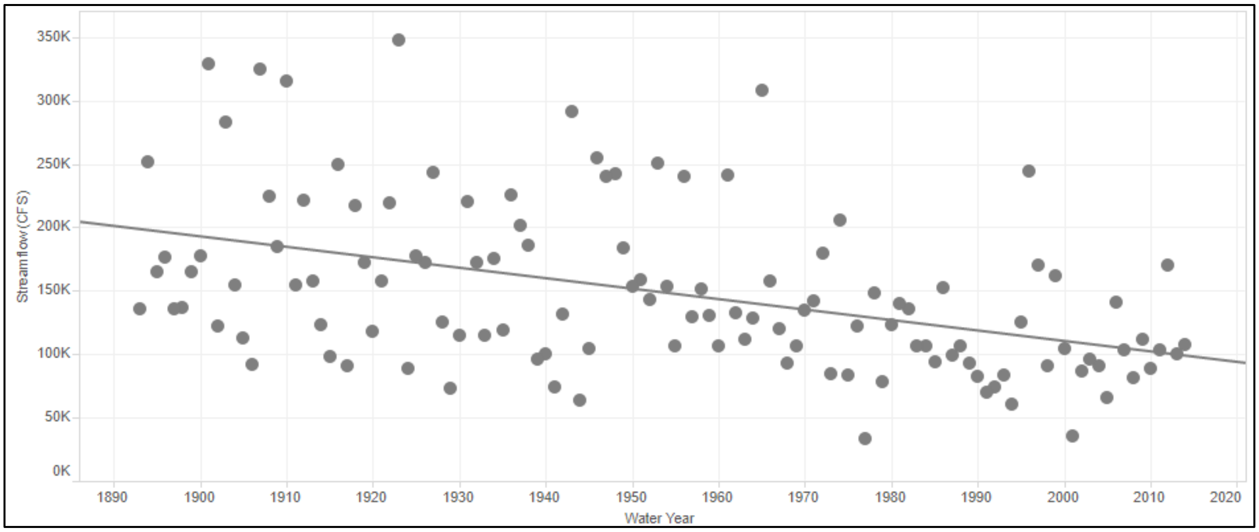

Figure 3-5. Willamette at Salem Complete Period of Record, 1892 through 2014.

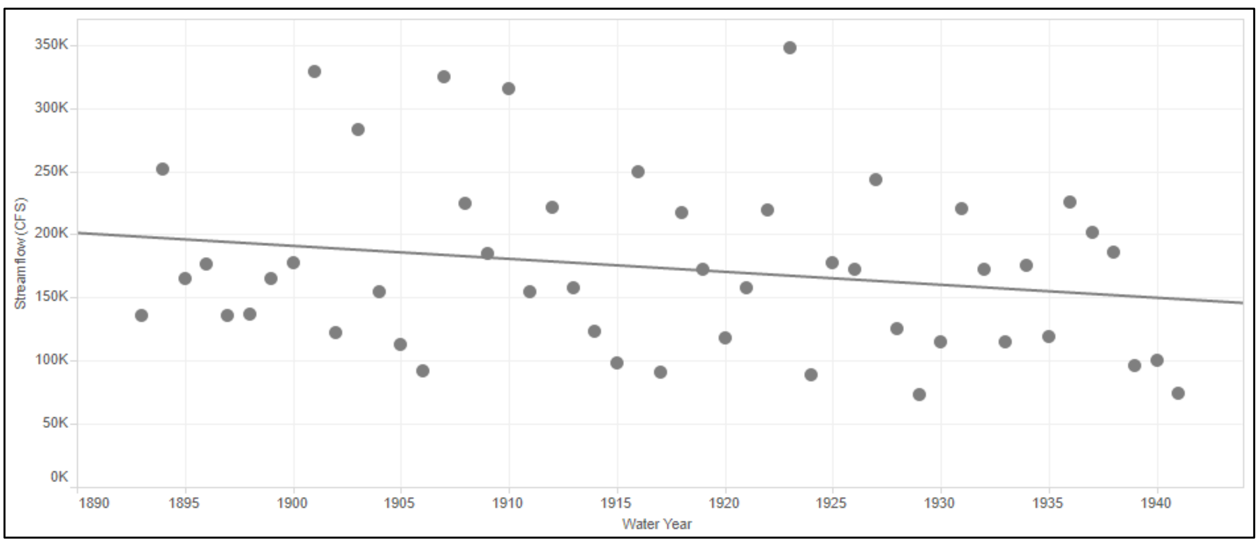

Figure 3-6. Willamette at Salem, Pre-regulation, 1892 through 1941.

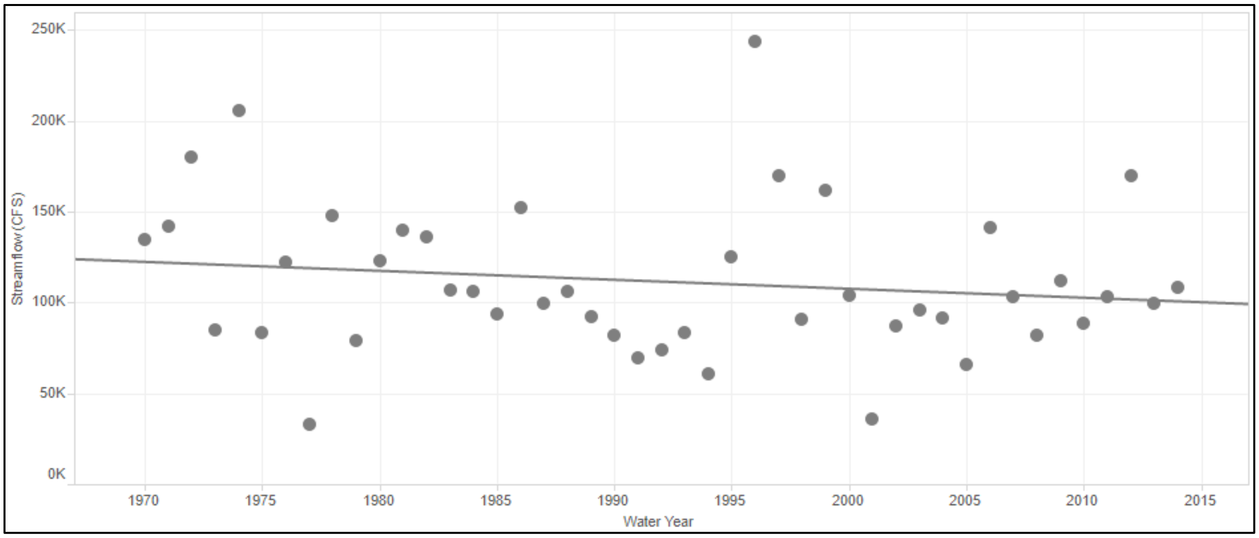

Figure 3-7. Willamette at Salem, Post-regulation, 1970 through 2014.

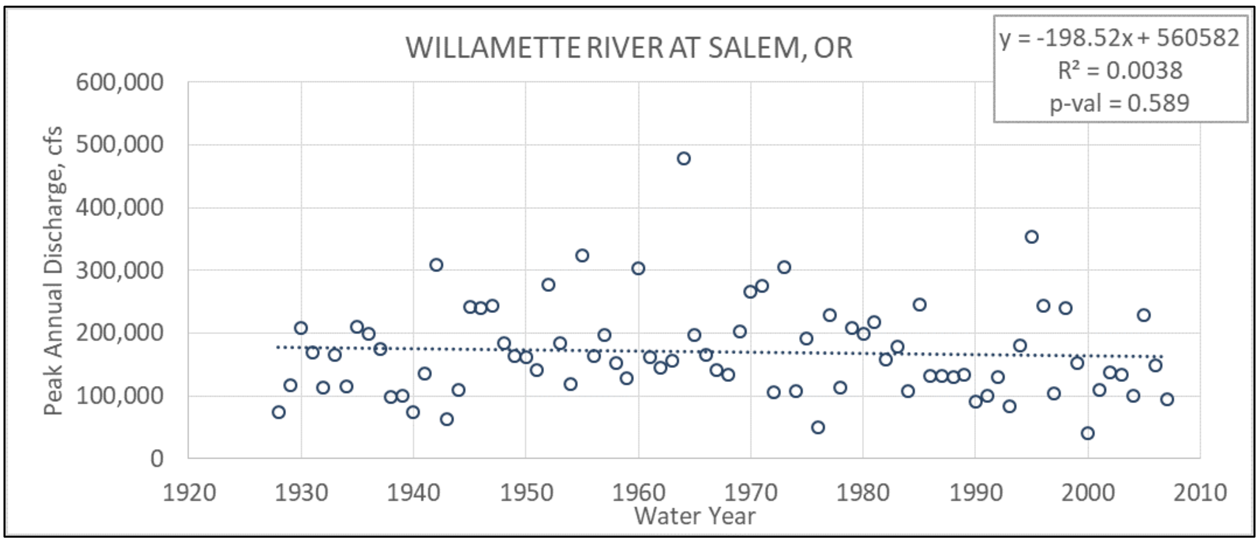

Figure 3-8. Willamette at Salem, Naturalized Flows, 1928 through 2008.

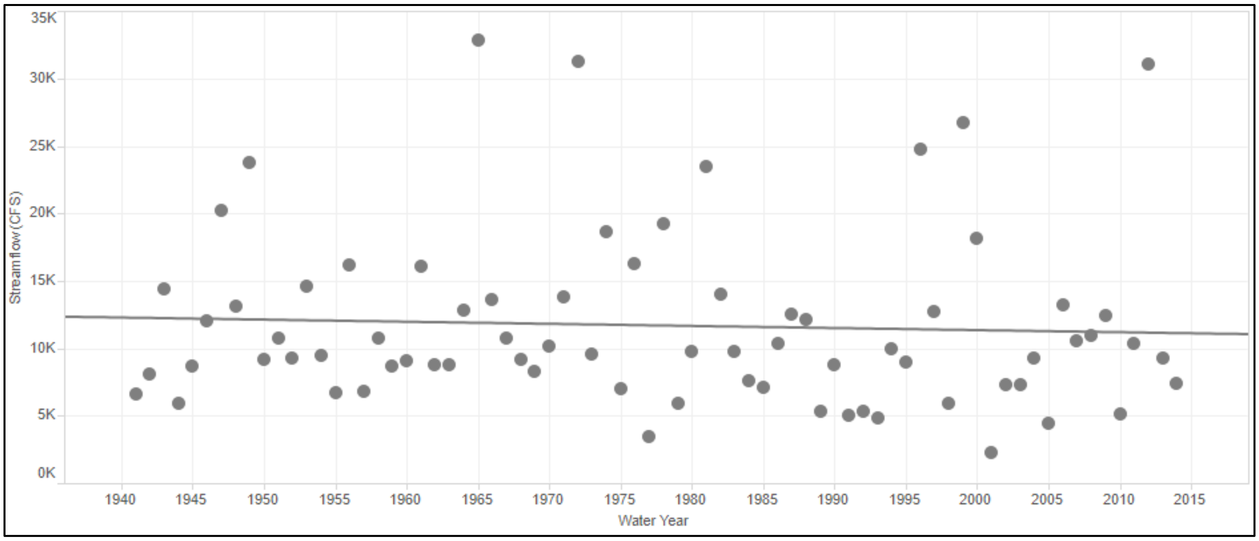

Figure 3-9. Luckiamute River near Suver, Complete Period of Record (minus data gaps), 1941 through 2014. Pristine.

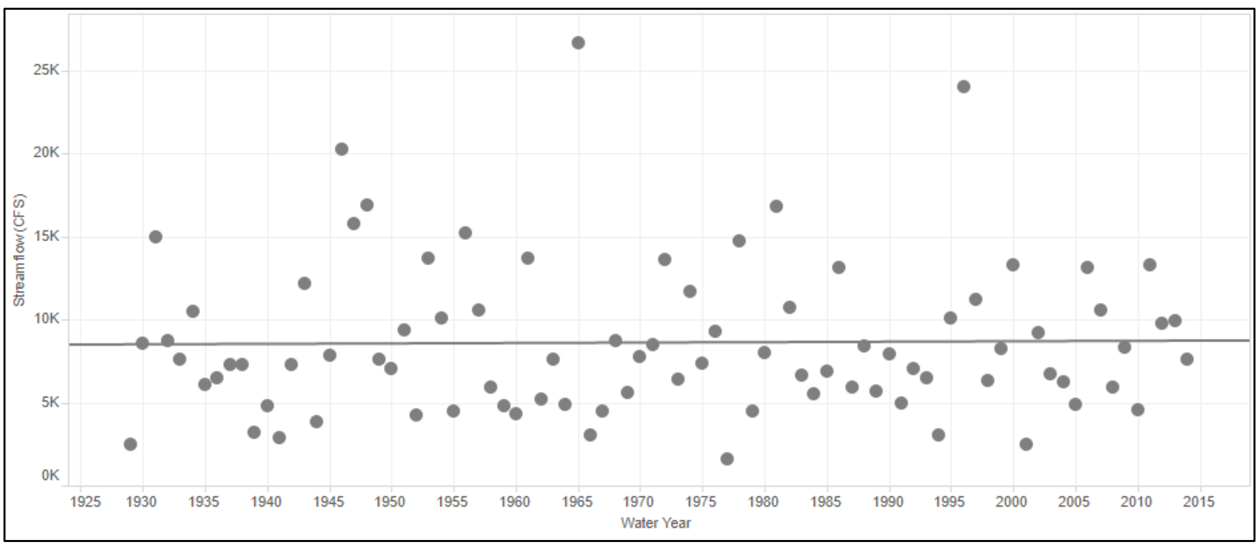

Figure 3-10. N. Santiam River below Boulder, Complete Period of Record, 1929 through 2014. Pristine.

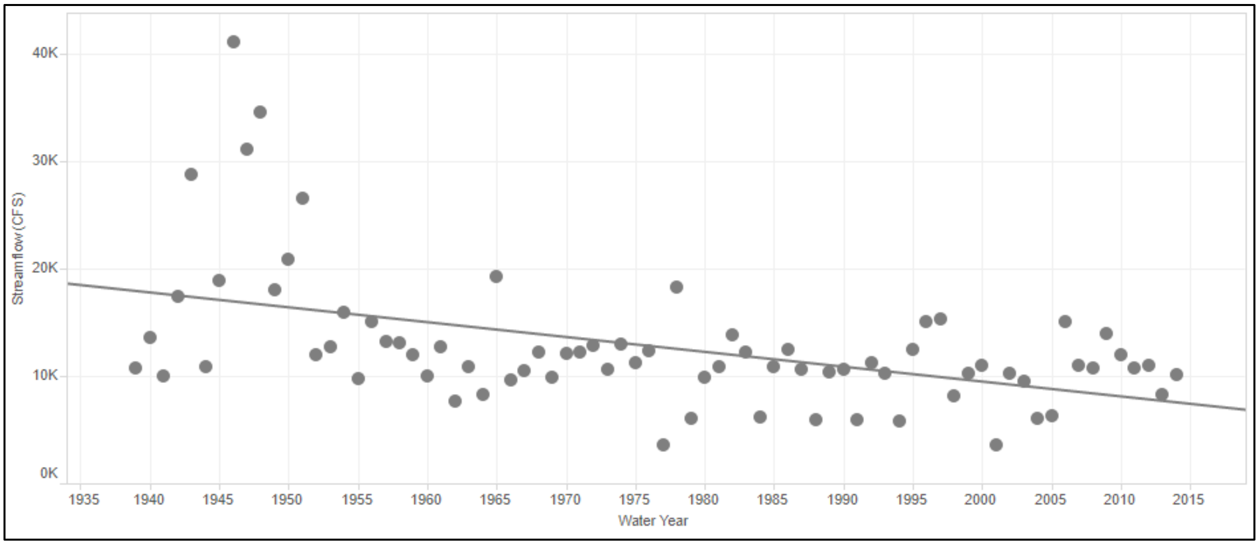

Figure 3-11. N. Santiam River at Niagara, Complete Period of Record (Minus Data Gaps), 1939 through 2014.

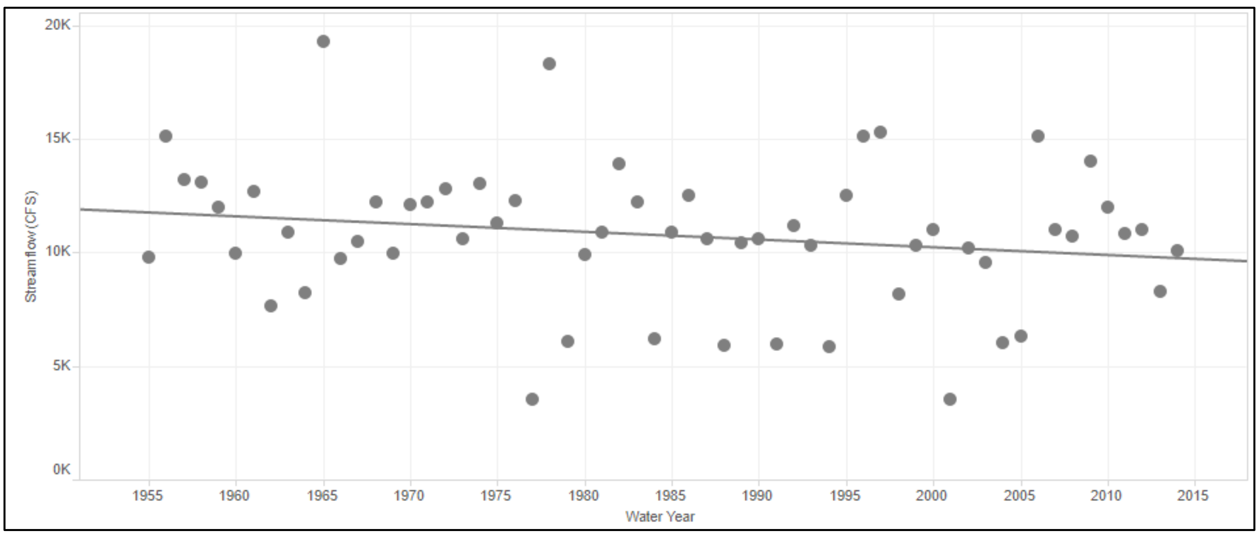

Figure 3-12. N. Santiam River at Niagara, Post-regulation, 1955 through 2014.

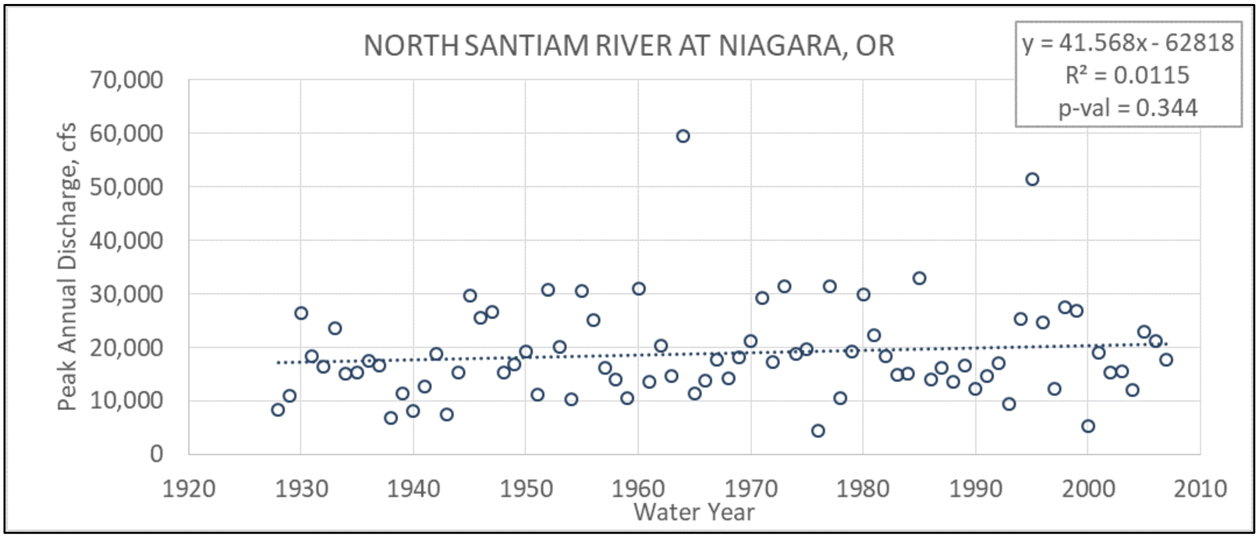

Figure 3-13. N. Santiam River at Niagara, Naturalized Flows, 1928 through 2008.

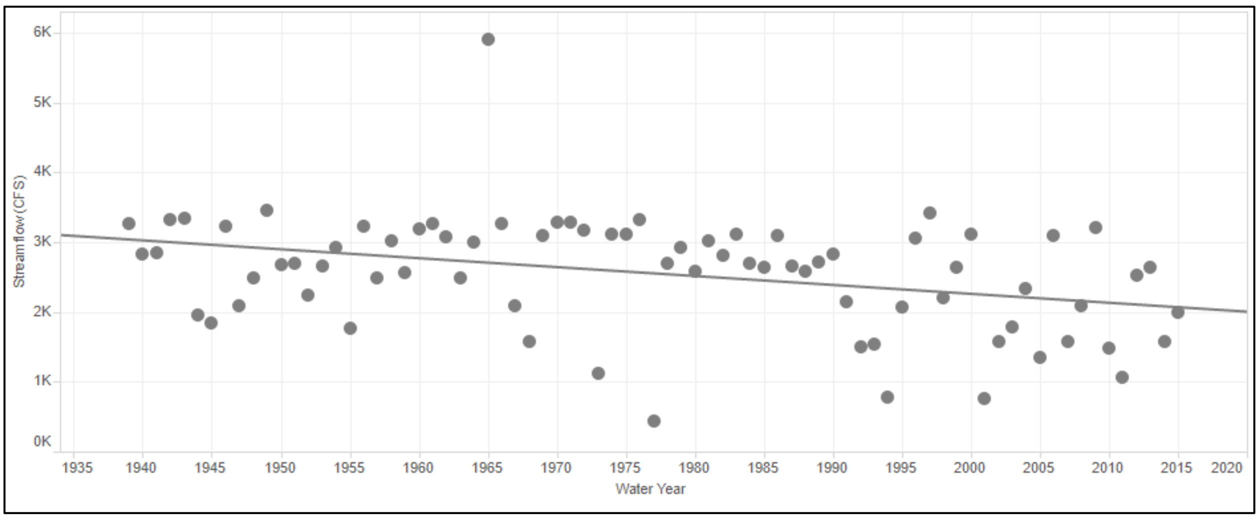

Figure 3-14. Coast Fork Willamette River below Cottage Grove Dam, Complete Period of Record, 1939 through 2014.

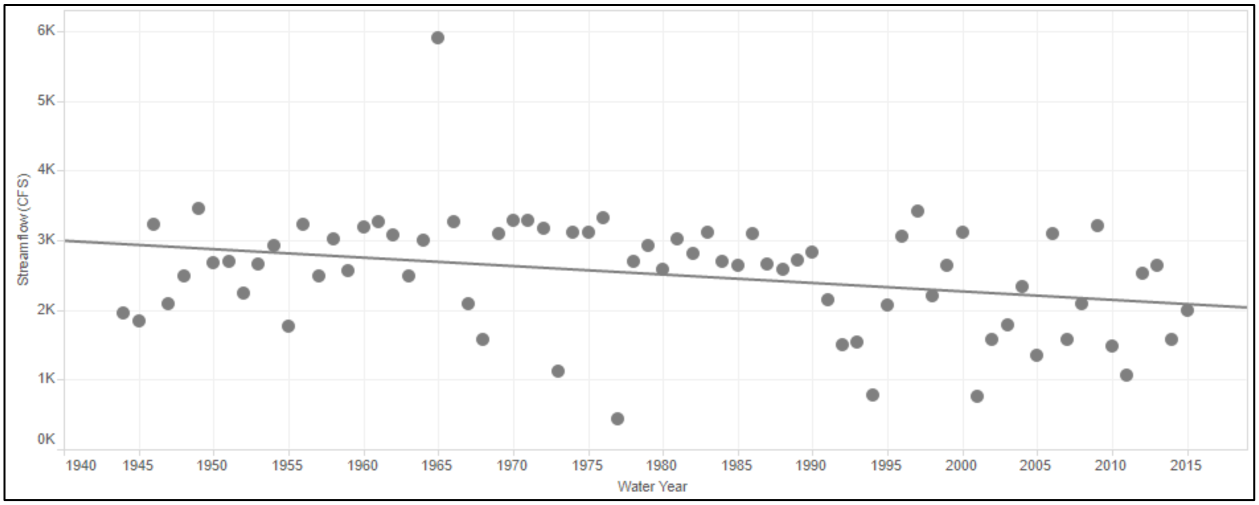

Figure 3-15. Coast Fork Willamette River below Cottage Grove Dam, Post-regulation, 1943 through 2014.

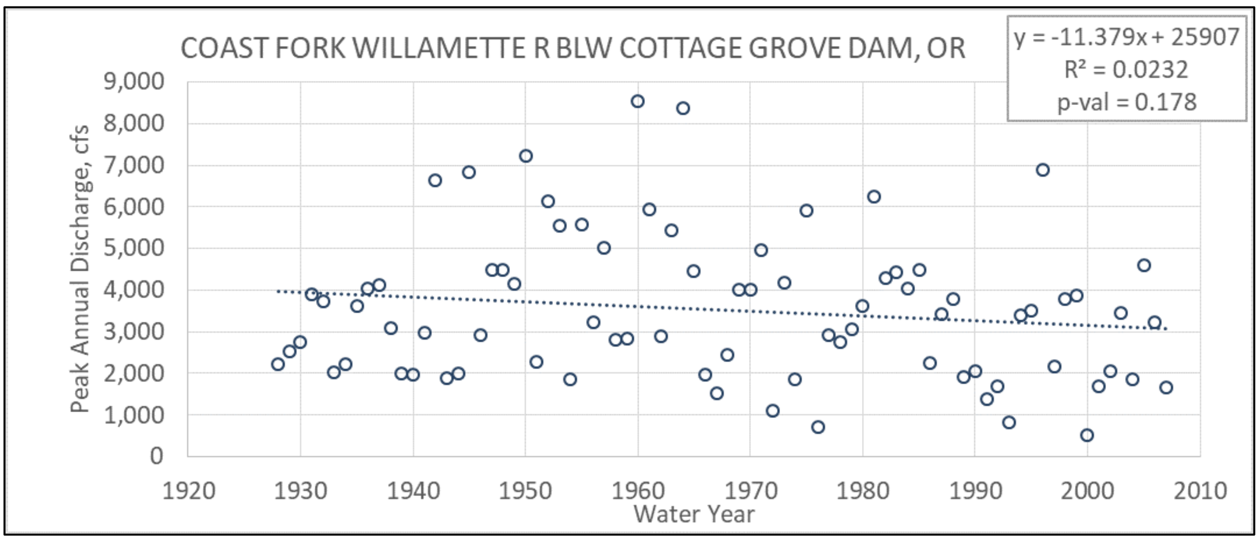

Figure 3-16. Coast Fork Willamette River below Cottage Grove Dam, Naturalized Flows, 1928 through 2008.

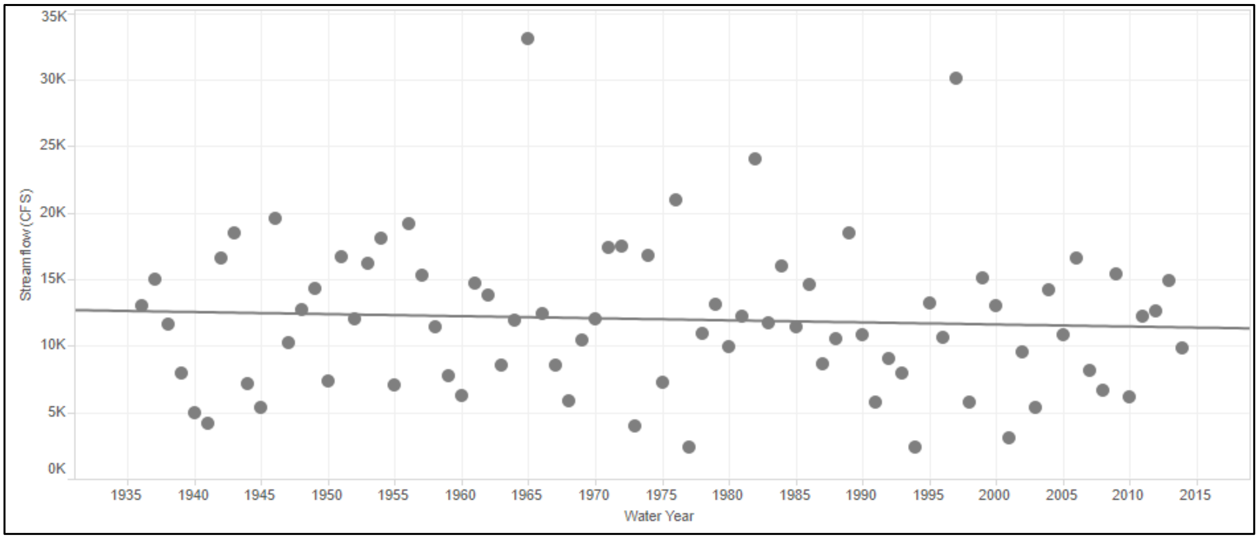

Figure 3-17. Row River above Pitcher Creek, Complete Period of Record, 1936 through 2014. Pristine.

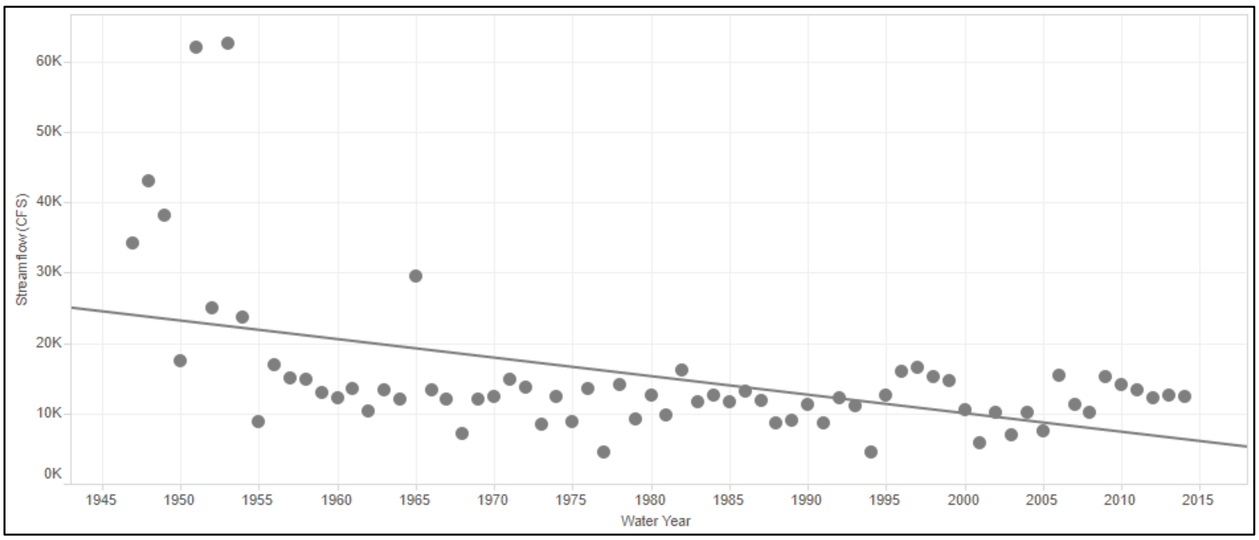

Figure 3-18. Middle Fork Willamette River near Dexter, Complete Period of Record, 1947 through 2014.

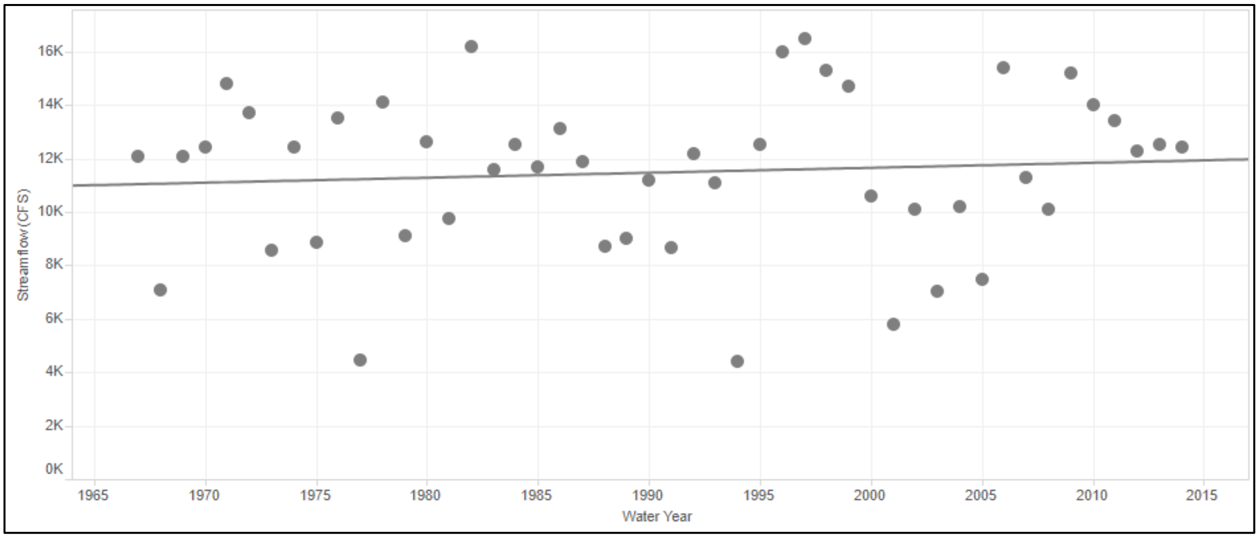

Figure 3-19. Middle Fork Willamette River near Dexter, Post-regulation, 1967 through 2014.

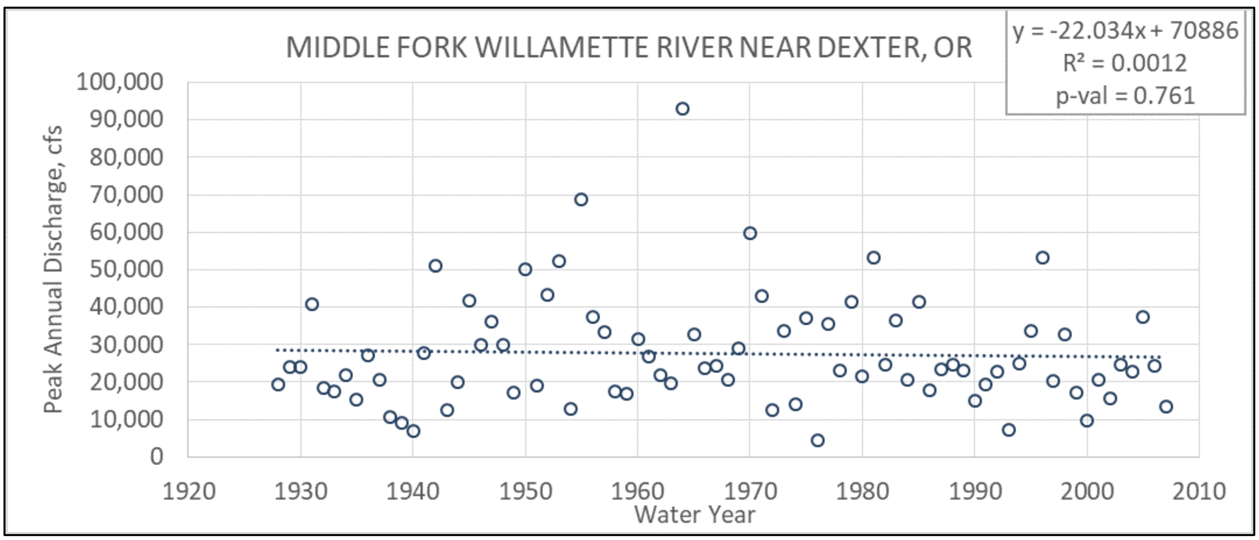

Figure 3-20. Middle Fork Willamette River near Dexter, Naturalized Flows, 1928 through 2008.

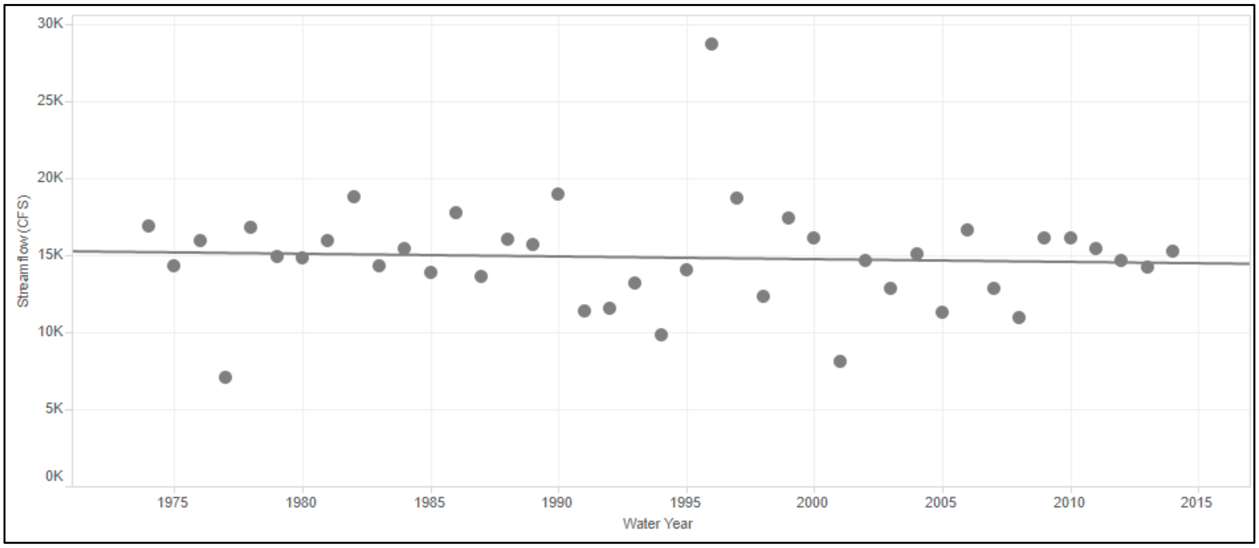

Figure 3-21. S. Santiam River near Foster, Complete Period of Record, Post-regulation, 1974 through 2014.

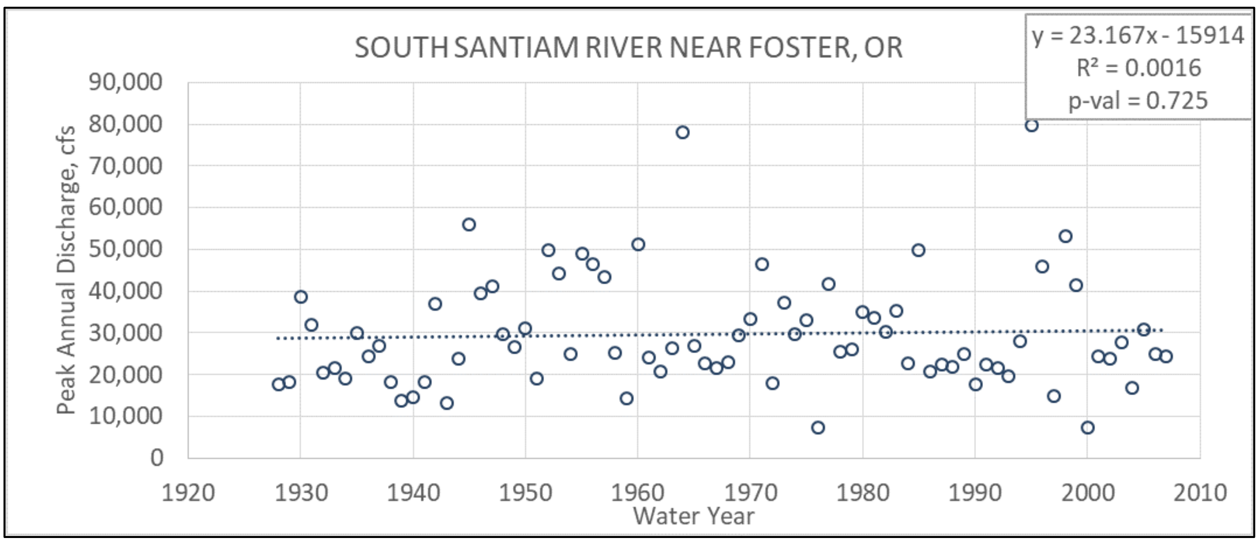

Figure 3-22. S. Santiam River near Foster, Naturalized Flows, 1928 through 2008.

3.4 Nonstationarity Detection

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The USACE Nonstationarity Detection (NSD) Tool (USACE 2018b) was used to assess whether the assumption of stationarity, is valid for a given hydrologic time-series dataset. The Time Series Toolbox (TST) USACE 2018c) has superseded the USACE NSD Tool. The capabilities in the legacy NSD Tool were added to the TST and NSD calculations are now identical to each other. Any reference to the USACE NSD Tool should be understood to also refer to the NSD Tool in the TST.

END NEW TEXT

Nonstationarities are detected using 12 different statistical tests that examine how the statistical characteristics of the dataset change with time (USACE 2017b, Engineering Technical Letter 1100-2-3, Guidance for Detection of Nonstationarities in Annual Maximum Discharges; USACE 2018b, Nonstationarity Detection Tool User Manual, version 1.2). The NSD Tool was applied to the same stream gage sites listed previously in Figure 3-23, and both the observed period of record and naturalized stream flow datasets were analyzed. For the simulated naturalized streamflow datasets, the TST was used to perform the NSD routines. A nonstationarity can be considered “strong” when it exhibits consensus among multiple NSD 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, which 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. Similar to nonstationarities, change points must also exhibit consensus, robustness, and significant magnitude of change. For discussion of other streamflow metrics of interest to the analysis, 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 historical 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 because 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 WVS 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 through 1988 also aligns well with the period in which the WVS dams were coming online 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. Because these simulated flows are not influenced by regulation and irrigation, it would be anticipated that the previously detected nonstationarities attributed to the construction of the dams would be absent. 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 homogenous, this does not imply that all other aspects of the flow regime are homogenous. 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 that were deemed pristine and largely free of influence from upstream regulation—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 NSD results for the North Santiam River at Niagara. The figures show the results of applying the NSD tests to the observed annual peak flows (NSD Tool) and naturalized annual peak flows (TST). 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 through 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 after. When the influence of these reservoirs was removed, no nonstationarities were detected.

Figure 3-29 and Figure 3-30 display the results of the NSD 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 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 and is not present in the naturalized flow record. This 1990 nonstationarity is more difficult to attribute to reservoir regulation 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, but 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 (e.g., 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 NSD Tool and indicated by the linear regression performed within the TST. Documentation of a change in the reservoir's regulation procedure around the late 1980s or early 1990s is lacking, but there appears to be at least a weak signal indicated here that cannot necessarily be attributed to regulation.

Figure 3-31 displays the NSD results for the Row River above Pitcher Creek and 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 NSD results for the observed, annual peak streamflow record at Middle Fork Willamette River near Dexter and Figure 3-33 displays NSD 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 through 1961, and a Lombard Mood nonstationarity spanning 1952 through 1956. NSD 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 NSD Tool's trend analysis tab was used to independently verify the linear trend analysis reported in the CHAT section. Overall, agreement upon trend direction and statistical significance was found between the NSD Tool and CHAT for all subbasins analyzed.

The NSD analysis across the Willamette River Basin for various gages as well as for observed and naturalized streamflow conditions resulted in the following conclusions:

- 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.
- It appears that climate change, long-term natural climate trends, and land use/land cover changes taken together are not significantly undermining the stationarity of the historically observed peak streamflow records in the Willamette River Basin.

Note that for all outputs generated from the TST, CPM indicates a change point method and applies to the statistical NSD tests.

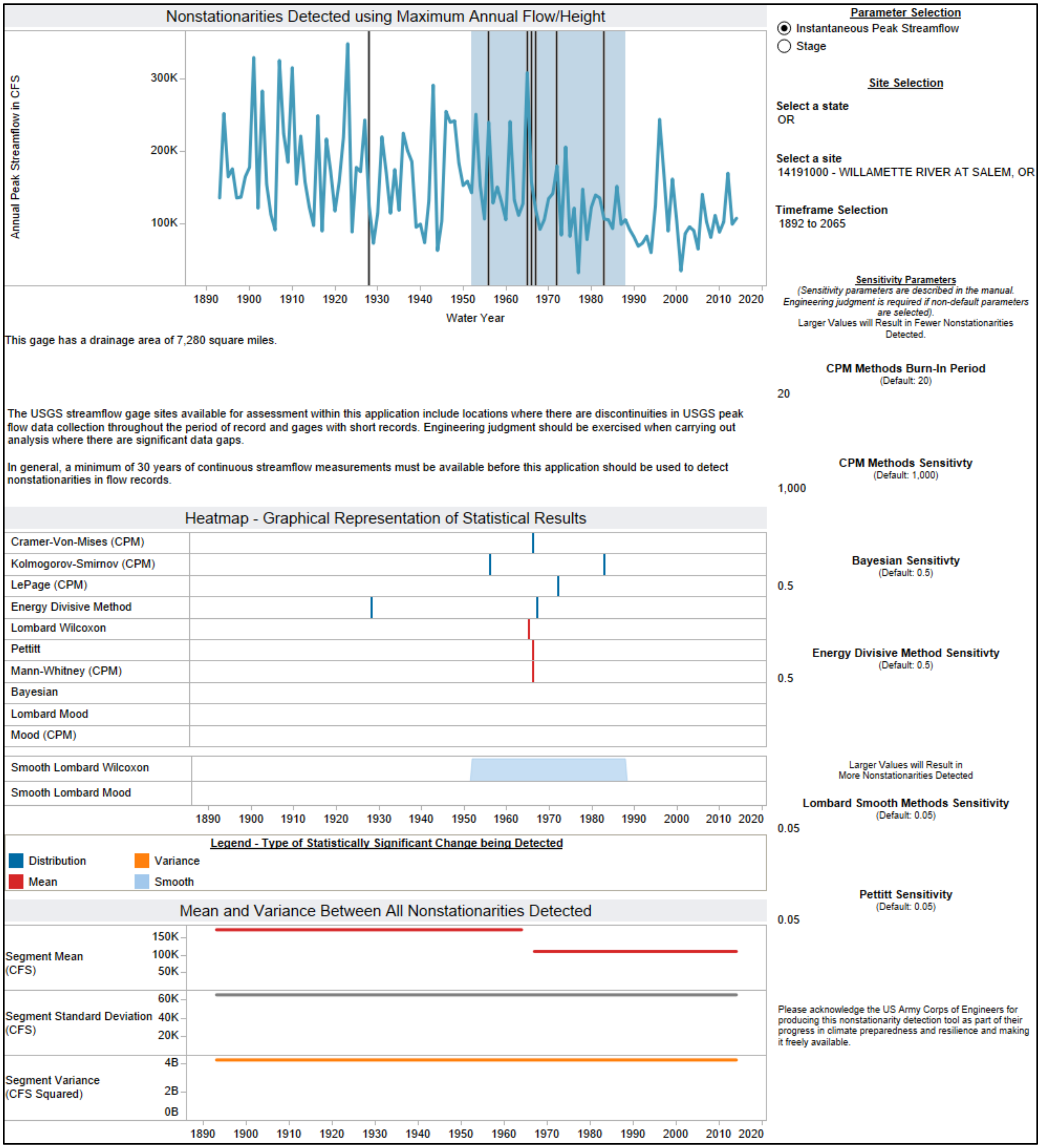

Figure 3-23. NSD for Willamette River at Salem, 1892 through 2014.

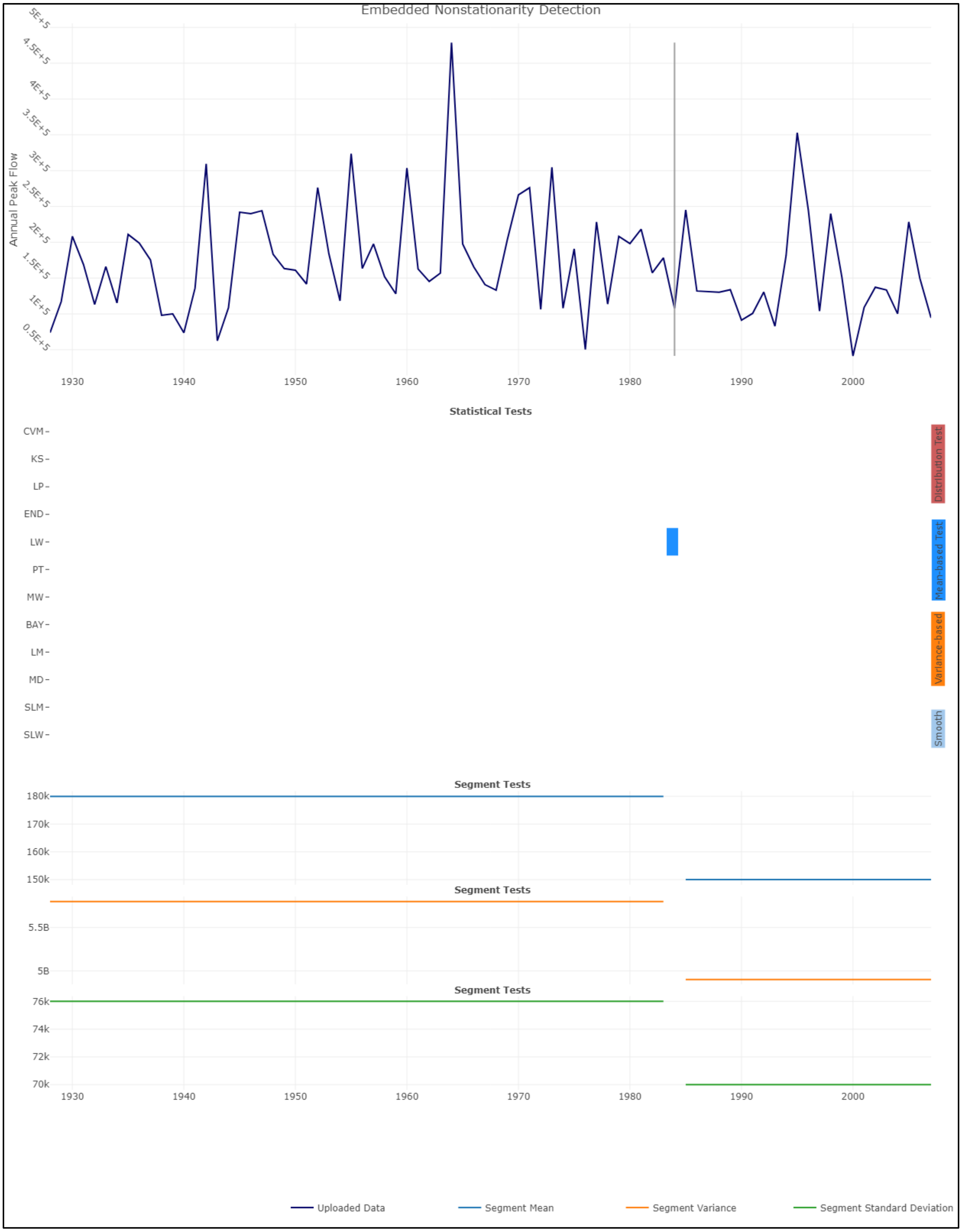

Figure 3-24. NSD Willamette River at Salem, Naturalized Flows, 1928 through 2008.

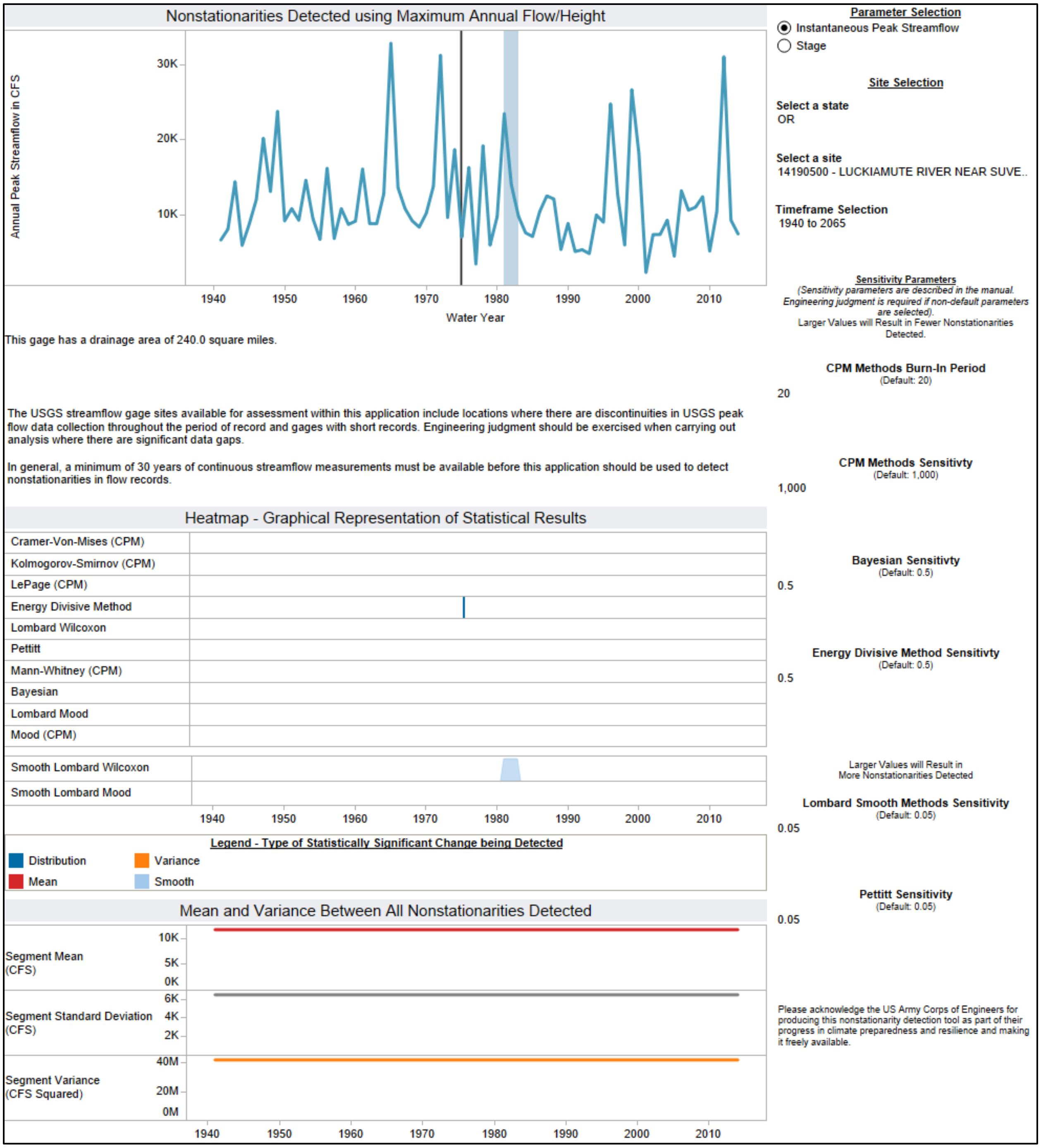

Figure 3-25. NSD Luckiamute River near Suver, 1940 through 2014.

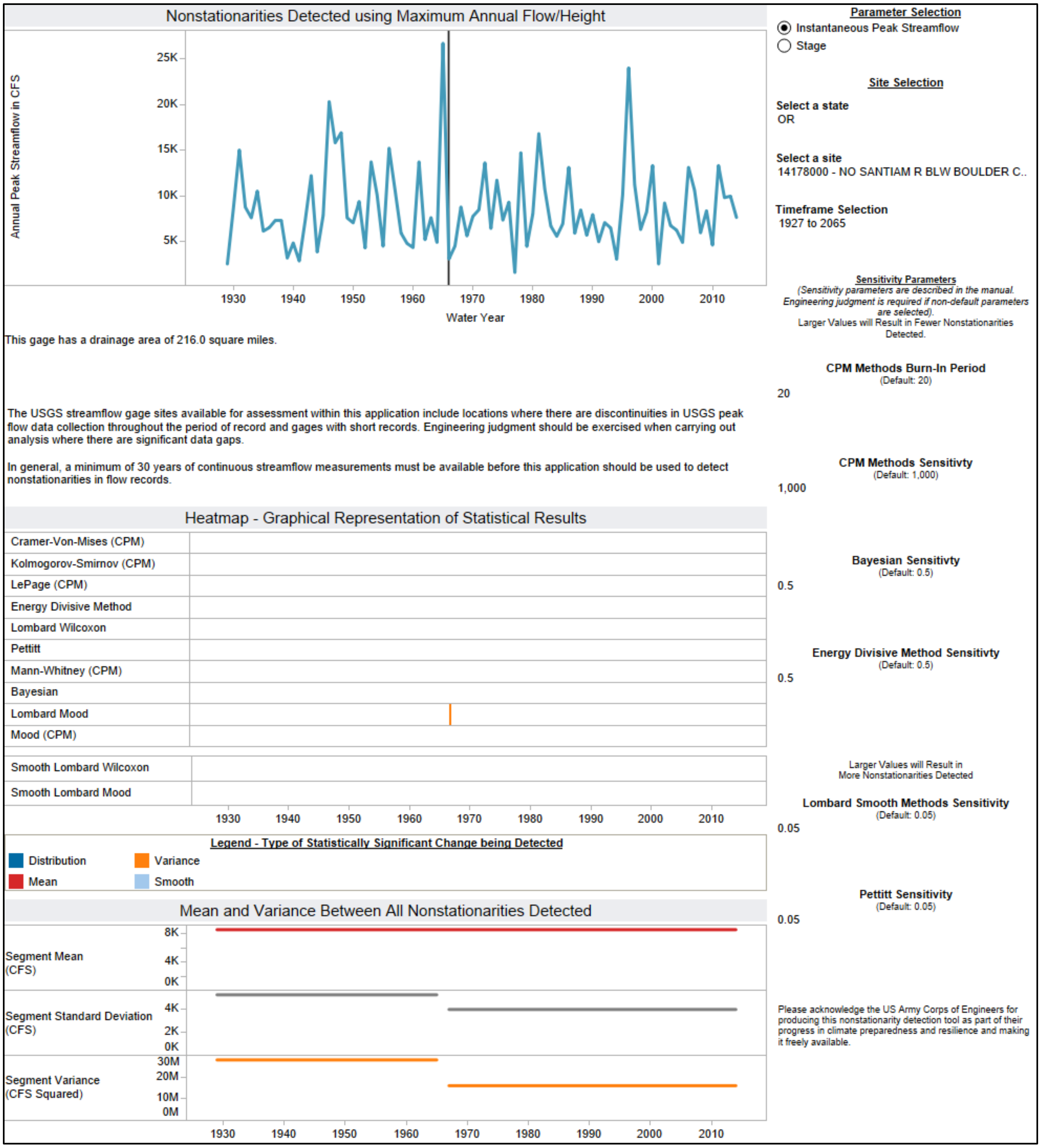

Figure 3-26. NSD North Santiam River below Boulder, 1927 through 2014.

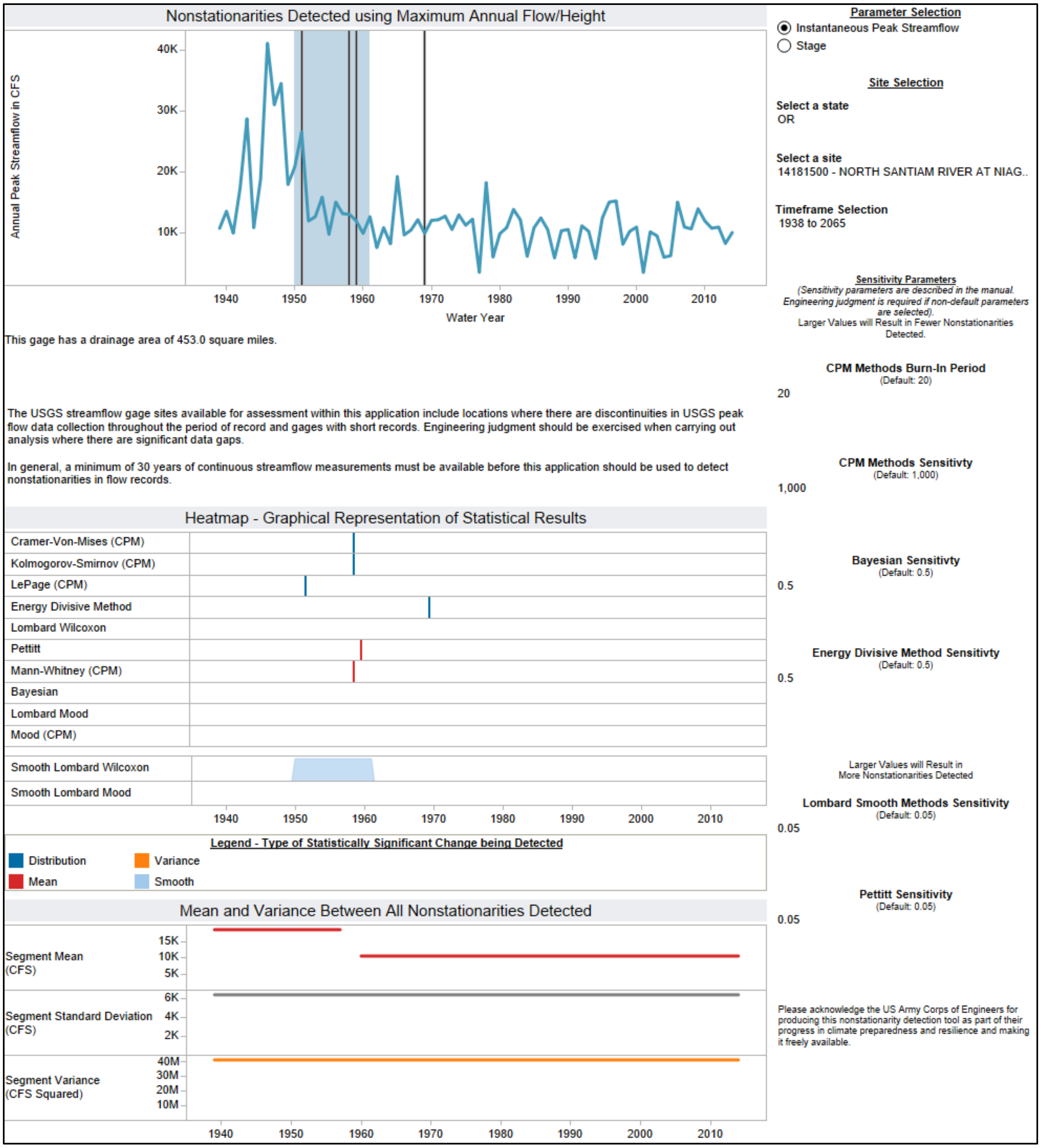

Figure 3-27. NSD North Santiam River at Niagara, 1938 through 2014.

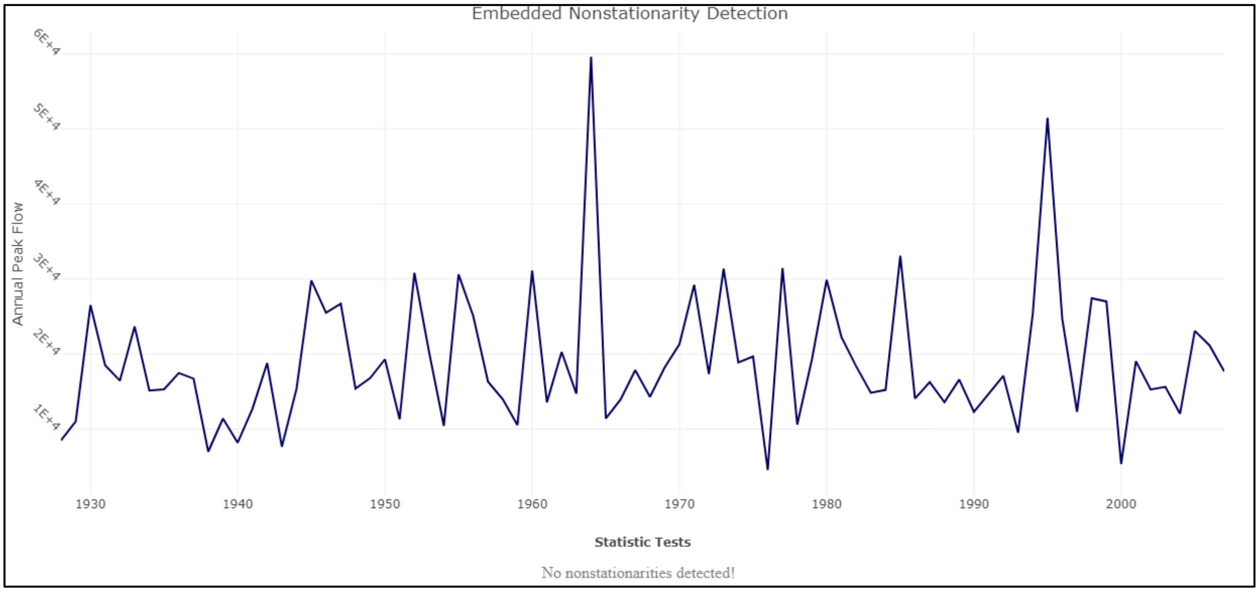

Figure 3-28. NSD North Santiam River at Niagara, Naturalized Flows, 1928 through 2008.

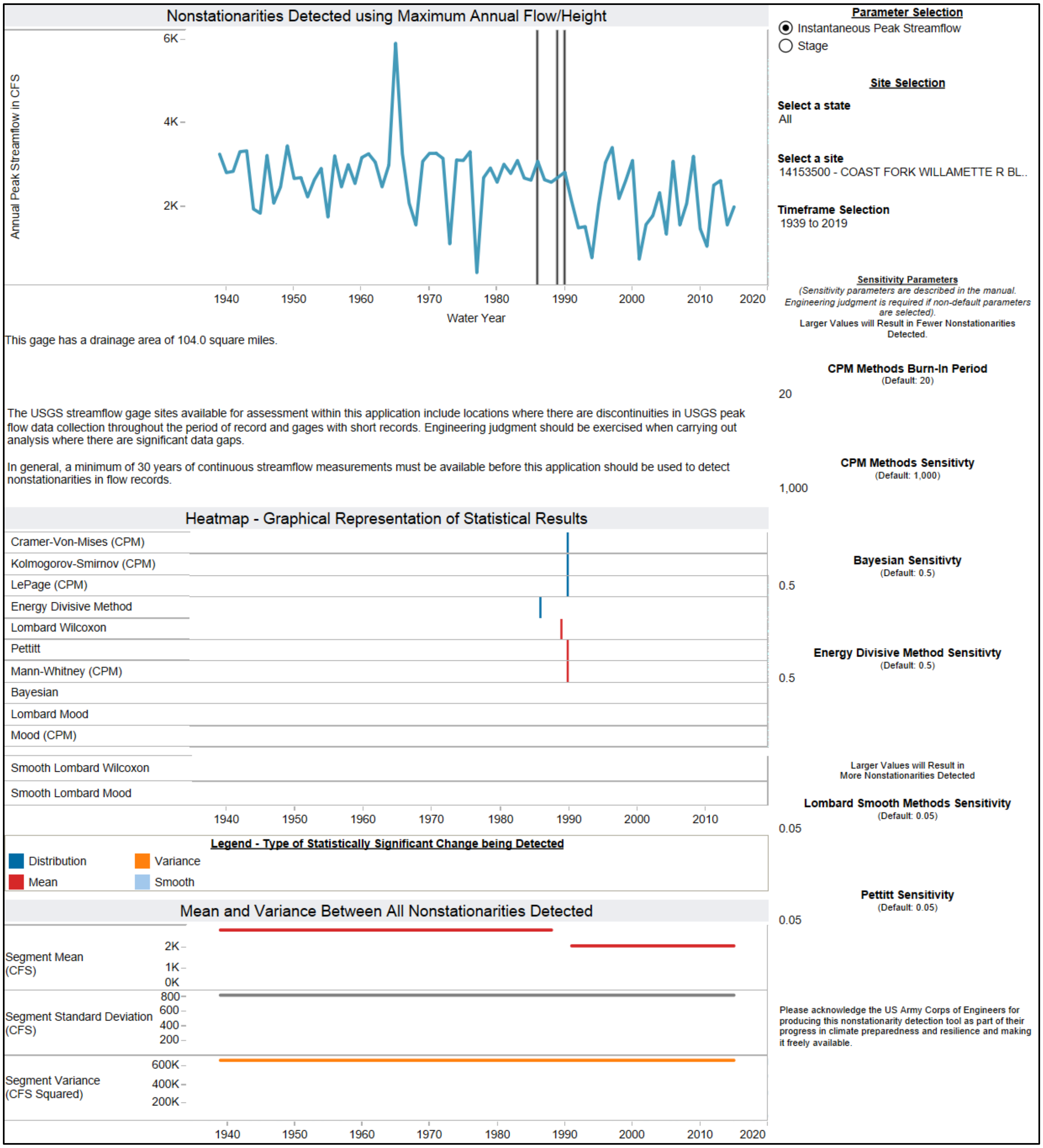

Figure 3-29. NSD Coast Fork Willamette River below Cottage Grove, 1939 through 2014.

Figure 3-30. NSD Coast Fork Willamette River below Cottage Grove, Naturalized Flows, 1928 through 2008.

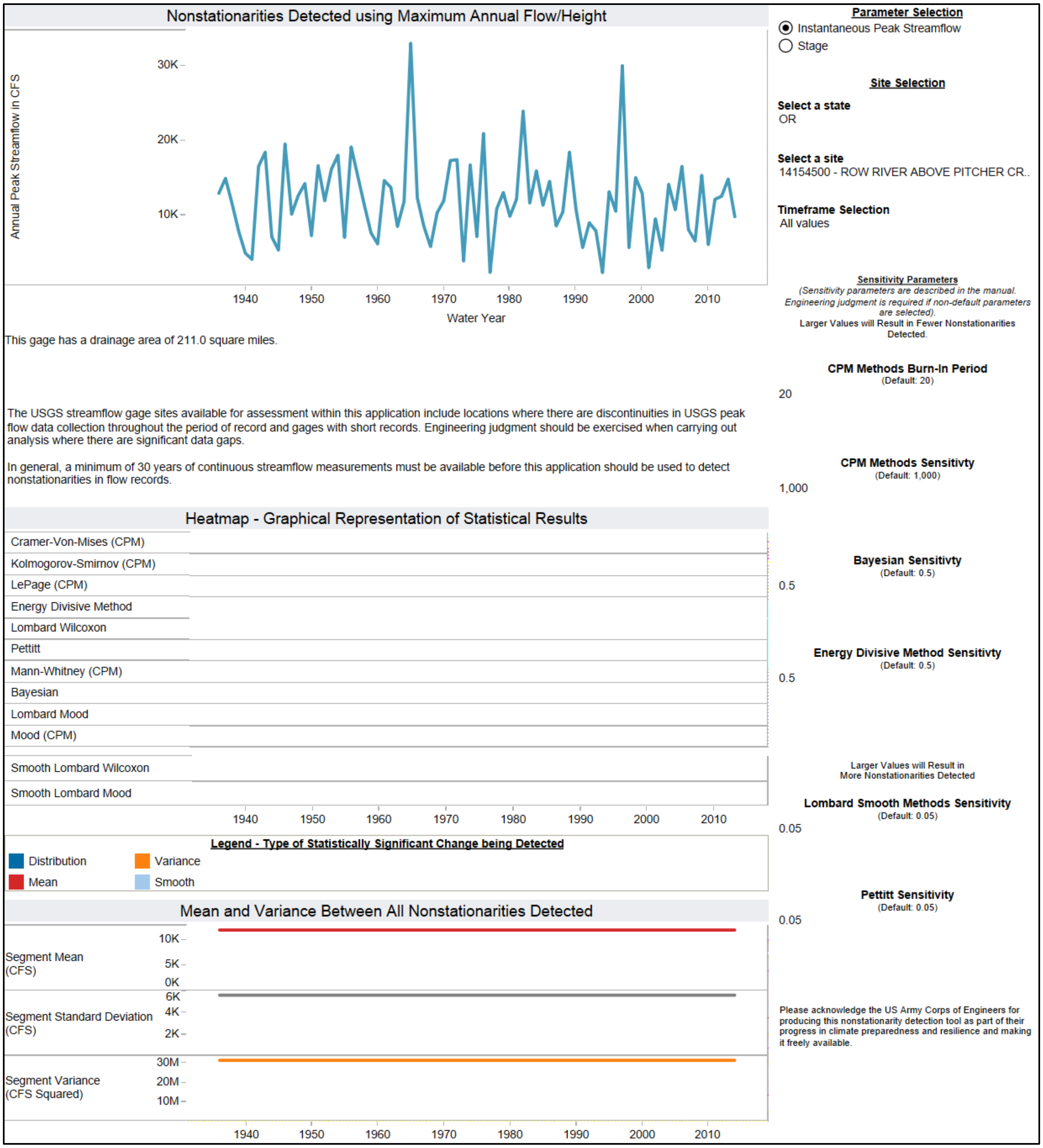

Figure 3-31. NSD for the Row River at Pitcher Creek, near Dorena, 1936 through 2014.

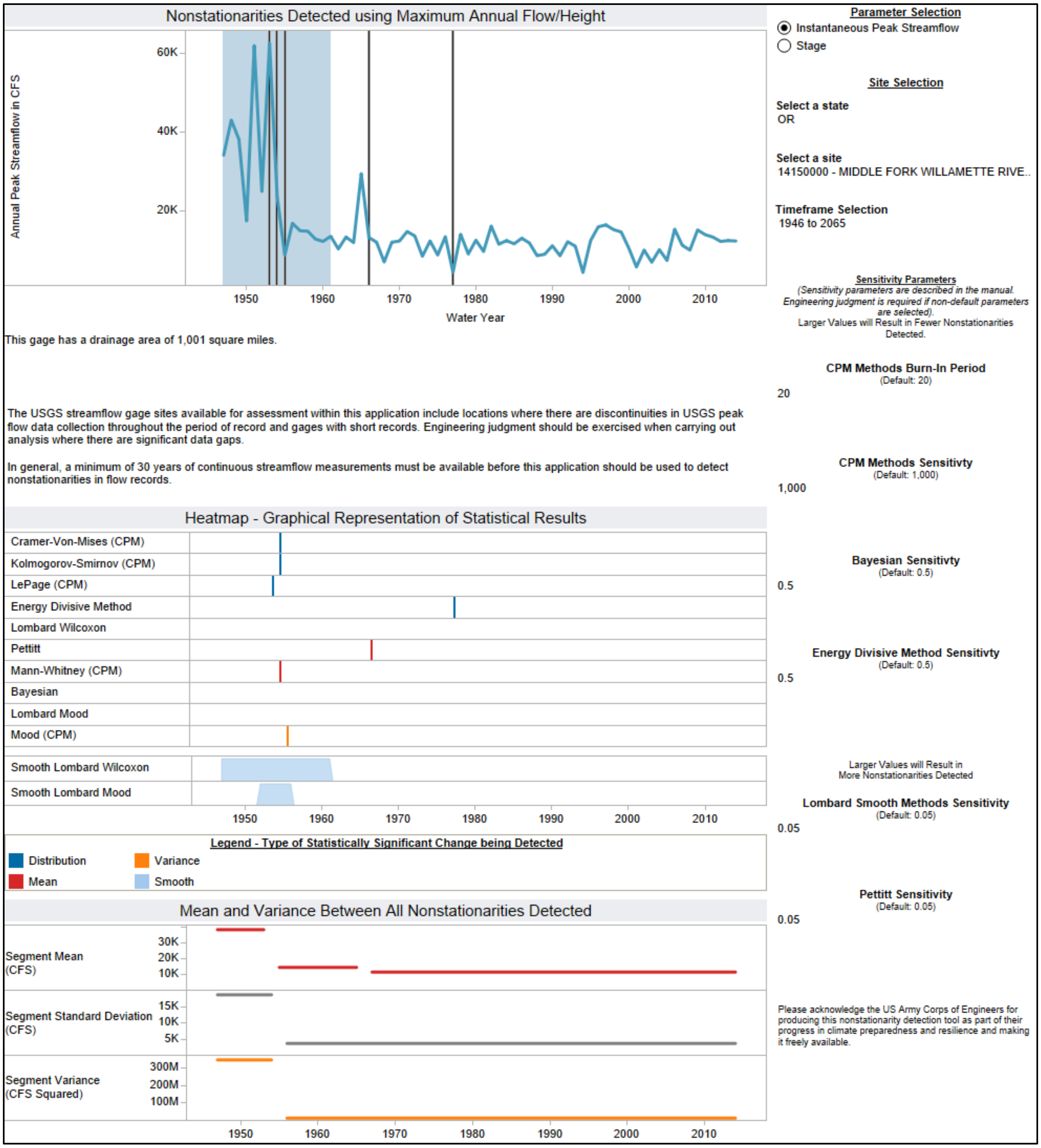

Figure 3-32. NSD Middle Fork Willamette River near Dexter, 1946 through 2014.

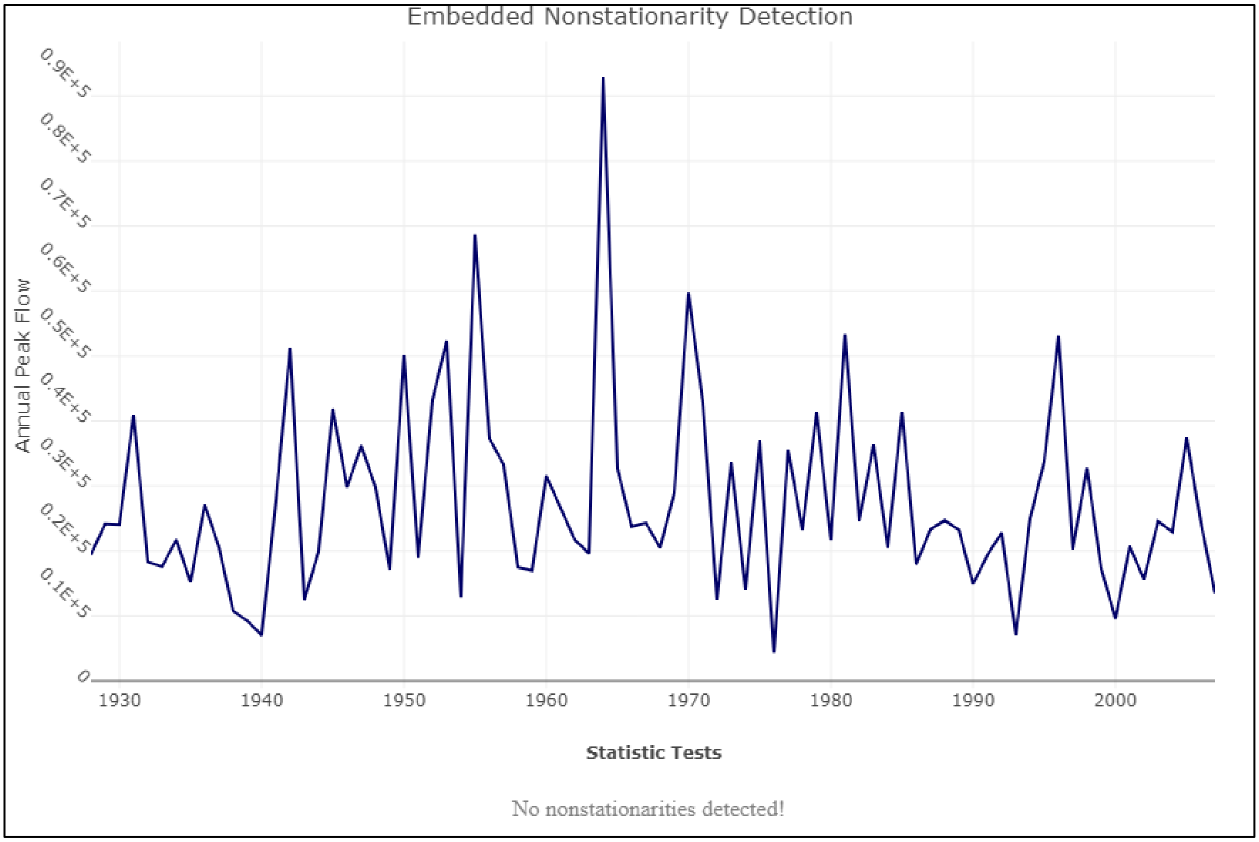

Figure 3-33. NSD Middle Fork Willamette River near Dexter, Naturalized Flows, 1928 through 2008.

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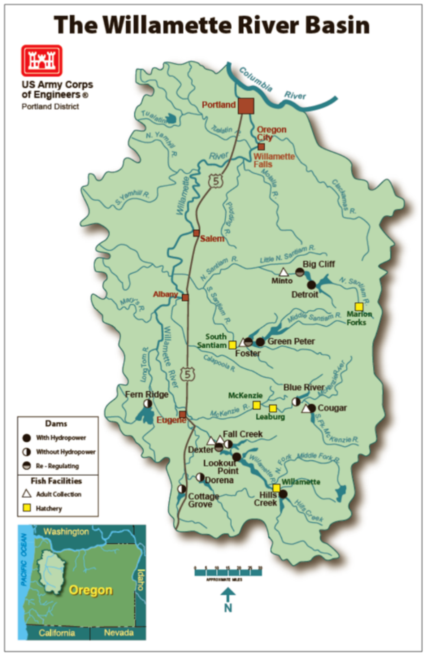
Overall, the agreement across the watershed and through various time periods indicates that all statistically significant trends are likely due to the influence of upstream regulation and likely not due to climatic shifts driving changes in hydrology. Trend detection and statistical significance was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

Additional NSD analyses were performed for Willamette River Basin Y unregulated subbasin tributaries. These tributaries are of interest because these basins are not subject to the additional layers of analysis required to deregulate flows and any trends or lack of trends identified would be more reliable. Given the scale of this study, it was appropriate and worthwhile to include it. The analyses are graphically summarized in Figure 3-35 through Figure 3-40. NSD evaluation was made for Willamette River unregulated subbasins, shown in Figure 3-34.

ID	Descriptor	Bld YR
HCR	Hills Creek	1961
LOP	Lookout Point	1953
DEX	Dexter	1954
FAL	Fall Creek	1965
COT	Cottage Grove	1942
DOR	Dorena	1949
FRN	Fernridge	1941
CGR	Cougar	1963
BLU	Blue River	1968
GPR	Green Peter	1967
FOS	Foster	1967
DET	Detroit	1953
BCL	Big Cliff	1953



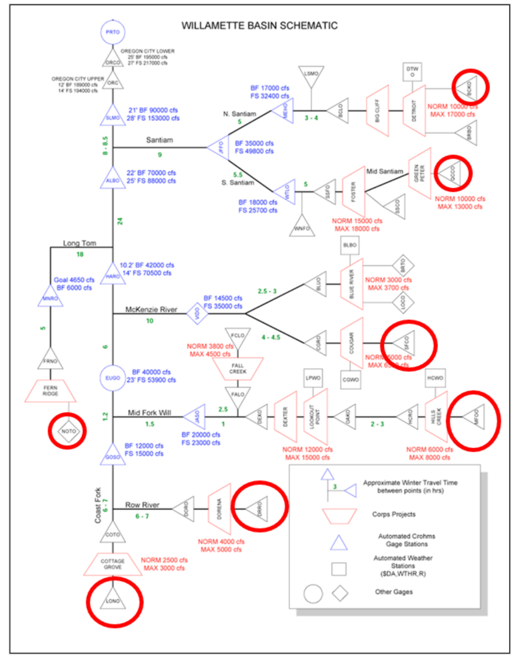


Figure 3-34. Locations of Additional NSD Analyses Sites.

No significant NSDs occurred in the basins analyzed. Note that it takes a positivity of three or more tests to establish high significance of the NSD detect.

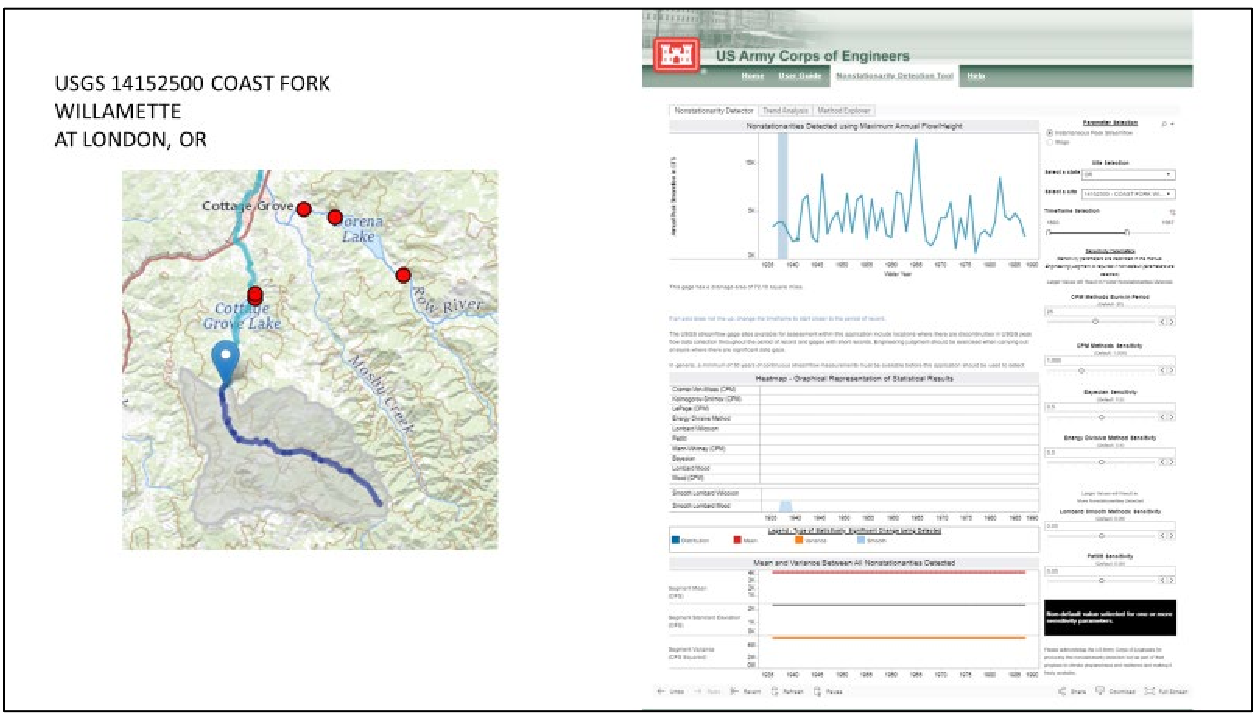


Figure 3-35. Coast Fork Willamette River NSD Analyses.

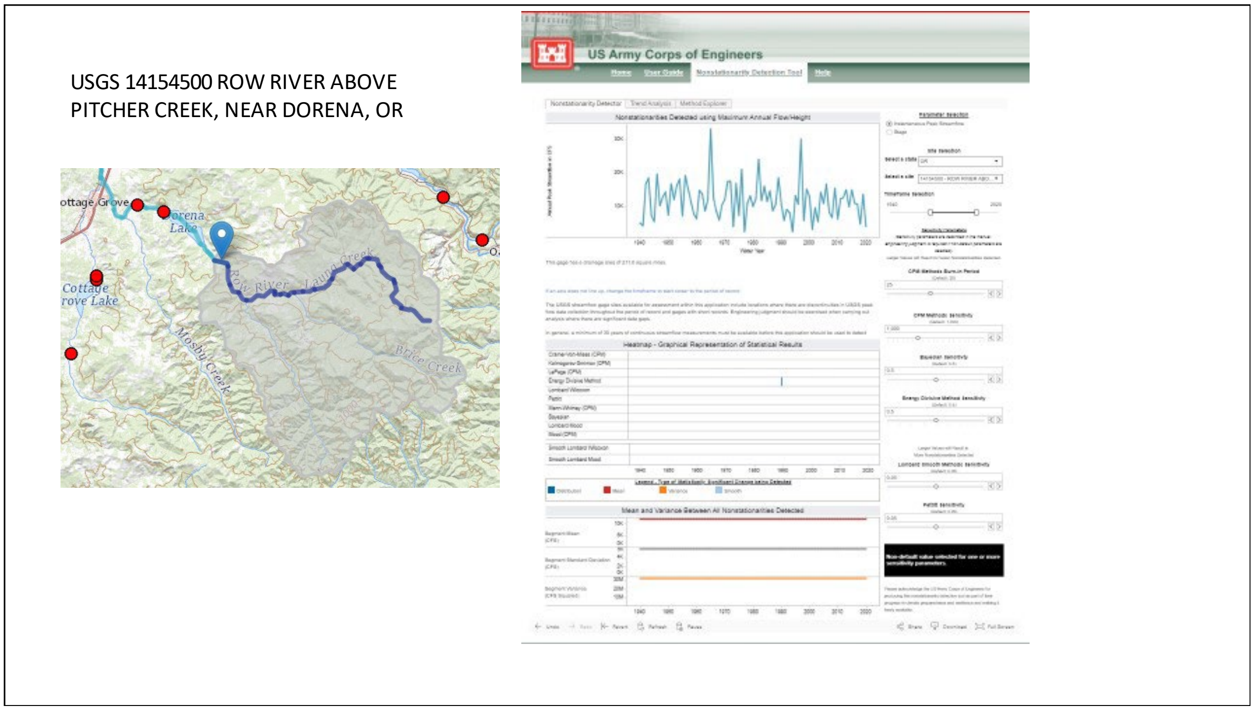


Figure 3-36. Row River NSD (Pristine) Analyses.

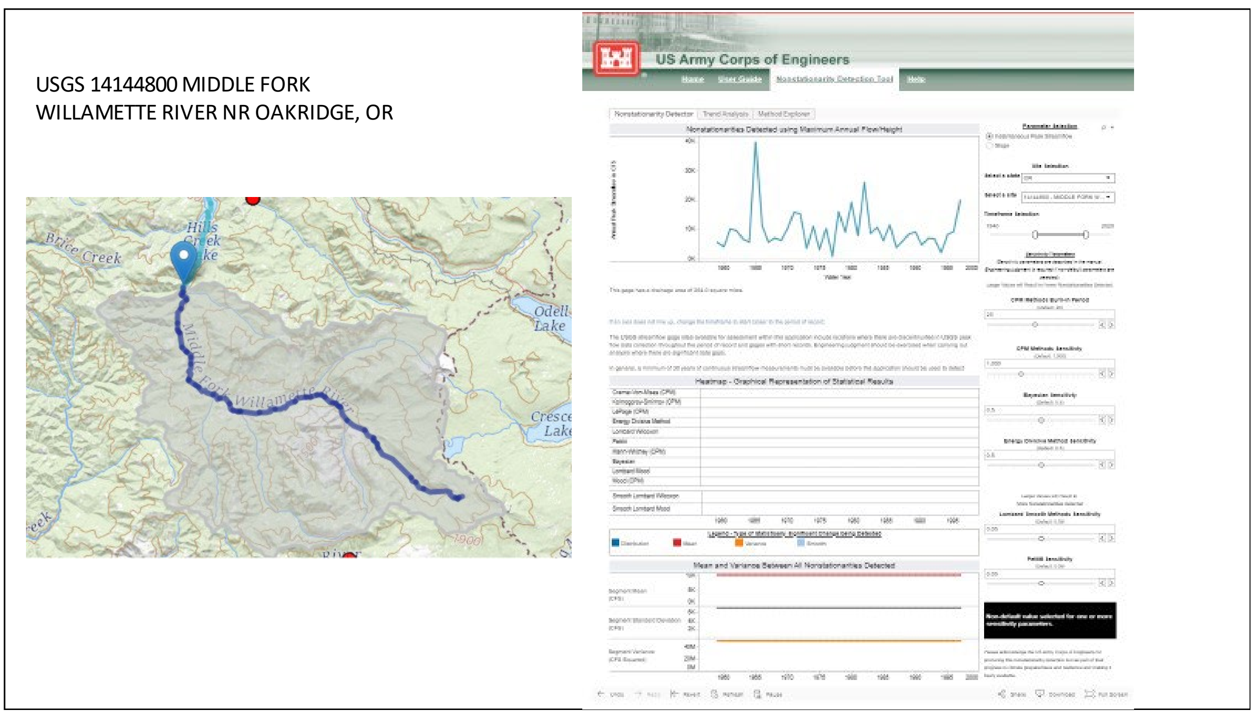


Figure 3-37. Middle Fork Willamette River NSD Analyses.

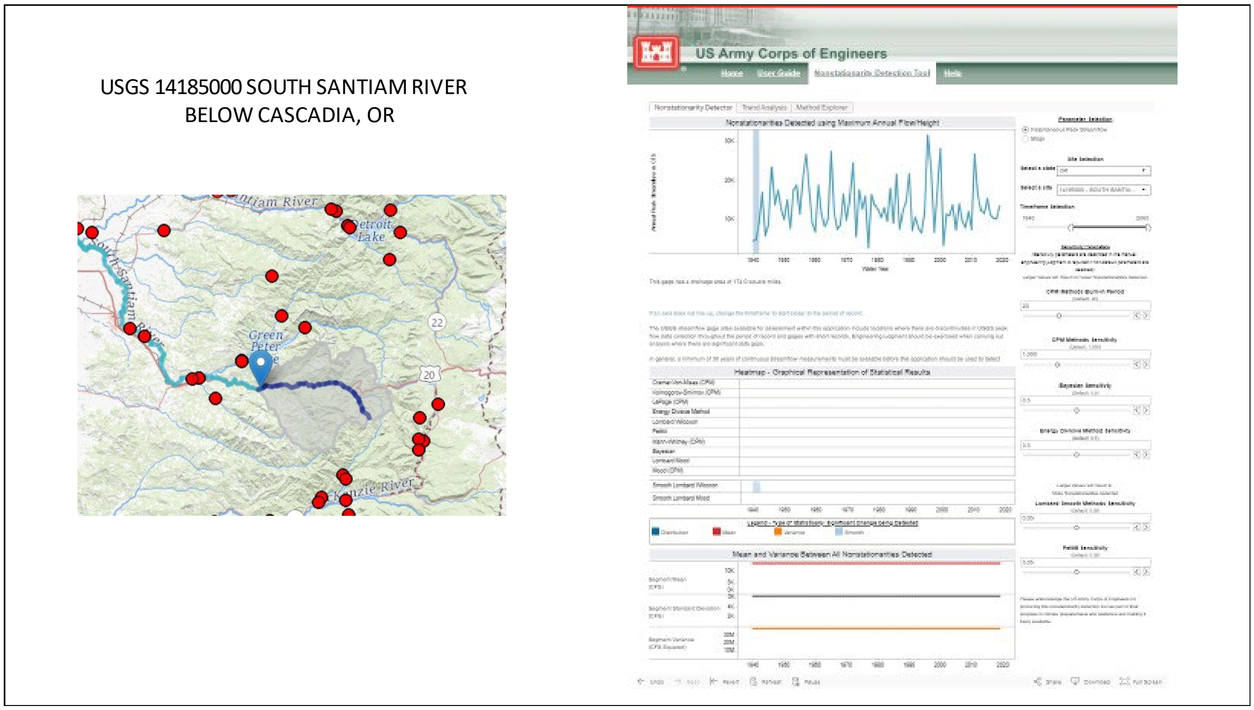


Figure 3-38. South Santiam NSD Analyses.

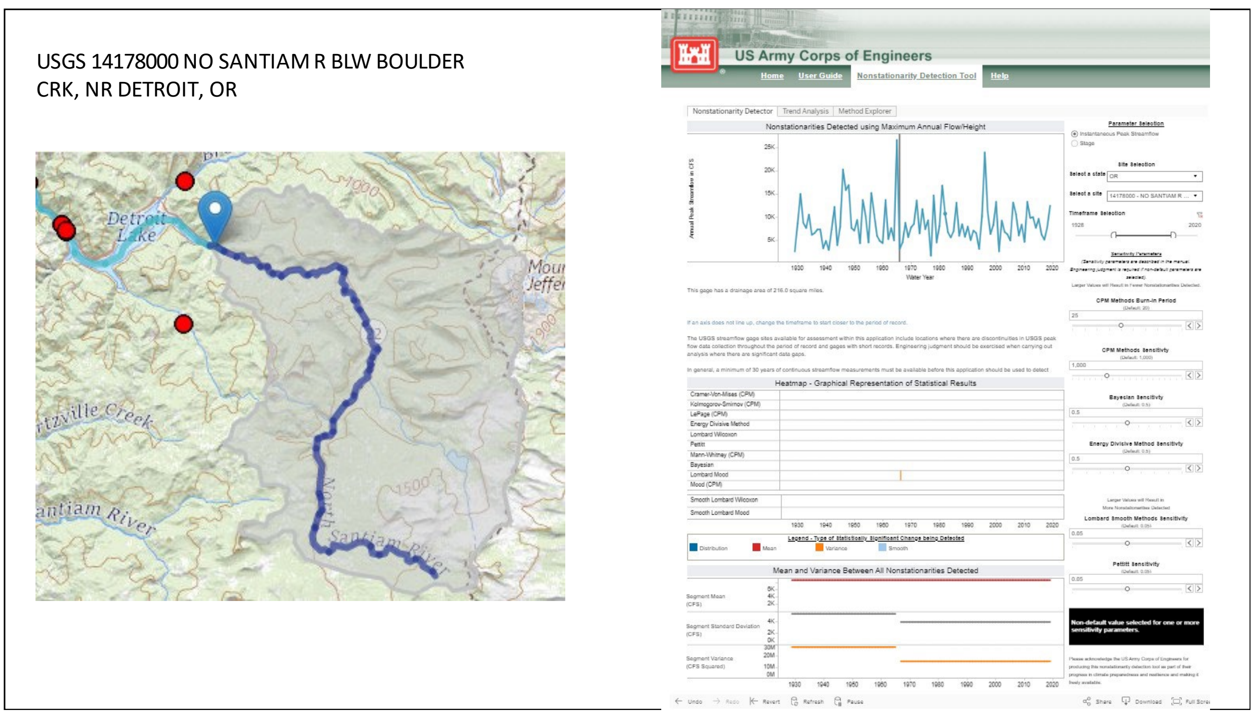


Figure 3-39. North Santiam NSD Analyses.

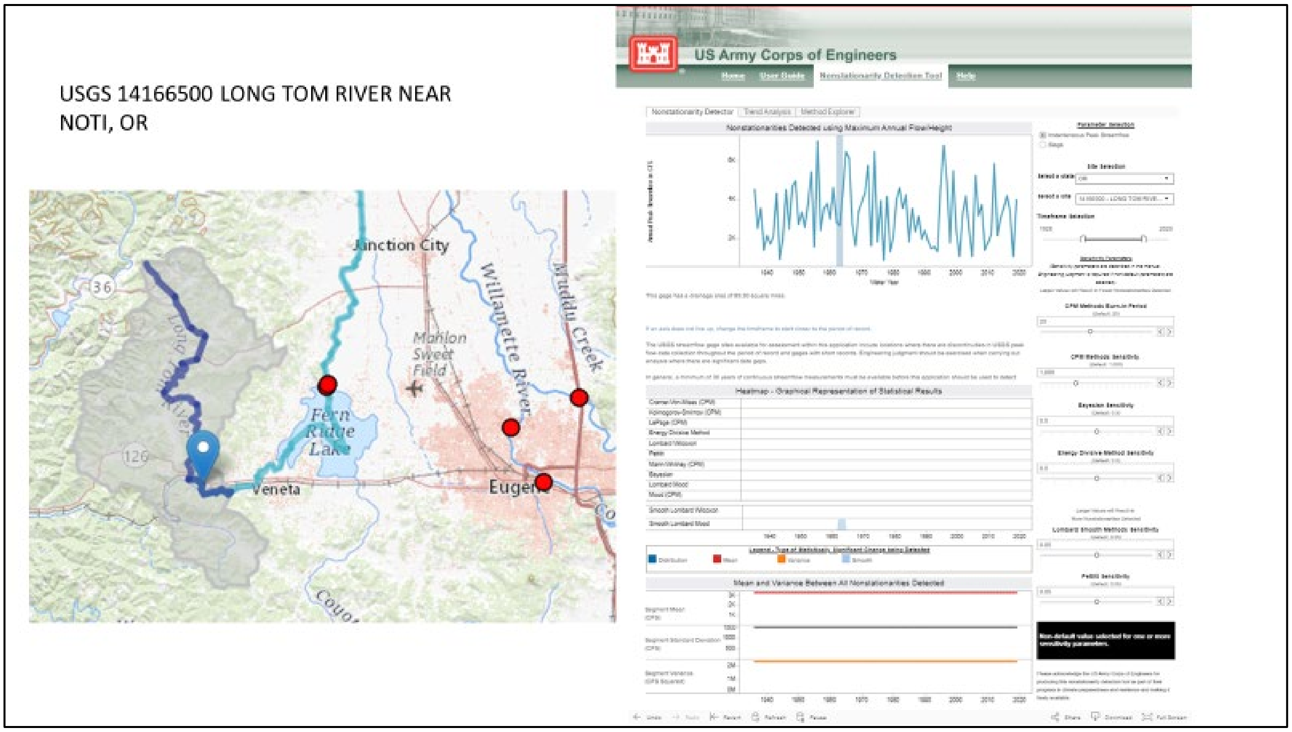


Figure 3-40. Fern Ridge NSD Analyses.

3.5 Nonstationarity and Trend Analyses for Additional Hydrologic Variables.

USACE prepared additional trend and nonstationarity analyses. The analyses were performed to assess potential annual and seasonal change in Willamette River downstream flows (i.e., at Salem, OR). The assumption of annual and seasonal stationarity was also tested. The analyses informed the decision to use the full range of years of the period of record in ResSim (USACE 2017c) and other EIS modeling efforts.

Strong evidence that climate change was driving any streamflow nonstationarities in the Willamette River Basin was lacking. Analyses did identify trends, but only for the 1-day average annual minimum flows (e.g., negatively sloped) trends across the period of record, which was statistically significant (p-value less than 0.05) (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. The details and results of the analyses are discussed below. However, it is relevant to note that additional trend analyses were performed and are summarized in Table 3-2. The additional trend analyses include statistical significance tests (e.g., T-test, Mann-Kendall, and Spearman Rank Order). These analyses lend support to the analyses presented here.

Daily unregulated flow at Salem, OR for 1928 through 2019 (91 years) were used for analyses purposes. Note that the WVS EIS ResSim analysis period of record is water years 1935 through 2019. An additional 7th year was added to the trend analyses dataset. The source of these 7 additional years was the Modified Flow dataset (BPA 2020). The Mann-Kendell test was initially performed to determine whether trends were statistically relevant. The critical periods within a water year are:

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

Seasonality time windows were chosen that correspond to periods important to the Willamette Valley System water management operations. NOAA-NMFS also questioned whether the full period of record was adequately representative of more recent (e.g., past 10, 15, and 30 years) extreme events. Concern focused on refill (March through May) and low flow metrics occurring in the summer conservation (June through September) and early fall months. Overall, these analyses indicated that for the historical period of record, evidence supported use of the complete period of record for ResSim and other EIS modeling purposes.

END NEW TEXT

Analyses were performed at Salem, OR. Salem is a primary regulation control point and possesses 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 in Figure 3-41. Overall, the evaluated periods did not show any statistically significant trends or differences between recent years.

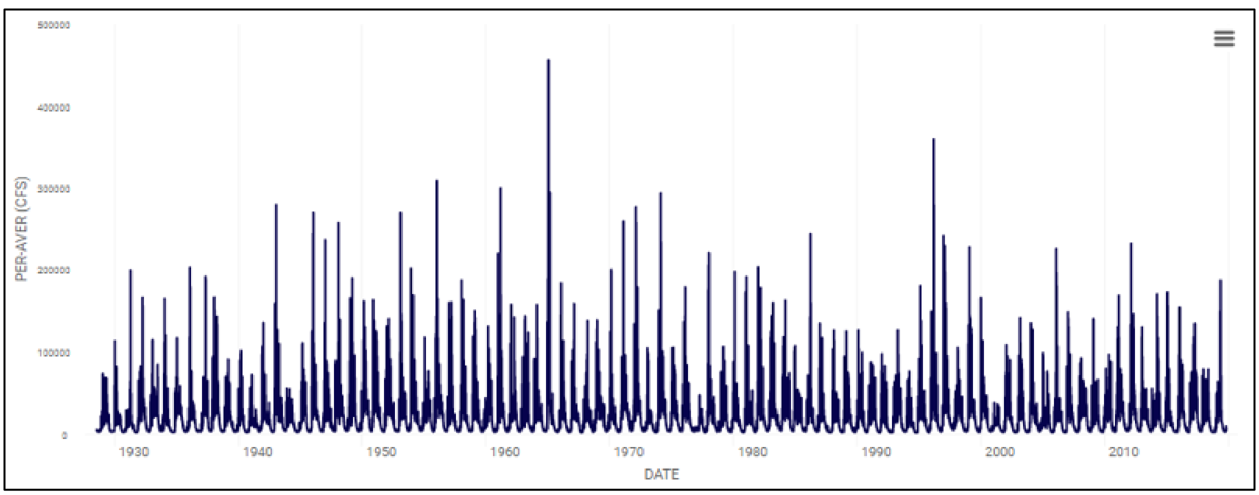


Figure 3-41. Salem, Oregon, Unregulated Daily Average Flows, 1928 through 2019.

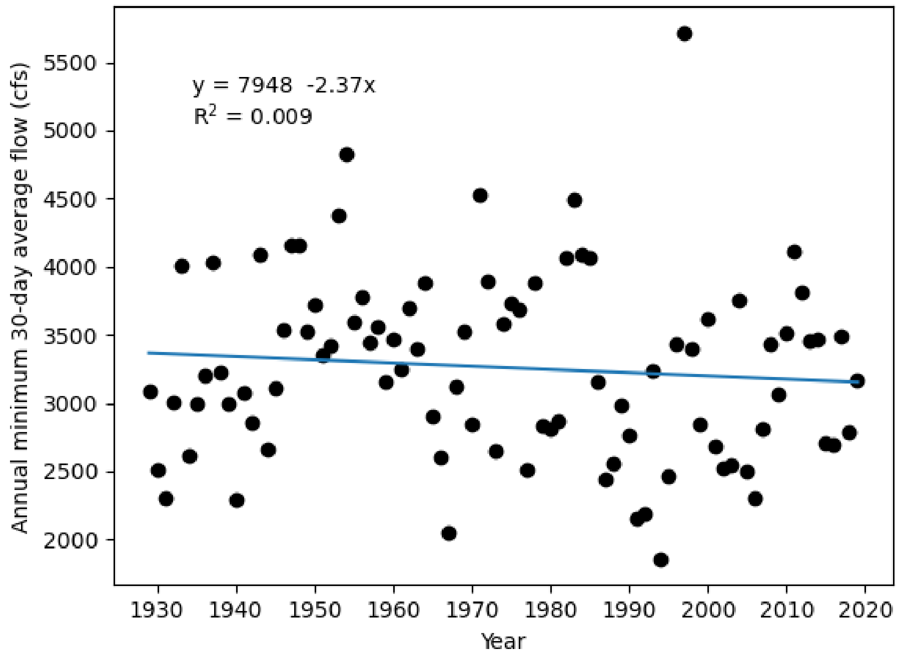


Figure 3-42. Salem, Oregon, 30-day Minimum Flow.

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

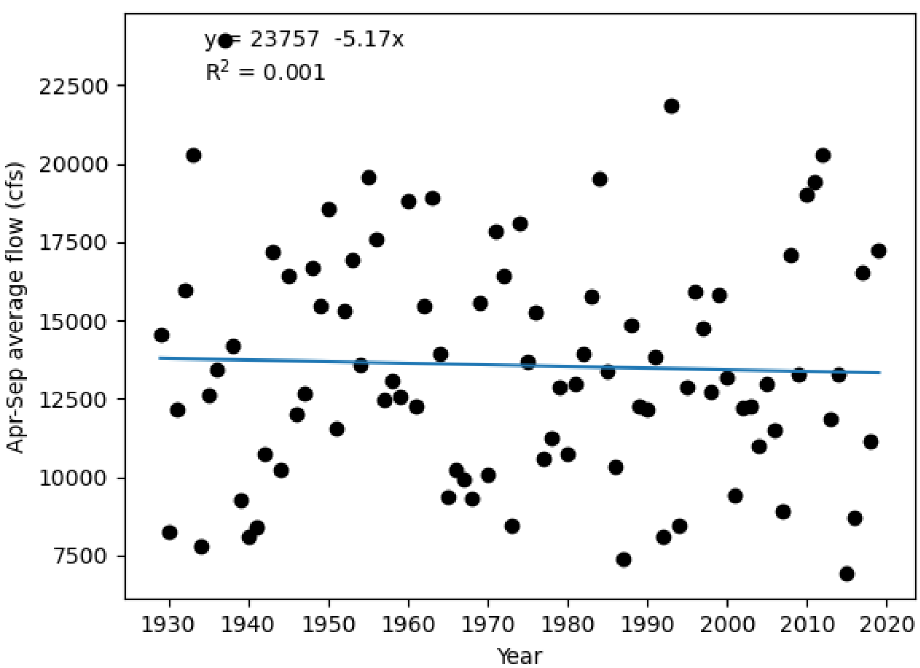


Figure 3-43. Salem, Oregon, April through September.

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

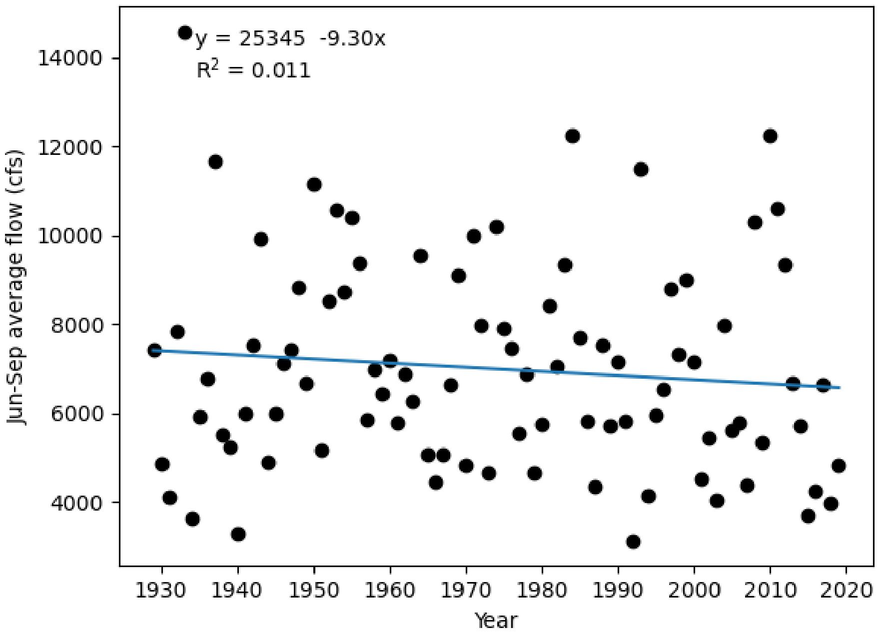


Figure 3-44. Salem, Oregon, June through September.

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

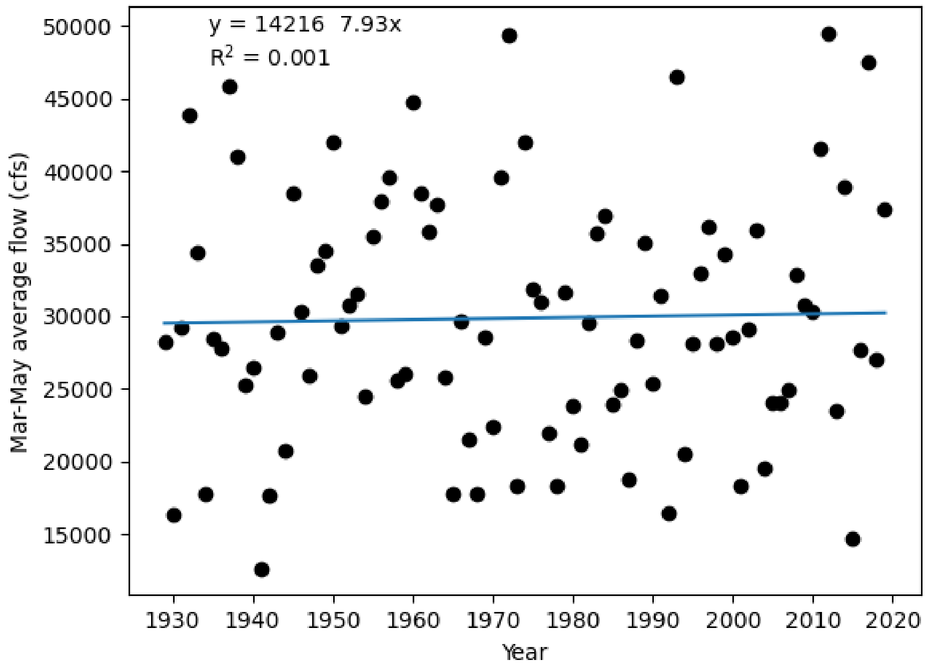


Figure 3-45. Salem, Oregon, March through May.

For March through May average flow, there was no discernible trend through the period of record. The Mann-Kendall Test, p-value of 0.90, which is greater than 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 TST, summarized in Table 3-2.

The TST is a web-web-centric application that performs trend analyses as well as nonstationarity analyses on a given timeseries. The tool is located at: https://climate.sec.usace.army.mil/tst_app/.

Annual monthly and seasonal mean 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. Caution is needed when discussing directionality of trends that are nonsignificant. However, it may provide context for understanding and what may be the variable of concern. Most trends for the daily unregulated flows at Salem trended negative (Table 3-2). The exceptions were the winter months and the refill season (March through 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 because the 1-day annual minimum flow estimates have significant variability due to the computation method for producing unregulated flows. Overall, there appeared to be significant variability, which was attributed to how unregulated flows are computed. Removing the effects of reservoirs and routing naturalized flows downstream introduces some computational errors because 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.

NSD was also evaluated. The threshold for instantaneous NSD significance is a positive detection across three 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.

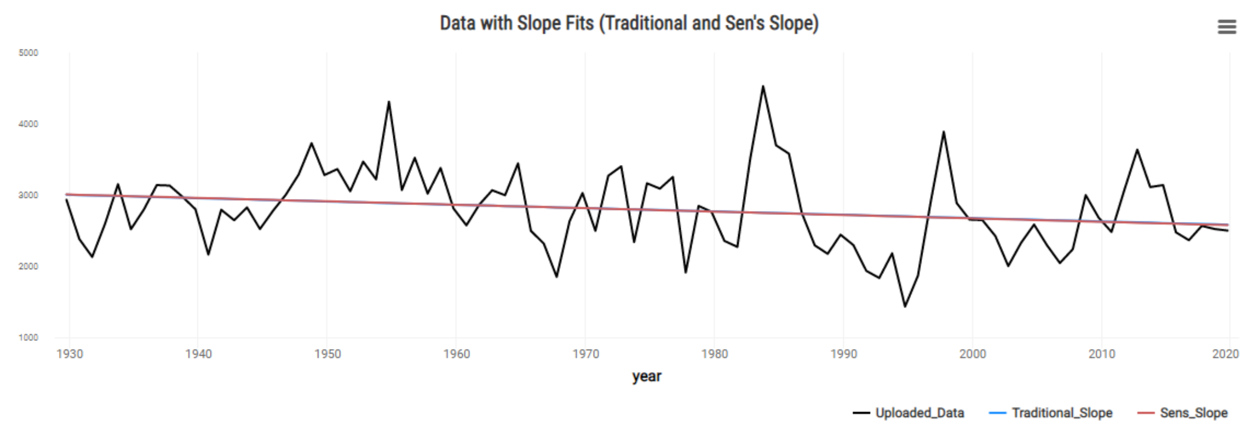
Table 3-2. Unregulated Salem, Oregon Time-series, Trend, and Nonstationarity Analyses.

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 Max 1-day	-235.23	0.32	0.36	No
Annual Min 1-day	-4.78	**0.03**	**0.01**	**Yes(1946,1985,1986,1995)**
Annual Min 7-day Mean	-1.94	0.49	0.30	**Yes(1946,1985)**
Annual Apr-Sep Av	-4.03	0.82	0.81	No
Annual Jun-Sep Av	-10.06	0.25	0.28	No
Annual Mar-May Av	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 3-46 shows the negative-sloped trend line. Figure 3-47 graphically shows the NSDs. Of the eight detections, four were deemed significant because three 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 3-46. Salem, Oregon Unregulated 1-day Minimum Flow Trend.

SLM_UNREG_TS_1-DayMin.csv

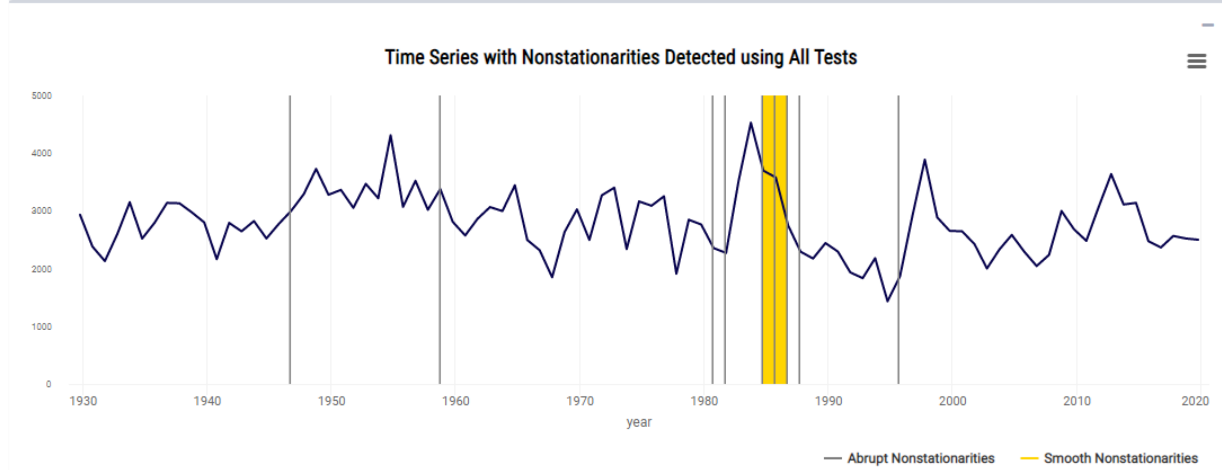


Figure 3-47. Salem, Oregon Unregulated 1-day Minimum Flow Nonstationarity Detections.

3.6 Summary of Observed Trends in Climate

Based on the literature review, there is consensus among the available sources supporting trends of increasing temperatures within Willamette River 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 River 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.

4. PROJECTED TRENDS IN FUTURE CLIMATE AND CLIMATE CHANGE

4.1 Literature Review

4.1.1 Recent U.S. 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 climate models (GCMs). Figure 3-1 summarizes the findings of the Literature Synthesis regarding projected hydroclimate and hydrologic (streamflow) trends. Additional discussion is provided in the following paragraphs.

Temperature. The 2015 USACE Literature Synthesis found strong consensus 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 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 regarding projected changes in hydrology for the region. Large variability in the projected hydrologic parameters (e.g., runoff, streamflow, SWE) exist across the literature and vary with location, hydrologic modeling approach, GCM used, and adopted emission scenario.

4.1.2 Fourth National Climate Assessment

In addition to the observed trends, the NCA4 (USGCRP 2018a) 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°F 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 historical baseline period of 1986 through 2015. Additionally, projections are shown for two emission scenarios, or representative concentration pathways (RCPs) of greenhouse gases. RCP 8.5 is a higher emission scenario and RCP 4.5 is a moderate emission scenario.

Note that, in general, increases in projected temperature are greater in higher latitudes and lessen farther south in the United States. 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 U.S. under all emission scenarios.

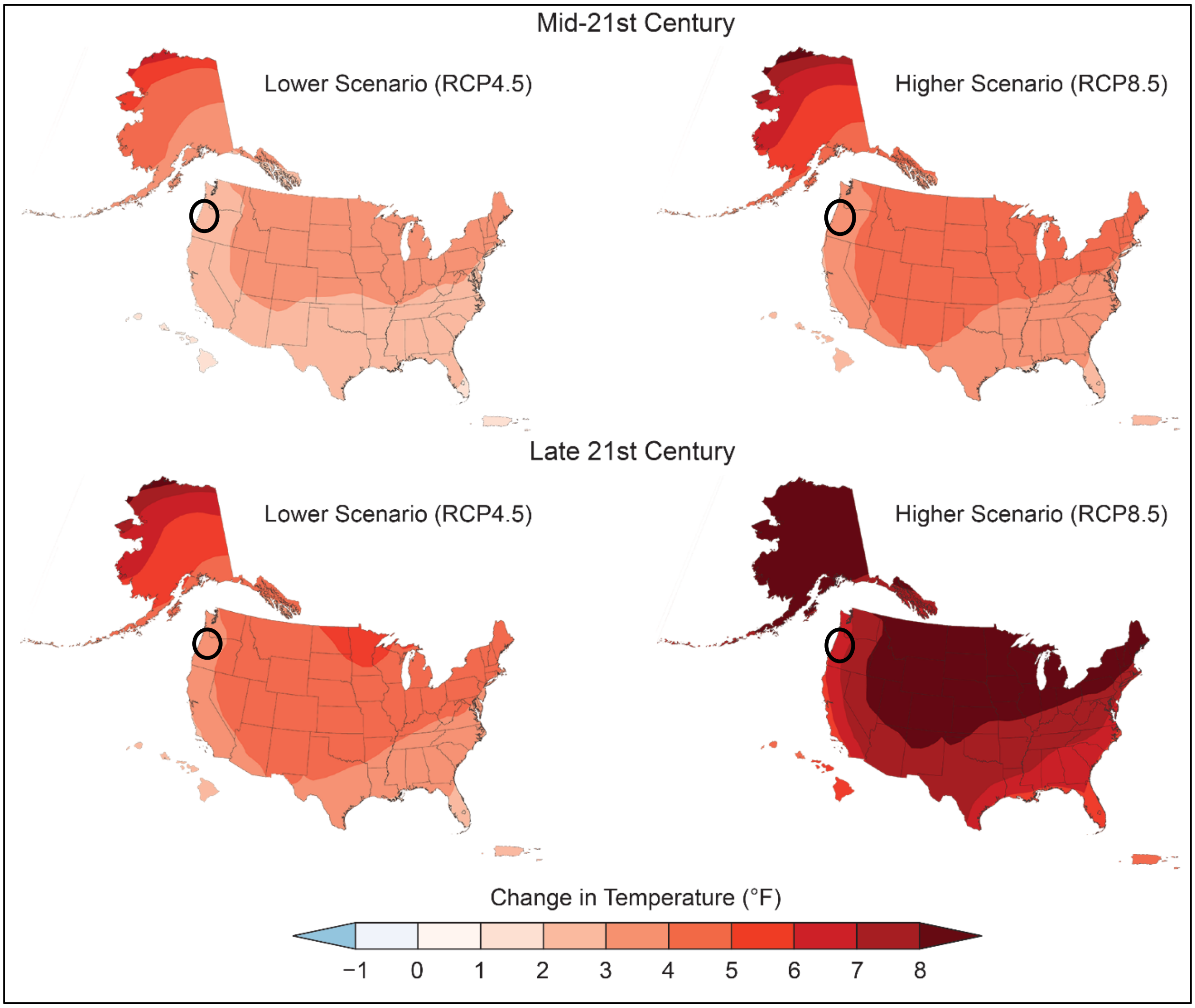


Figure 4-1. Future Projections of Temperature.

Precipitation. Both increases 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 historical period of 1986 through 2015. Note that there is significant variation in projections depending on location and season. Also note that red dots indicate the projected trends due to climate change are large when compared with natural variations in climate, whereas the hatched areas show 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 River Basin analysis area, most of the trends in precipitation can be considered relatively insignificant except for decreases in summer 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.

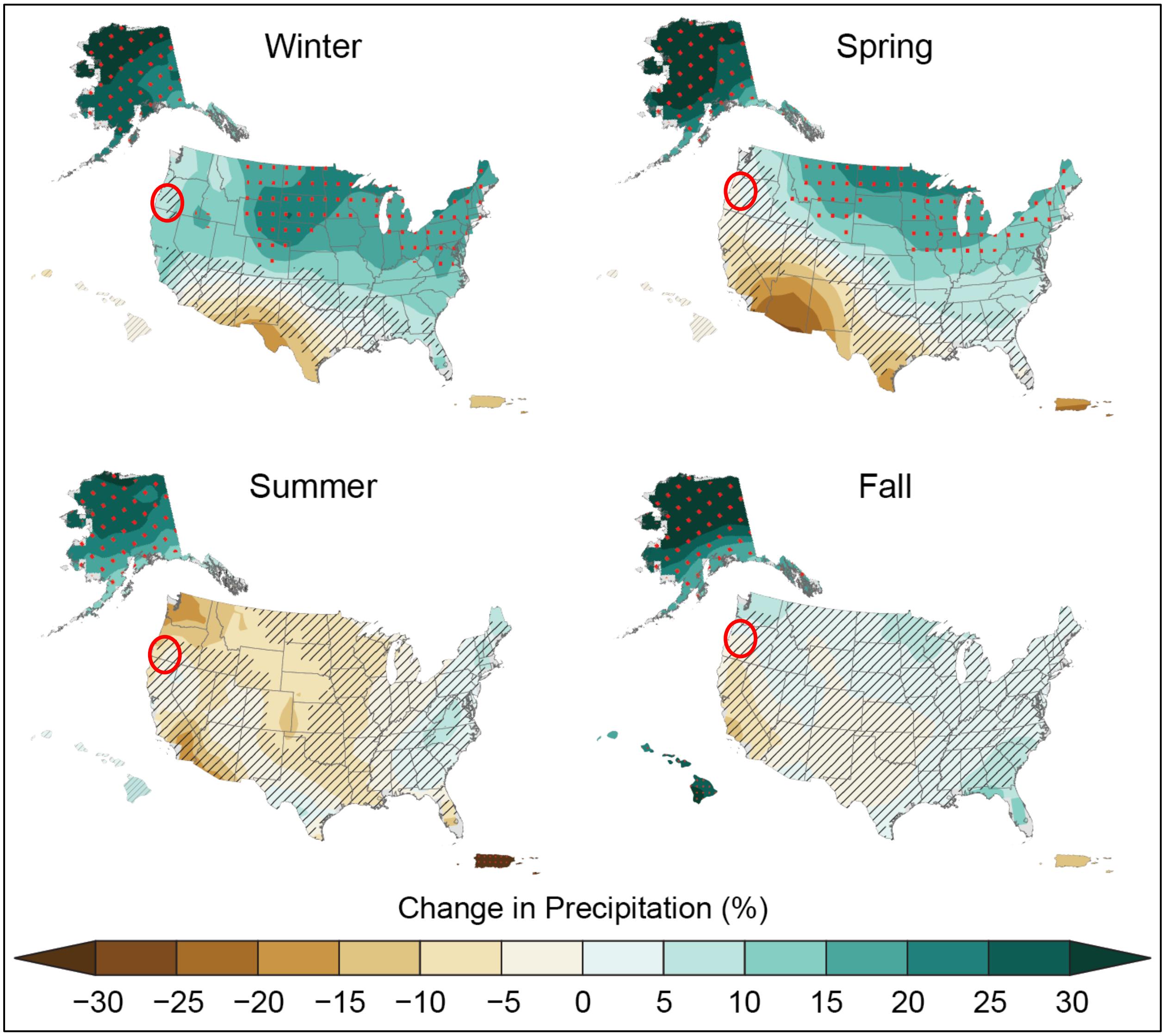


Figure 4-2. Observed Percent Change in Precipitation during the 1 Percent Event.

The observed increases in frequency and intensity of heavy precipitation 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 percent of storms between 2070 and 2099. Note that in the vicinity of the Willamette River Basin, under a moderate emission scenario (RCP 4.5), the annual precipitation falling during the heaviest 1 percent of events is expected to increase by approximately 10 percent to 19 percent. Under a higher emission scenario (RCP 8.5), the Basin is expected to experience extreme event precipitation increases of 30 percent to 39 percent. These trends are consistent with what would be expected with warmer temperatures because increased evaporation rates lead to higher levels of water vapor in the atmosphere which in turn leads to more frequent and intense precipitation events.

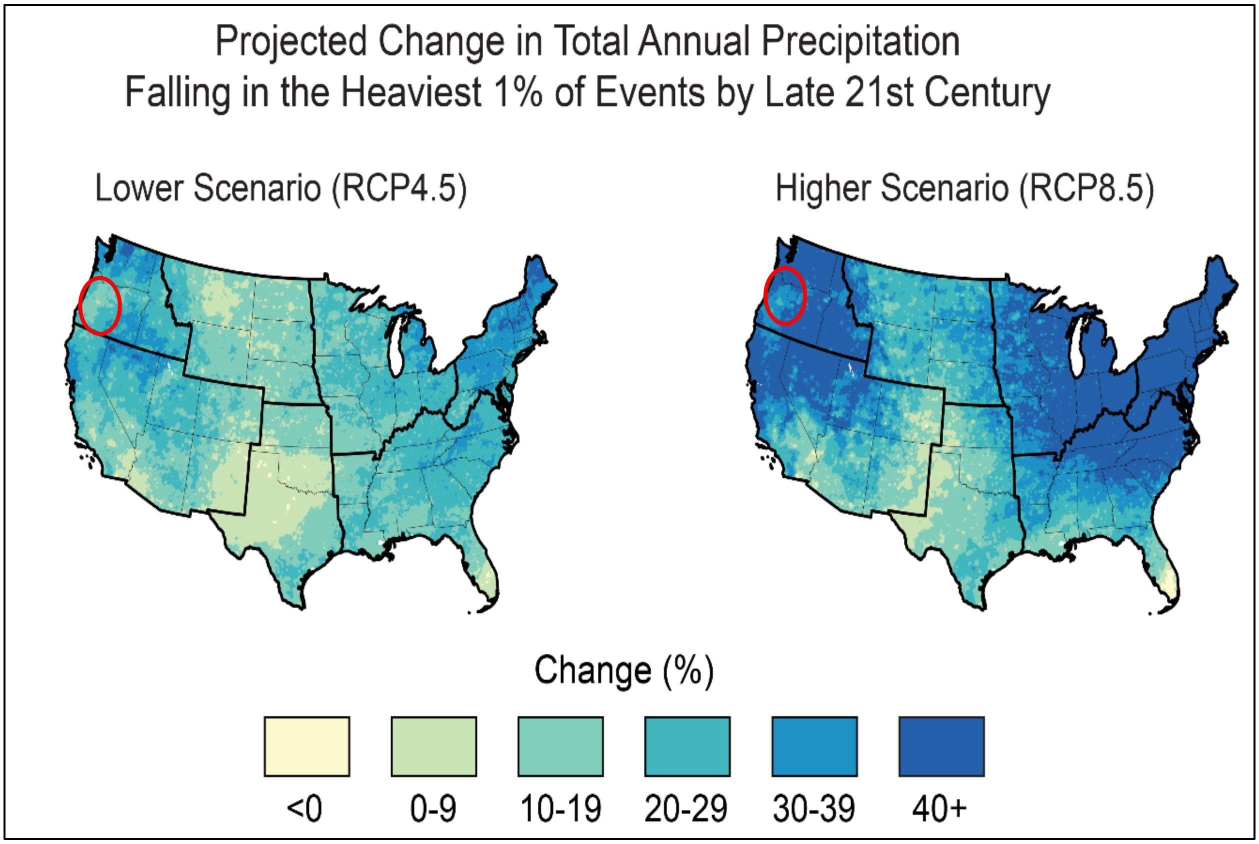


Figure 4-3. Projected Change in Future Precipitation (RCP 4.5/8.5).

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, which may increase stress on reservoirs. Many basins that 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 (USGCRP 2018a) qualitatively discusses 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 historical records that are limited in length (approximately 10 to 100 years). Selected points from this discussion relevant to the Willamette River 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 to 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. illustrate a much wider range of climate variability than does the instrumental record (beginning around 1900). This historical variability includes wet and dry periods with statistics very different from those of the 20th century. Infrastructure design that uses recent historical data may underrepresent the risk seen from the paleo record, even without considering future climate change.

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

- 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. Such methods are not readily available, even at a research stage, for supporting the EIS analyses. Also, the spatial resolution of such analyses and data would not support the EIS needs. The PDT considered this information early in the process.

END REVISED TEXT

- 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. Because 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 model (VIC) for the Columbia River Basin, of which the Willamette River Basin is a part. The resulting streamflow projections were based on nine GCMs and 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). Nineteen unique combinations of GCMs and emission scenarios were considered; eight based on scenario A1B, eight based on scenario B1, and one historical baseline scenario.

CMIP3 GCM scenarios A1B and B1 represent moderate and optimistically low greenhouse gas emission scenarios, respectively. 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 RCP 6.0 and RCP 4.5, respectively.

According to the Willamette Basin Review Feasibility Study (USACE 2018d), the OCCRI report describes general climate projections for 2030 through 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 because all the GCM models reviewed had the same result. The amount of precipitation, however, varied among the various GCM models by both season and whether there is an increase or decrease in precipitation. Regardless of the precipitation changes, the models show that the warming temperatures decrease the snow water equivalent (SWE) as a proportion of the cumulative precipitation (P) in the Willamette River Basin. Willamette River subbasins, 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 subbasins, 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 rainfall precipitation also showed less snow accumulation, which affects the streamflows in each subbasin.

The combination of changes in precipitation patterns and increasing temperatures results in future streamflows that have higher winter flows and lower summer flows on average. Subbasins within the Willamette River Basin display differing sensitivity to these changes, which are largely correlated to the subbasin's projected loss of snowfall and that subbasin'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. The Hills Creek, Cougar, 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 toward 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 similar to those described above for Lookout Point, Dexter, and Fall Creek Dams. However, this project's results were described separately in the OCCRI report (2015) because the project is slightly more sensitive to melting snowpack due to its higher topographic elevation and because the number of scenarios showing increasing winter flows is slightly different.

The OCCRI report (2015) 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 "Climate Change and Freshwater Resources in Oregon" in 2010 (Chang and Jones 2010). The report summarizes existing literature for the state of Oregon in a similar manner to the USACE literature syntheses. In general, the PSU study agrees with many of the conclusions previously described, stating: "Many Oregon streams will experience higher winter flows and reduced summer flows as temperature rises and the variability of precipitation increases."

4.4 Willamette Basin Review

The Willamette Basin Review Study, completed in 2019 (USACE 2019), focuses on reviewing and assessing reservoir operations within the Willamette River Basin for the purposes of municipal and industrial water supply, agricultural irrigation, and fish and wildlife minimum inflows. A semi-quantitative analysis was applied to 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 Willamette Basin Review focused primarily on water supply, which is driven by volume of runoff.

The Willamette Basin Review Study references much of the same literature included within this analysis and in general draws very similar conclusions. The report concludes that: "the warming climate [of the Willamette River 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 available research targeted at identifying the timing of potential, future shifts in seasonality. For the Willamette River 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 WVS's ability to refill their reservoirs. However, the impacts that climate change could potentially have on the ability of WVS to refill are very sensitive to the seasonality of inflows and therefore a great deal of uncertainty exists associated with how climate change could potentially impact WVS'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 water demand currently 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 et al. (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 RCP 8.5. RCP 8.5 represents a relatively high emission scenario corresponding to an ultimate radiative forcing of 8.5 Watts square meter. Basins 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 Warner et al., "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 River Basin is located at approximately 44.5°N. Looking specifically at the latitude associated with WVS, the paper projects extreme precipitation events (1 percent chance exceedance or 99th percentile) to increase from approximately 20 mm/day to 24 mm/day; an increase of 20 percent 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 percent 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

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

Queen et al. (2021) published a study called, "Ubiquitous Increases in Flood Magnitude in the Columbia River Basin under Climate Change" that 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 40 GCM projections, focusing the analysis on the highest emission scenario (RCP 8.5). The flow frequency analysis estimated the 10 through 1 percent Annual Exceedance Probability (AEP) flood statistics for time windows 1950 through 1999 and 2050 through 2099. Flood statistics from the two 50 percent AEP 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 River Basin. 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 slightly over 1.6. Spatially, the flood magnification ratio changes were higher at headwater locations, as were the largest changes and highest variability between projections. In the Willamette River Basin, the flood ratios appeared to vary by flow magnitude as well. The more frequent events tended to have higher flood ratios compared to less frequent events (e.g., the 1 percent AEP flood ratio was less than the 10 percent).

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Queen et al. (2021) found that for the rain-dominant Willamette River Basin, the quantity and frequency of rain driven floods are projected to increase. The authors noted that the flood ratio estimates 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. Projections for future increasing precipitation intensity (e.g., driven by atmospheric rivers) contained in the GCMs will still lead to more severe future flood ratios in the Basin.

4.7 NOAA State Climate Summary for Oregon, 2022

National Oceanic and Atmospheric Administration (NOAA) publishes state climate change summaries through the National Centers for Environmental Information (NCEI). The following summarizes observed and projected warming through 2100.

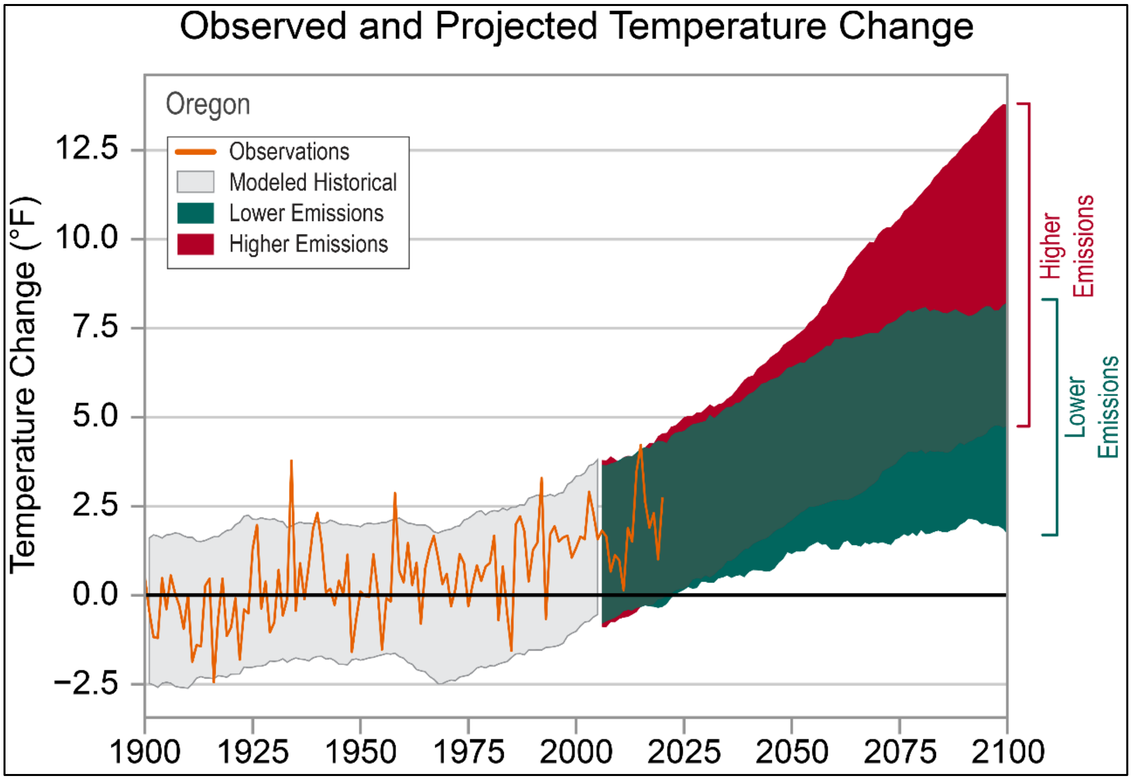

Figure 4-4. Observed and Projected Temperature Change for Oregon.
Source: NOAA 2022 https://statesummaries.ncics.org/chapter/or/

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

Observed and projected changes are shown in Figure 4-4 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 RCP 4.5 (lower) and RCP 8.5 (higher) emissions scenarios. Observed temperatures (orange line) have risen about 2.5°F since 1900. Shading indicates the range of annual temperatures from the set of models. The temperature changes shown above are the result of GCM models forced by reconstituted historical greenhouse gas data. In effect, the historical period shown above is not an observed dataset but a reconstruction based on GCM modeling forced with historical greenhouse gas input.

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Other primary findings for Oregon pertaining to the Willamette River Basin analysis area included:

- 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. Note that this agrees with the USACE Literature Synthesis but not NCA4.

- 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 for this analysis, there is general agreement regarding the hydrologic trends that can be expected in the future. In general, the following statements represent the probable hydrologic future that can be expected within the Willamette River Basin:

- Winter 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.

- Summer 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 summer months to supply adequate quantities of water for irrigation, water supply, and required ecologic minimum flows.

- The seasonal timing of the transition from higher winter flows to lower summer 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 historical norms. This has various hydrologic implications, including increased atmospheric moisture, evapotranspiration rates, frequency of wildfires, hydropower demand, and water supply demand.

5. CLIMATE HYDROLOGY ASSESSMENT (CHAT)

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

The USACE Climate Hydrology Assessment Tool (CHAT) (USACE 2016a) was used to assess projected, future trends within the Willamette River Basin HUC-1709. The tool displays the range of historical period annual maximum monthly streamflows up to 2005 through 2099. Future period projections span 2006 through 2099. The results shown in this document reflect the data and analyses used by the PDT at the time. The use of the newer version of CHAT would not materially change the potential effects to Resources.

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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). At this outlet, the Willamette River has a drainage area of approximately 11,200 square miles as compared with the 7,280 square mile basin 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 5-1 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 projections increases as time moves away from the model initiation point. The difference in RCPs grows considerably during the latter half of the century, indicative of a substantial source of uncertainty in assumed emissions. 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/year, which is roughly a 5 percent increase through 2100. This would not have high operational system impact. The relative change is small compared to average annual basin flow. It should be noted that the p-value associated with this trend is less than 0.0001, indicating that the trend should be considered 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. 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.

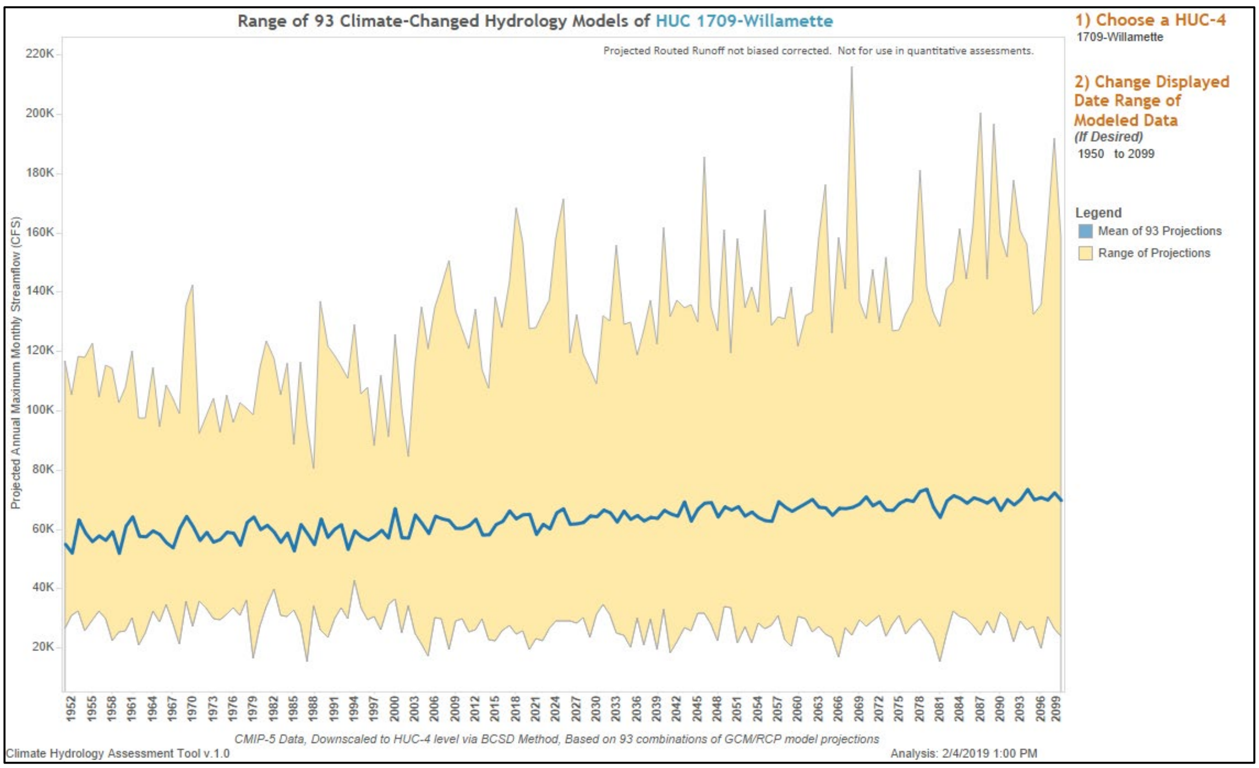

Figure 5-1. Range of GCM/RCP Projections for the Willamette River Basin, HUC-1709.

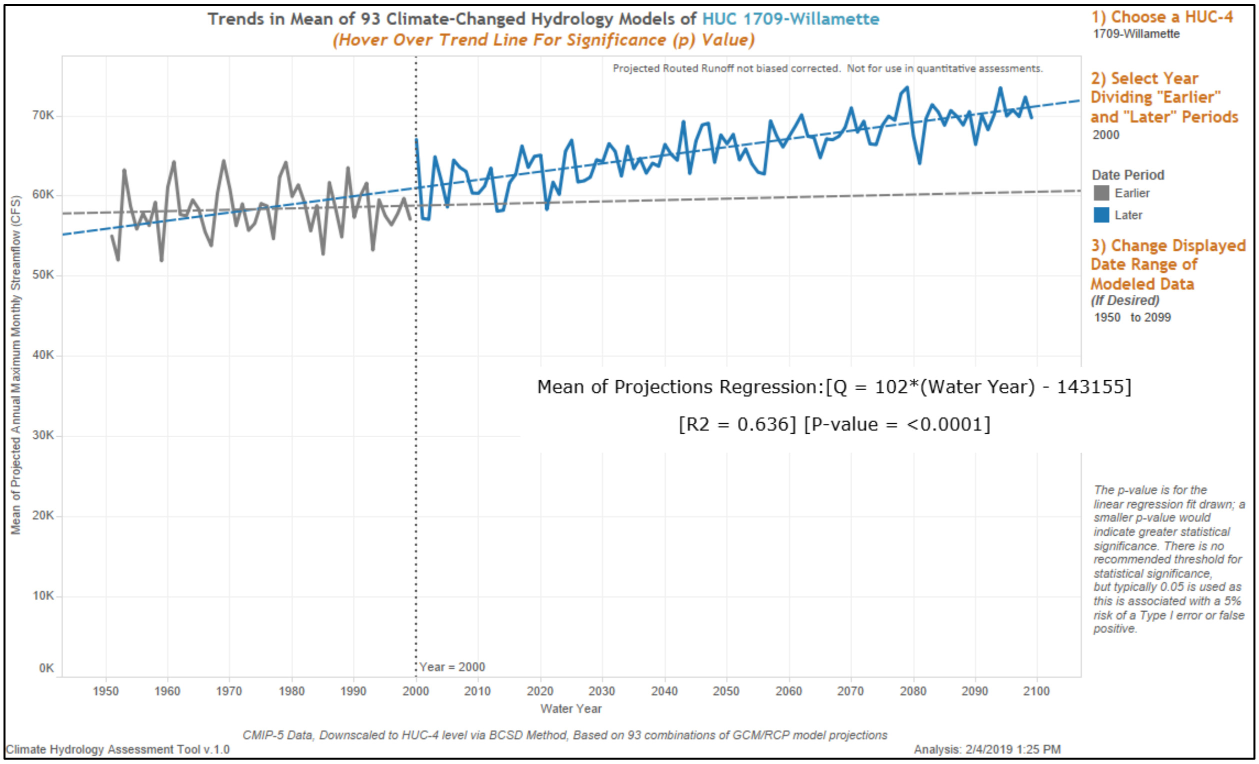

Figure 5-2. Mean of GCM/RCP Projections for the Willamette River Basin, HUC-1709.

6. VULNERABILITY ASSESSMENT (VA)

The USACE Watershed Climate Vulnerability Assessment Tool (VA Tool) (USACE 2016b) 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 HUC-4 watersheds within the continental United States. The VA 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 percent 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. The top 50 percent of the traces is called “wet” and the bottom 50 percent 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 that the VA Tool’s results highlight some of the variability 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 percent 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 VA 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 VA 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 vulnerabilities and none were found. For the designated business lines, the Willamette River Basin (HUC-1709) is not within the top 20 percent of vulnerable watersheds within the continental United States 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 is most suited to general qualitative determinations. The VA business lines analyzed for this EIS are:

- 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.** Focuses on the EIS Proposed Action, effects, and impacts to the WVS 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.** Focuses on WVS streamflow temperature and total dissolved gas levels. Hazardous algal blooms have also become an issue for water quality. The proxy VA business line is primarily Ecosystem Restoration.

- **Fish and Aquatic Habitat.** Focuses on WVS management and impacts to Chinook salmon, bull trout, and Pacific lamprey. The proxy for this RA is primarily the Ecosystem Restoration and Regulatory business lines.

- **Hydraulics-Sediment-Transport.** Focuses on WVS Proposed Action impacts to change in sediment transport in Willamette River Valley subbasin reaches. Flood Risk Reduction, Ecosystem Restoration, and Regulatory were primary VA business lines for this RA.

- **Wetland-Veg-Wildlife.** Focuses 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.** Focuses on impacts to the archeological and cultural resources for this resource area. Regulatory was considered the primary VA business lines for this RA.

- **Recreation.** 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.** Focuses on the conservation authorities that USACE also manages in the WVS. The 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. The EIS-specific VA Tool indicators are summarized in Table 6-1. The following output graphics and tables summarize the eight 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)

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

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:::

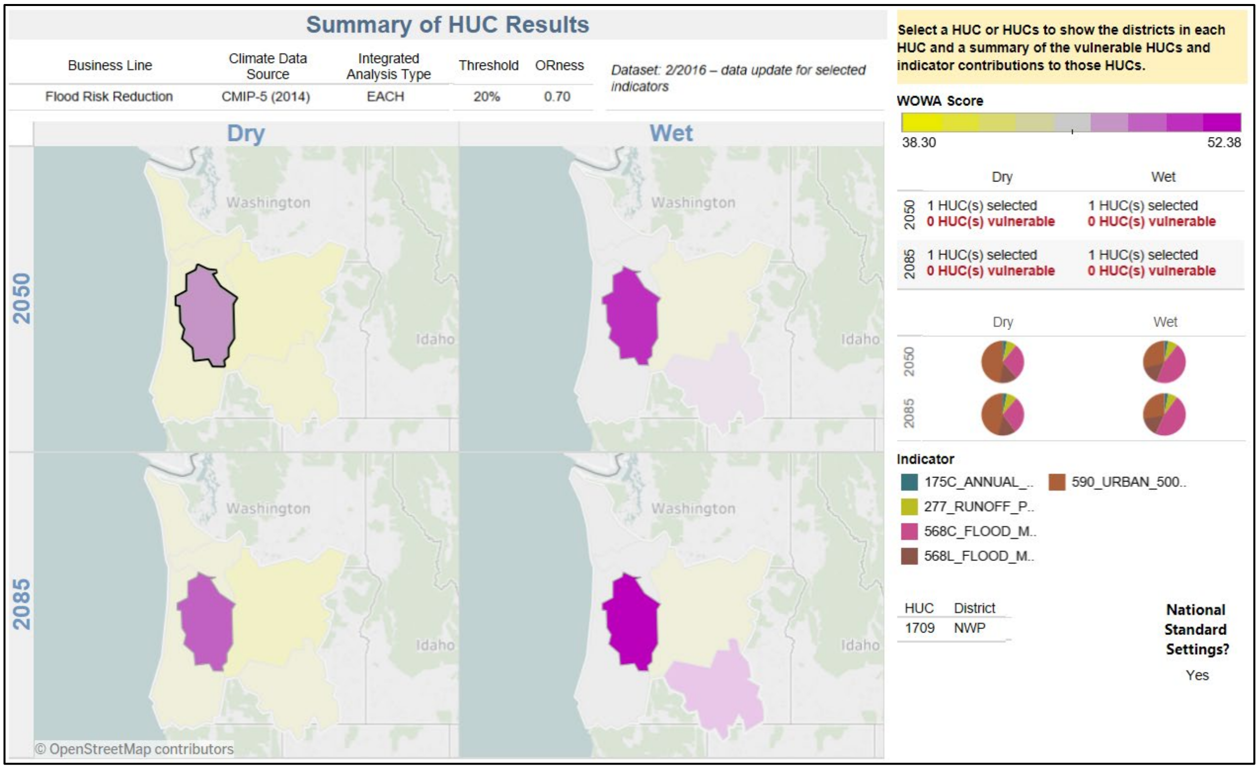

Figure 6-1. VA Tool Flood Risk Reduction Business Line.

Table 6-2. VA Flood Risk Indicators.

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

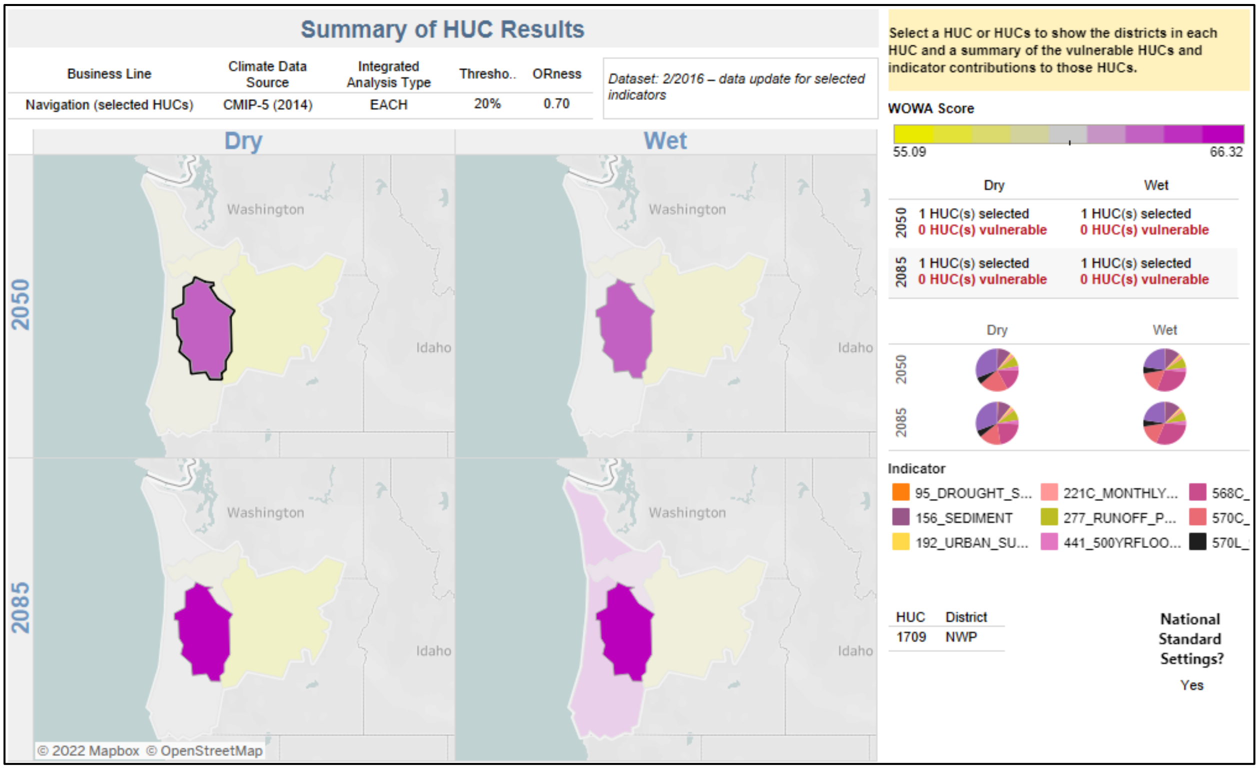

Figure 6-2. VA Tool for Navigation Business Line.

Table 6-4. VA Navigation Indicators.

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

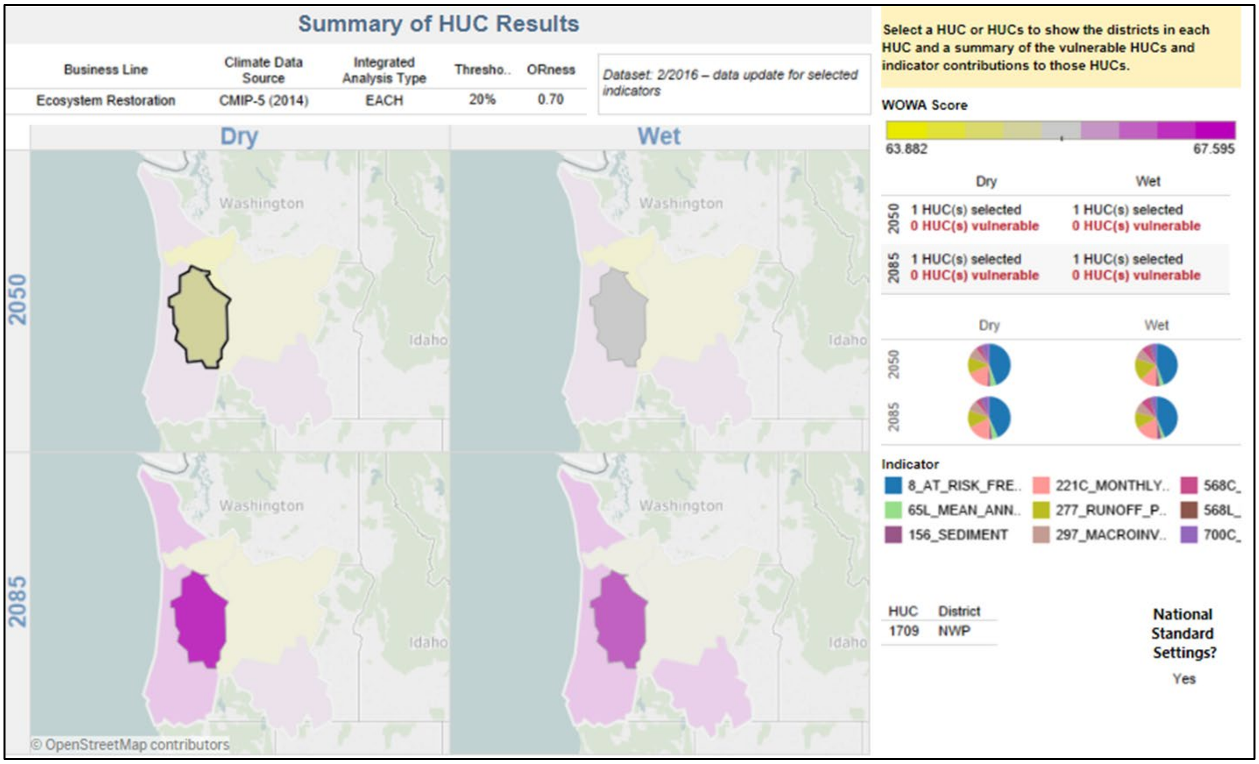

Figure 6-3. VA Tool Ecosystem Restoration Business Line.

Table 6-6. VA Ecosystem Restoration Indicators.

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	Ecosystem Restoration	Ecosystem Restoration
Epoch:	**2050**	**2085**
Dry Scenarios	65.27	65.54
Wet Scenarios	67.08	66.39

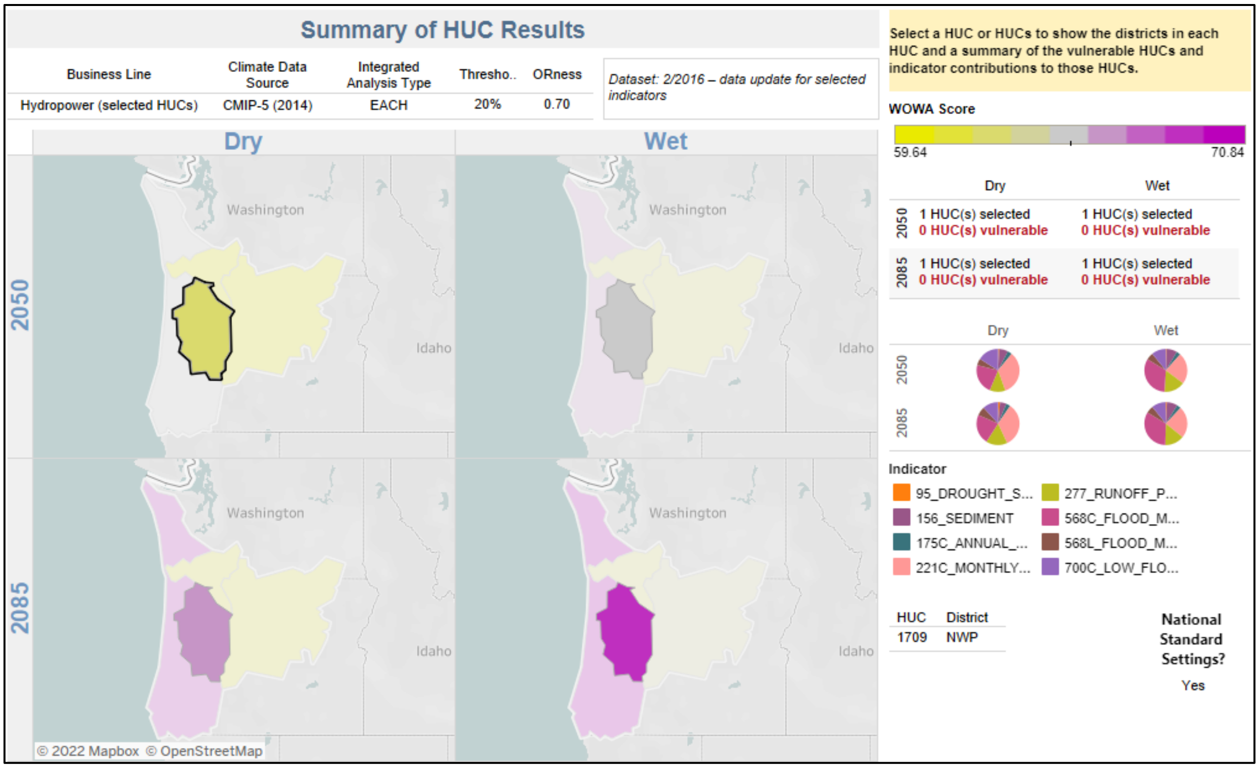

Figure 6-4. VA Tool Hydropower Business Line.

Table 6-8. VA Hydropower Indicators.

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 6-9. VA WOWA Score for Hydropower.

WIL HUC 17094	Hydropower	Hydropower
Epoch:	**2050**	**2085**
Dry Scenarios	65.27	65.54
Wet Scenarios	67.08	66.39

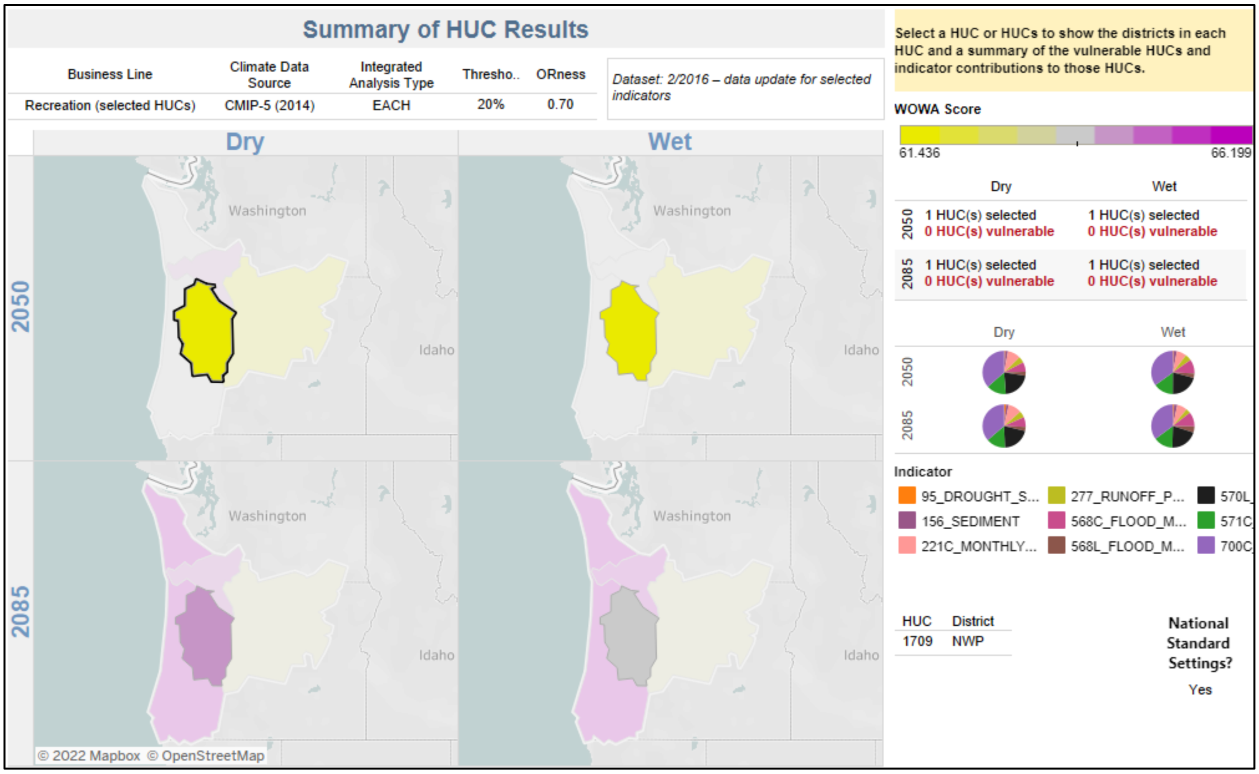

Figure 6-5. VA Tool Recreation Business Line.

Table 6-10. VA Recreation Indicators.

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	Recreation
Epoch:	**2050**	**2085**
Dry Scenarios	61.11	64.12
Wet Scenarios	61.436	63.61

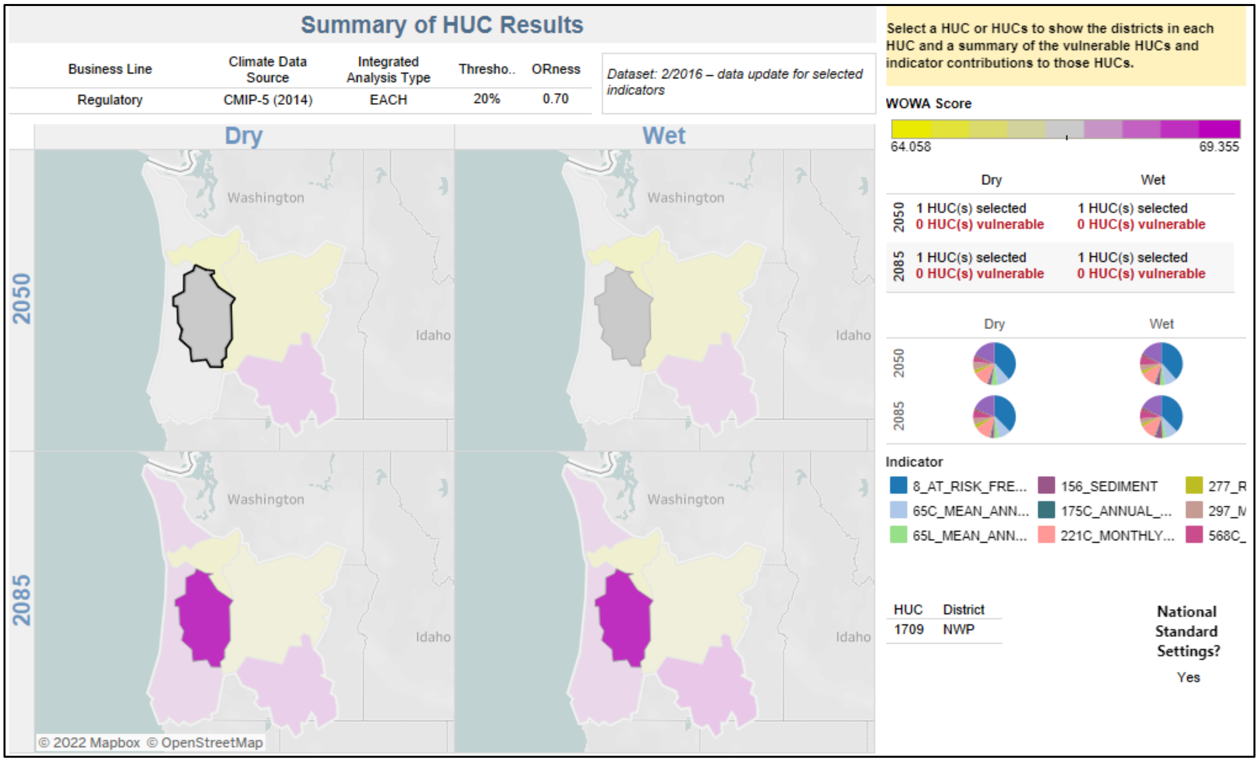

Figure 6-6. VA Tool Regulatory Business Line.

Table 6-12. Regulatory Indicators.

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

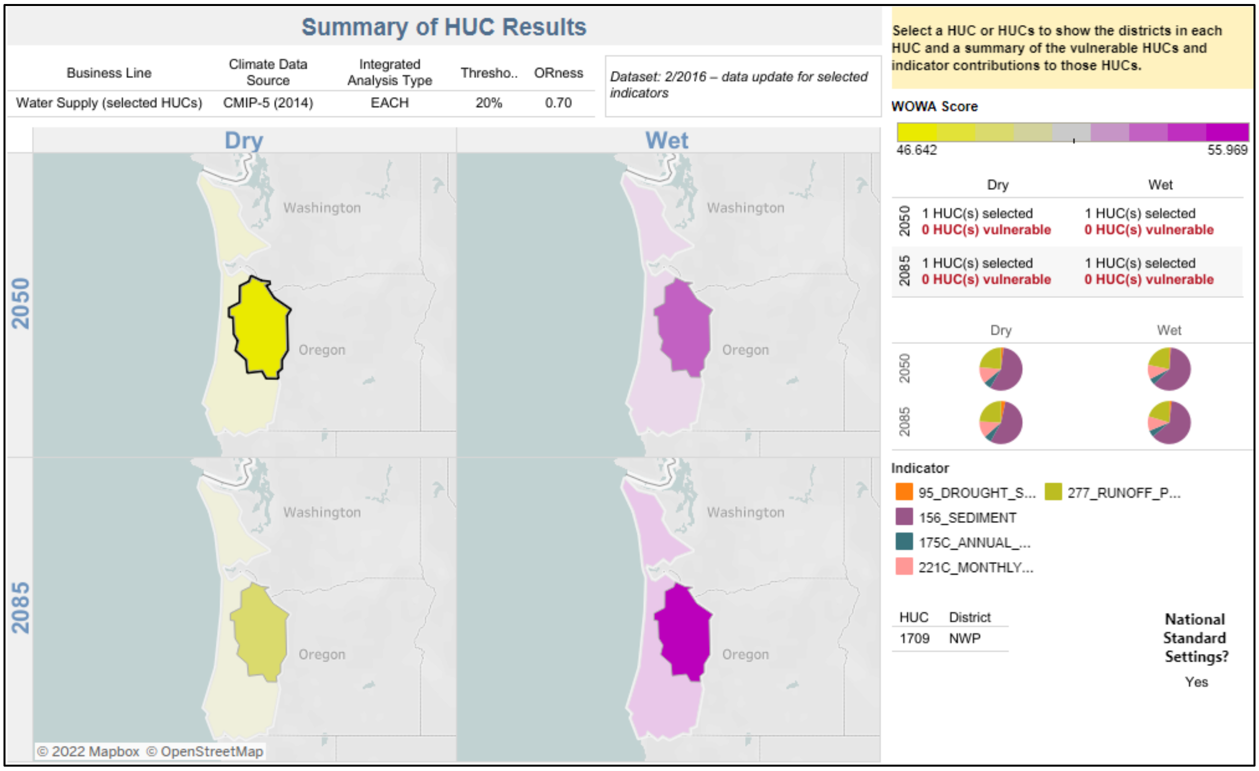

Figure 6-7. VA Tool Water Supply Business Line.

Table 6-14. Water Supply Indicators.

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

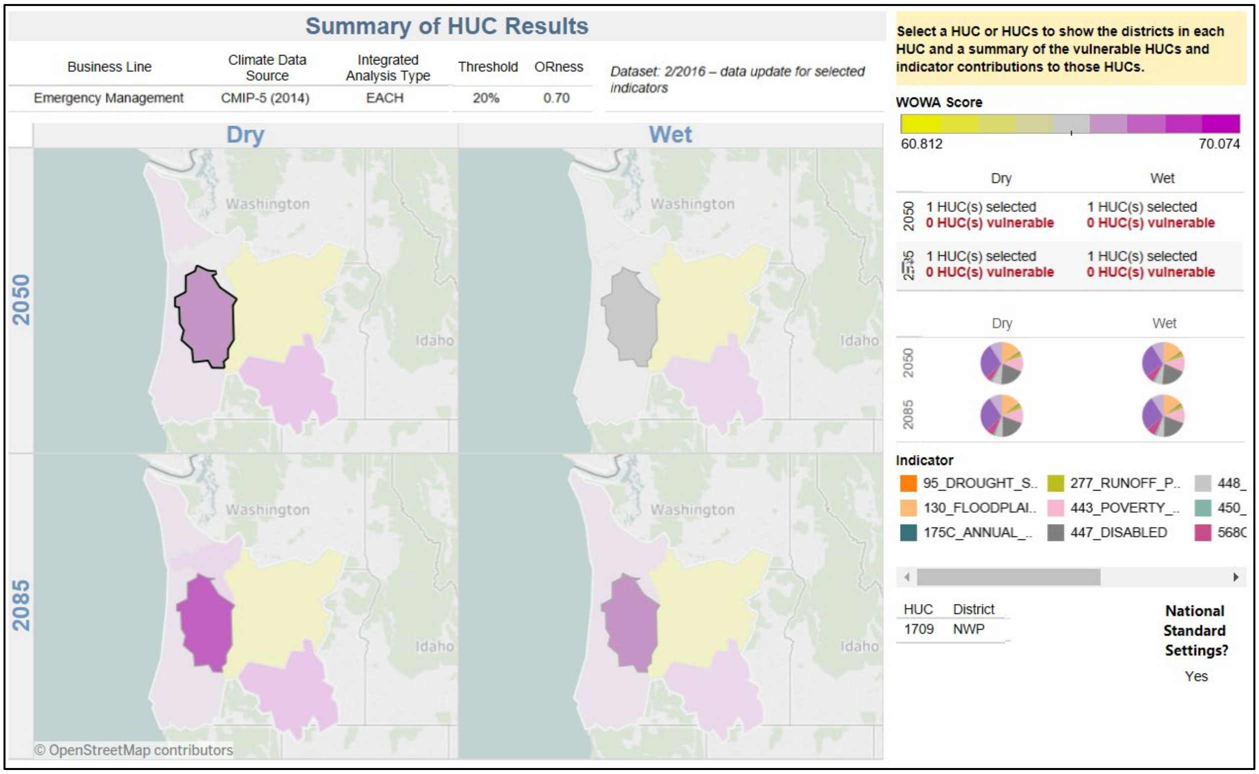

Figure 6-8. VA Tool Emergency Management Business Line.

Table 6-16. Emergency Management Indicators.

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)**

(Note: Red indicates the top vulnerability indicators.)

Table 6-17. VA WOWA Score for Emergency Management.

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

6.3 VA Implications for Resource Areas

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

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 No-action Alternative (NAA) flood risk reduction objective and may increase future costs associated with flood damage. This trend broadly agrees with conclusions drawn from the literature review and the CHAT results discussed in Section 3.1, Climate Change Literature Syntheses and Section 3.3, Climate Hydrology Assessment. The literature review highlighted an increase in winter/early spring flows and decreasing summer flows.

Low flow metrics included in the VA Tool are a drought severity index, a low flow reduction factor, and the 90 percent AEP flow. The low flow reduction factor and 90 percent AEP flow variables contribute significantly to the Emergency Management and Recreation business lines' VA scores for the Willamette River Basin. Despite including low flow metrics in the VA score, these variables do not contribute significantly to the Ecosystem Restoration, Water Supply, and Hydropower VA Tool output for the Willamette River Basin. VA driver 95 "drought severity," was not a primary driver, although it occurred often. Driver 95 was conspicuously absent for the Willamette River Basin's 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.

VA drivers 221L and 221C, which represent the local and cumulative coefficient of variation of monthly runoff, are variables that indicate the 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" (VA Tool metric description). 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" (VA Tool metric description) compared to historical norms.

Although the VA Tool does not provide directionality or variability for the indicator, it may reflect winter increasing flows and less summer base flow. The literature points to a decrease of relative flow and volume in the summer. 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 through 2085) and an 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). Other factors that could drive vulnerability exist, such as Wildfire risk that drives potential increase in sediment transport and the change in land cover that 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.

END REVISED TEXT

7. SUMMARY AND CONCLUSIONS

This climate change assessment was prepared to support the Willamette Valley System (WVS) Environmental Impact Statement (EIS). The Willamette Valley System operates 13 dams and reservoirs (projects) to meet multipurpose objectives. These include operations to reduce the risk and associated damages of flooding throughout the Basin as well as 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. The EIS PDT identified relevant climate change factors early in the process. Factors such as ambient temperature change, evaporation at reservoirs, changing flow peaks and timing, more frequent and intense occurrence of wildfires and their effects, changing SWE, and increasing water temperatures were perceived likely to impact EIS resource areas. Refer to Appendix F2 for additional discussion and analysis of these climate factors.

THE DEIS HAS BEEN REVISED TO INCLUDE THE FOLLOWING INFORMATION IN THE FEIS

Climate change was considered early in the EIS Preferred Alternative selection process. An explanation of the Preferred Alternative formulation is contained in FEIS Appendix A. Measures were brainstormed and screened out based on various criteria and rationale. Some brainstormed measures were seemingly well suited to address a particular climate stressor. For example, increasing water temperatures could be offset with a thermal regulation (temperature control) tower. The temperature control towers at each site in the Basin would likely offer some downstream cooling. However, the cooling effects can be localized and may not have long-term persistence. While providing a tower at each site could offset downstream water temperatures, the cost to build may be prohibitively expensive. Maximize Storage and deviations from prescribed shared water allocation, which are goals of the alternative but are not measures, would conceptually be climate resilient. Reallocation was out of scope of the WVS EIS. Regulation curve updates were considered but screened out due to impacts to the constraint of not impacting flood risk management purpose.

END NEW TEXT

Relevant climate change factors were consequential for the future climate vulnerability analyses and identification of residual risk. The Corps Climate Preparedness and Resilience (CPR) Community of Practice (USACE 2023) defines residual risk 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 DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

The nonstationarity detection (NSD) analyses and attribution of observed annual peak streamflows in the Basin led to the determination that there is little evidence for changing hydroclimate affecting the observed peak streamflow hydrology in the Willamette River 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 flows either. Flood-level streamflow change is often the metric of greatest concern for water managers in the Willamette Valley System operations. But increasing concern has been given to the low flow metric changes as the most immediate vulnerability to manage. The low water metric changes are increasingly impactful to future WVS operations for ecosystem, water quality, etc.

END REVISED TEXT

It is estimated that the WVS 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 results. The directionality of projected changes highlights the need for flexibility in future flood risk, refill, biological opinion, 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 WVS 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 described in the EIS. However, proposed EIS operations focused on ameliorating the stressors that are also climate change factors will likely make any Preferred Alternative measures more resilient to future climate change factors.

Significant hydro-regulation capacity and flexibility are incorporated into existing water management plans. Therefore, the WVS is uniquely suited to be more resilient to future seasonal flow 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.

Potential resilience measures that 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. These 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 for 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 WVS 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 and re-evaluated 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 (i.e., climate variable that causes the risk), the hazard (i.e., resulting dangerous environmental condition), the harms (i.e., potential damage to the project or changed project output), and a qualitative assessment of the likelihood and uncertainty of this harm.

The residual risk table identifies climate change risks that remain after the proposed EIS actions are implemented. Residual risks are assigned a risk rating: likely, less likely, or highly likely.

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-year 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 as well. Table 7-1 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; maximum impacts will 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.

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING TABLE IN THE FEIS

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

Trigger	Hazard #	Hazard	Harm (or reduction in harm where specified)	Likelihood of Harm
Decreased Summer Precipitation in Combination with Warmer Summer Temperatures	1	Increased Wildfire intensity and frequency.	Wildfires can result in increased erosion that would further increase sediment loads and turbidity, and could further reduce the quantity and quality of some fish species and habitat.	LIKELY
			Wildfire would negatively affect all types of cultural resources.	
			Degradation of water quality in streams and rivers throughout the WRB (e.g., Higher pollutant loads etc.).	
	2	Decreased summer flows/prolonged conservation season low flow conditions (worsened by increased E-T due to warmer temperatures).	Climate change is likely to increase the demand for Municipal and Industrial (M&I) water supply and agricultural irrigation. A decrease in flow and water volumes in the summer may have an adverse effect on water supply as users aren't able to withdraw water from the stream for consumptive uses.	LIKELY
			Reservoirs will have to release more water to meet downstream flow targets as local inflows will be less. Reservoir storage volume is the primary driver for providing augmentation flows in summer and autumn. Immediately downstream of each dam, water temperature is dependent on temperature management (the ability to mix cooler, deeper lake water with warmer, surface lake water). Decreased water supply in the conservation season. WVS projects may reach their minimum water surface elevations more frequently. Reduced water levels in the summer that expose archaeological sites.	LESS LIKELY to LIKELY
			If reservoir levels are lower due to low summer flows and long-lasting droughts, shoreline erosion could occur and cause sedimentation and increased turbidity affecting water color, clarity, and texture.	LESS LIKELY to LIKELY
Increase in Frequency of Winter Extreme Precipitation Events	3	Future flood volumes may be larger than present and large flood volumes may occur more frequently. Flood hydrographs may be flashier.	Increased flooding (more frequent bank-full flows), Rule Curves dictating reservoir operations might not suffice during extreme wet conditions, and increased winter precipitation that erodes archaeological sites.	UNLIKELY

Increase in Frequency, Duration, and Intensity of Droughts	4	Future droughts may be more severe than at present. Future droughts might occur at increasing frequency.	Lower summer streamflows imply that reservoirs will have to release more water to meet downstream flow targets. Downstream flow targets may not be met and Rule Curves dictating reservoir operations might not suffice during extreme dry conditions.	LIKELY
Warmer Winter Temperatures	5	Shift from a combined rainfall-snowmelt regime to a rainfall only regime resulting in lower late winter/spring flows.	Reservoirs might not adequately fill. Reservoir storage volume is the primary driver for providing augmentation flows in summer and autumn. Immediately downstream of each dam, water temperature is dependent on temperature management (the ability to mix cooler, deeper lake water with warmer, surface lake water). Decreased water supply in the conservation season. Higher winter flows occurring in December-January would not be stored as the guide curves for Willamette Projects generally begin February 1. Therefore, climate change will likely lead to decreased release volumes in spring and summer compared to the NAA and could shorten the recreational season/reduce recreational opportunity.	HIGHLY LIKELY
			Reduction in Harm: Flood risk contribution from the annual spring snow melt a may be reduced, especially in higher elevation reservoirs that are presently influenced by snowpack.	HIGHLY LIKELY
	6	Shift from a combined rainfall-snowmelt regime to a rainfall only regime resulting in Higher Winter Flows.	Higher winter flows may increase TDG (Total Dissolved Gas) levels if no TDG management is in place, as turbine capacity at power projects would likely be exceeded more often and result in “spill” releases through non-power outlets.	LIKELY
			Increased winter and early spring flows may complicate WVS ability to initiate refill earlier.	LIKELY
			Reduction in Harm: Because the WVS will likely experience increasing winter (December through March) flow volumes due to climate change generally, it is possible that projects may be able to capture some additional flow, which could produce incremental increases in power generation during the winter.	LIKELY
			Because precipitation is not stored as snow (SWE) upstream of the reservoirs, fall and winter inflows are likely to increase, which could result in more frequent flood risk management operations and demand on the flood risk management storage within the reservoirs.	UNLIKELY
Increasing Temperatures	7	Warmer water temperatures.	Impairment/loss of lamprey, steelhead, and Chinook salmon habitat.	HIGHLY LIKELY
			Degradation of water quality in streams and rivers throughout the WRB (e.g., more HAB etc.).	
Increasing Variability in Spring Precipitation	8	Decreased spring flows.	Increased variability in spring precipitation may result in less reliable reservoir refill.	LIKELY

8. REFERENCES

Bonneville Power Administration (BPA). 2011. Level Modified Streamflow.

BPA. 2020. Level Modified Streamflow.

Chang, H. and Jones, J. 2010. *Climate Change and Freshwater Resources in Oregon*, Portland State University.

Climate Impacts Group. 2010. Final Report for the Columbia Basin Climate Change Scenarios Project, University of Washington. Available at http://warm.atmos.washington.edu/2860/report/

Climate Impacts Group. 2018. Website of Site Specific Data, for the Willamette River at Salem. Available at http://warm.atmos.washington.edu/2860/products/sites/?site=4060

Hegewisch, K. C., V. Laquindanum, E. Fleishman, H. Hartmann, and M. Mills-Novoa. Climate Toolbox Tool Summary series. Available at https://climatetoolbox.org/tool-summaries. Accessed: 2022.

U.S. Global Change Research Program (USGCRP). 2018a. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, Chapter 2, National Topics: Our Changing Climate. Washington, DC, USA, 1515 pages. doi: 10.7930/NCA4.

USGCRP. 2018b. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, Chapter 3, National Topics: Water. Washington, DC, USA, 1515 pages. doi: 10.7930/NCA4.

USGCRP. 2018c. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, Chapter 24, Northwest Region. Washington, DC, USA, 1515 pages. doi: 10.7930/NCA4.

National Oceanic and Atmospheric Administration (NOAA). 2022. https://statesummaries.ncics.org/chapter/or/. Accessed: June 2022.

Oregon Climate Change Research Institute (OCCRI). 2015. *Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins*.

Queen, L. E., P. W. Mote, D. E. Rupp, O. Chegwidden, and B. Nijssen. 2021. Ubiquitous increases in flood magnitude in the Columbia River basin under climate change. Hydrology and Earth System Science. Volume 25, pages 257–272. https://doi.org/10.5194/hess-25-257-2021.

U.S. Army Corps of Engineers (USACE). 2015. Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions, Pacific Northwest Region 17.

USACE. 2016a. Climate Hydrology Assessment Tool (CHAT).

USACE. 2016b. Vulnerability Assessment (VA) Tool and User Guide. Version 1.1. Issued November 2016.

USACE. 2016. Engineering and Construction Bulletin 2016-25, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. Issued 16 September 2016.

USACE. 2016. Willamette Basin Year in Review, Water Year 2015 (commonly referred to as the After Action Report, AAR).

USACE. 2017a. Master Water Control Manual for the Willamette Valley Project, Oregon. Draft version.

USACE. 2017b. Engineering Technical Letter (ETL) 1100-2-3. Guidance for Detection of Nonstationarities in Annual Maximum Discharges. Issued 28 April 2017.

USACE. 2017c. Appendix D, Willamette Basin Review – Flow Dataset Used for ResSim Analyses.

USACE. 2017. Appendix C, WBR – Calculation of Water Volumes Required to Meet Willamette BiOp Minimum Flows.

USACE. 2018a. Engineering and Construction Bulletin 2018-14. Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. Issued 10 September 2018.

USACE 2018b. Nonstationarity Detection (NSD) Tool and User Guide. Version 1.2. Issued May 2016, updated September 2018.

USACE. 2018c. Time Series Toolbox, Trend Analysis and Nonstationarity Detection.

USACE. 2018d. Willamette Basin Review Feasibility Study, Appendices A, B, and K. Draft version.

USACE. 2019. Qualitative Assessment of Climate Change Impacts, Willamette River Basin, Oregon. Northwest Division, Portland District, Dam and Levee Safety Section (CENWP-ENC-HC).

USACE. 2023. Climate Preparedness and Resilience (CPR) Community of Practice (CoP) Applications Portal. https://maps.crrel.usace.army.mil/projects/rcc/portal.html. Accessed 2023.

Warner, M., C. Mass, and E. Salathe. 2015. Changes in Winter Atmospheric Rivers along the North American West Coast in CMIP5 Climate Models. Journal of Hydrometeorology. Volume 16, pages 118–128. https://doi.org/10.1175/JHM-D-14-0080.1.

White, K., J. Arnold, and C. D. M. Smith. 2015. Recent U.S. Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Pacific Northwest Region 17.

Oregon State University. 2023. Willamette Water 2100. Available at http://inr.oregonstate.edu/ww2100. Accessed 2023.

US Army Corps of Engineers®
Portland District

WILLAMETTE VALLEY SYSTEM OPERATIONS AND MAINTENANCE

FINAL ENVIRONMENTAL IMPACT STATEMENT

APPENDIX F2: SUPPLEMENTAL CLIMATE CHANGE INFORMATION

APPENDIX F2 HAS BEEN MODIFIED FROM THE DEIS
INSERTION OF LARGE TEXT IS IDENTIFIED; MINOR EDITS ARE NOT DENOTED

Summary of changes from the DEIS:

- **Additional information has been provided to introduce the tool and to document various technical aspects of the Climate Change Toolbox in Chapter 1, Introduction.**
- **DEIS Table 2-1, Relevant Climate Factors Analyzed in Resource Topics, was revised for consistency with equivalent tables in EIS sections. This table was renamed to Relevant Climate Factors Analyzed by Resource.**
- **References regarding the Willamette River projected flows generated as part of the RMJOC-II have been added.**
- **Additional information regarding RMJOC-II Climate Change Projections has been added in Section 3.1, Overview of RMJOC-II Climate Change Projections.**
- **Additional information regarding precipitation, temperature, and natural streamflow assessments has been added in Section 3.1, Overview of RMJOC-II Climate Change Projections.**
- **Additional information was added to clarify confidence in temperature increase expectations and its relationship to changes in precipitation, evapotranspiration, runoff, or snowmelt response.**
- **Additional information on wildfire risk has been added to Section 3.1.5, Wildfire Risk.**
- **Section 3.1.6, Invasive Species, was added to provide information on expansion of non-native invasive species due to future changes in precipitation, temperature, and other climate factors into the Willamette Valley aquatic and terrestrial environments.**
- **Figure 3-7, Willamette River Subbasins, has been added.**

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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 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.

USACE Northwest Division (NWD) and Portland District (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's RMJOC-II climate projection information was used as the basis for much of the discussion that follows. 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 (CIRC 2020) (https://climatetoolbox.org/), a regional suite of assessment tools, was also used for EIS purposes to demonstrate comparative climate trend changes between different WVS sites and projects (project refers to dams and their associated reservoirs) over the historical as well as projected future years.

THE DEIS HAS BEEN REVISED TO INCLUDE THE FOLLOWING INFORMATION IN THE FEIS

The Climate Change Toolbox was created by the University of California Merced and is supported by the National Oceanic and Atmospheric Administration (NOAA)-RISA, CIRC, NIDIS, the Northwest Climate Adaptation Science Center, and the USDA Northwest Climate Hub. Please note that the Climate Change Toolbox is "a collection of tools for addressing questions relating to climate monitoring, water resources, fire conditions, forecasts, and projections." The tool also includes output directed at "addressing questions relating to agriculture." The Climate Change Toolbox relies upon projections from a variety of climate and downscaled hydrologic datasets. From the tool's metadata file, the following tool background information and context is given:

> The 20 climate models and 2 scenarios (Representative Concentration Pathways (RCP) 4.5 and 8.5) were downscaled to an approximately 4-km resolution across the U.S. for compatibility with the gridMET data and the tool itself.
>
> Hydrology projections from 10 global climate models (GCMs) and 2 scenarios were simulated using the Variable Infiltration Capacity (VIC v 4.1.1.2) hydrology model, forced with the downscaled MACAv2-Livneh data 1950–2005 (historical) and 2006–2100 (future) to 1/16th degree to produce metrics such as snow water equivalent, soil moisture, runoff, and evaporation. The climate data was downscaled using gridded historical

observations of meteorology from Livneh (v13 for USA and v14 for British Columbia, Canada).

A smaller ensemble of GCMs will result in less definition of the true model variability and uncertainty. This resolution is still useful for inferring future hydroclimate and hydraulic trend direction through the 21st century. Due to an incomplete probability description due to a small ensemble, the PDT is cautioned not to use specific numerical results from the toolbox. The Climate Toolbox and RMJOC-II study data were developed separately, albeit from similar Coupled Model Intercomparison Project 5 (CMIP5) and GCM scenario datasets. The tool and the RMJOC studies used data generated from the CMIP5, but each provides information not provided by the other. Additional information concerning Climate Change Toolbox outputs can be found at the climatetoolbox.org link provided above.

END NEW TEXT

2. RELEVANT CLIMATE CHANGE FACTORS

The WVS EIS PDT identified early in the process which climate factors were likely most applicable to the National Environmental Policy Act (NEPA) EIS analysis. Their importance and relevance were evaluated with respect to EIS analysis 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 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.

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

The nine relevant climate change factors are:

1. Ambient air temperature changes.

2. Water temperature changes.

3. Precipitation changes.

4. Seasonal timing of flow peaks and volumes.

5. Low summer flow—shortage/volume/frequency.

6. Change in snowpack accumulation and spring freshet timing.

7. Reservoir evaporation/reach evapotranspiration effects.

8. Wildfire intensity/frequency changes.

9. Wildfire impacts to water quality.

Table 2-1. Relevant Climate Factors Analyzed by Resource.

Resource Topic	Ambient temp **(1)**	Water temp (2)	Precipitation (3)	Flow peak and timing (4)	Summer low flow (5)	Spring snow melt (6)	Evapotrans-piration (7)	Wildfire (8)	Wildfire effects (9)
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 (including 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 (including ESA/sensitive species and critical habitat)	X	X	X	X	X	X	X	X	X
Wildlife, Birds, and Terrestrial Habitat (including 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
Cultural Resources	–	–	–	X	X	–	–	X	–
Visual Resources	–	X	X	X	X	X	X	X	X

Resource Topic	Ambient temp **(1)**	Water temp (2)	Precipitation (3)	Flow peak and timing (4)	Summer low flow (5)	Spring snow melt (6)	Evapotrans-piration (7)	Wildfire (8)	Wildfire effects (9)
Noise	–	–	–	–	–	–	–	X	–
Tribal Resources	X	X	X	X	X	X	X	X	X

The relevant hydroclimate variables, with the exception of wildfire intensity, reflect the operations and maintenance -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. Wildfire could also impact additional operations areas, such as disrupting power transmission, water supply (e.g., pumping etc.), etc.

END REVISED TEXT

3. SUPPLEMENTAL DATA SOURCES

THE DEIS HAS BEEN REVISED TO INCLUDE THE FOLLOWING INFORMATION IN THE FEIS

The RMJOC-II and derivative Columbia River Basin (CRB) climate studies characterize the 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 evaluating relative difference analyses, for example, ensemble median change between baseline, historical period, future epochs, etc., it was not "designed" to support reservoir routing modeling in watersheds like the Willamette River. In discussions with PDT modelers and in coordination with USACE Vertical Team Alignment Memorandum (VTAM), vertical alignment consensus was reached on the determination of the "actionability" of the RMJOC-II and CMIP5 streamflow datasets for reservoir routing, including water temperature modeling uses in this EIS. The consensus was that the datasets did not support the quantitative modeling requirements and was not actionable for these purposes. The dataset usage was hindered by bias correction and GCM downscaling model accuracy and uncertainty as well as the inherent shorter travel times in the Willamette River Basin itself. Variable Infiltration Capacity (VIC) is flow routing model performance, which the subject stream dataset depends on, is better in large basins but not as skilled in smaller subbasins. For this and other technical reasons, it was not appropriate to use RMJOC-II-generated future period of record streamflow for quantitative (e.g., hydro-regulation) modeling or as a definitive way to assess final climate projection impacts to WVS EIS alternatives. The RMJOC-II reports are on the following websites:

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 useful for making qualitative determinations about how relevant climate factors are likely to change. The Climate Change Toolbox was created by the University of California Merced and is supported by

NOAA-RISA, CIRC, NIDIS, the Northwest Climate Adaptation Science Center, and the USDA Northwest Climate Hub. 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. The Climate Change Toolbox relies upon projections from a variety of climate and downscaled hydrologic datasets. From the tool's metadata file, the following tool background information and context is given:

> The 20 climate models and 2 scenarios (RCP 4.5 and 8.5) were downscaled to an approximately 4-km resolution across the U.S. for compatibility with the gridMET data and the tool itself.
>
> Hydrology projections from 10 global climate models (GCMs) and 2 scenarios were simulated using the Variable Infiltration Capacity (VIC v 4.1.1.2) hydrology model, forced with the downscaled MACAv2-Livneh data 1950–2005 (historical) and 2006–2100 (future) to 1/16th degree to produce metrics such as snow water equivalent, soil moisture, runoff, and evaporation. The climate data was downscaled using gridded historical observations of meteorology from Livneh (v13 for USA and v14 for British Columbia, Canada).

For these reasons, the tool and its results were found very useful for supplementing PDT understanding of likely climate change trends in the Willamette Valley. There are important considerations to keep in mind when using the Climate Toolbox. First, the tool utilizes nine global circulation models (GCMs) as the basis for 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, it 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 Parts I and II (RMJOC 2018; RMJOC 2020). RMJOC-II hydroclimate change trends have been used in follow-on climate change studies in the CRB such as Columbia River Treaty studies (CRT 2021) and the Columbia River System Operations Environmental Impact Statement (CRSO EIS) (USACE et al. 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-II Part I (2018). This study represents the most recent and best available technical information for future climate change in the Columbia River Basin, including the Willamette Valley.

Part II of the RMJOC-II studies (2020) focused on regulation modeling results in the major subbasins of the Columbia River Basin. Current regulation operations modeling was not undertaken for the Willamette River Basin. Detailed reasoning for the decision is contained in RMJOC-II Part II (RMJOC 2020). Future projection flows were found to be an unreliable representation of future flow conditions. Use of these flows in regulation modeling would likely lead to high uncertainty in the modeling results.

END NEW TEXT

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 [USGCRP] 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 historical period 1970–1999 by another 1.5°F to 3°F by the 2030s (WYs 2020 through 2049) and 2°F to 5°F by the 2070s (WYs 2060 through 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 Part I. GCM scenario projections (numbers in the bar plot) are relative to the historical baseline period, 1970 through 1999. Annual and seasonal median shifts were highest under the RCP 8.5 GCM scenarios.

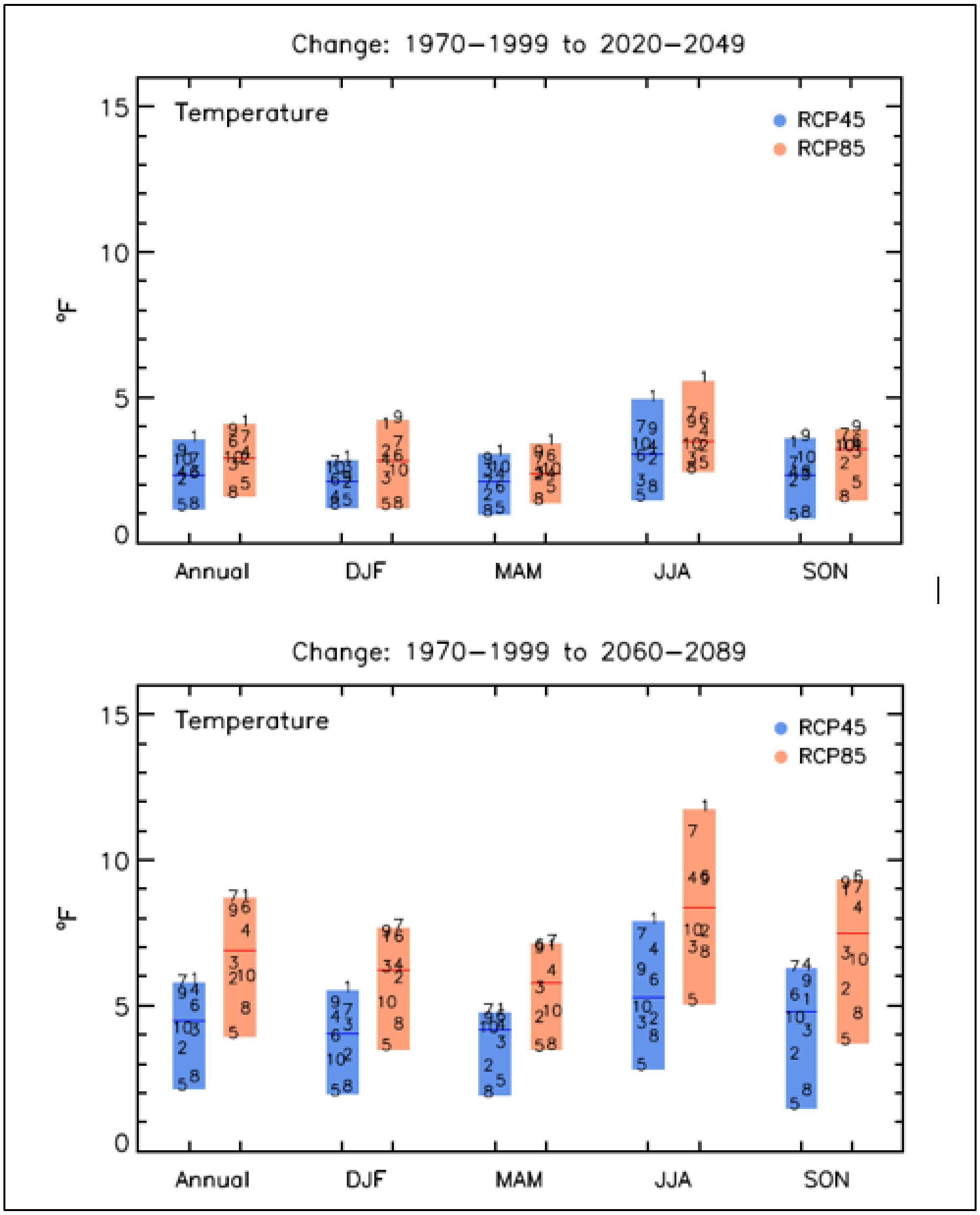

Figure 3-1. Projected Willamette River Basin Average Temperature Change (RMJOC 2018).

Recent years (2000 through present) are, on average, warmer compared to 1970 through 1999. NOAA published revised "climate normals" for historical years:

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

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

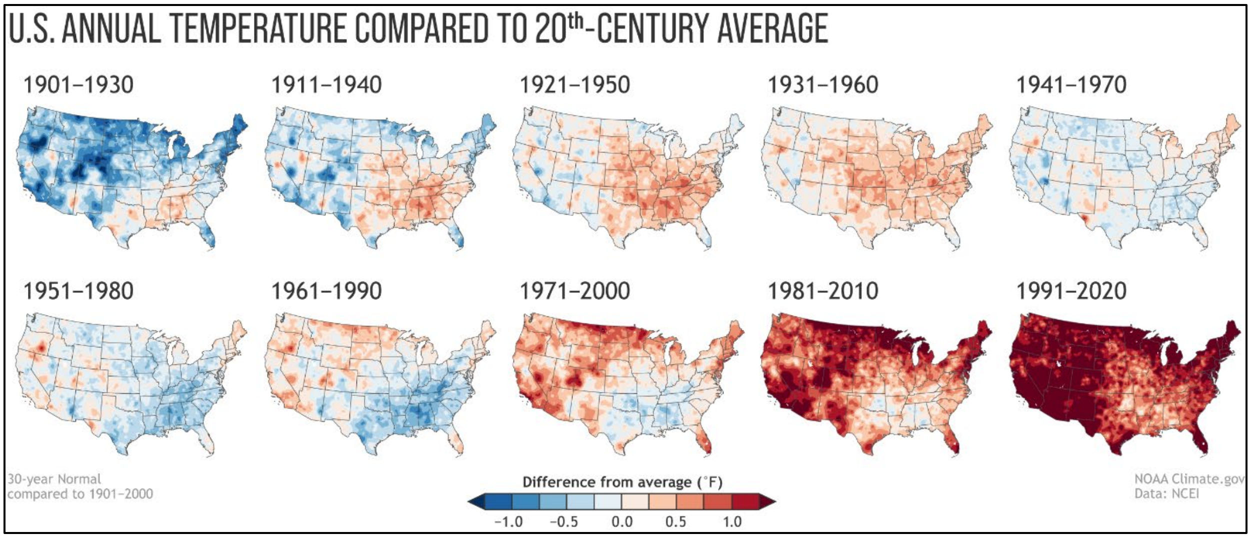

Figure 3-2. NOAA Annual Observed Temperatures.

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

Regionwide warming is expected to increase into the future, continuing the trends shown 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 in 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. Future projection 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 level of precision for the Willamette Valley.

3.1.2 Precipitation

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RMJOC-II Part II (2018) found that observed precipitation trends are less certain than observed temperature trends (Figure 3-3). However, across both RCP 4.5 and RCP 8.5, the majority of GCMs project marginal increases in annual precipitation. More operationally substantial changes are projected to occur seasonally, with the largest increases in the winter months, December through February (DJF), and decreases in the summer months, June through August (JJA). Trends in the RMJOC II are for the entire CRB but were determined at The Dalles, OR. The Dalles is a primary system computational control point (CCP) for Northwest Division water management. The general trends are similar for the Willamette Valley. Although the median trend derived based on the full ensemble at The Dalles is consistent with the median trends found throughout the CRB, including for the Willamette River Subbasin, the range of GCM outputs varies considerably throughout the CRB.

Caution interpreting future trends is warranted. The study (RMJOC 2018) identified high interannual variability in the observed datasets. Higher interannual variability in observed datasets could translate to more model uncertainty in projections. Further, the warmest or driest GCMs at The Dalles may not be the same in all subbasins. To capture the uncertainty associated with projected hydrometeorological outputs derived based on GCMs, it is important to consider the range of model outputs, which is best captured by using a large ensemble set as was adopted as part of the RMJOC study.

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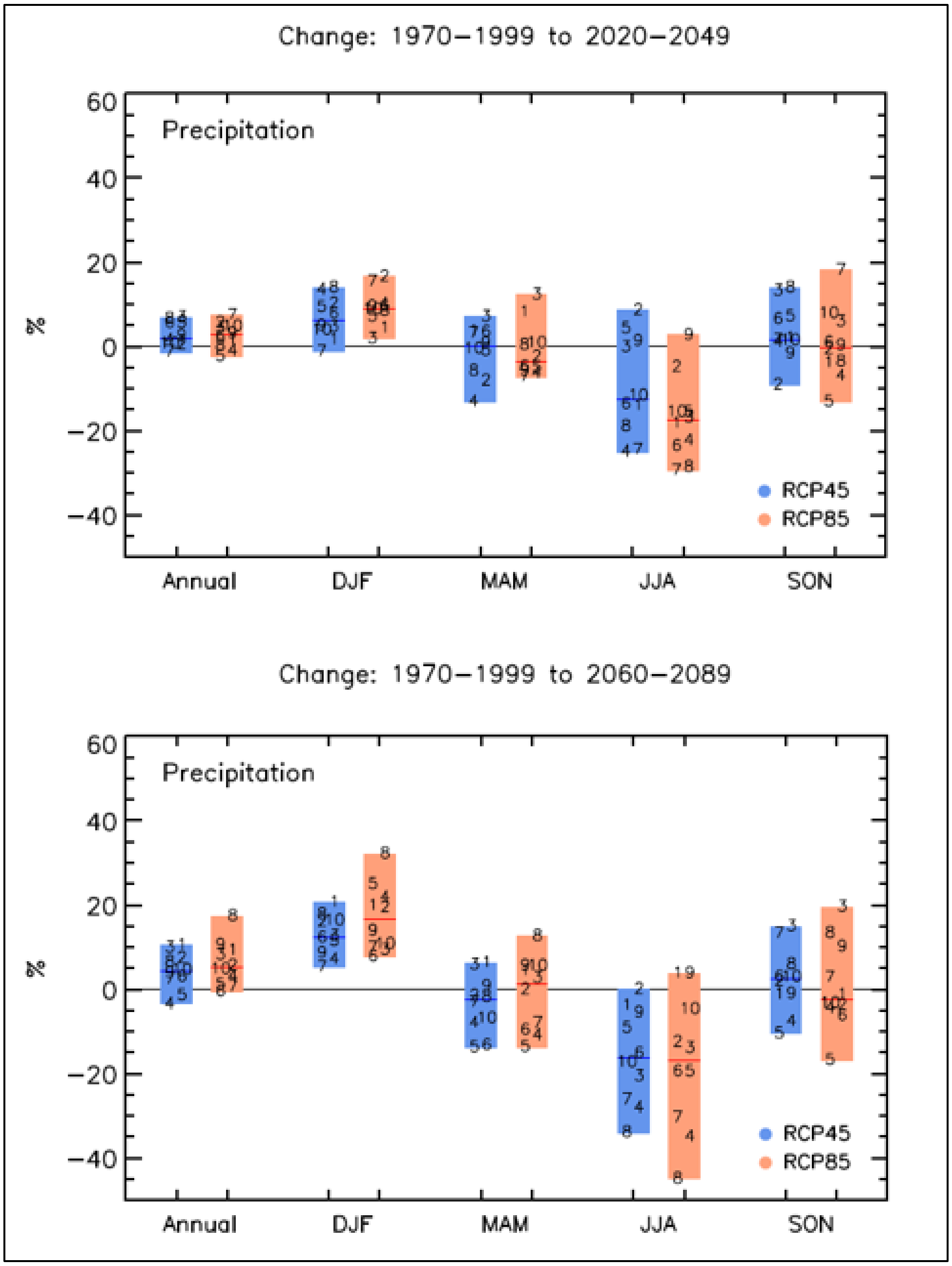

Figure 3-3. Projected Willamette River Basin Average Precipitation Change (RMJOC 2018).

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 Willamette River Basin is for a decrease in most medium to low elevation subbasins. In the Willamette River Basin, the forecast is for near total reduction of annual snowpack toward the end of 21st century (RMJOC 2018). Figure 3-4 depicts Columbia River Basin (the Willamette Valley is denoted via white circles) 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 RCP 8.5 and downscaled via Bias Corrected and Spatial Downscaling (BCSD). Areas in tan historically have less than 10 mm of snow water equivalent (RMJOC 2018). The RMJOC-II streamflow ensemble dataset is composed of 160 GCM scenarios.

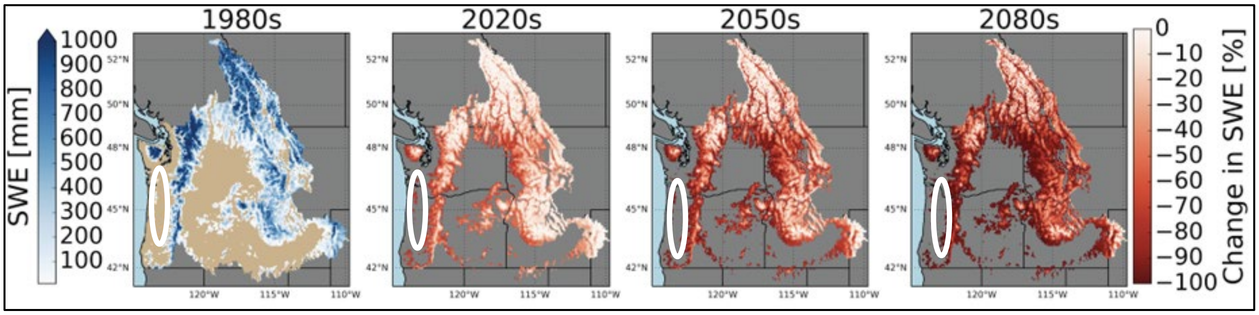

Figure 3-4. Projected Willamette River Basin Average Snow Water Equivalent (RMJOC 2018).

SWE drives runoff patterns as well as streamflow temperatures. However, the complexity of correlating the water temperature response to the flow changes driven by snow melt runoff is not accurate. Caution should be exercised when attempting to extrapolate SWE projections of future water temperatures. For this reason, the WVS EIS climate change assessment primarily focuses on SWE as a major component driving the historical spring freshet (spring snow melt), rather than its impact on water temperature. In the near term, it is likely that the spring freshet will occur earlier but will decrease to near 100 percent reduction by the end of the 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 primary driver of runoff in the Cascade Range basins is rainfall. Rainfall has been the primary contributor to peak annual runoff response throughout the Willamette River Basin historically. The spring feshet is still an important contributor to high flow peaks and volumes later in the water year. The annual maximum runoff occurs 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 Willamette Valley (RMJOC 2018). The overall projection is for median increases of winter flows and volumes with decreasing late spring and summer flows (Figure 3-5).

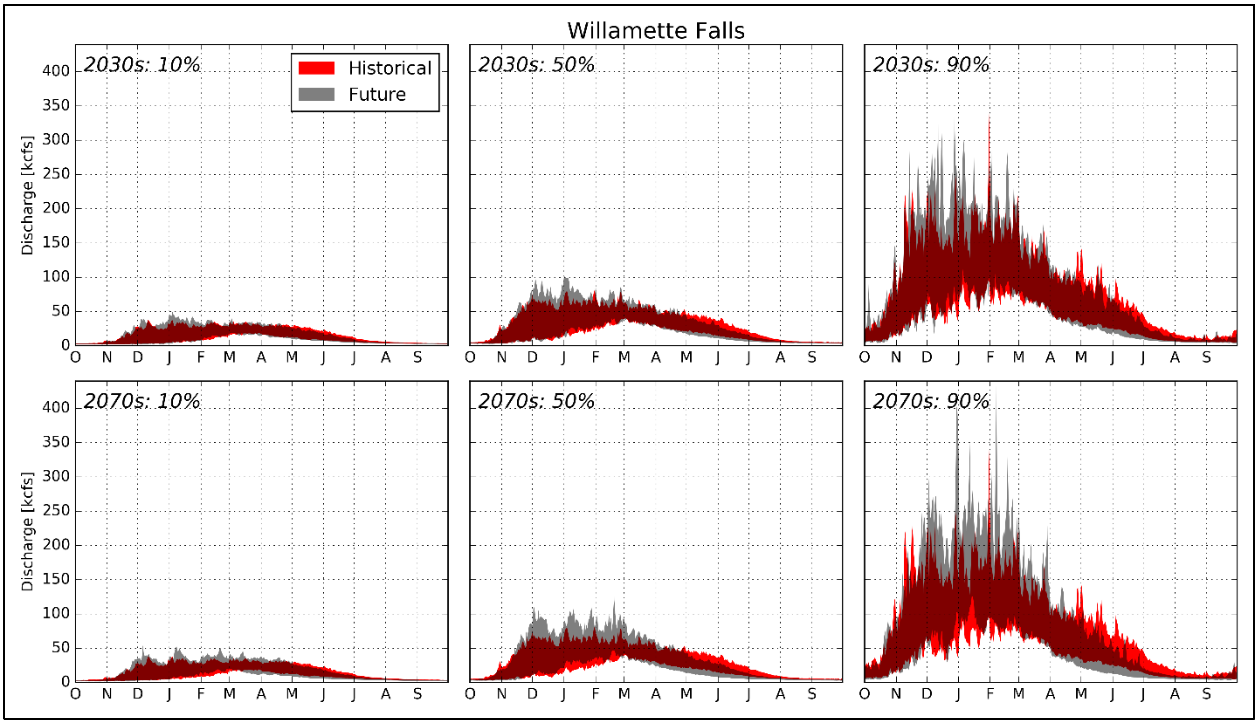

Figure 3-5. Projected Willamette River Basin Average Naturalized Streamflows (RMJOC 2018).

3.1.5 Wildfire

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The Fourth Climate Change Assessment (Chapter 24, Pacific Northwest), prepared by the U.S. Global Change Research Program, indicated that wildfires are increasing and other changes are clear signs of a warming planet (USGCRP 2018).

> 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 that 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 (USGCRP 2018).

Warmer winters have led to reductions in the mountain snowpack, increasing wildfire risk (Chapter 6, USGCRP 2018). Existing water, transportation, and energy infrastructure already face challenges from flooding, landslides, drought, wildfire, and heat waves. Climate change is projected to increase the risks from many of these extreme events (Key Message 3, USGCRP 2018). The Sixth Oregon Climate Assessment notes that the total annual area burned in Oregon has increased during the last 35 years (OCCRI 2023).

In late summer and autumn and prior to the onset of the autumn rains, particularly strong and dry easterly winds, known colloquially as east winds, promote the rapid spread of wildfire. East winds were key drivers of the largest wildfires on record in western Oregon, including the 2020 Labor Day fires (Abatzoglou et al. 2021, Mass et al. 2021, Reilly et al. 2022). Despite recent advances, understanding of how anthropogenic emissions may affect local winds in Oregon remains limited. Due to their coarse spatial resolution, global climate models and all but the highest-resolution regional climate models cannot adequately simulate mountain slope and valley winds, coastal winds, sea breezes, and winds associated with mesoscale convective systems (Doblas-Reyes et al. 2021). Large numbers of simulations from multiple high-resolution (1 to 10 km [0.6 to 6 mi]) regional climate models ultimately will be required to estimate, with high confidence, changes in these types of winds across Oregon (OCCRI, 2023).

END NEW TEXT

The Willamette River 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 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 after an above average hot and dry summer (Abatzoglou et al. 2021). Whether these conditions were accentuated by climate change trends and whether this pattern could become more frequent in the future remains a question. Climate change modeling does predict increasing fire risk days in the future (Climate Toolbox 2022).

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 frequency. Other post-fire impacts 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 operations and maintenance costs and alter the effectiveness of current water supply infrastructure (e.g., intakes), etc.

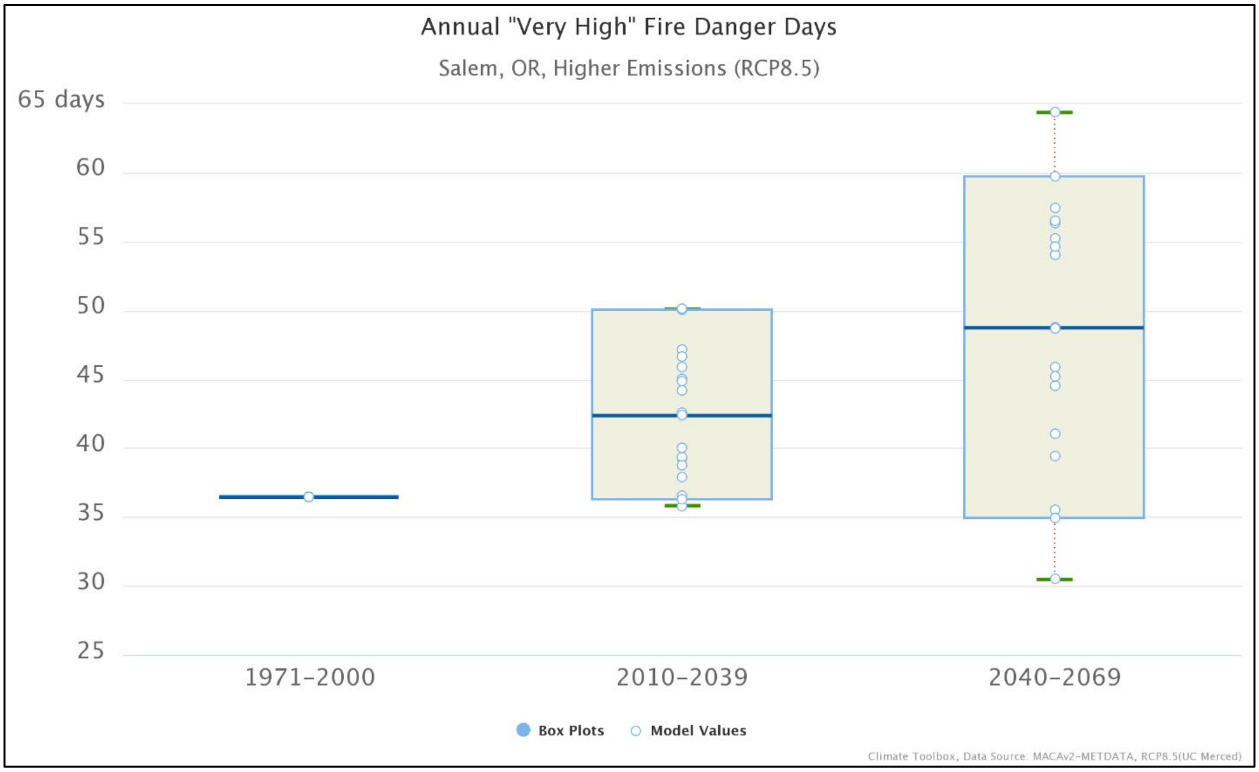

Figure 3-6. Salem, Oregon Annual Very High Fire Danger Days.

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While Salem is not historically a location of high fire risk, Figure 3-6 does provide the trend direction of wildfire risk through the end of the century. The figure shows an increase in median annual "very high" fire danger days and the variability between GCM scenario projections are portrayed. Below are excerpts that further summarize wildfire impacts and post-fire hydrologic sediment and runoff response in the basin (from Section 4.3 River Mechanics and Geomorphology):

> Climate change (RFFA 9) would increase winter inflows and sediment supply to the WRB, both upstream and downstream of the WVS dams and reservoirs. Additionally, there is a causal relationship between wildfires and increased sediment supply (Alden Research Laboratory, Inc. 2021). Expected increases in high fire risk days and associated increases in forest fire acreages are expected to increase WRB sediment yields due to climate change. Reservoirs act as sediment traps and would partially mitigate increases in sediment supply in regulated reaches. Additionally, climate change generally decreases conservation season flows and, therefore, conservation season reservoir stages (Section 4.2, Hydrologic Processes). This could increase bank exposure, decrease reservoir storage, and increase fine grained suspended sediment concentrations in the reservoirs and sediment releases downstream. As climate change does not increase

> operational range, but only stages within the operational range, this conservation season change is expected to be negligible to minor (Section 3.3.2.1.5, Climate Change). Effects would be additive with the other RFFAs within their respective seasons.

3.1.6 Invasive Species

The Willamette River Basin is sensitive to all the above projected climate trends. There is concern that future climate change effects may induce or allow for greater expansion of non-native invasive species into the Willamette Valley aquatic and terrestrial environments (from Gervais et al. 2020):

> Plants were the best-represented taxonomic group in these studies, and a variety of invasive plants are predicted to expand their ranges (e.g., McDonald et al. 2009; Chapman et al. 2014; Brummer et al. 2016). That being said, where spatially downscaled predictions are available, dynamics of invasive plants in the PNW itself are likely to be highly variable both within and between species (e.g., Bradley et al. 2009).

As the effects of climate change become clearer, the subject of invasives and their correlation with changing climate should be re-evaluated.

END NEW TEXT

3.2 Climate Change in the Willamette River Subbasins

Climate change is regional in scope and extent. Therefore, this WVS 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 was on the 13 Corps projects shown.

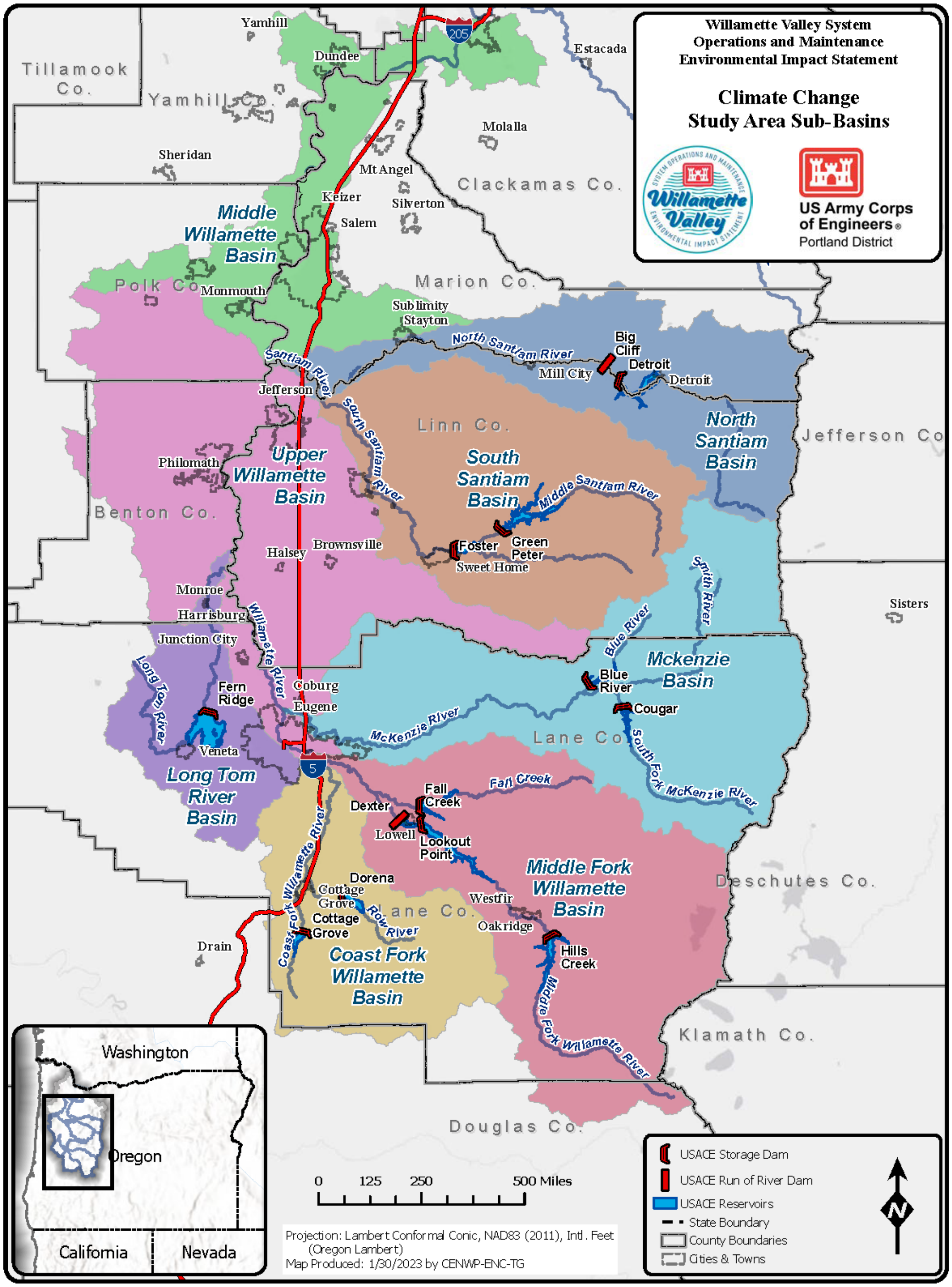

Figure 3-7. Willamette River Basin Subbasins.

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

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

3.2.1 Current Regulations

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 percent of the upstream watershed of Portland, OR. USACE Willamette Valley System storage projects are operated at or below the rule curve unless regulating to a highwater event. The rule curve provides guidance to reservoir regulators on how to manage the storage in the reservoir to meet the multipurpose 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. When downstream control points reach bankfull flow, USACE project outflows are reduced to project minimums to reduce downstream flood impacts. Rain events cause the reservoirs to rise and then stored water is evacuated once the flood threat has passed. Flood peak reduction is constrained by the large unregulated area below Salem as well as limited flood space in the tributary reservoirs themselves. At the local scale, USACE operates dams in the tributaries to minimize downstream flooding at local points.

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 River Basin conservation season occurs from approximately May through November and is a time when water stored in the system is released for multiple uses, including biological resources, water quality, power generation, irrigation, municipal and industrial 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 flood risk management operations, which occur primarily in December and January.

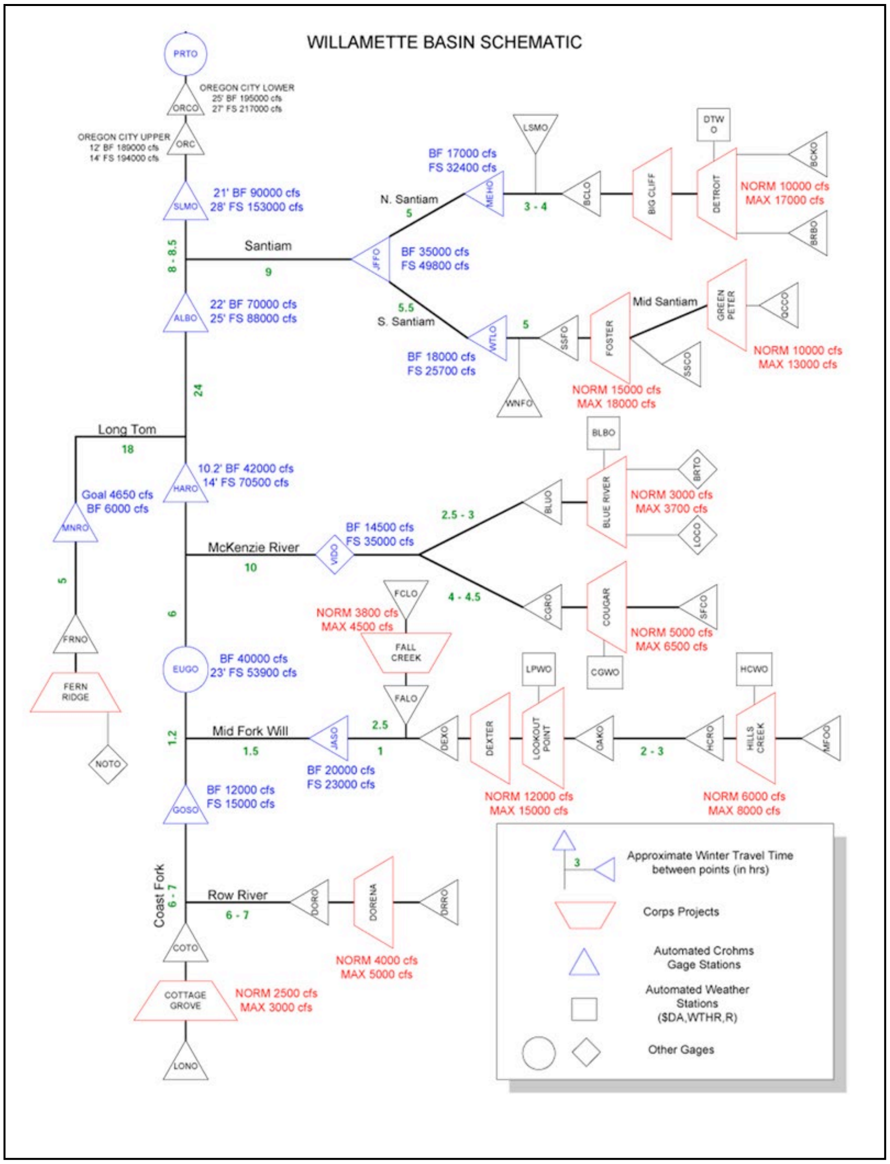

Figure 3-8. WVS Regulation Schematic.

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Conceptually, operations could be changed to adapt to the shift in runoff timing. However, increase in winter flows cannot be used to meet summer demand. Maximum flood space is required during the winter months, especially considering projected future increases in winter volume. High water events that occur during refill cannot be stored above the existing rule curve elevations and therefore cannot be used to meet demand later in the season. Additional system storage would likely be required to benefit from higher winter and early spring inflows projected for the future.

END NEW TEXT

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 RCPs, RCP 4.5 and RCP 8.5, based on results generated in support of the RMJOC-II reports and results obtained from the Climate Toolbox. These two RCPs represent future scenarios for emissions of greenhouse gases. Figure 3-9 graphically summarizes the RCP scenarios. RCP 8.5 trends more extreme by 2100.

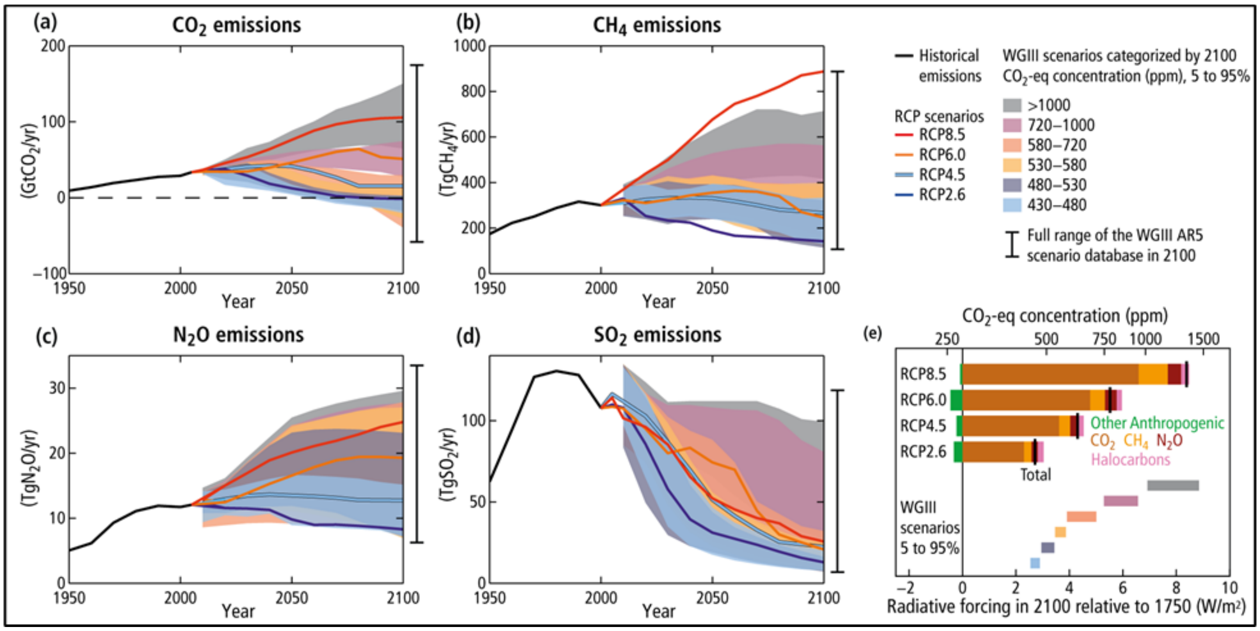

Figure 3-9. IPCC Representative Concentration Pathways (RCPs).
Source: https://ar5-syr.ipcc.ch/topic_futurechanges.php

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 planning guidance recommends assuming a 100-year lifetime for major infrastructure. USACE climate change assessment period is recommended to extend up to 100 years. Often, the GCM datasets do not extend 100 years from a project completion date. This is the case here, and for the purposes of this EIS the climate change evaluation is through the end of the 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.

The RMJOC-II streamflow ensemble dataset is composed of 160 GCM scenarios. In Figure 3-10, the total GCM scenario set (160) is disaggregated and there are subsets of RCP 8.5 and RCP 4.5 (80 each). RCPs 4.5 and 8.5 are most often used for long-term planning studies; therefore, RCP 6.0- and RCP 2.6-based scenarios were excluded from this study.

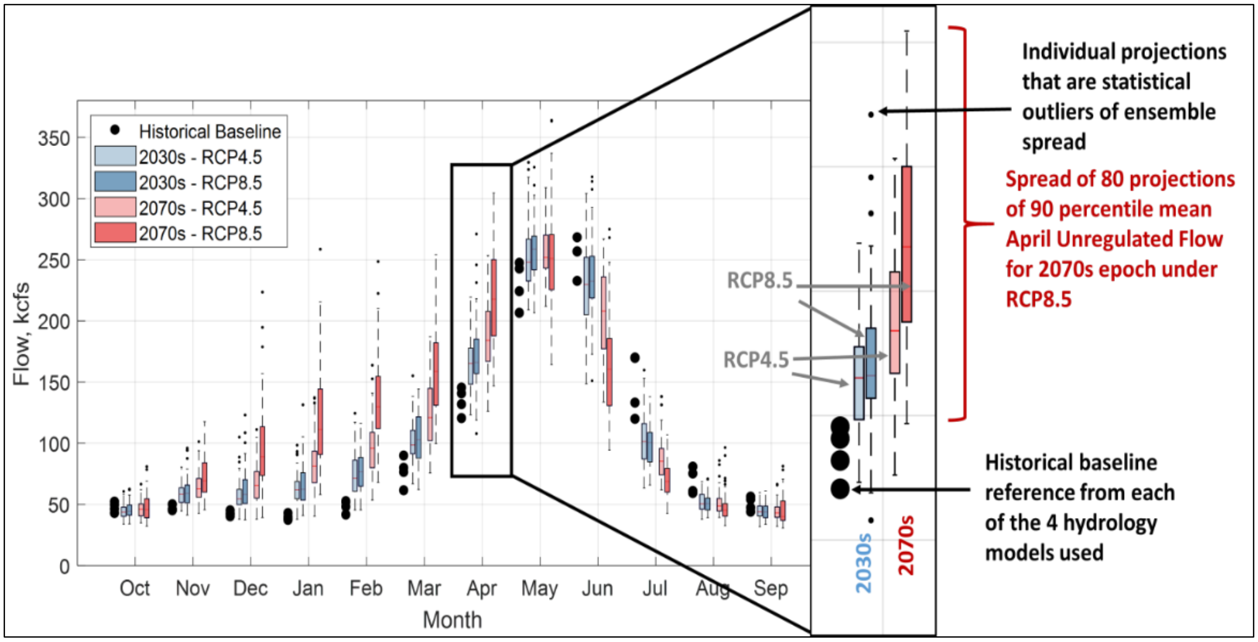

Figure 3-10. Example Historical and Future Predictions Graph.

3.2.4 Middle Willamette River

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The Middle Willamette 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 graphically shows the basin delineation and major features, including land cover, as of 2016. Land cover shown in the appendix maps are included to serve as context for climate change impacts, especially impacts to the natural environment (i.e., the affected environment). The maps also include cities, towns, USACE dams and reservoirs, and transportation routes. Overall impacts to the affected environment are common to all habitats and USACE business lines under all alternatives, including the No-action Alternative.

Figure 3-11 is provided as context for the overall climate change impacts to the affected environment.

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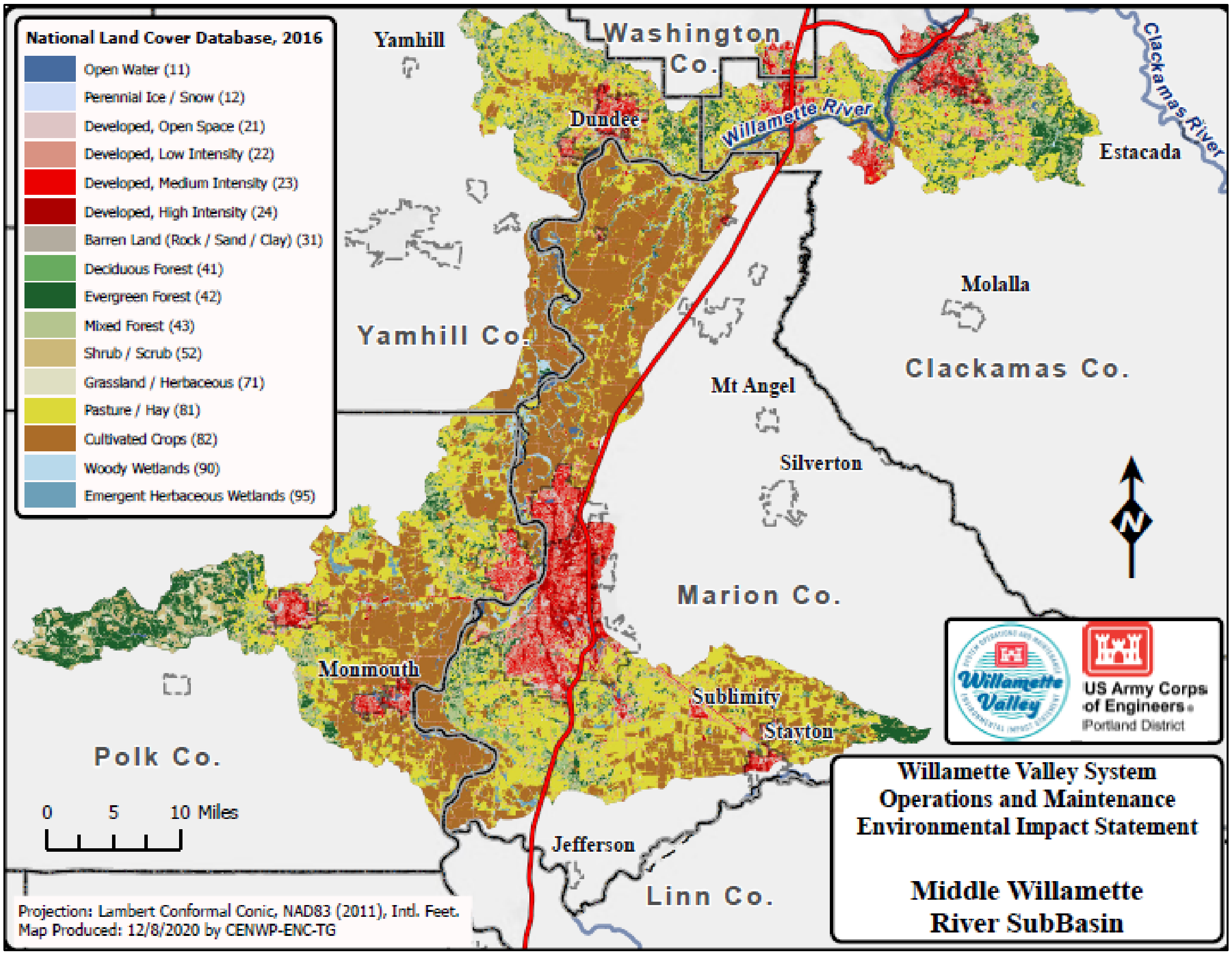

Figure 3-11. Middle Willamette River Subbasin.

This portion of the Basin contains the 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 mainstem Willamette River flows that reach the Middle Willamette River Subbasin are highly regulated due to upstream water management operations. Below Salem, local flows are primarily unregulated. Regulation has reduced flood peaks substantially while moderating low-flow conditions during the summer.

Relative to pre-dam conditions, Willamette Valley System regulation reduces peak high water during the winter flood season, November through March, and increases low summer flows. The WVS also makes thermal regulation possible through release of cooler reservoir outflows. Given that many climate change projections are for warmer conditions, increased winter volumes, and less baseflow in the summer, WVS project storage and regulation operations offer the opportunity to offset (to a degree) the potential negative impacts of climate change on the Basin's climate change hydrology and hydroclimate trends of concern.

Figure 3-12 is derived from the Climate Toolbox. The figure graphically shows average annual temperatures trending upward with an increasing rapidity into the 21st century. At Salem, OR in the Middle Willamette River Subbasin, the annual median temperature is projected to increase about +7.5°F from 2001 to 2100 or 2099, compared to the 1971–2000 baseline. Caution should be taken in applying these projections. The following Climate Toolbox figures can be used with confidence to identify the direction and relative scope of climate factor trends, but individual values should not be used as threshold or design values.

It is expected that the Willamette Valley floor (roughly along the axis of the I-5 corridor) will experience the greatest relative warming. End-of-century mean summer temperatures are projected to be 10.4°F greater than 1971–2000 temperatures (Figure3-13).

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 substantial stressor of concern for the fish and wildlife operations at USACE projects. Although it is difficult to directly project climate-impacted water temperature, ambient air temperature changes can serve as a proxy for future water temperature conditions.

Precipitation in the Middle Willamette River Subbasin is projected to increase in the winter months with some of the most pronounced increases being in the months of December through February (DJF). Figure 3-14 graphically shows expected precipitation change using box plots of winter (DJF) precipitation change. The plots graphically show the historical and three 30-year future epochs. Shown below, winter precipitation is projected to increase by approximately 2.2 inches (from the Climate Toolbox). This change would likely stress USACE flood space and winter flood operations.

Average summer precipitation (already low) is expected to decline by 0.2 inches by the end of the century (Figure 3-15). Lower summer precipitation could stress sustainability of regulated conservation flows and, with increasing air temperatures, increase the need for downstream thermal regulation.

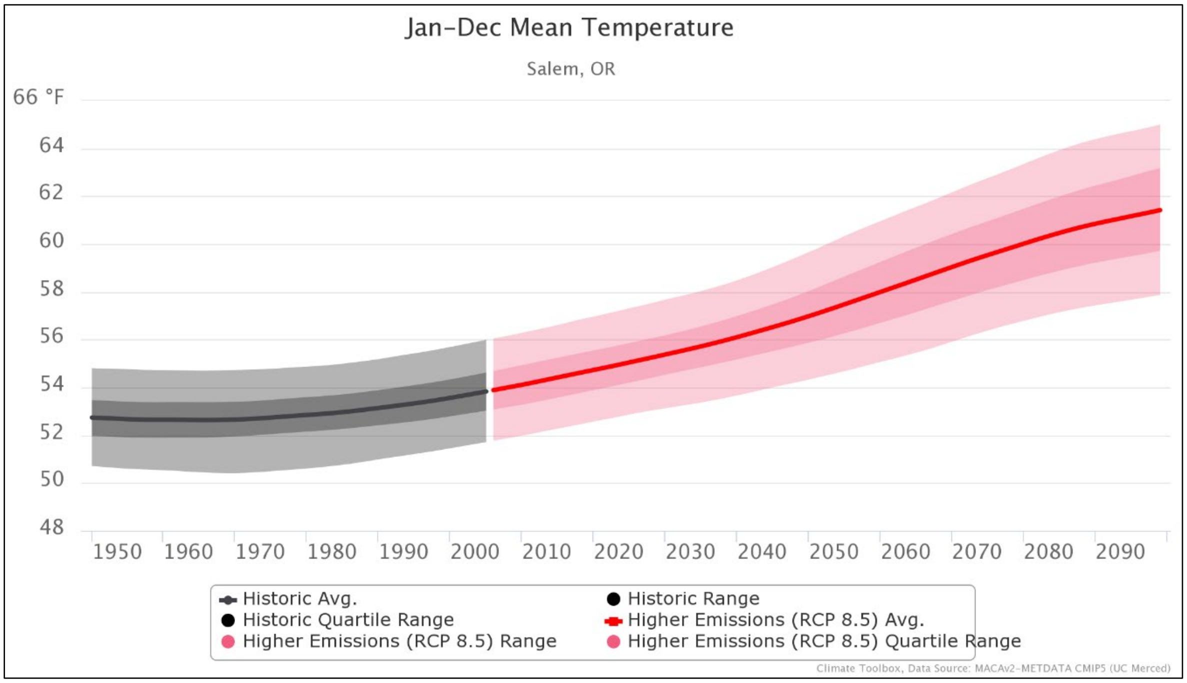

Figure 3-12. Average Annual Temperature Trends at Salem, Oregon, 1950–2100.

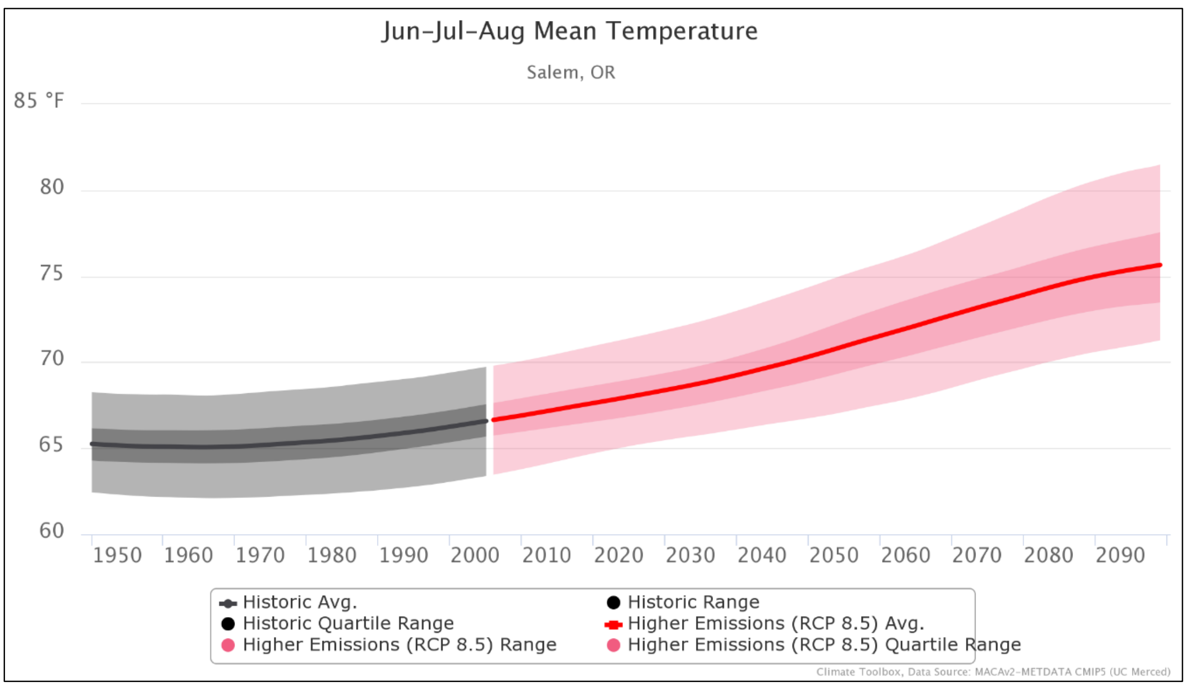

Figure 3-13. Average Annual Summer Temperature Trends at Salem, Oregon, 1950–2100.

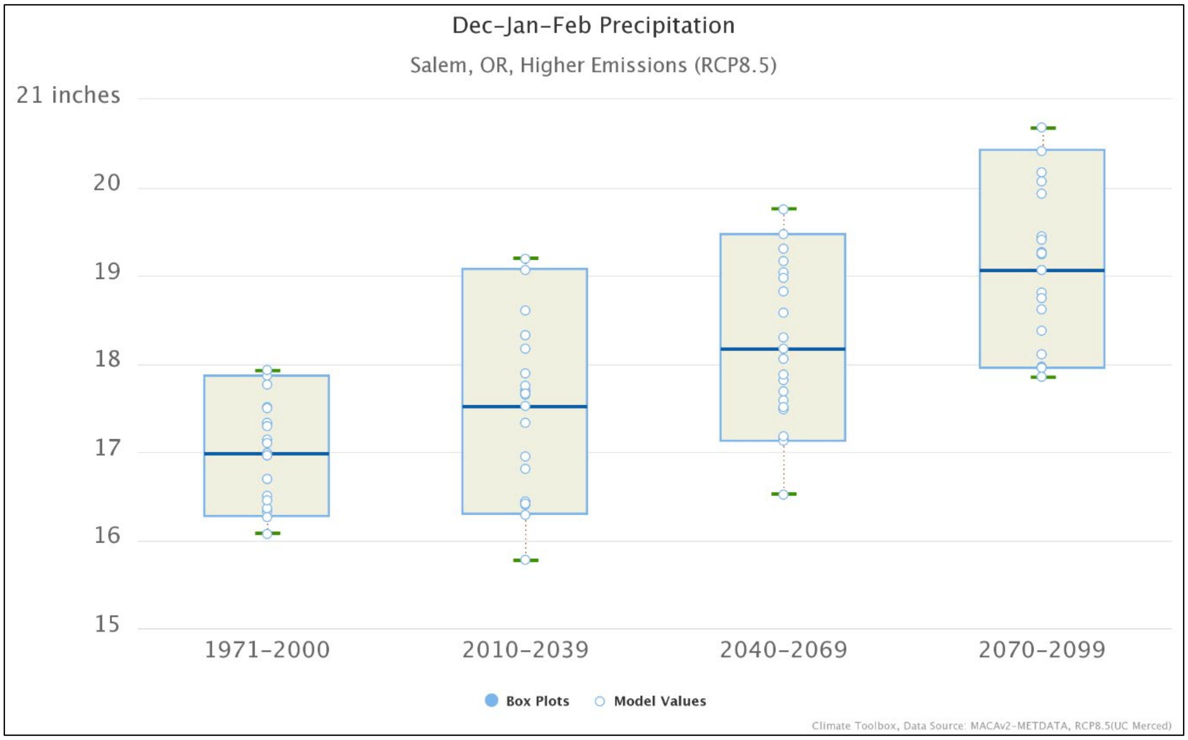

Figure 3-14. Median Winter Precipitation Trends at Salem, Oregon, 1950–2100.

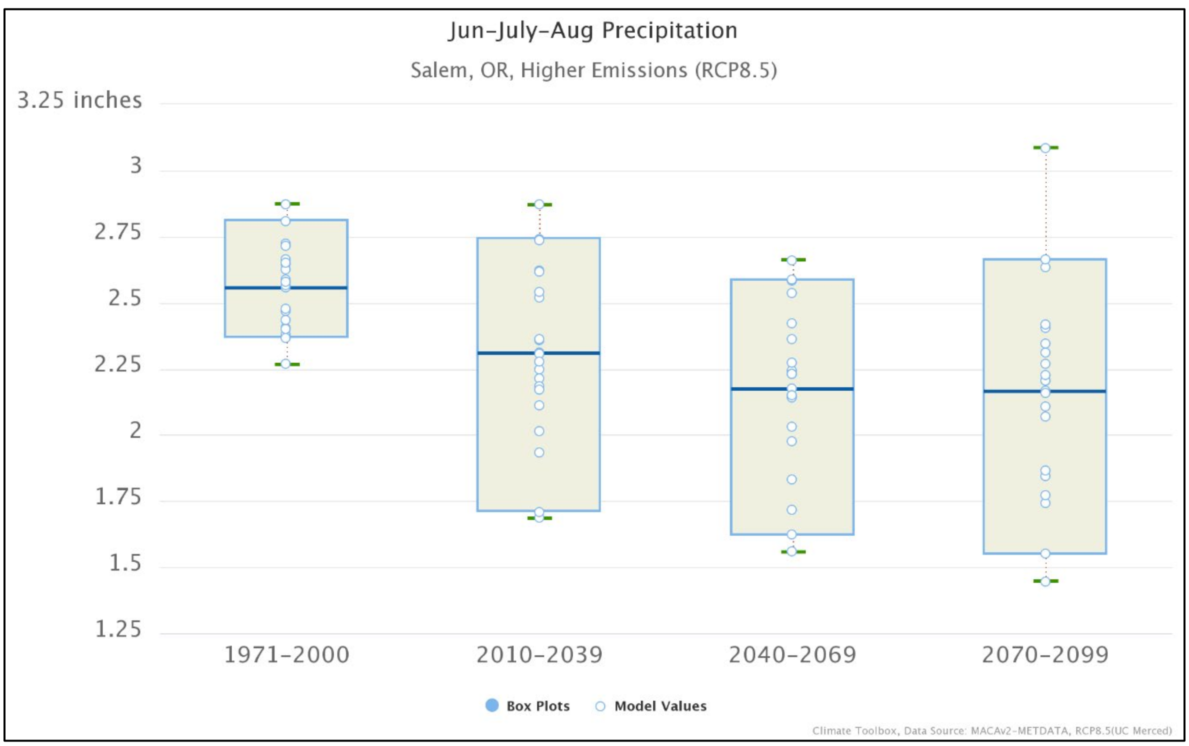

Figure 3-15. Median Summer Precipitation Trends at Salem, Oregon, 1950–2100.

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).

Figure 3-16 (RMJOC 2018) graphically depicts the projected changes in seasonal unregulated (naturalized) streamflow at Salem, representing the prevalent future trends in the Middle Willamette River Subbasin. The summary hydrographs highlight the 10th percentile (more frequent, low flows), 50th percentile (median), and 90th percentile (less frequent, high flows) exceedance. This is graphically summarized for the Willamette River at Salem, OR for the historical period (1975–2005), the 2030s (2020–2049), and the 2070s (2060–2089) (RMJOC 2018). Refer to Figure 3-10 for a legend and explanation of the summary hydrograph presentations.

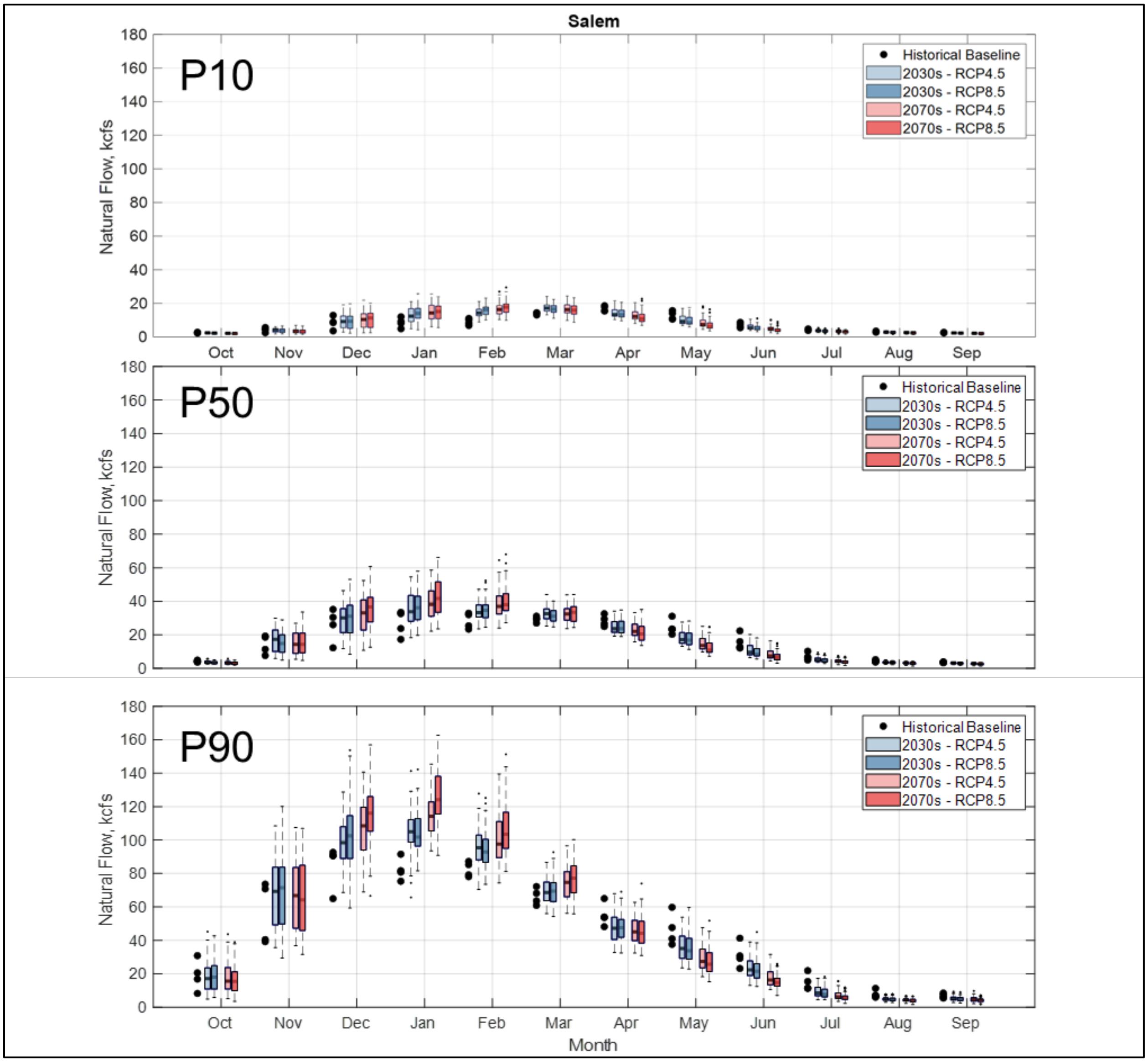

Figure 3-16. Willamette River at Salem, Oregon Summary Hydrographs.
Source: RMJOC-II, 2018.

Note that there is minimal spring melt response (freshet) at Salem, OR. This is likely due to the downstream reach attenuation of the spring melt runoff.

Table 3-1 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 through March while shoulder seasons (spring and fall) with summers tend to decrease relative to modeled baseline flows.

Table 3-1. Salem 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.

THE DEIS HAS BEEN MODIFIED TO REVISE THE FOLLOWING INFORMATION IN THE FEIS

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 operations. For example, minimum flows for fisheries and releases for consumptive uses are dependent on and driven by concurrent refill inflows and demands in the conservation season, respectively.

Increasing fire risk is similarly driven by higher ambient temperatures and low precipitation. Figure 3-17 graphically shows the trend of high fire risk days in the future.

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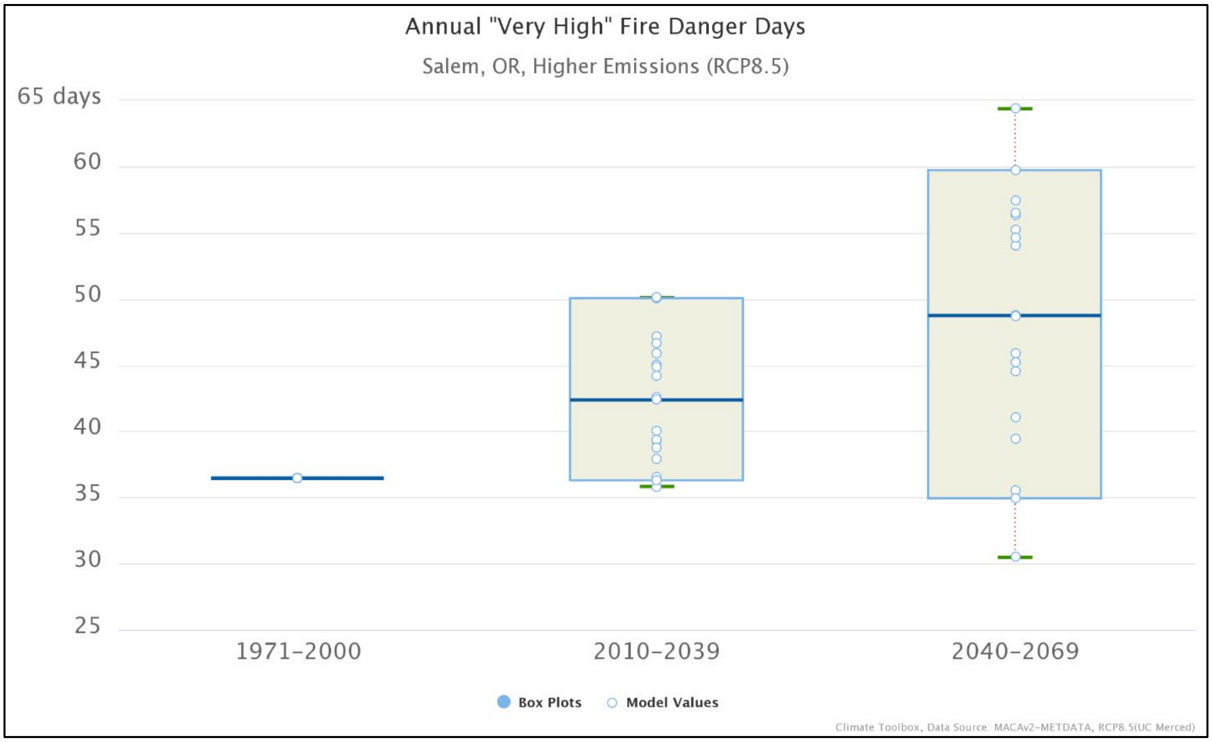

Figure 3-17. Salem, Oregon Annual Very High Fire Danger Days.

3.2.5 Upper Willamette River Subbasin

The Upper Willamette River Subbasin is shown in Figure 3-18. The subbasin straddles the Interstate 5 (I-5) corridor and stretches between two major metropolitan areas: Albany, OR at the north end to the Eugene/Springfield metro area to the south. The principal Corps dam in this subbasin is Fern Ridge on the Long Tom River.

Warming is projected in the Upper Willamette River Subbasin. Figure 3-19 shows that average annual temperatures at Eugene, OR are projected to increase by 8°F compared to the 1971–2000 baseline by the end of the century. End-of-century mean summer temperatures are projected to be +10.3°F warmer, as shown in Figure 3-20. Spring peak runoff from SWE is negligible in the Upper Willamette River Subbasin as elevations are lower. The peak flow from snowmelt is attenuated but the spring volume would likely help keep tributaries and mainstem flows elevated into the summer months.

Like the rest of the low-lying Willamette Valley, precipitation in the Upper Willamette River Subbasin is projected to increase in the winter months, December through February. Figure 3-21 graphically shows expected winter precipitation change at Eugene, OR with box plots of winter (DJF) precipitation change for historical and three future 30-year epochs. As shown in Figure 3-21, winter precipitation is projected to increase by approximately 2.2 inches, the same as projected for Salem, OR. Summer precipitation (Figure 3-22) is already very low and will decrease similarly to Salem, OR as shown.

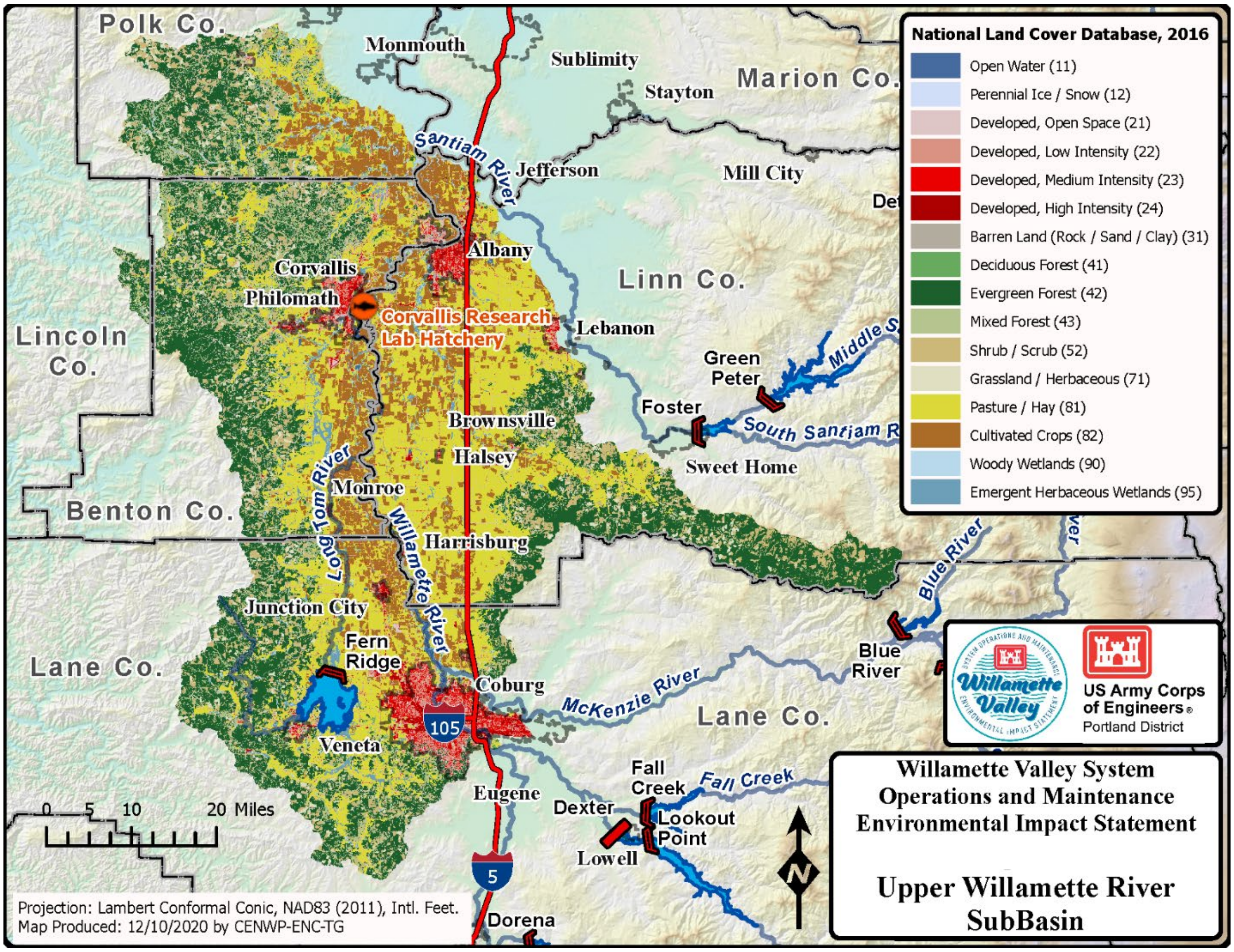

Figure 3-18. Upper Willamette River Subbasin.

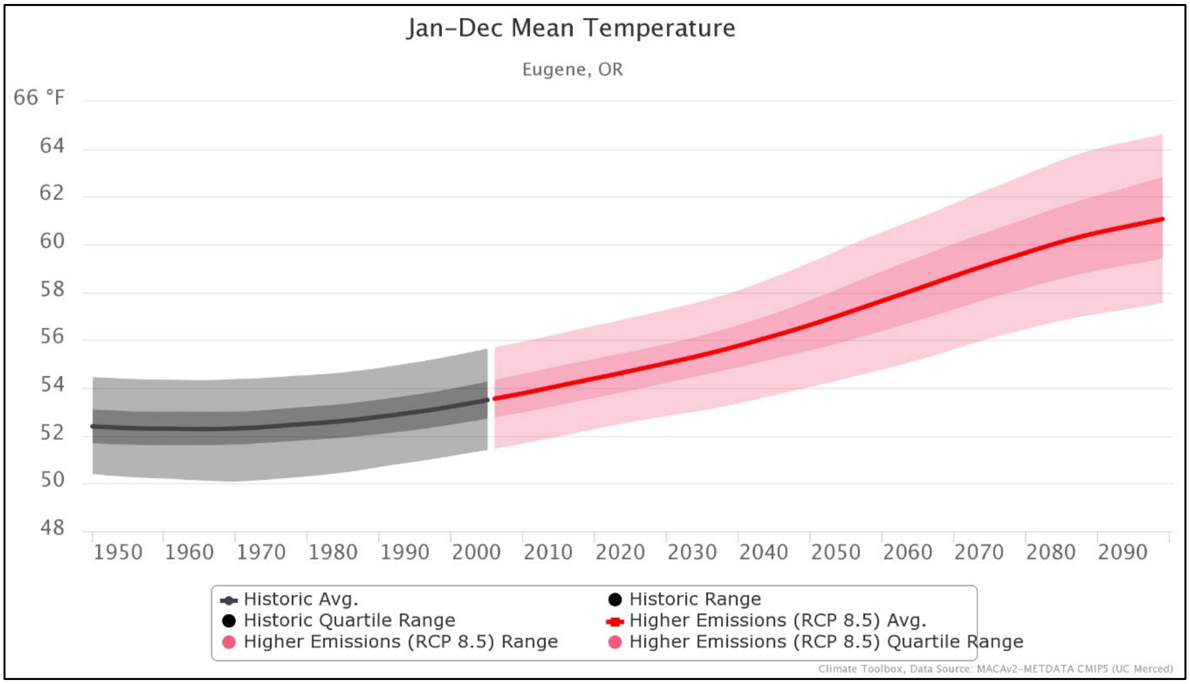

Figure 3-19. Average Annual Temperature Trends at Eugene, Oregon, 1950–2100.

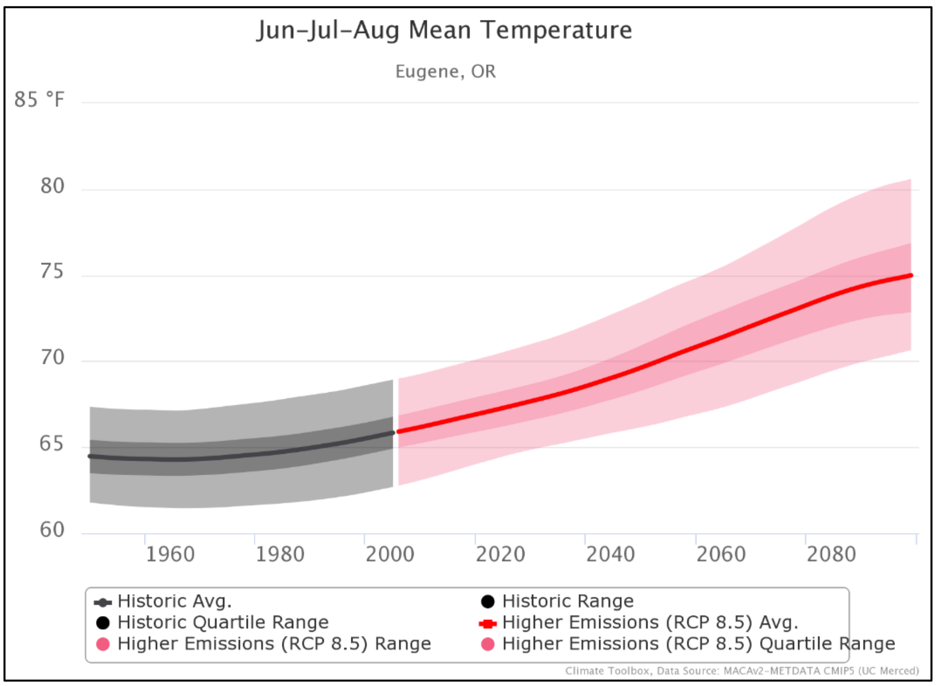

Figure 3-20. Average Annual Summer Temperature Trends at Eugene, Oregon, 1950–2100.

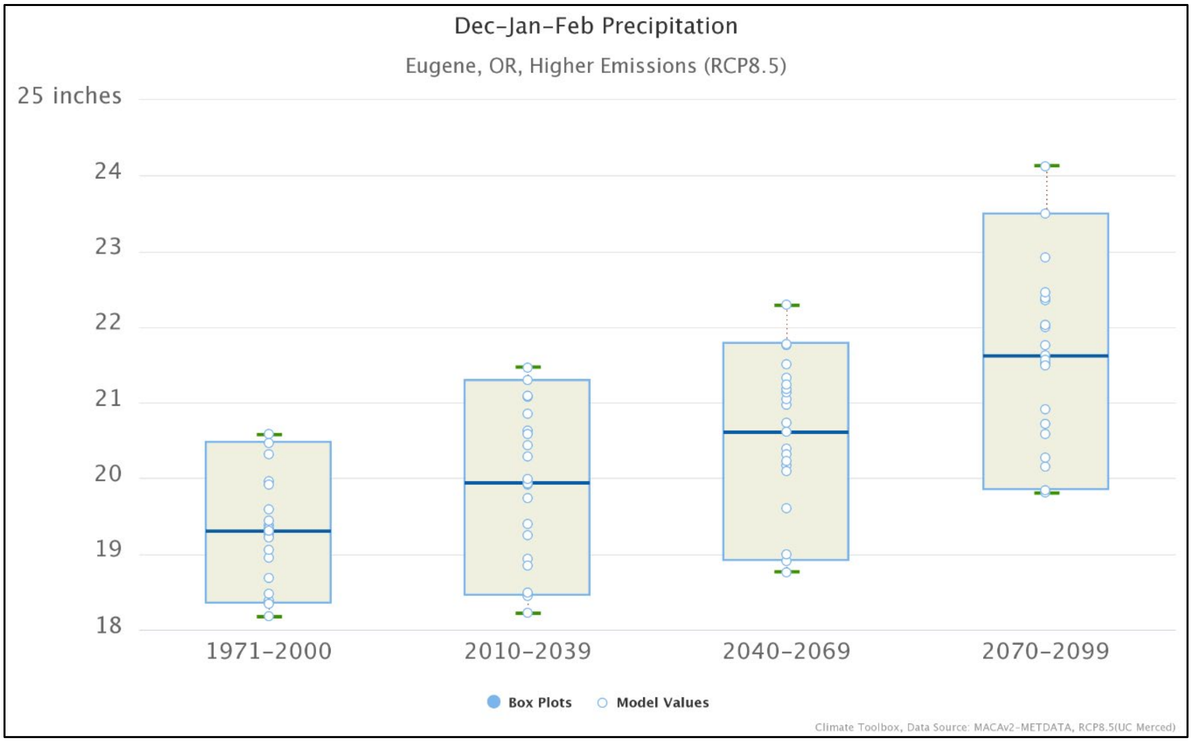

Figure 3-21. Median Winter Precipitation Trends at Eugene, Oregon, 1950–2100.

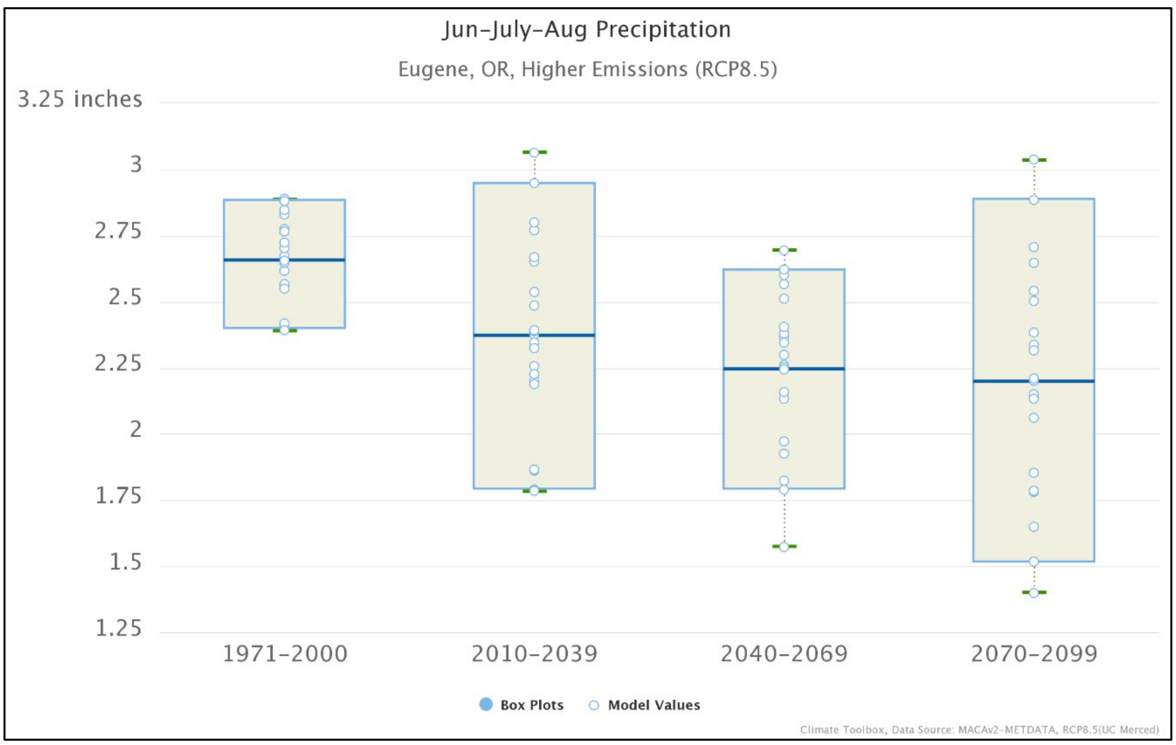

Figure 3-22. Median Summer Precipitation Trends at Eugene, Oregon, 1950–2100.

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 River Subbasin, as reported at Albany, are shown in Figure 3-23. Figure 3-23 reflects the same overall trends as the exceedance plots at Salem, OR, shown in the previous section.

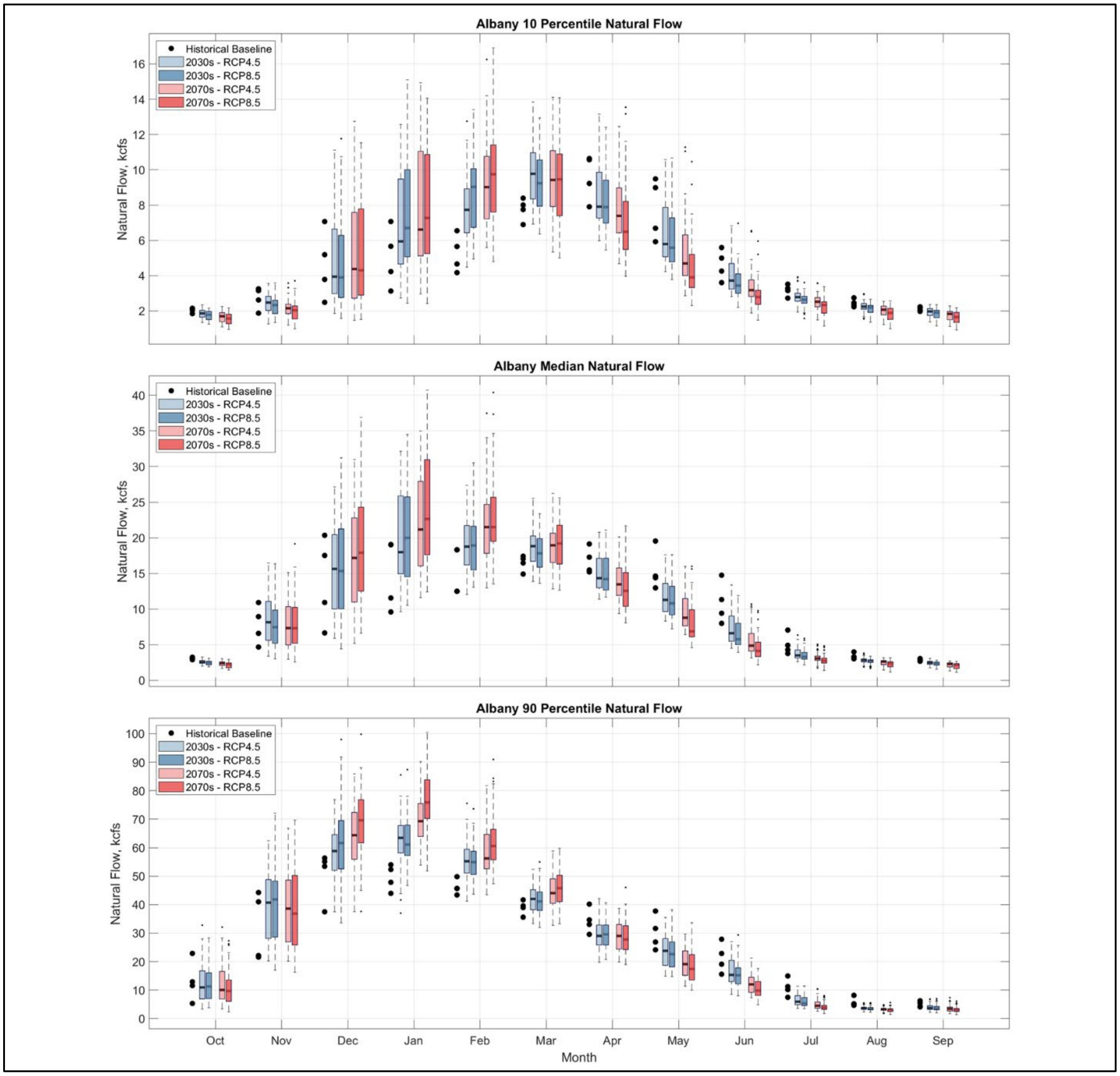

Figure 3-23. Willamette River at Albany, Oregon Summary Hydrographs.

Source: RMJOC-II, 2018

Table 3-2 summarizes the percent change in the median future relative to historical baseline flow. It exemplifies the relative degree of monthly and seasonal change. Positive flows tend to increase in November, December, and March while flows in spring through fall seasons tend to decrease relative to modeled baseline flows.

Table 3-2. Albany 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 River Subbasin are very similar to the Middle Willamette River Subbasin. Higher winter (DJF) inflows and increasing frequency of systemwide winter flood events will likely complicate system and local flood risk management. During winter, increased project inflow and back-to-back high-water events could lead to increased severity of flooding. Back-to-back flood events tax available flood space, and 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 not be stored for use later in the conservation season and thus not available for use as summer minimum flow releases and thermal regulation operations (10 May through 15 November). The Willamette River April 2019 high-water 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 risk days. Figure 3-24 graphically shows the trend of high fire risk days in the future.

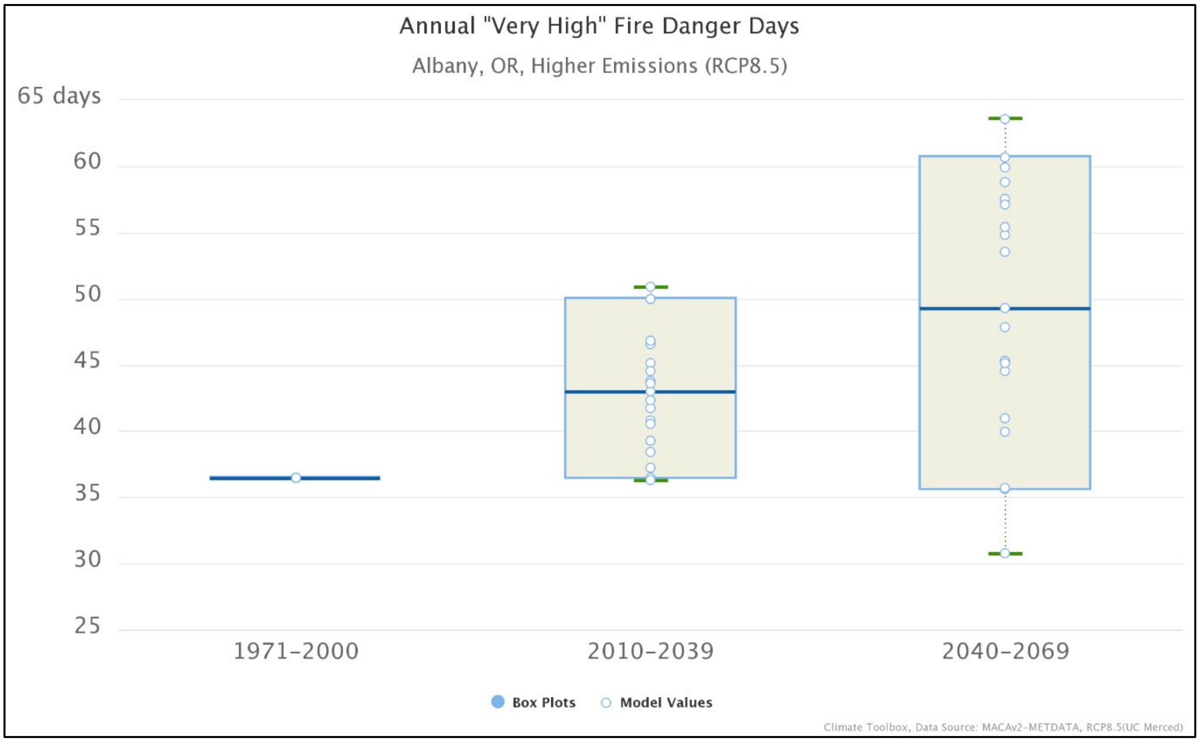

Figure 3-24. Albany, Oregon Annual Very High Fire Danger Days.

3.2.6 North Santiam River Subbasin

Figure 3-25 graphically shows the North Santiam River Subbasin. The North Santiam River Subbasin is approximately 766 square miles. The North Santiam fork combines with the mainstem Santiam River at Jefferson, OR. The subbasin is defined by steep and mountainous terrain until Gates, OR where the slopes become gentler and the river bottom lands expand to the valley floor. Toward the lower end of the subbasin at Stayton, OR there is extensive agriculture and residential properties. The North Santiam River Subbasin average elevation is 2,900 feet while the high elevation is 10,457 feet on Mount Jefferson. The low spot in the subbasin is approximately elevation 160 feet (NAVD88).

The North Santiam River headwater project 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 a re-regulation (“rereg”) project and serves to attenuate and mitigate power peaking flows from Detroit Dam. Big Cliff Dam also has power generation capacity at 18 MW from one turbine. ESA-listed species are present in the subbasin as well. There is a fish hatchery at Marion Forks on the North Santiam River above Detroit. ESA-listed species in the North Santiam River Subbasin include winter steelhead and spring Chinook salmon.

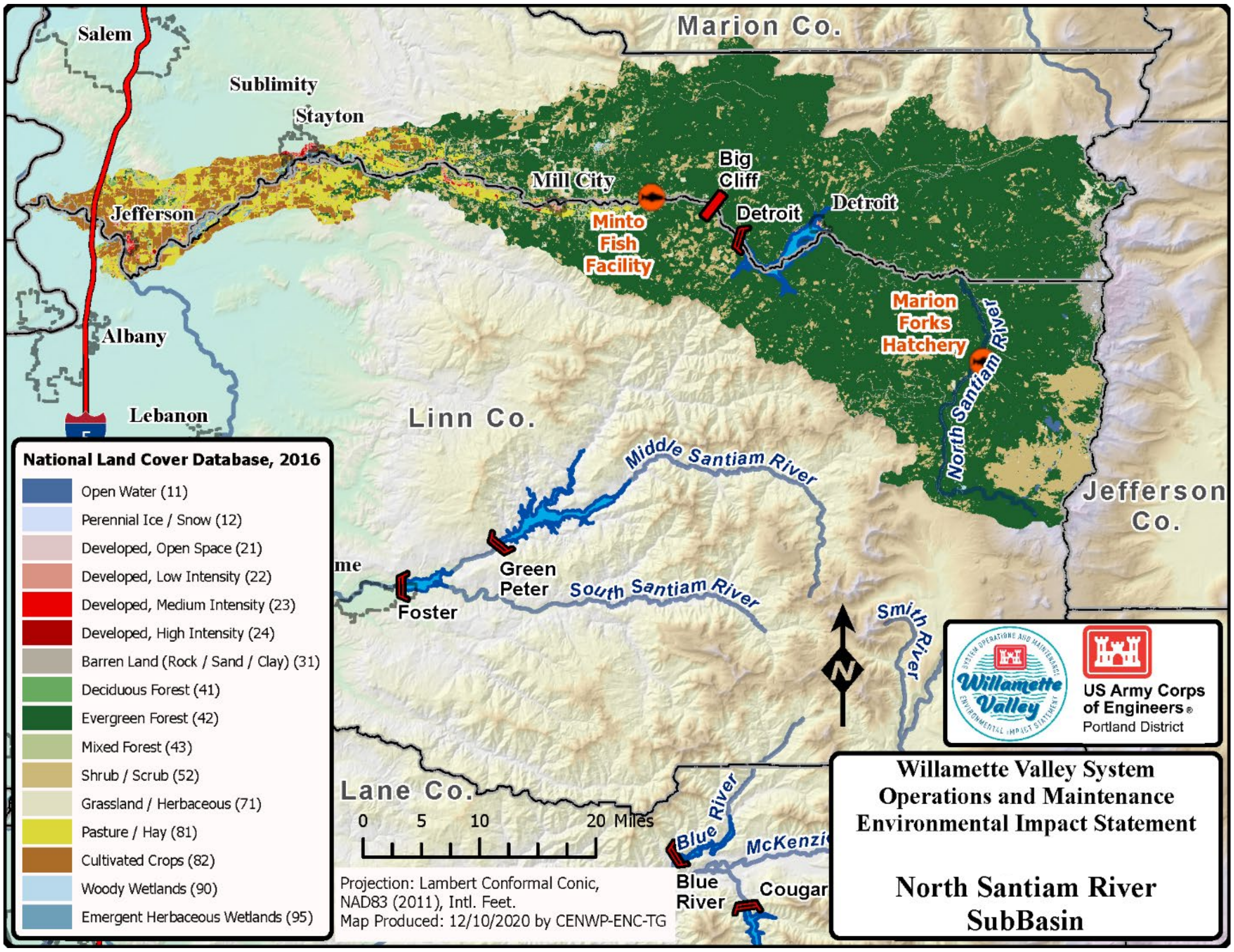

Figure 3-25. North Santiam River Subbasin.

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

Future (ambient) temperature projections in the subbasin have potential implications for the large water temperature downstream control tower as well as the fish collection project proposed at Detroit Dam. The temperatures at Detroit Dam are projected to increase as shown in Figure 3-26 (annual change) and Figure 3-27 depicting summer projections at the site.

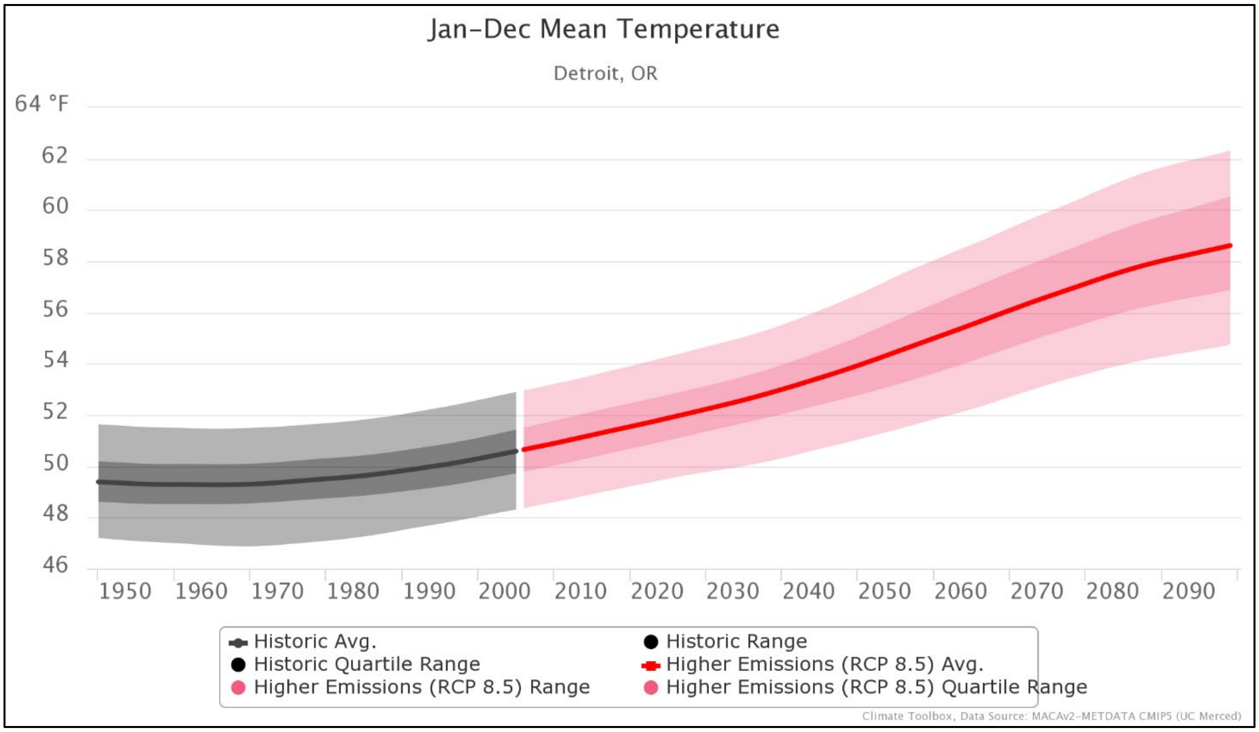

Figure 3-26. Average Annual Temperature Trends at Detroit, Oregon, 1950–2100.

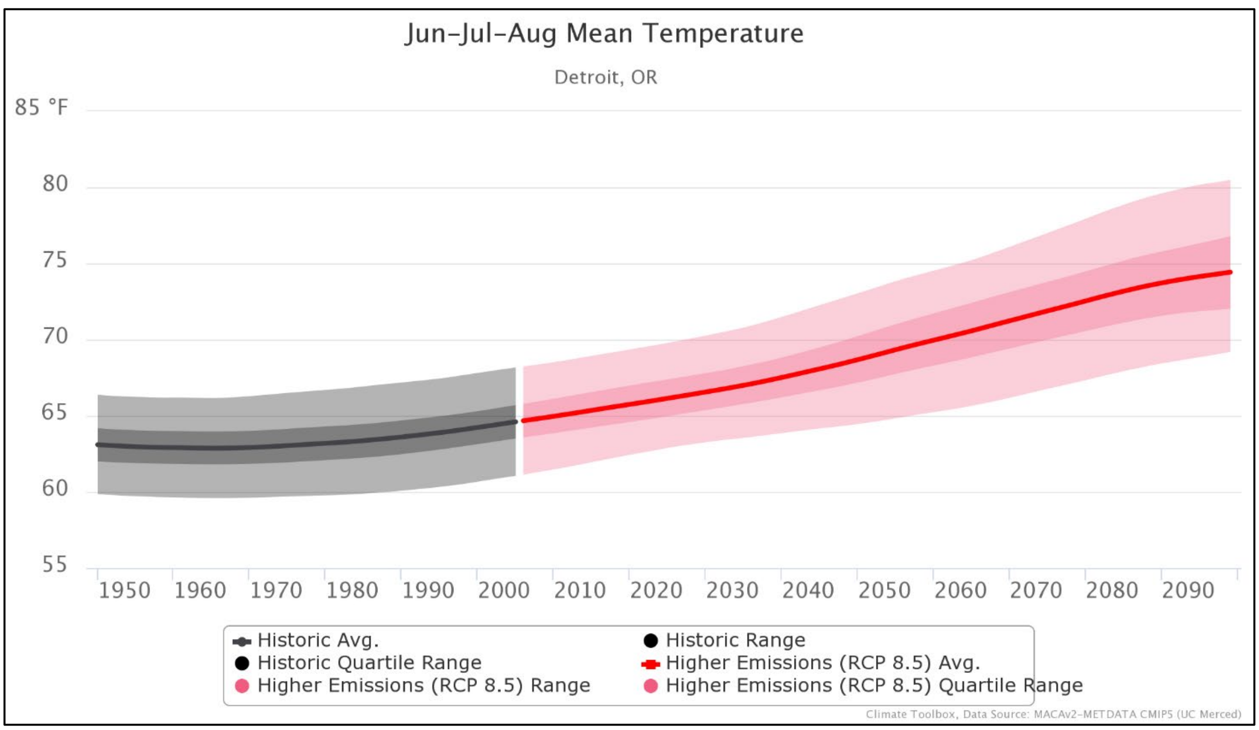

Figure 3-27. Average Annual Summer Temperature Trends at Detroit, Oregon, 1950–2100.

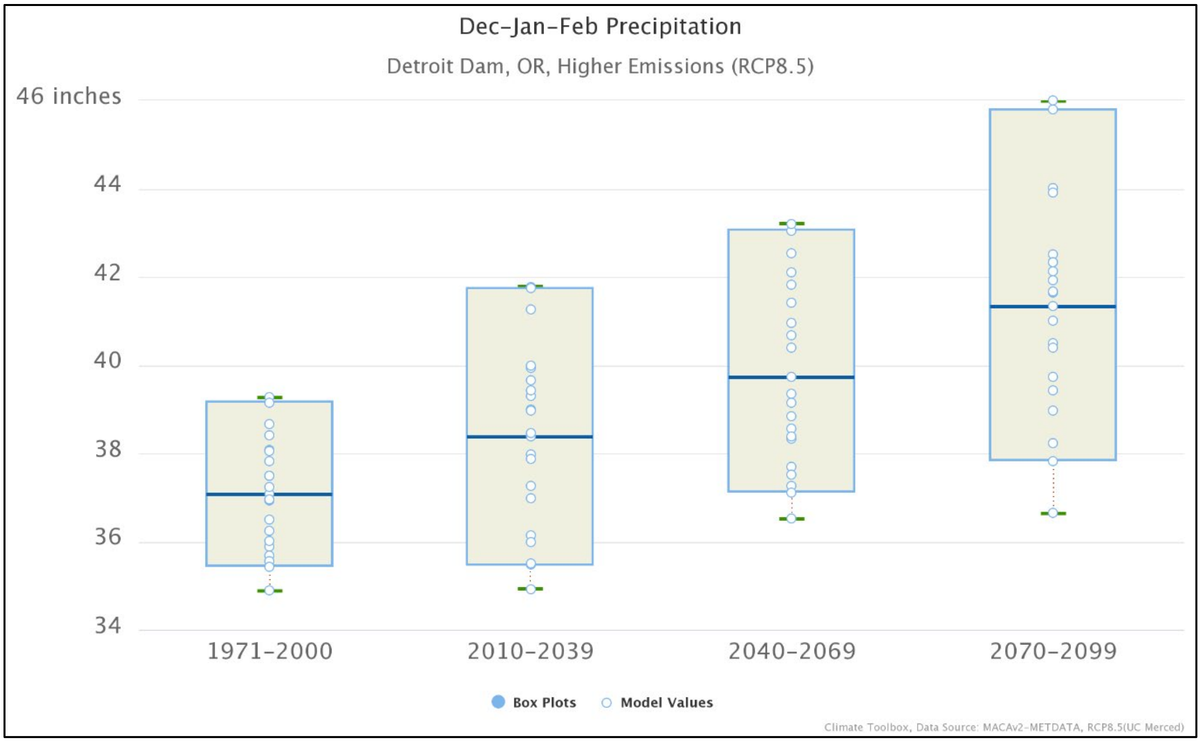

Figure 3-28. Median Winter Precipitation Trends at Detroit, Oregon, 1950–2100.

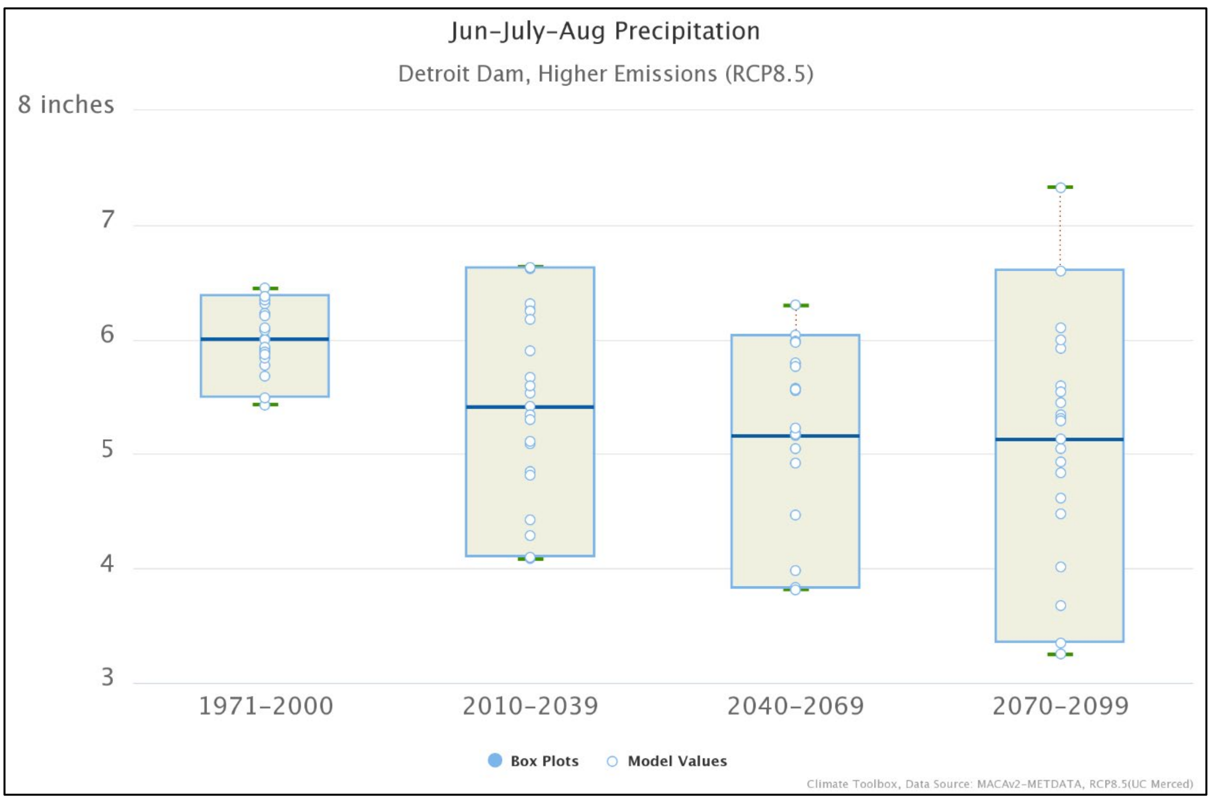

Figure 3-29. Median Summer Precipitation Trends at Detroit, Oregon, 1950–2100.

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 aquatic species. However, overall ecosystem function and habitat health are also very sensitive to projected air temperature and water temperature increases. Figure 3-26 through Figure 3-29 summarize projections indicating increasing temperature trends are likely through the end of the century. For the North Santiam River Subbasin, the relative change is projected to be somewhat greater than in the Middle and Upper Willamette River Subbasins. Figure 3-26 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 the end of the century. End-of-century temperature means for the critical summer season (JJA) are projected to rise +11.5°F as shown in Figure 3-27.

The projected precipitation changes at Detroit Dam are shown to trend upward in the winter and decline in the summer. It is likely that the upper subbasin will experience a future decrease in SWE and become more rain dominated. Streamflow projections mirror the future precipitation trends. SWE, already declining, is likely to become extremely marginal to non-existent by the end of the century (RMJOC 2020). The Detroit Dam unregulated summary hydrographs highlighting the 10th (more frequent, low flows), 50th (median), and 90th (less frequent, high flows) exceedance percentiles are shown in Figure 3-30. Hydrographs at Big Cliff Dam, a re-regulating dam, would follow a similar trend to Detroit Dam. Table 3-2 summarizes the percentile flow changes in terms of relative flow change.

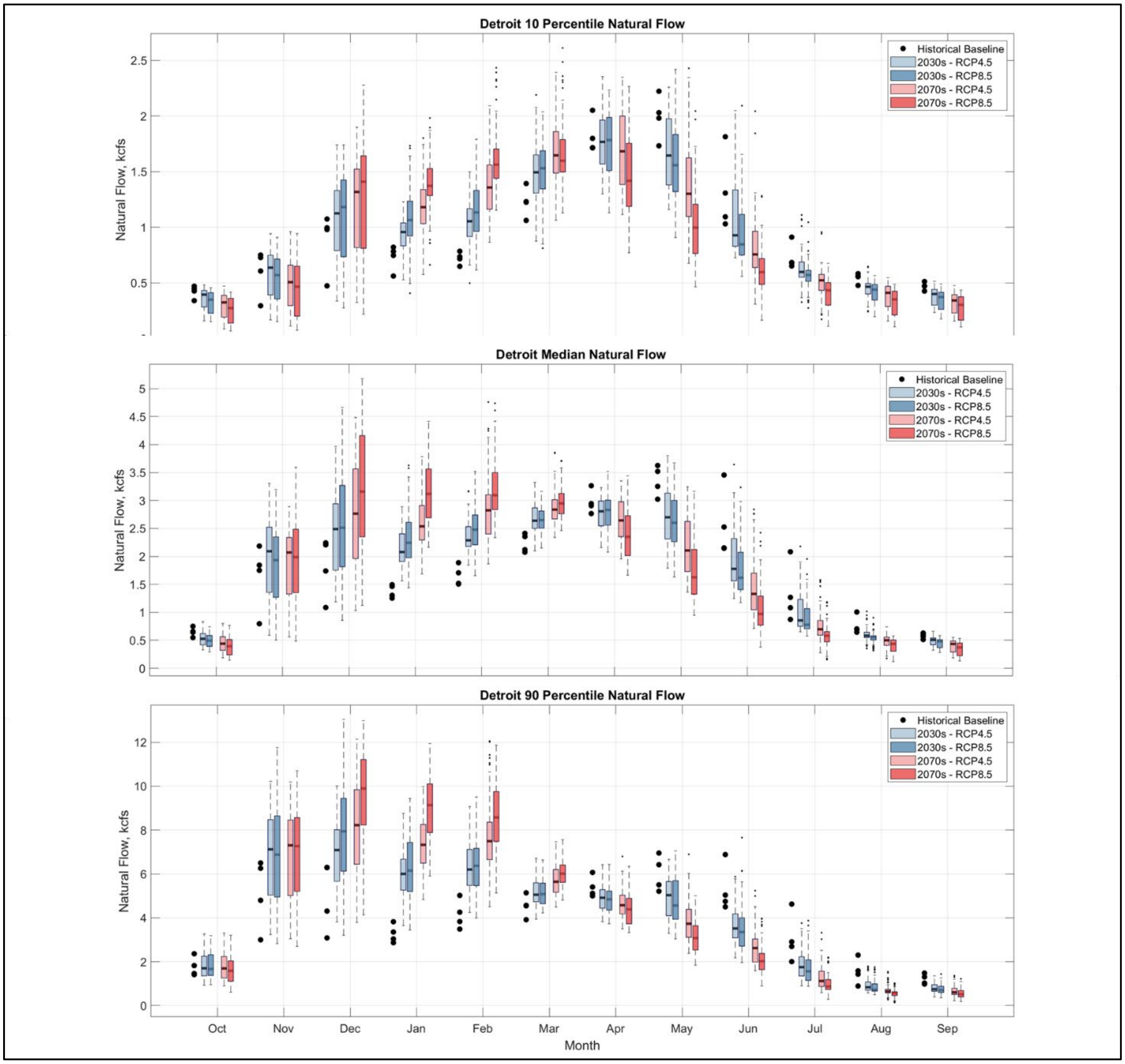

Figure 3-30. North Santiam River at Detroit Dam, Oregon Summary Hydrographs.

Table 3-3. Detroit Dam 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 winter flows is indicated by the November through March relative increases in median flows. This is in contrast with the pattern seen in the valley floor, characterized as a single annual (winter) peak and no spring pulse in May. Detroit Dam, OR summary hydrographs portray the different streamflow patterns of a snowpack-affected basin. The historical pattern is for an annual peak in the winter (DJF) followed by a lesser annual rise from the snow melt pulse peaking in May.

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

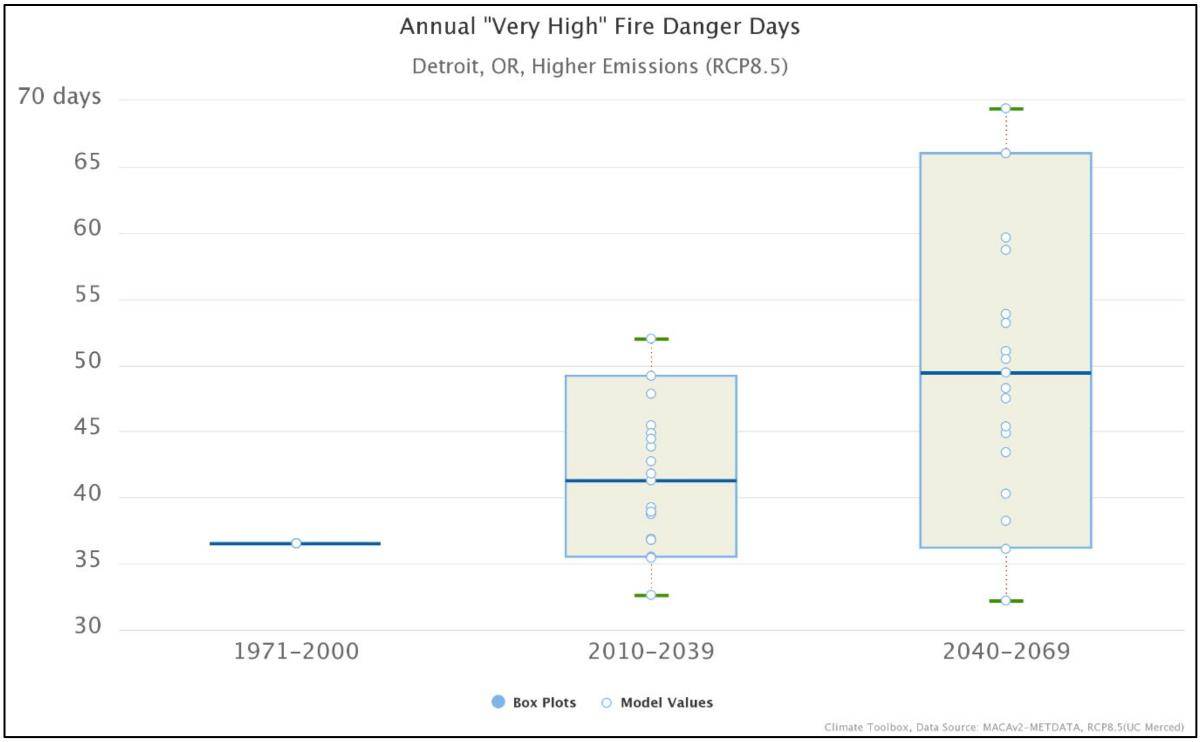

Figure 3-31. Detroit, Oregon Annual Very High Fire Danger Days.

As shown in Figure 3-31, the area surrounding Detroit Dam is likely to experience higher fire risk in the future. Median change is upward for both future epochs. The variability of the fire risk 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 Subbasin

The South Santiam River drainage area is approximately 1,040 square miles and is about a third larger than the North Santiam Subbasin (740 square miles). The majority (about 2/3) of the basin is steep and mountainous. The South Santiam River Subbasin average elevation is comparable to the North Santiam River Subbasin, being approximately 2,000 feet (NAVD88). The South Santiam River Subbasin high point is about 5,800 feet (NAVD88) while the low elevation is approximately 215 feet (NAVD88). Green Peter Dam and reservoir straddles the Middle Santiam River. Foster Dam, located about 7 miles downstream, moderates Green Peter Dam power peak releases.

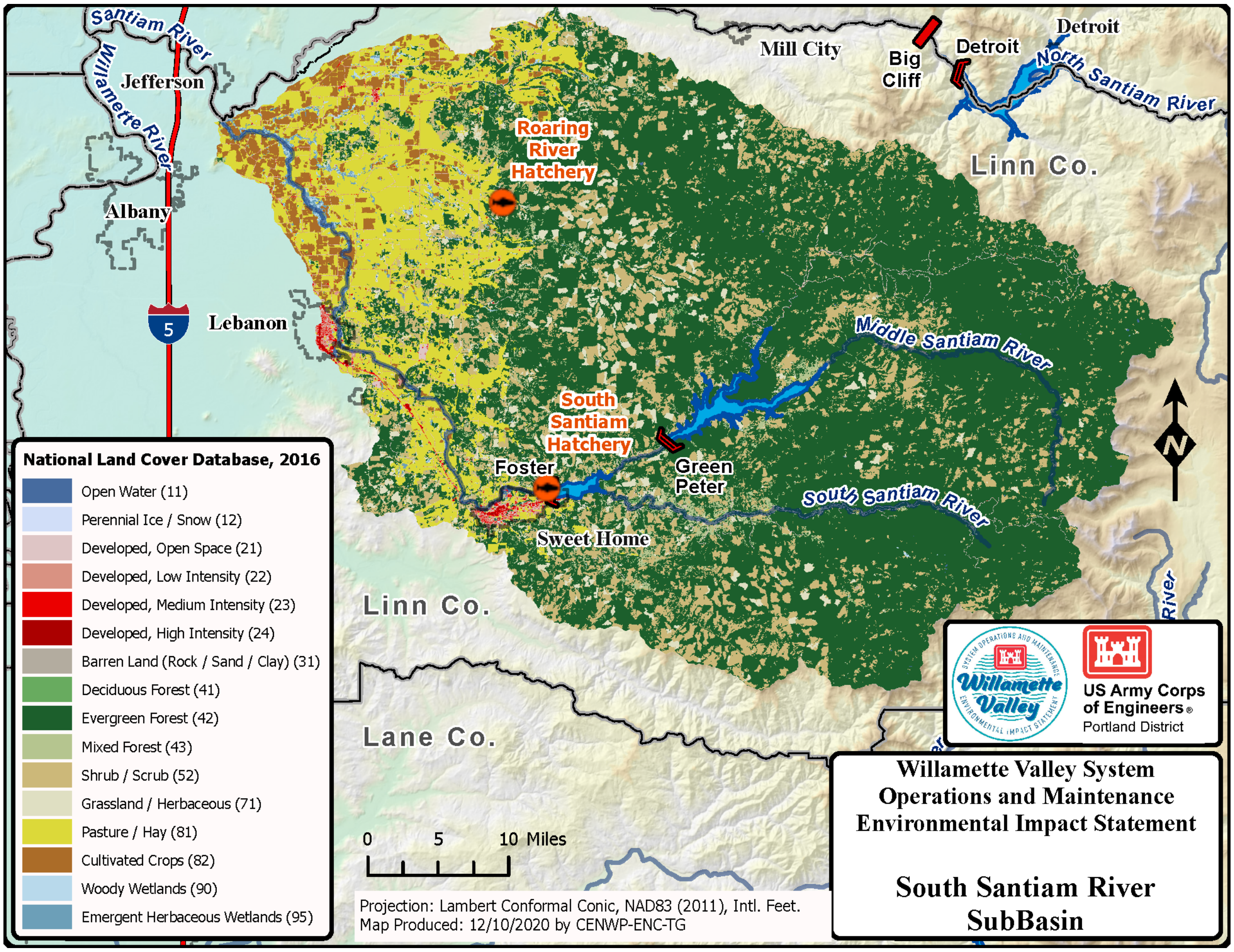

Figure 3-32. South Santiam River Subbasin.

Similar to the North Santiam River Subbasin, temperatures in the South Santiam River Subbasin are projected to increase as shown in Figure 3-33 (annual change) and Figure 3-34 (summertime (JJA) averaged projections at the site).

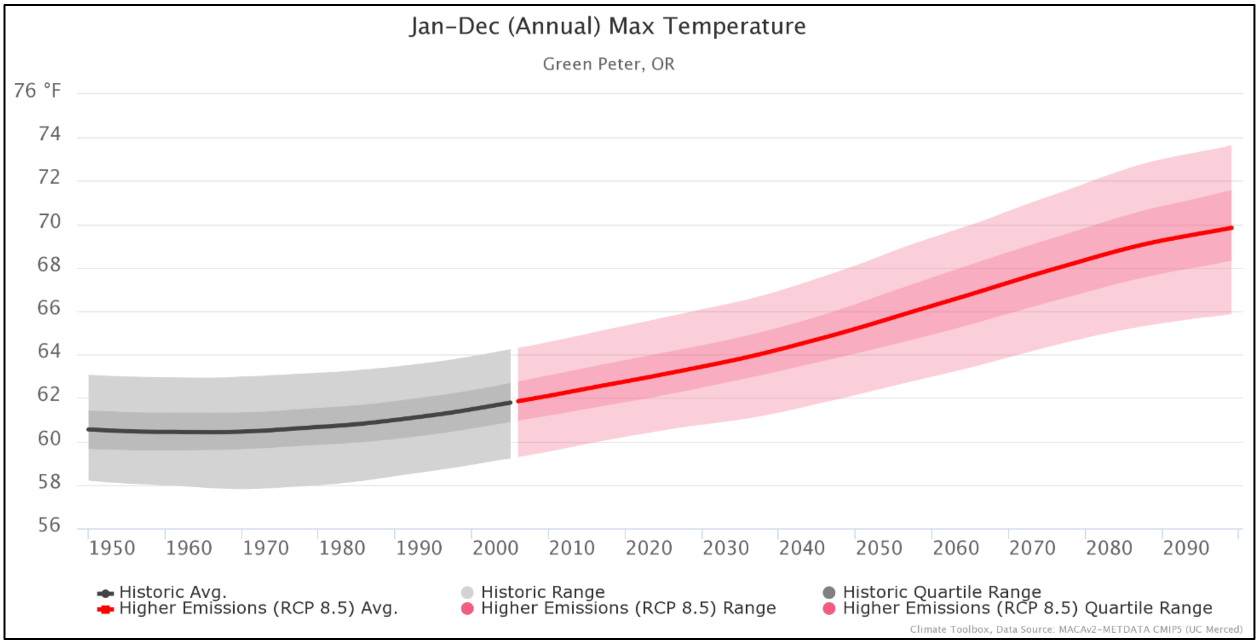

Figure 3-33. Average Annual Temperature Trends at Green Peter Dam, Oregon, 1950–2100.

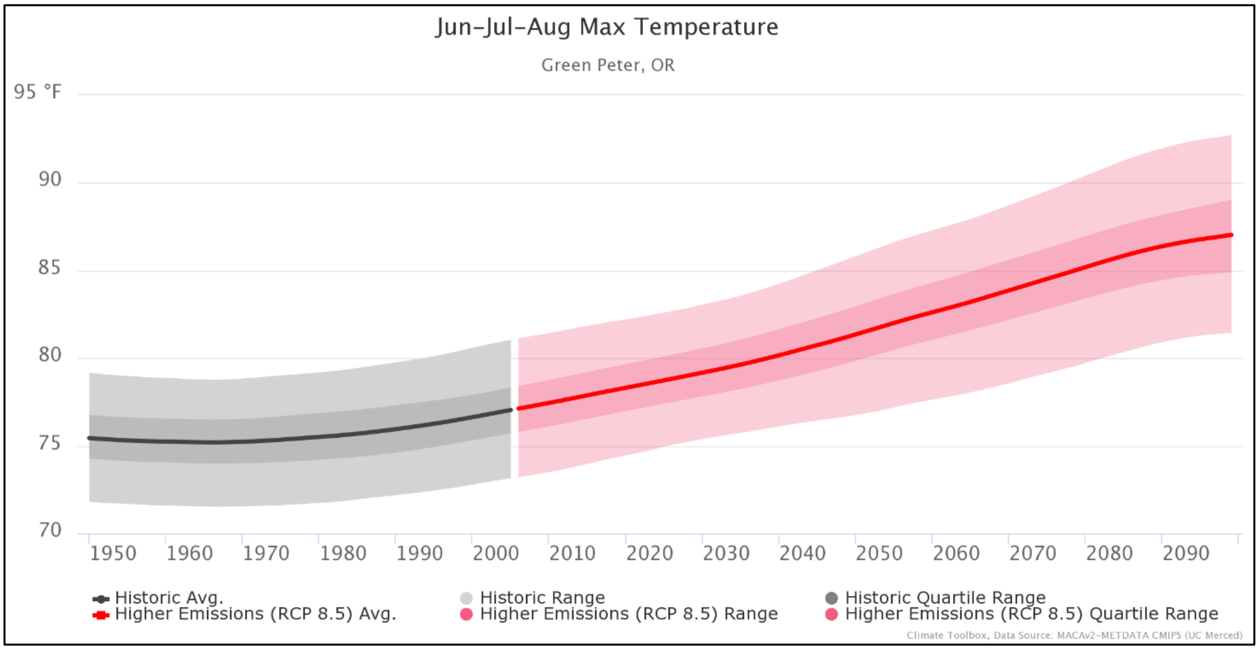

Figure 3-34. Average Annual Summer Temperature Trends at Green Peter Dam, Oregon, 1950–2100.

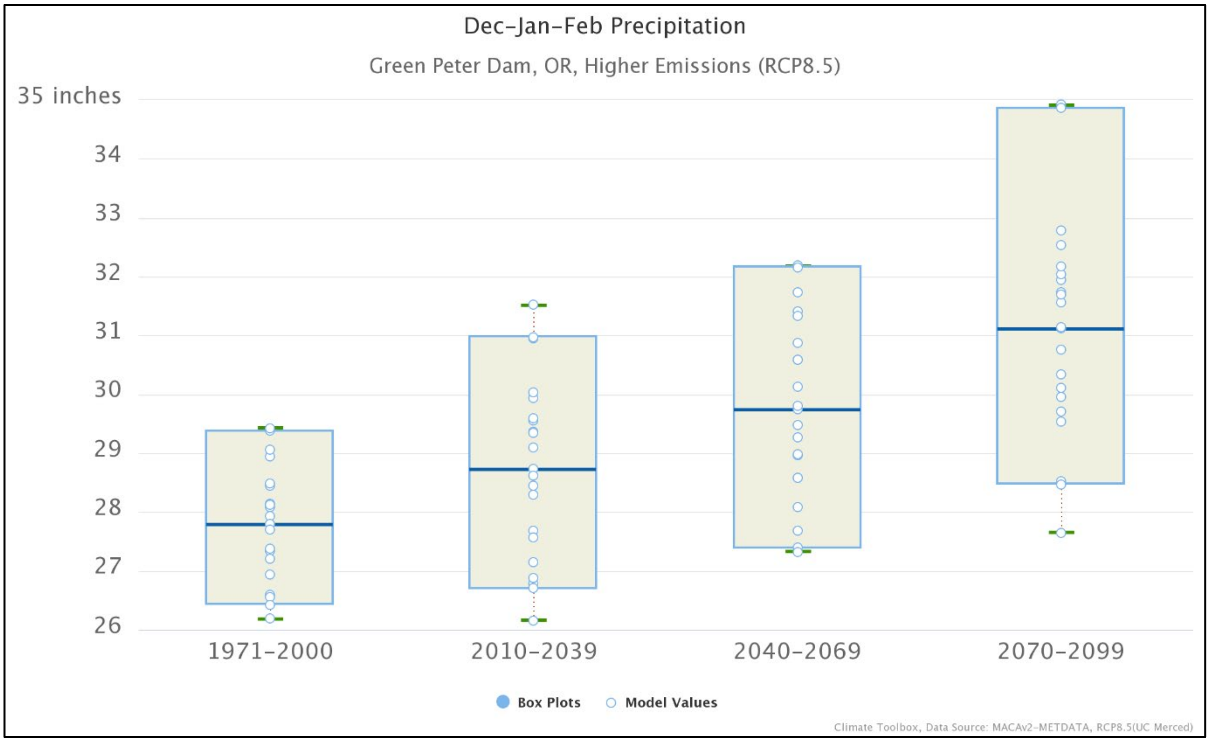

Figure 3-35. Median Winter Precipitation Trends at Green Peter Dam, Oregon, 1950–2100.

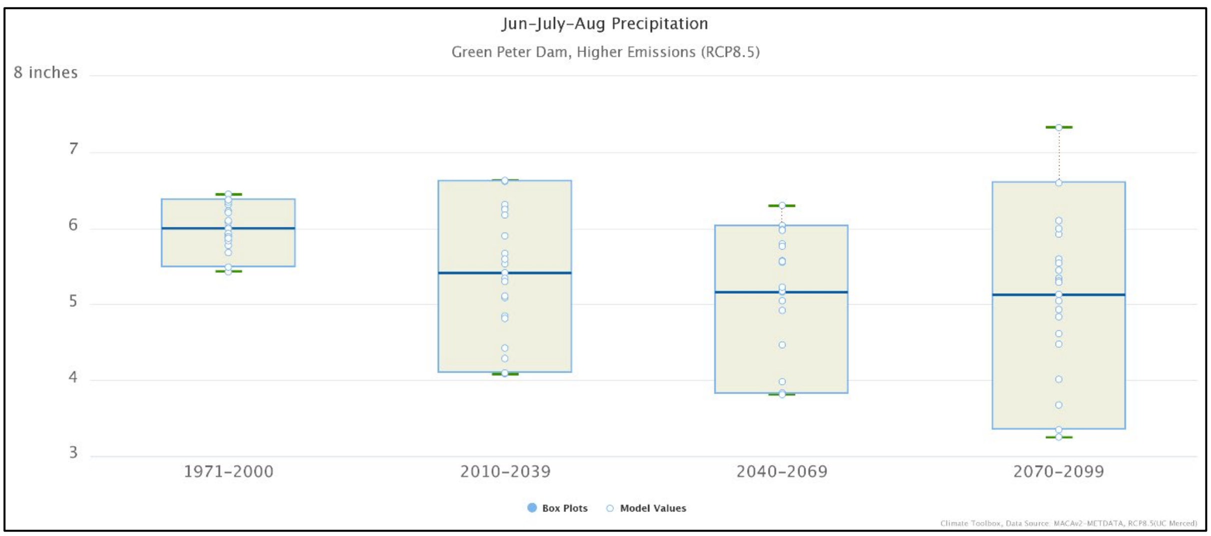

Figure 3-36. Median Summer Precipitation Trends at Green Peter Dam, Oregon, 1950–2100.

The South Santiam River Subbasin (headwater site) pattern is very similar to the adjoining North Santiam River Subbasin. Green Peter Dam unregulated, naturalized hydrographs show the effect of warming temperatures—transitioning a snow-impacted basin to an entirely rainfall-dominated basin by the middle and end of the century. The dominant signal is streamflow volume shifting from a winter and spring distribution to one almost entirely occurring in winter. This has substantial 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 projected increases in winter volume and an earlier seasonal refill period projected further into the 21st century. 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 River Subbasin 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 the end of the century. The Green Peter Dam unregulated summary hydrographs highlighting the 10th (more frequent, low flows), 50th (median) and 90th (less frequent, high flows) exceedance percentiles are shown in Figure 3-37 for Green Peter Dam. Foster Dam downstream follows a similar trend to Green Peter Dam.

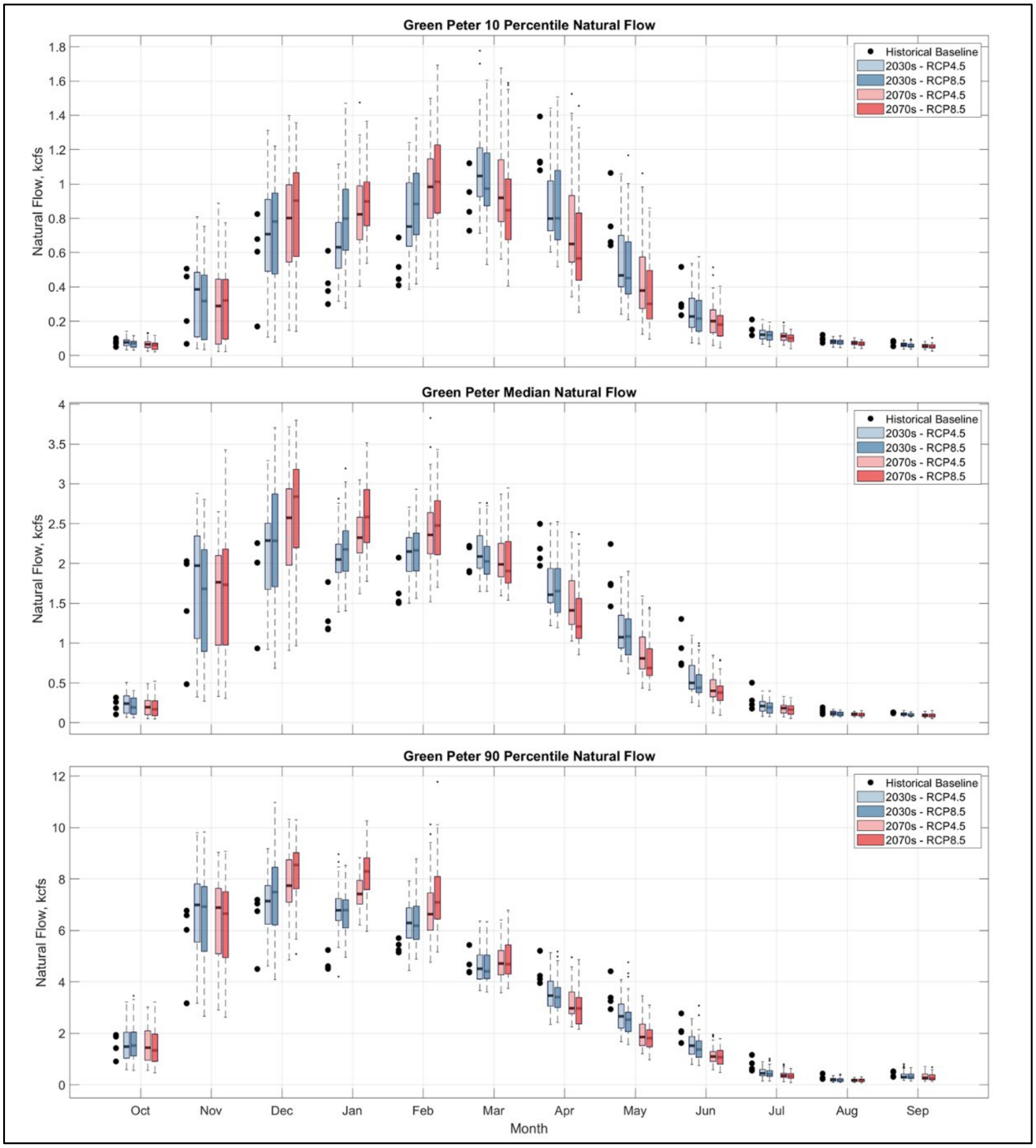

Figure 3-37. South Santiam River at Green Peter Dam, Oregon Summary Hydrographs.

Table 3-4. Green Peter Dam 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 winter flows is indicated by the November through March, median flow increase. Contrasting with the pattern seen in the valley floor, Green Peter Dam, OR summary hydrographs portray the different streamflow patterns of a snowpack-affected basin. The historical pattern is for an annual peak in the winter (DJF) followed by a lesser annual rise from the snow melt pulse peaking in May.

The future pattern will reflect higher winter volume and a diminished (or eliminated) spring runoff. It is likely that change in timing and quantity will complicate water management in the Willamette Valley. Operational approaches should consider potential effects from these projected changes to effectively navigate likely changes in the future.

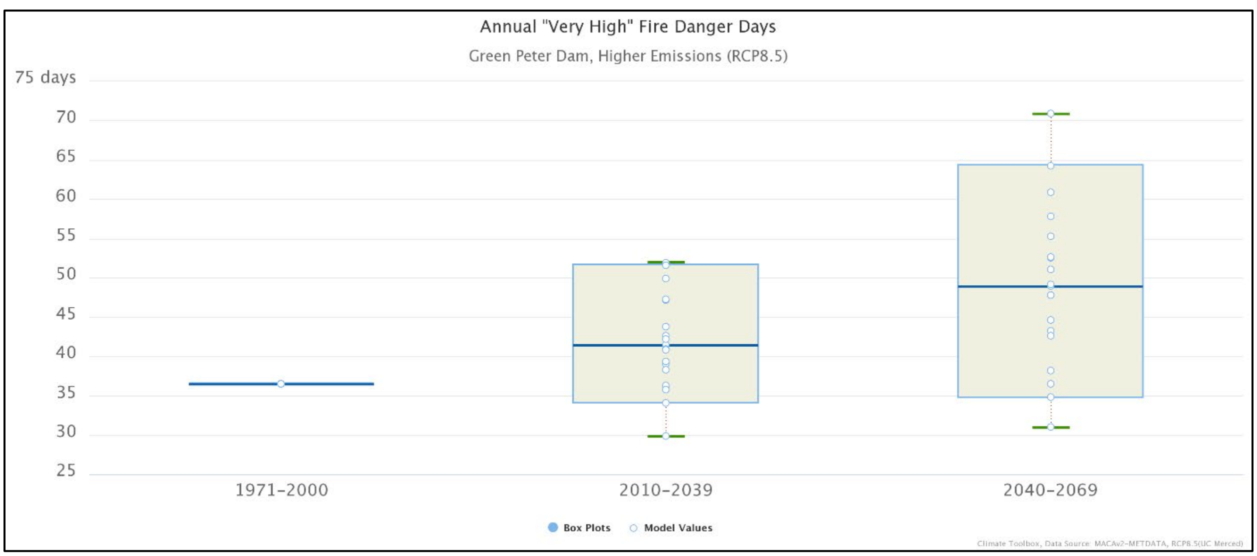

Figure 3-38. Green Peter Dam, Oregon Annual Very High Fire Danger Days.

As shown in Figure 3-38, Green Peter Dam and surrounding areas are likely to experience higher fire risk in the future. Median change is upward for both future epochs. The variability of the fire risk 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 Subbasin

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

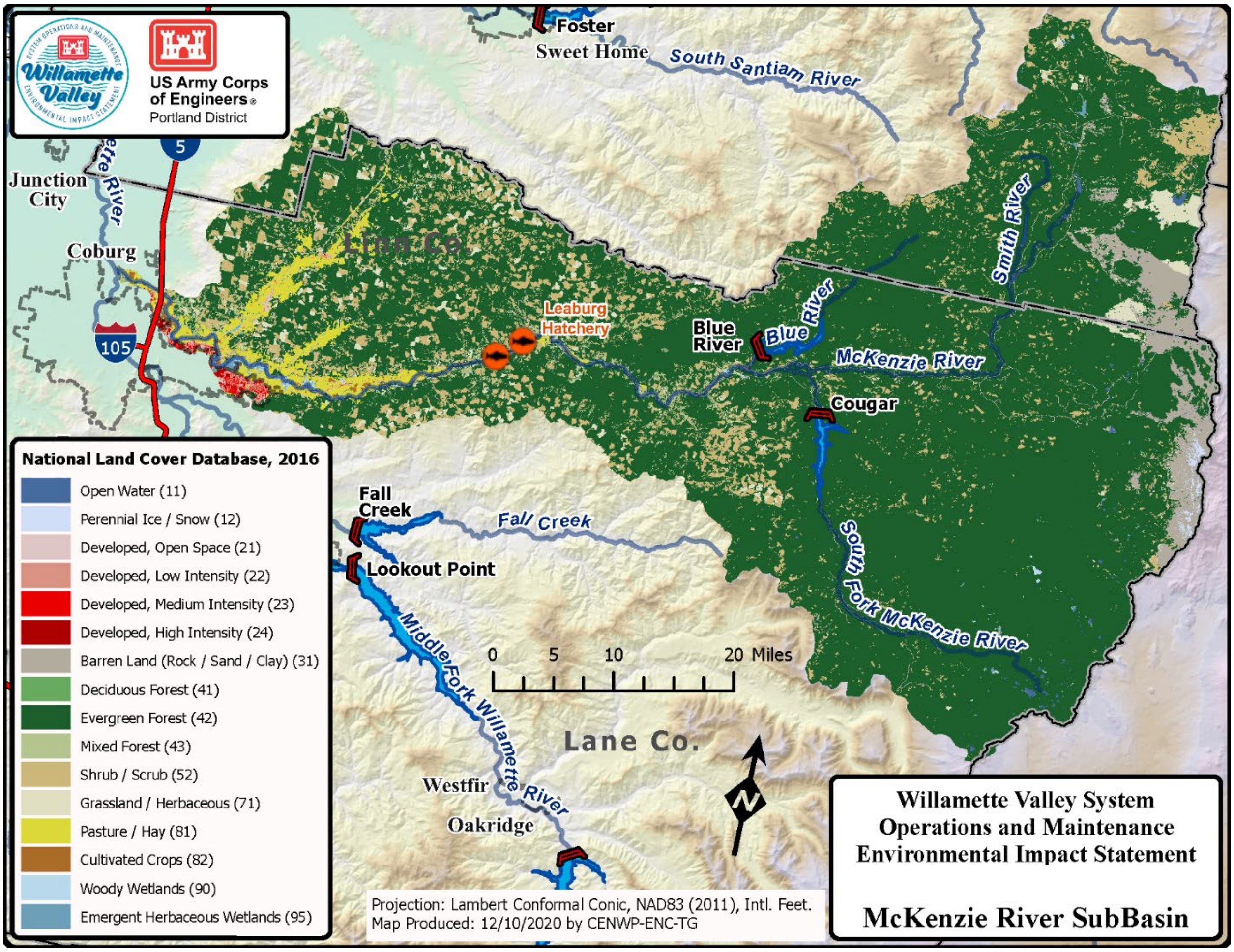

Figure 3-39. McKenzie River Subbasin.

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

Figure 3-40 and Figure 3-41 depict the average annual and summer (JJA) air temperature changes at Cougar Dam. As the subbasin experiences increased warming, there will likely be impacts to future temperature operations at Cougar Dam. Blue River Dam is operated with Cougar Dam to facilitate flood risk management locally to Springfield/Eugene and downstream system control points. Water temperature control measures at Blue River Dam have been determined to be not feasible. There are two hatcheries in the subbasin located at Leaburg, OR and downstream on the McKenzie River mainstem.

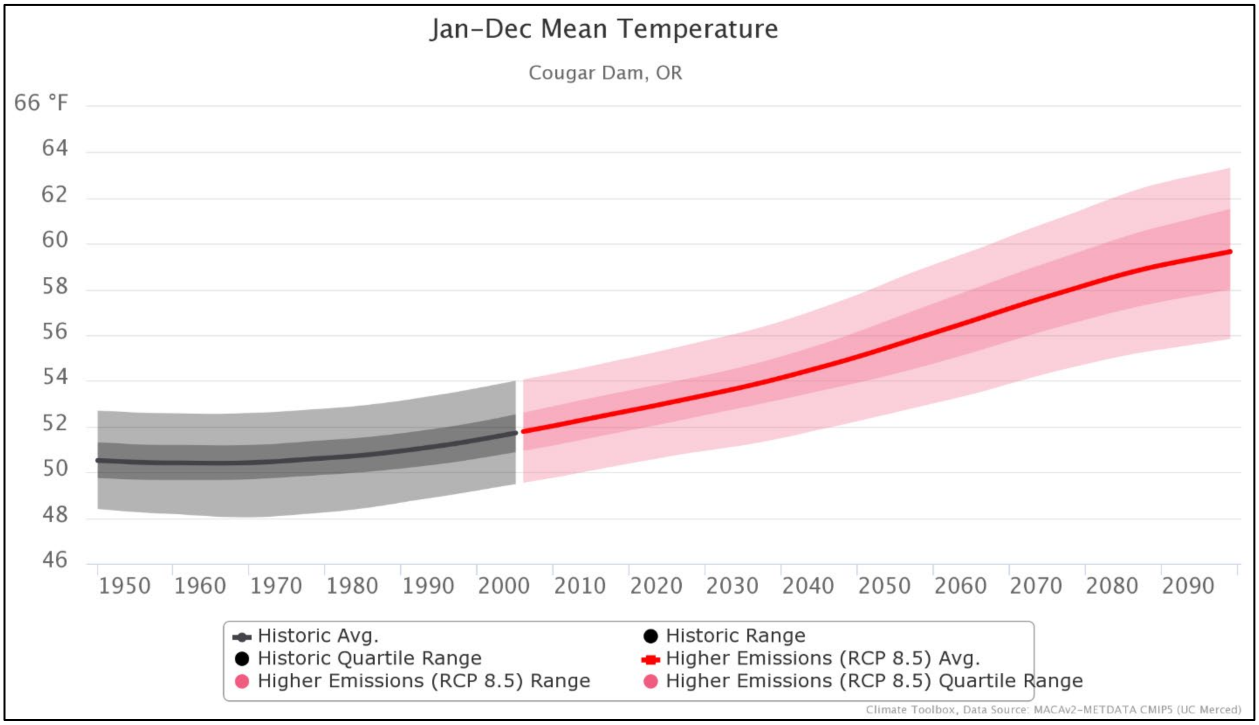

Figure 3-40. Average Annual Temperature Trends at Cougar Dam, Oregon, 1950–2100.

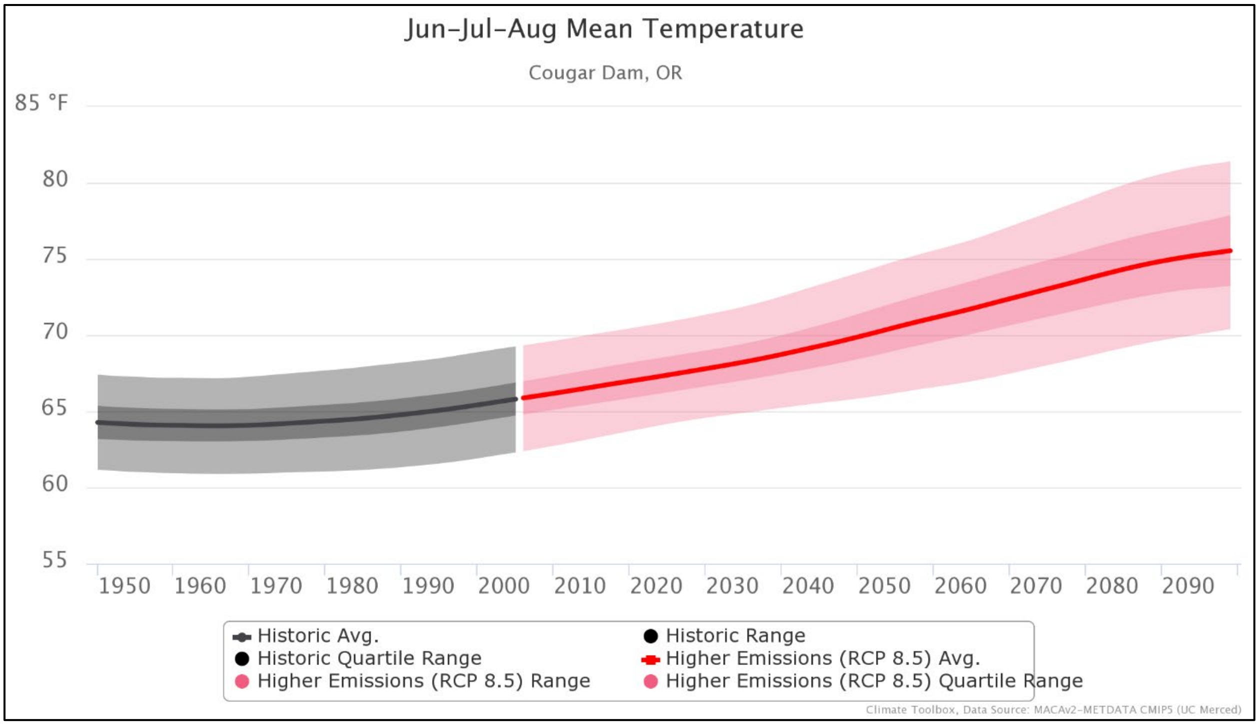

Figure 3-41. Average Annual Summer Temperature Trends at Cougar Dam, Oregon, 1950–2100.

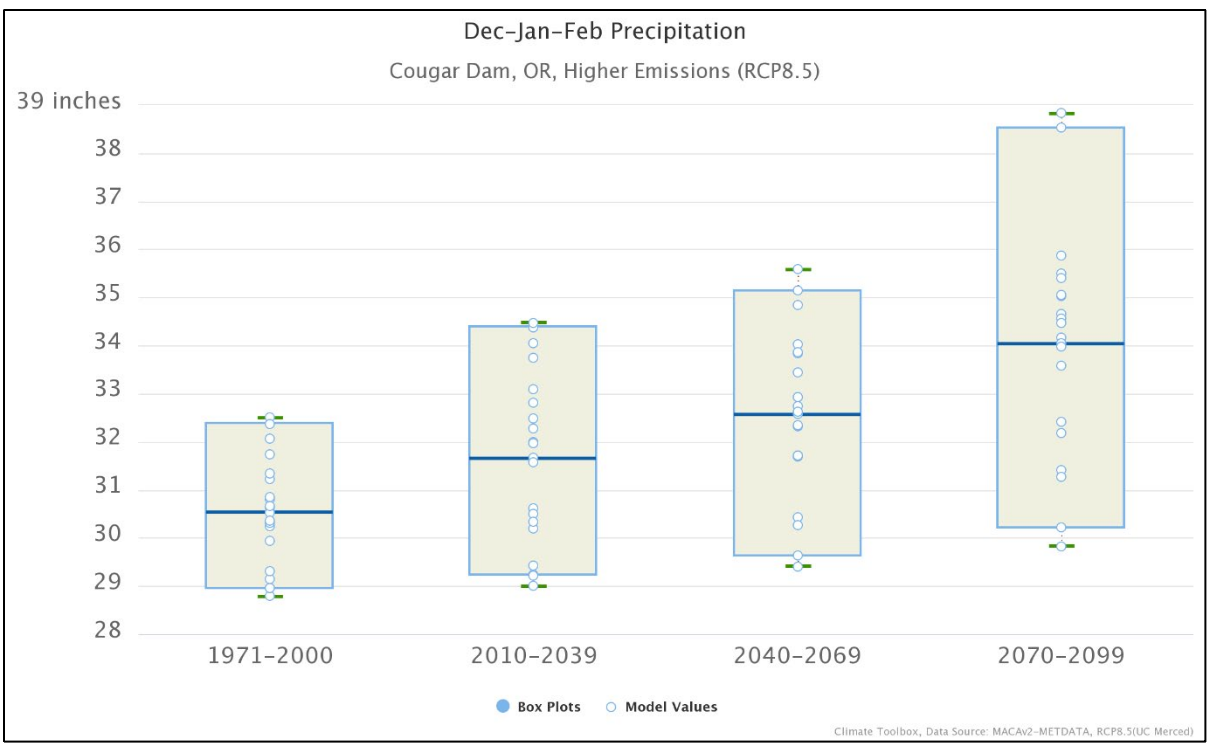

Figure 3-42. Median Winter Precipitation Trends at Cougar Dam, Oregon, 1950–2100.

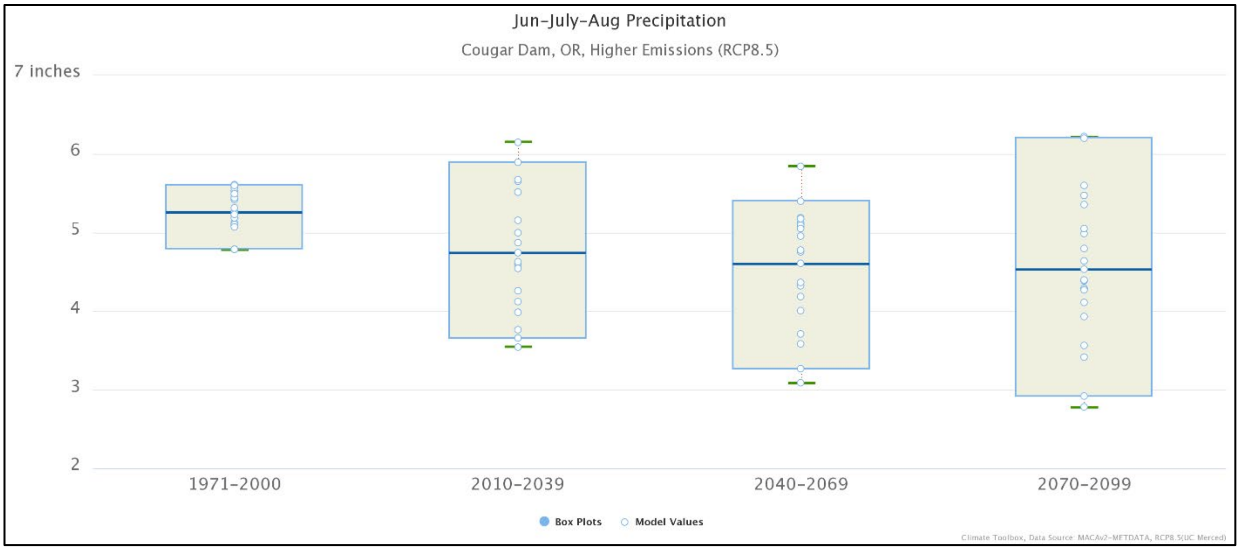

Figure 3-43. Median Summer Precipitation Trends at Cougar Dam, Oregon, 1950–2100.

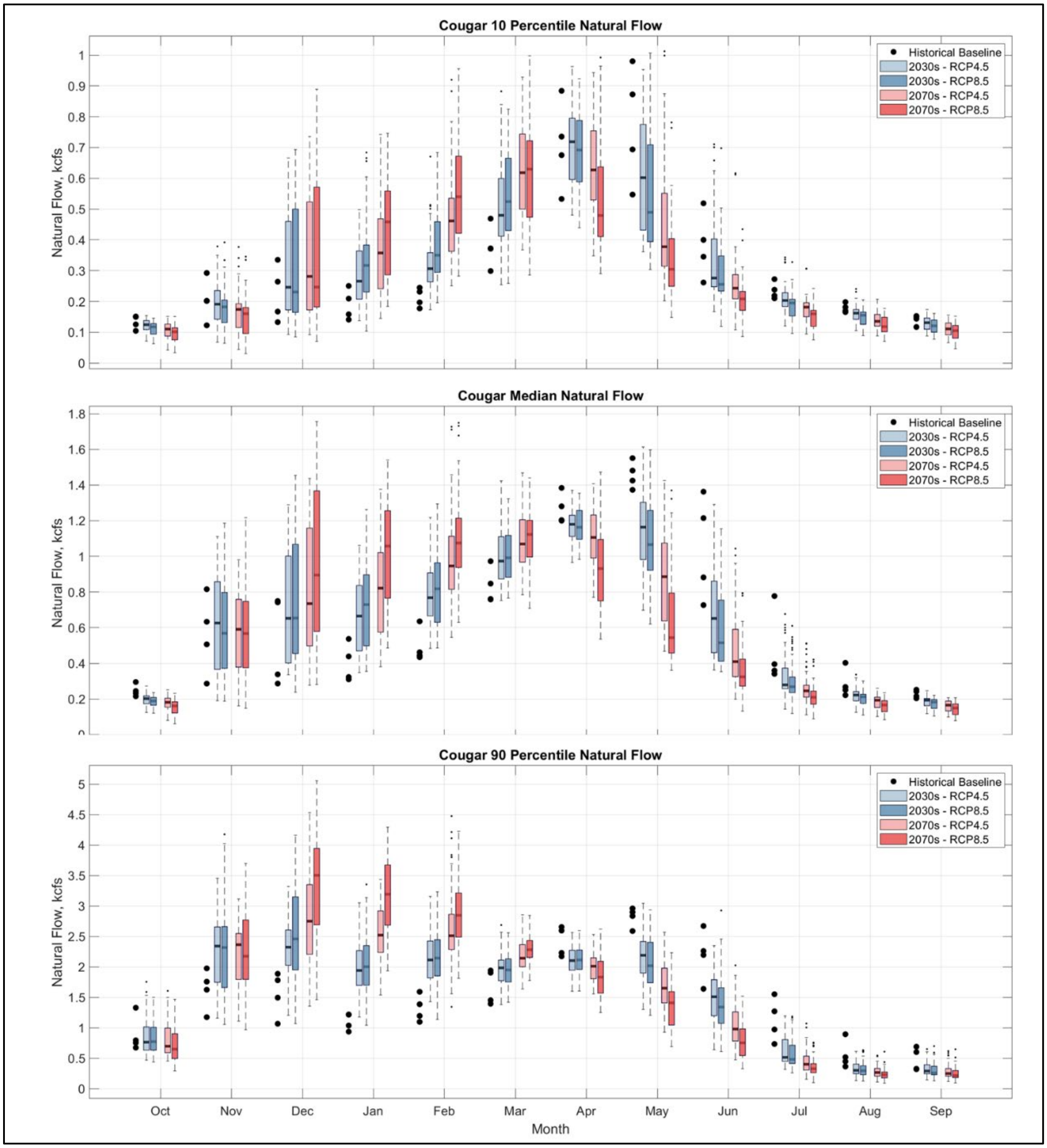

Figure 3-44. McKenzie River at Cougar Dam, Oregon Summary Hydrographs.

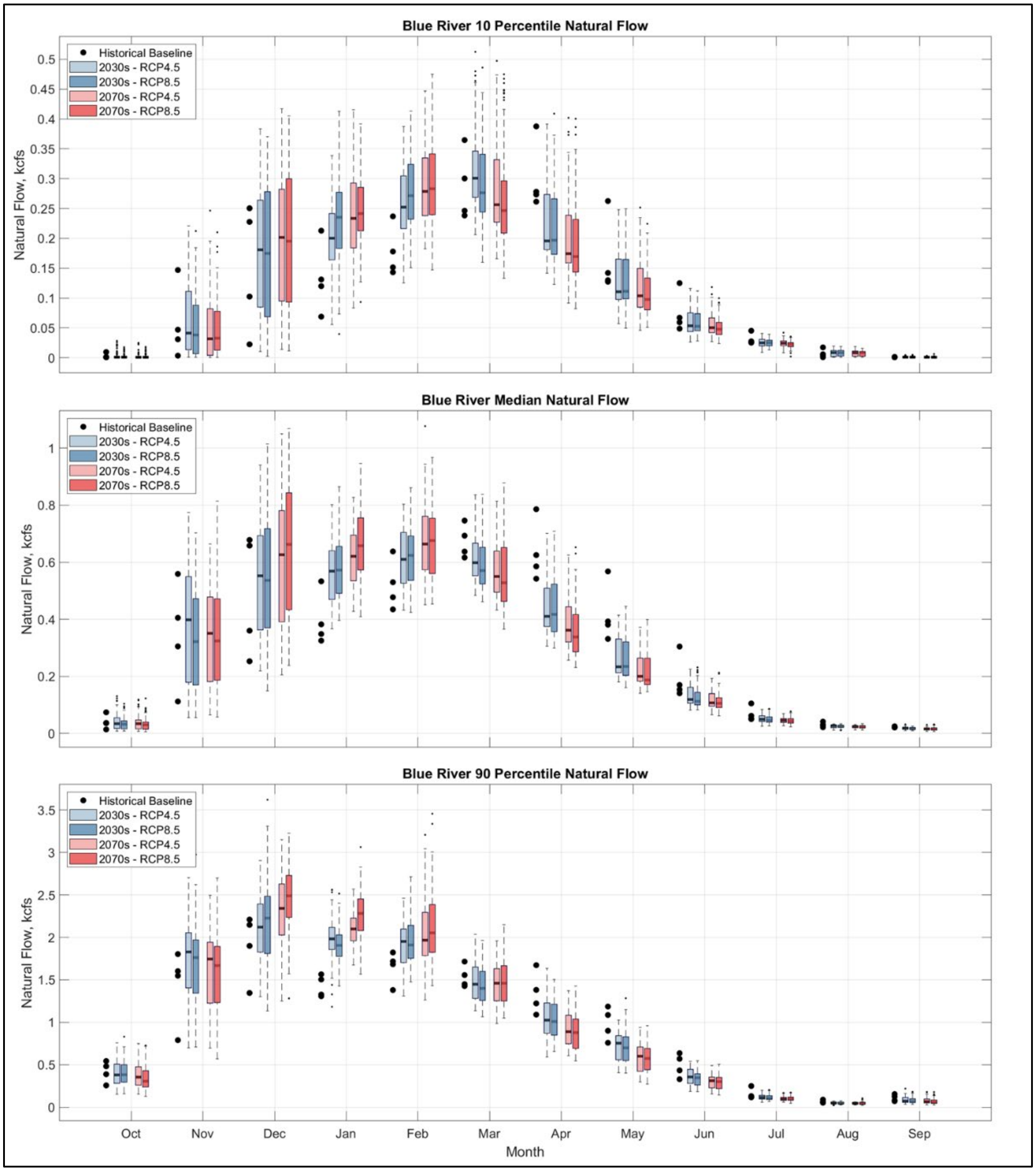

Figure 3-45. Blue River Dam, Oregon Summary Hydrographs.

Overall, the McKenzie River Subbasin (at Cougar Dam and Blue River Dam) future hydroclimate and hydrology trends are similar to that seen in the Santiam River Subbasins. Both Cougar Dam and Blue River Dam hydrographs show 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 one almost entirely occurring in winter. Table 3-5 and Table 3-6 summarize the relative change in flows for the 10th, 50th, and 90th percentile flows for Cougar and Blue River Dams, respectively.

Table 3-5. Cougar Dam 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. Blue River Dam 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 winter high flows (P90) is indicated by the November through 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 winter (DJF) followed by a lesser annual rise from the snow melt pulse peaking in May.

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

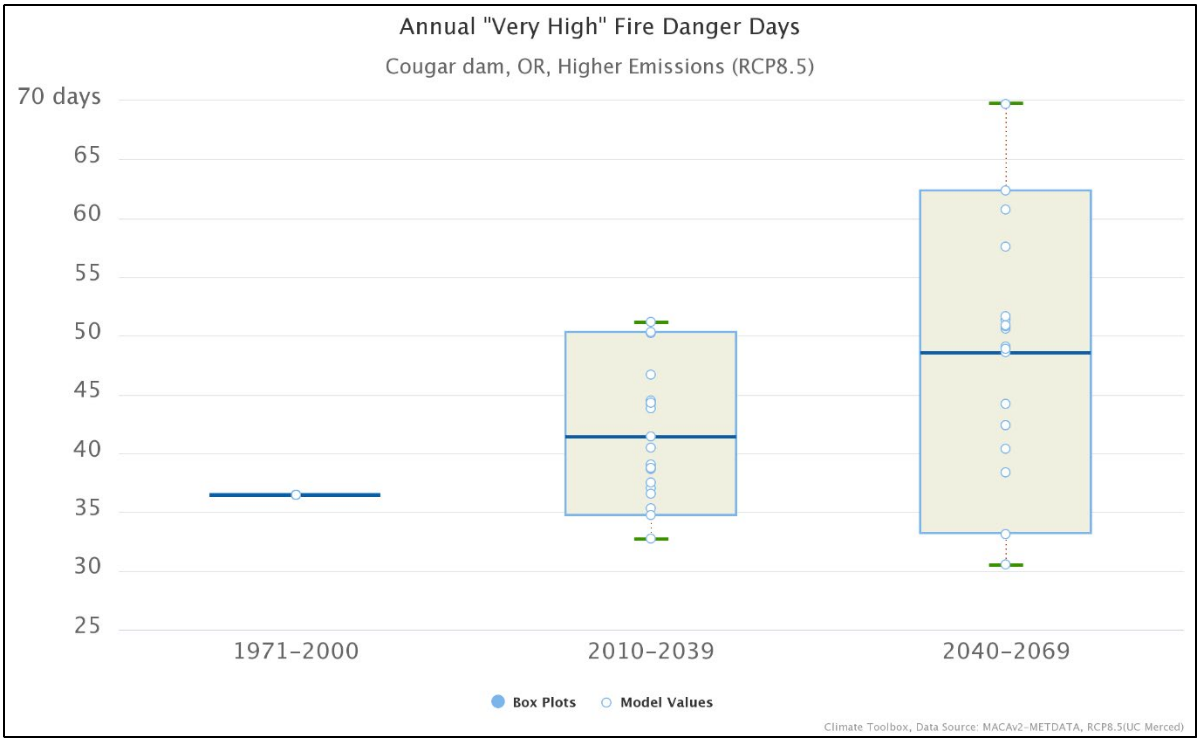

Figure 3-46. Cougar Dam, Oregon Annual Very High Fire Danger Days.

The fire risk at Cougar Dam, OR is chosen as representative for the subbasin. Blue River high fire risk 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 Subbasin

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

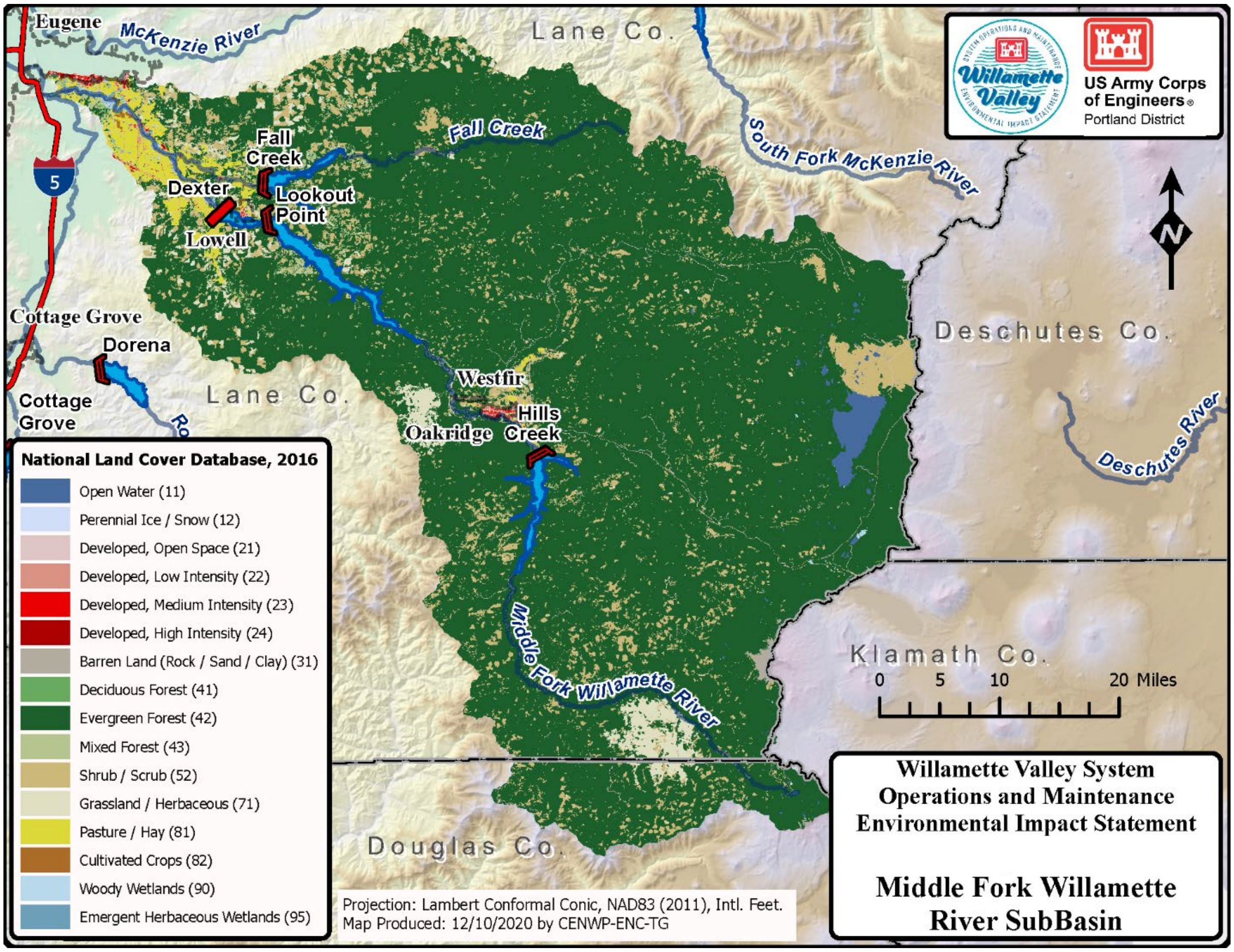

Figure 3-47. Middle Fork Willamette River Subbasin.

The Middle Fork Willamette River Subbasin contains four USACE projects. Hills Creek, Lookout Point, and Dexter Dams are located on the MF Willamette River. Hills Creek Dam is the most upstream project on the MF Willamette River, and Fall Creek Dam is on Fall Creek, tributary to the MF Willamette River. Currently, ESA-listed spring Chinook salmon and bull trout are present in the subbasin. Hills Creek and Lookout Point Dams are multipurpose 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 Dam has two turbines capable of producing 15 MW each and Lookout Point Dam has three turbines capable of producing 40 MW each. Dexter Dam is a re-regulation project located downstream of Lookout Point Dam and is used to control water levels created by peak hydropower generation at Lookout Point Dam. There is one turbine unit at Dexter Dam that produces 15 MW of power. Dexter Reservoir is heavily used for recreation in summer. Fall Creek Dam and Reservoir is a multipurpose project that does not have a powerhouse, and this reservoir also is heavily used for recreation in summer.

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Hydroclimate changes are similar across the MF Willamette River Subbasin. Future annual and seasonal precipitation and temperature trends, as well as trends in high fire risk days, are displayed for the Hills Creek Subbasin to provide insight into climate change impacts in the MF Willamette River. Overall, climate change projections for the future indicate substantial warming in the subbasin. Figure 3-48 and Figure 3-49 portray upward trends annually and in summer. Summer temperature changes are expected to have the greatest relative increases. Figure 3-50 through Figure 3-53 graphically summarize, via statistical box plots, the projected changes in precipitation and ambient temperatures for the critical winter and summer months.

END REVISED TEXT

Projected streamflow changes are shown at Lookout Point and Fall Creek Dams. Together, they are considered representative of the greater MF Willamette River Subbasin expected future patterns.

Hills Creek Dam is also shown and represents the more upstream, somewhat higher elevation and more pristine natural conditions subbasin. Fall Creek Dam 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 3-54, Figure 3-55, and Figure 3-56. Dexter Dam was not included because of its proximity to Lookout Point Dam.

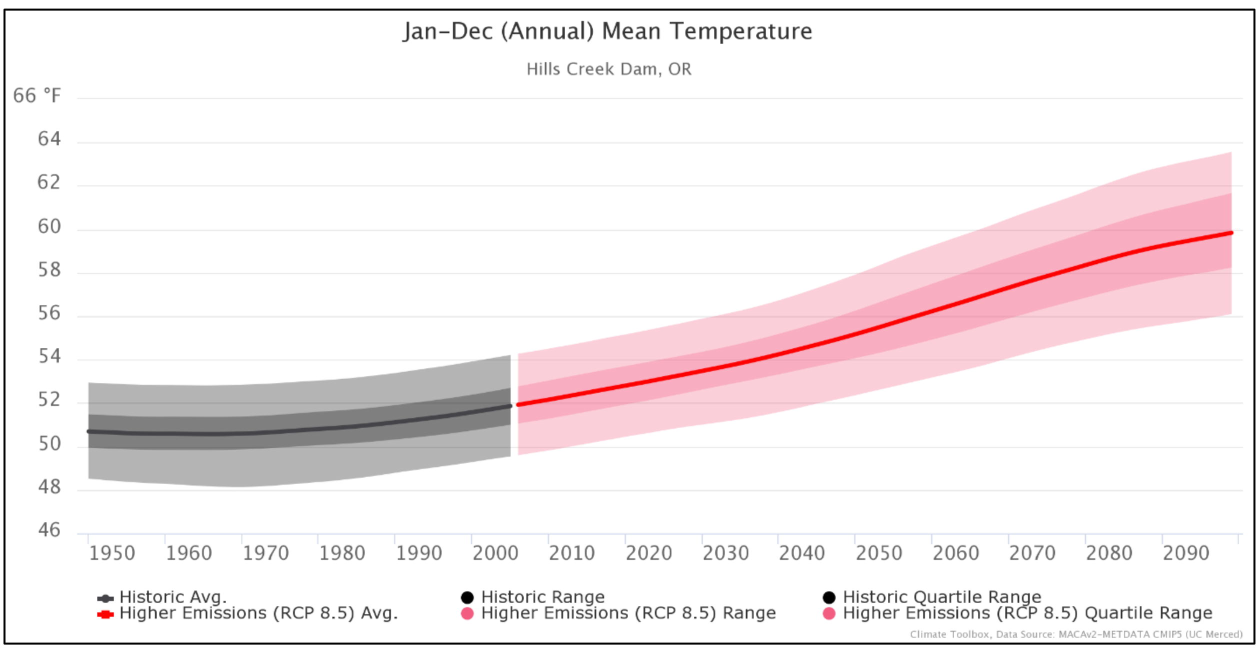

Figure 3-48. Average Annual Temperature Trends at Hills Creek Dam, Oregon, 1950–2100.

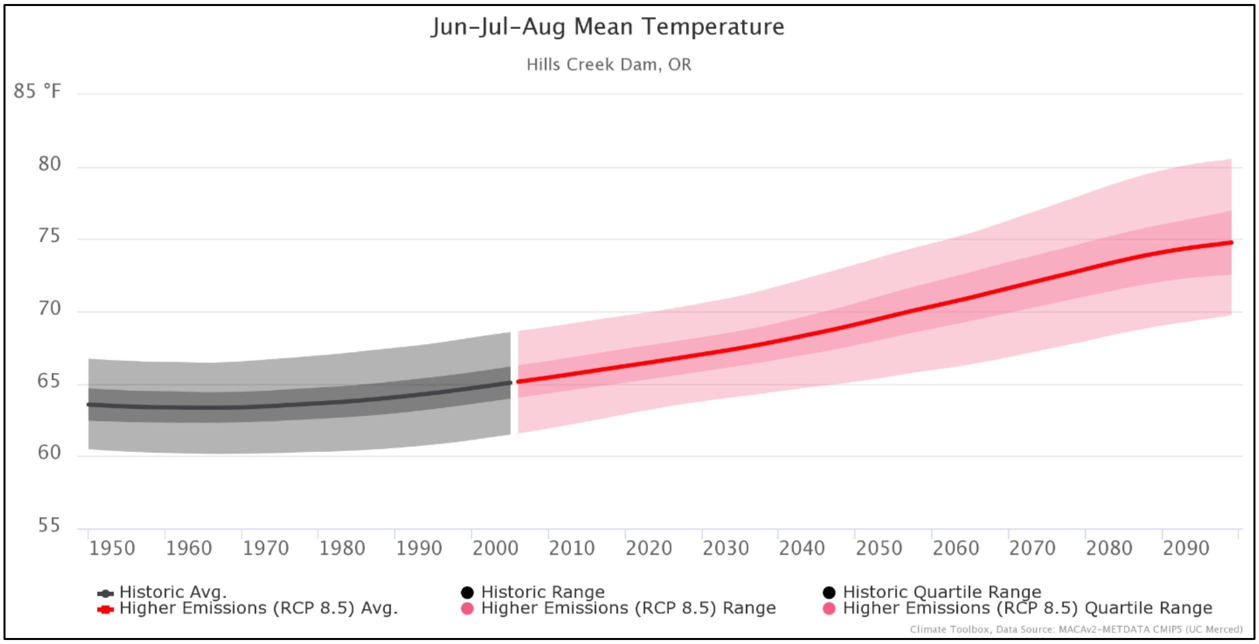

Figure 3-49. Average Annual Summer Temperature Trends at Hills Creek Dam, Oregon, 1950–2100.

For contrast, Lookout Point Dam projected temperatures are presented in Figure 3-50 and Figure 3-51. The trends are very similar between Hills Creek and Lookout Point Dams. However, temperature changes presented herein should not be used quantitatively and only to inform a qualitative determination.

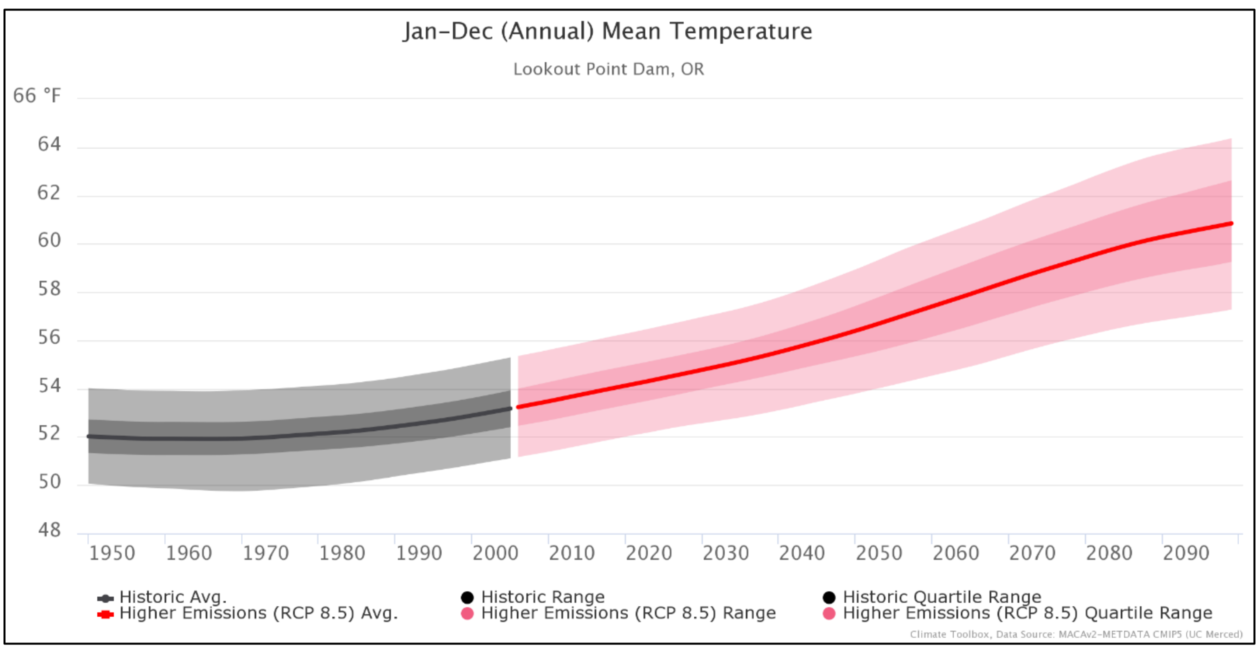

Figure 3-50. Average Annual Temperature Trends at Lookout Point Dam, Oregon, 1950–2100.

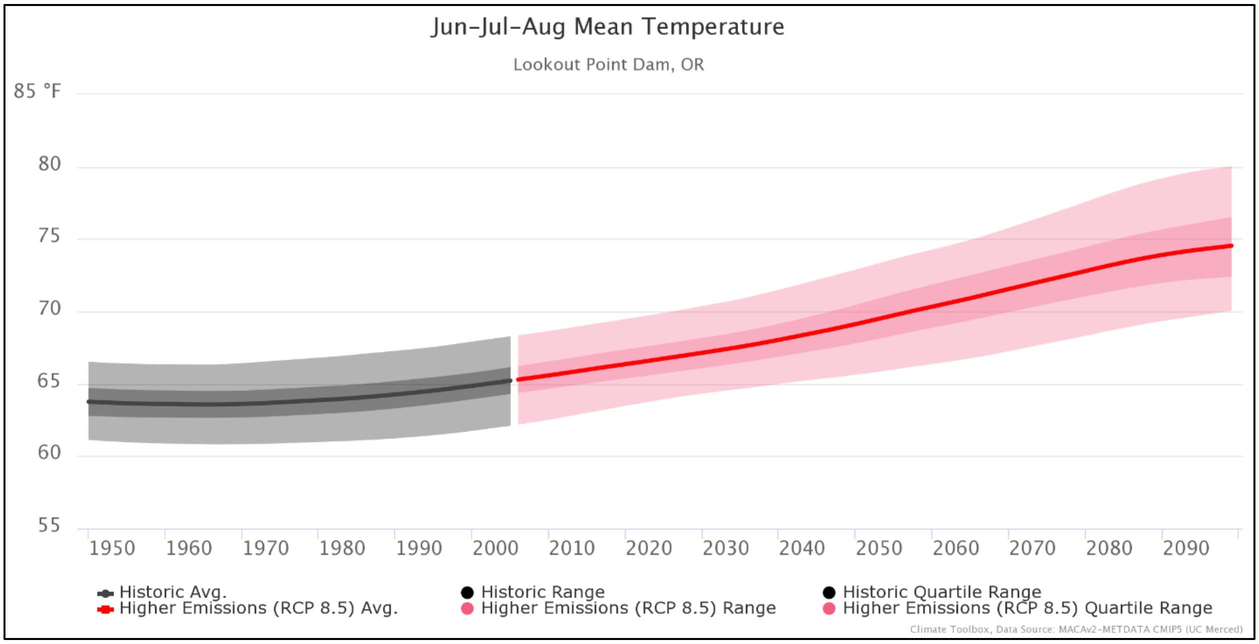

Figure 3-51. Average Annual Summer Temperature Trends at Lookout Point Dam, Oregon, 1950–2100.

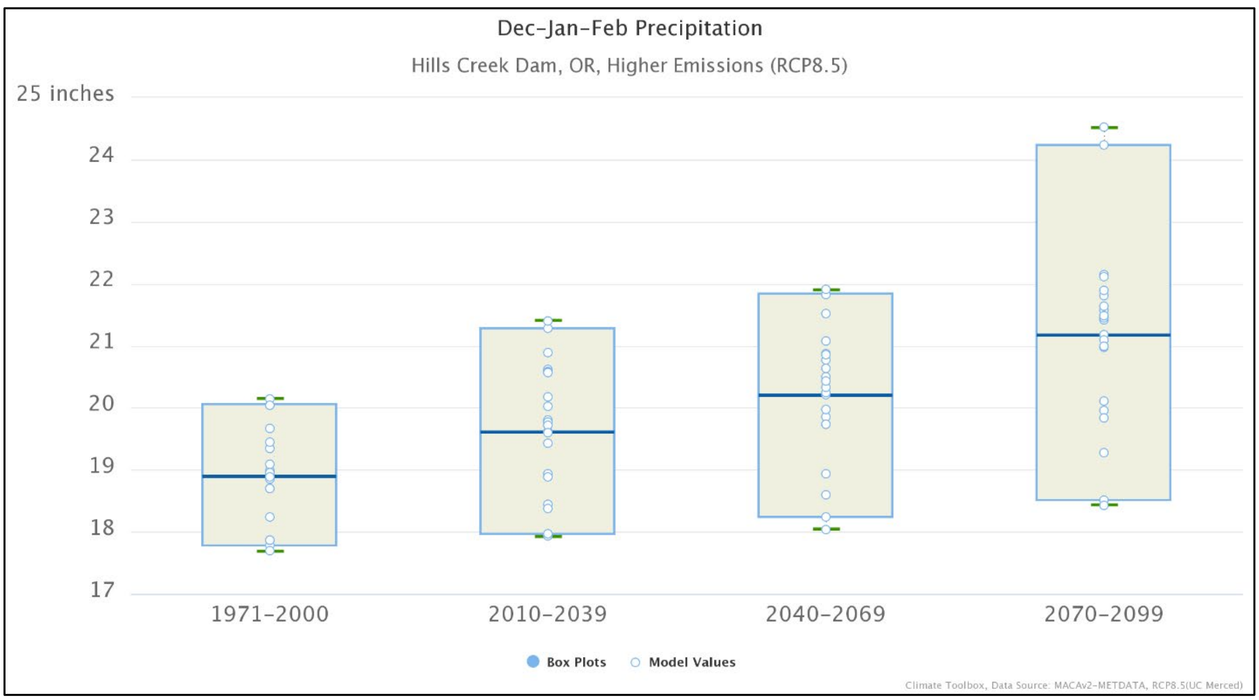

Figure 3-52. Median Winter Precipitation Trends at Hills Creek Dam, Oregon, 1950–2100.
Source: Northwest Climate Toolbox

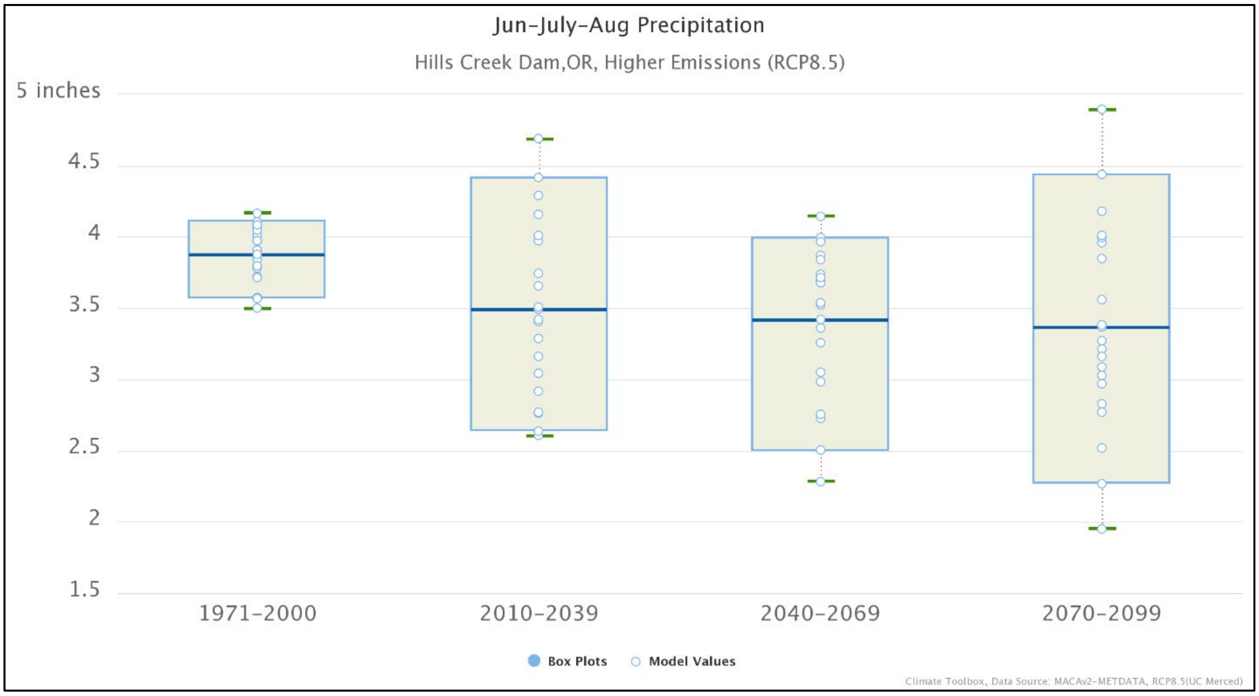

Figure 3-53. Median Summer Precipitation Trends at Hills Creek Dam, Oregon, 1950–2100.

Overall, the MF Willamette River Subbasin projected climate change patterns correspond to the trends projected for the rest of the Willamette River Basin. The summary hydrograph plots 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 winter. As shown below, this has implications for hydro-regulation operations in the future. Even though these are unregulated flows, the relatively higher percentage of change noted above could conceptually complicate the hydro-regulation.

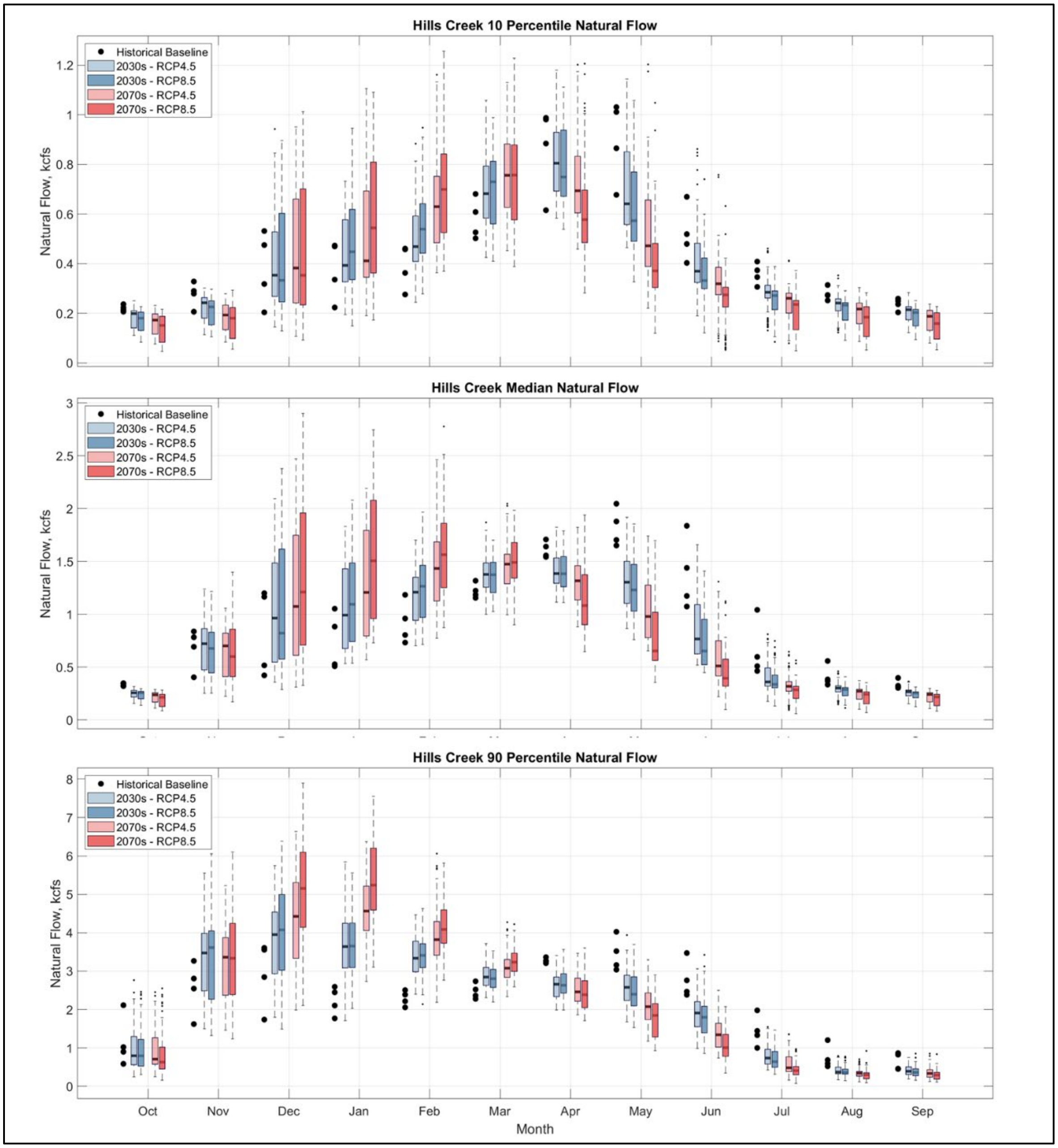

Figure 3-54. MF Willamette River at Hills Creek Dam, Oregon Summary Hydrographs.

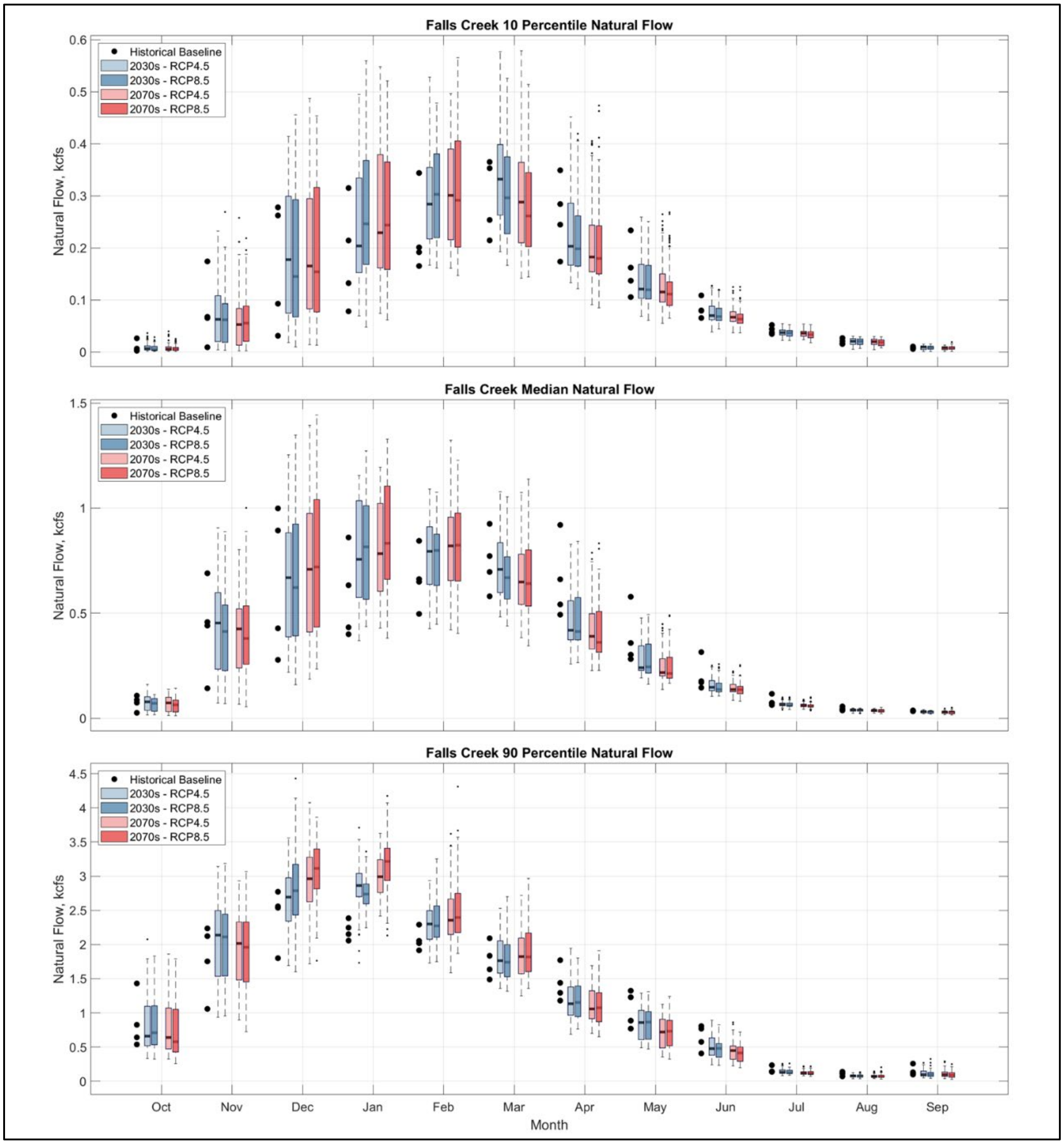

Figure 3-55. Fall Creek Dam, Oregon Summary Hydrographs.

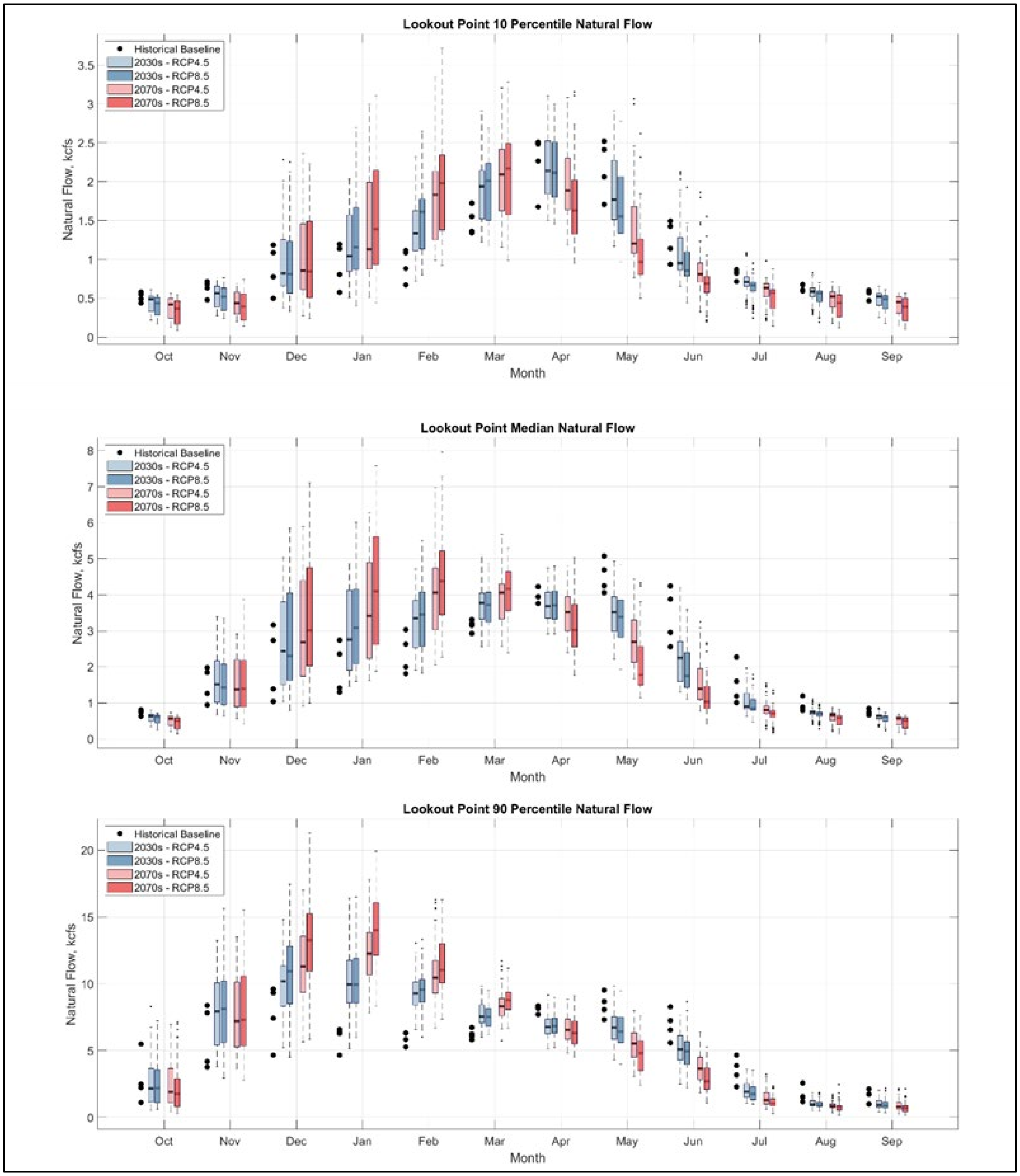

Figure 3-56. MF Willamette River at Lookout Point Dam, Oregon Summary Hydrographs.

Table 3-7 through Table 3-9 summarize the relative change in flows for the 10th, 50th, and 90th percentile flows for Cougar and Blue River Dams, respectively.

Table 3-7. Hills Creek Dam 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. Fall Creek Dam 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. Lookout Point Dam 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

MF Willamette River projections present the same broad hydrologic trends as forecast for the rest of the Willamette Valley subbasins, with an increase in winter high flows (P90) indicated by the November thru March and relative increases in P90 median flows. Projected reduction of SWE will drive the transition to a fully rain-dominated basin. The historical spring pulse in April and May is projected to disappear in the future under both emission scenarios (RCP 4.5/8.5).

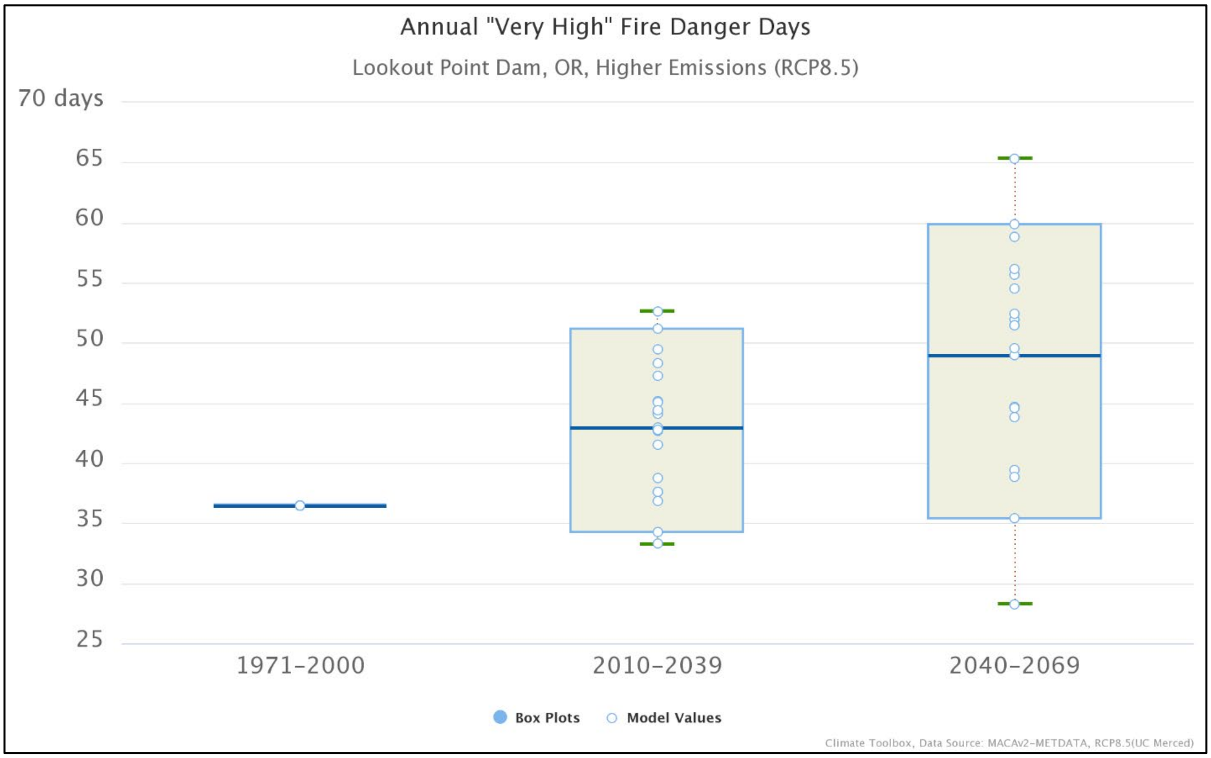

Figure 3-57. Lookout Point Dam, Oregon Annual Very High Fire Danger Days.

Lookout Point Dam is used as the proxy site for changing fire risk in the broader Middle Fork Willamette River Subbasin. It was chosen as the example site due to its central location in the subbasin. Conjecturally, Hills Creek Dam, being the headwater of the subbasin 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 Dam is similar in trending magnitude and variability relative to Lookout Point Dam.

3.2.10 Coast Fork Willamette River Subbasin

The Coast Fork (CF) Willamette River Subbasin is 667 square miles. The subbasin topography is steep, mountainous, and forested. However, the Coast Fork Willamette River Subbasin is at an average elevation of approximately 1,916 feet (NAVD88). The subbasin high point is about 5,950 feet (NAVD88) while the minimum elevation is 439 feet (NAVD88). The subbasin terminates at Creswell, OR.

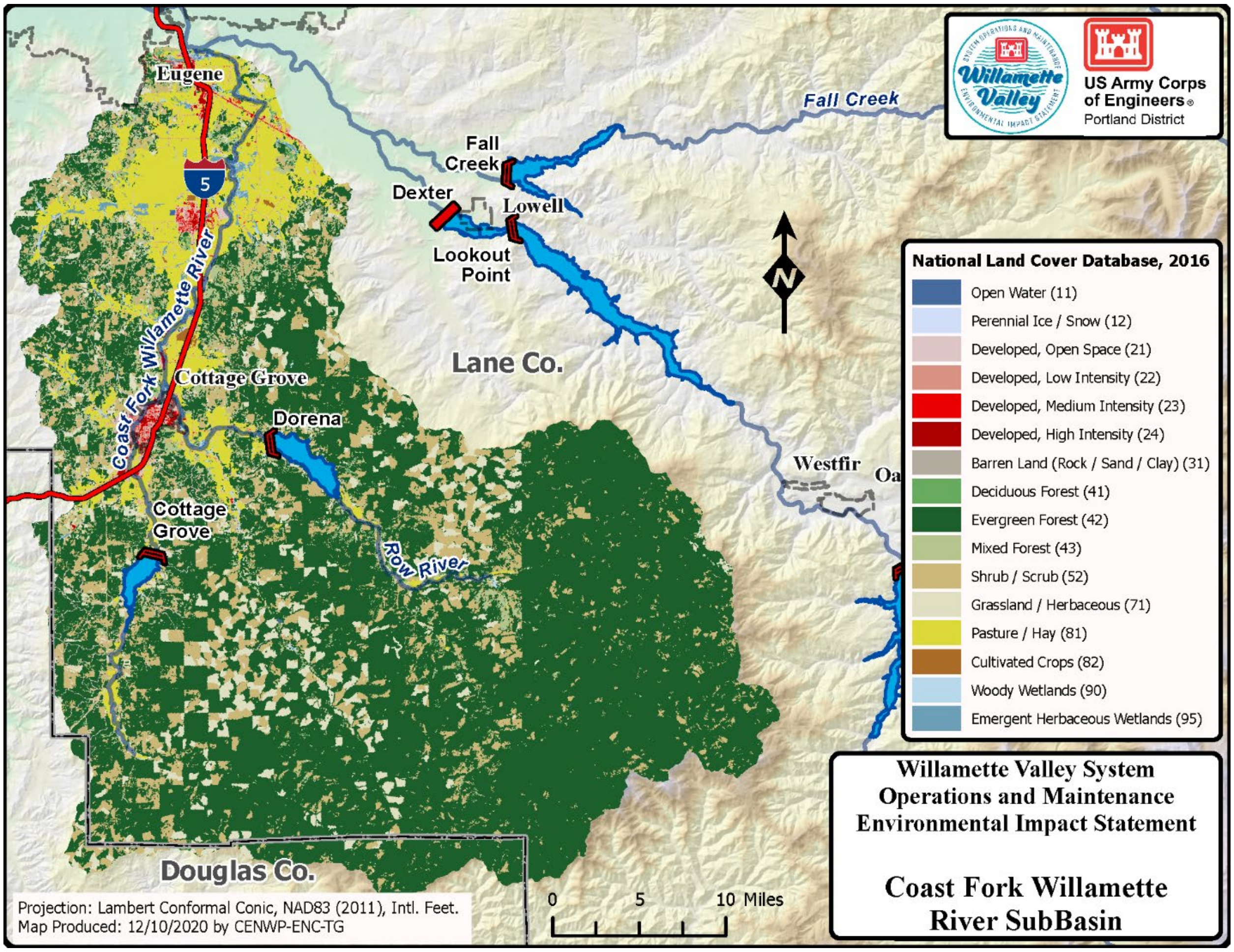

Figure 3-58. Coast Fork Willamette River Subbasin.

Cottage Grove Dam is a multipurpose (headwater) project on the Coast Fork (CF) Willamette River. Dorena Dam is a multipurpose project on the Row River, a tributary to the CF Willamette River. Dorena Dam 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).

Projected hydroclimate changes in temperature and precipitation are comparable to trends expected across the Willamette Valley. Figure 3-59 and Figure 3-60 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 winter and decrease in the summer (Figure 3-61 and Figure 3-62). Normal precipitation in the summer months is already very low.

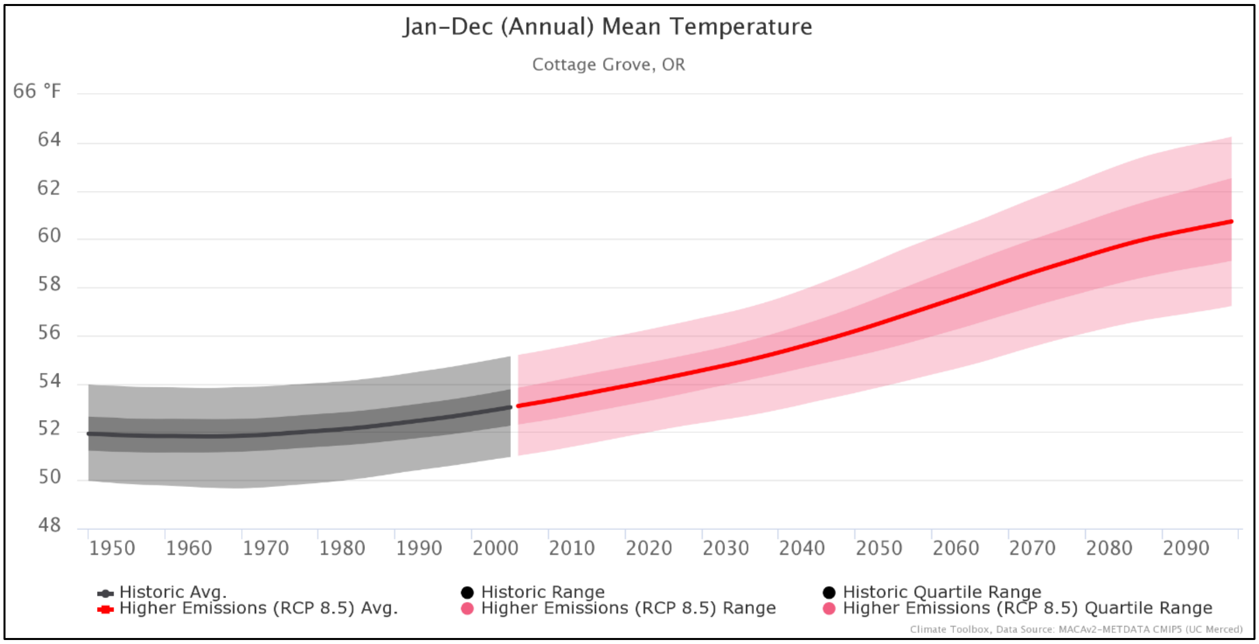

Figure 3-59. Average Annual Temperature Trends at Cottage Grove Dam, Oregon, 1950–2100.

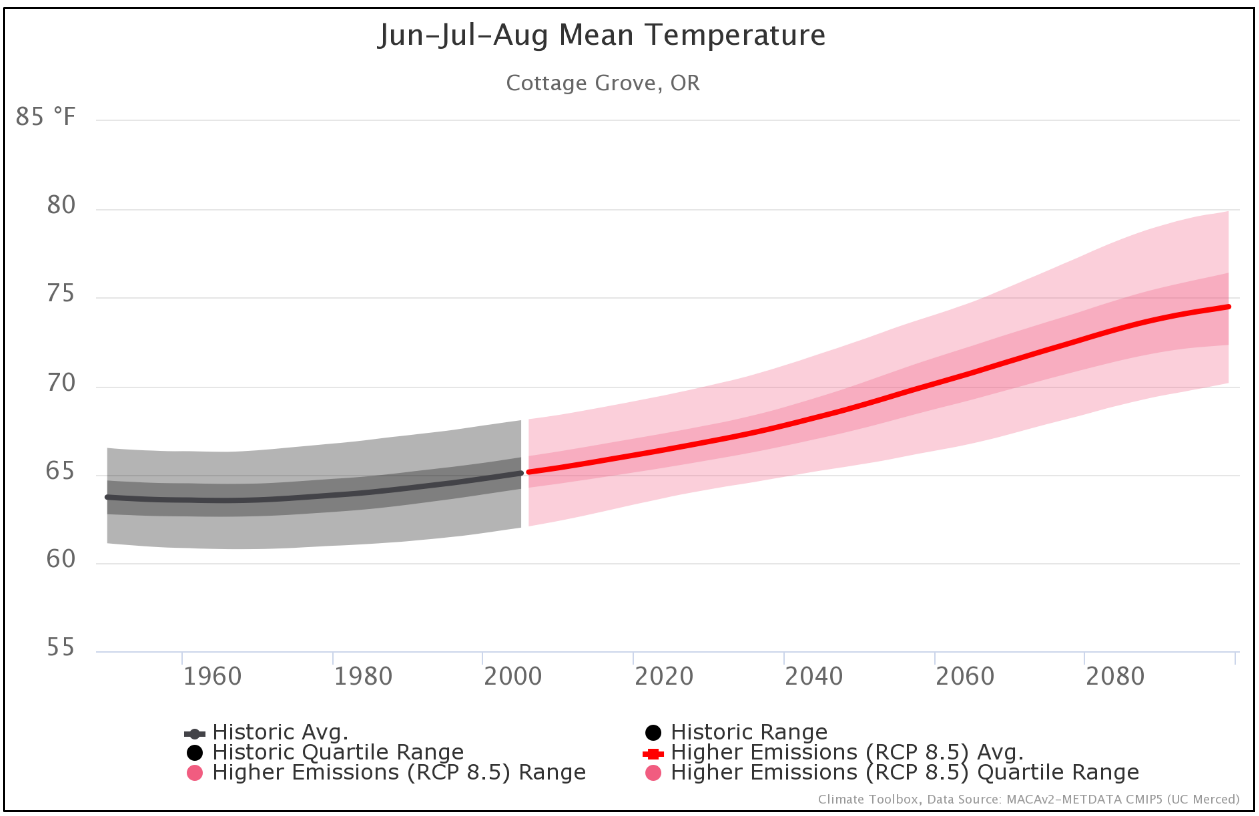

Figure 3-60. Average Annual Summer Temperature Trends at Cottage Grove Dam, Oregon.

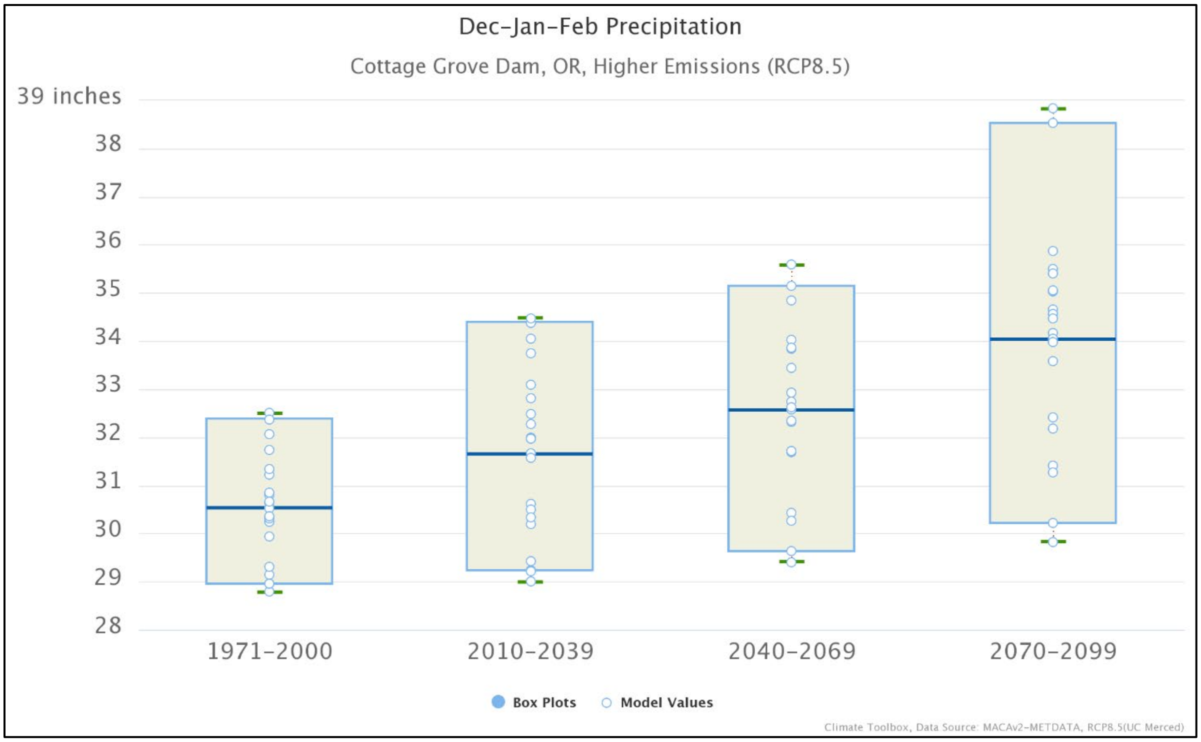

Figure 3-61. Median Winter Precipitation Trends at Cottage Grove Dam, Oregon.

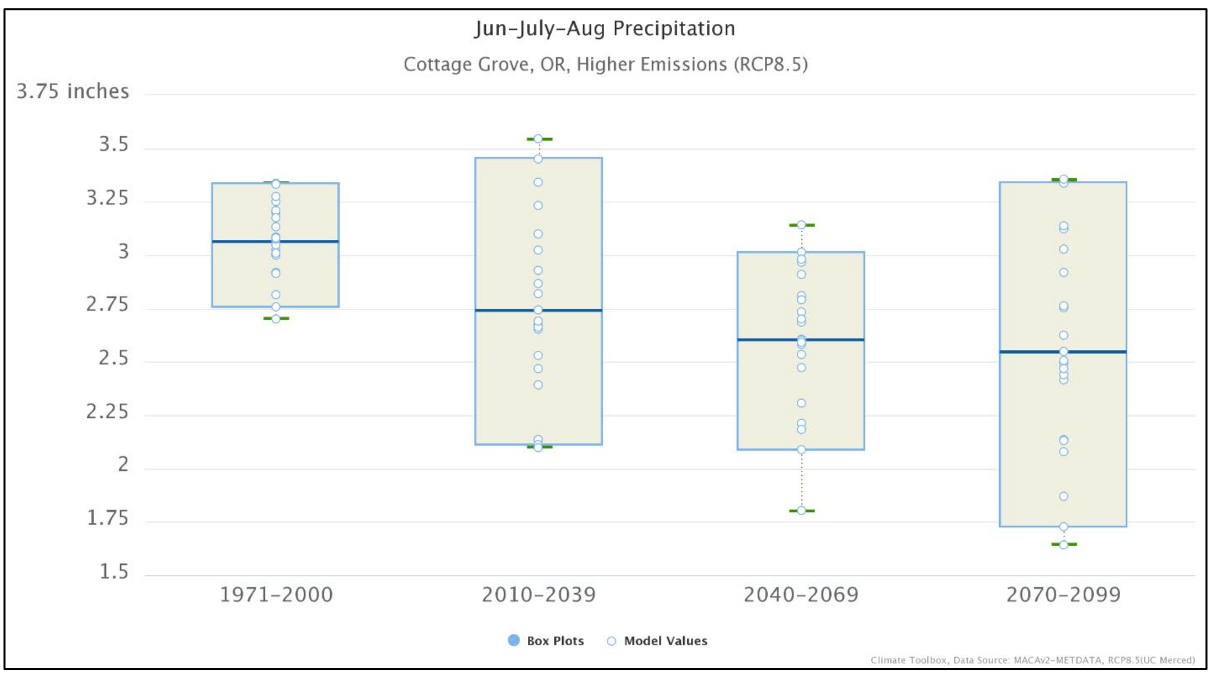

Figure 3-62. Median Summer Precipitation Trends at Cottage Grove Dam, Oregon.

The contributing area to the CF Willamette River at Cottage Grove Dam, OR is a lower elevation rain-dominated basin. Therefore, the projected changes are not as dramatic as shown for other subbasins discussed above. The primary change in future decades is toward greater winter 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 the conservation pool as demand rises and additional variability in the late winter and early spring could complicate refill. Mean Row River streamflows at Dorena Dam 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 winter 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 flood risk management.

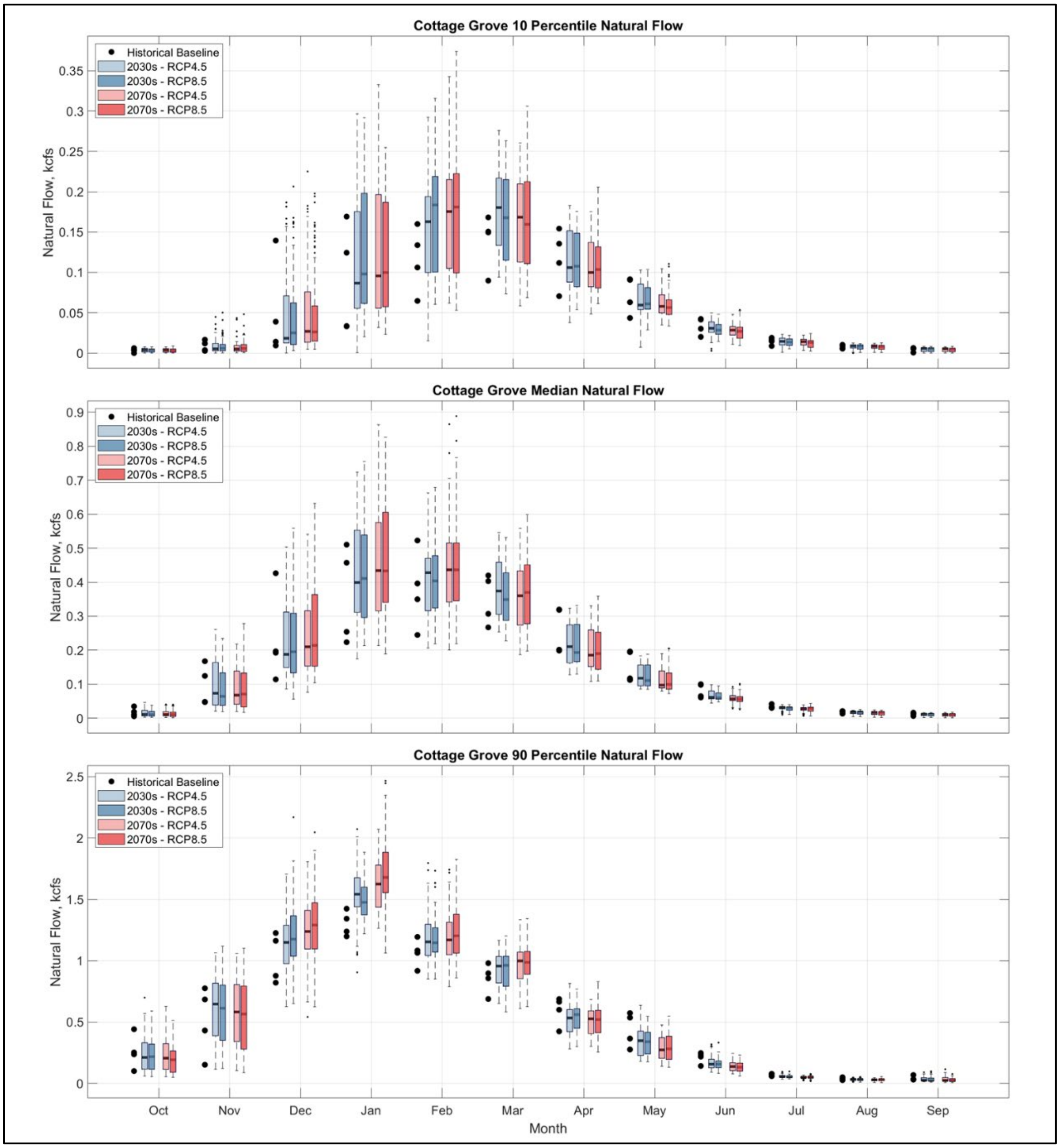

Figure 3-63. Coast Fork Willamette River at Cottage Grove Dam, Oregon Summary Hydrographs.

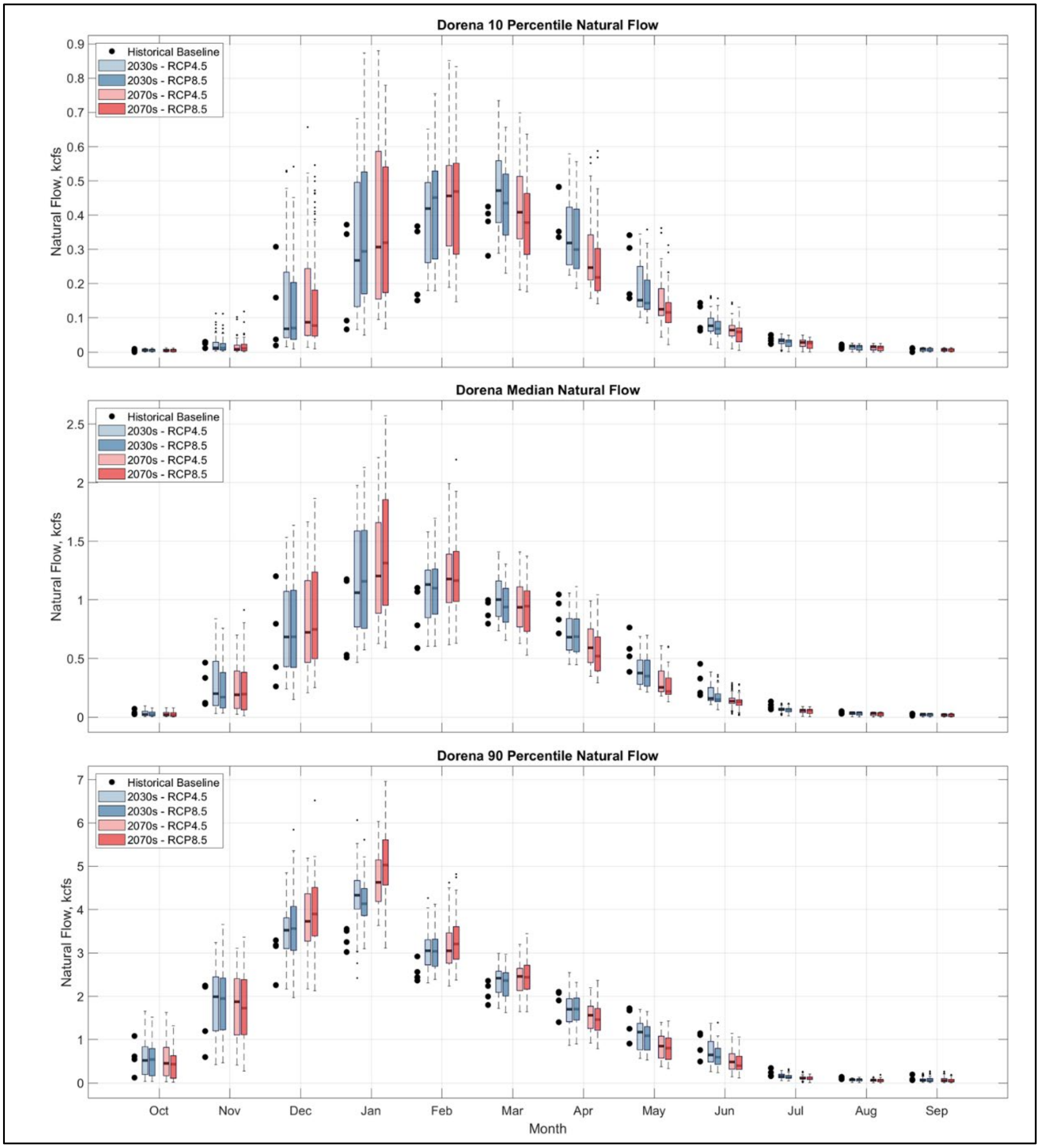

Figure 3-64. Row River at Dorena Dam, Oregon Summary Hydrographs.

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

Table 3-10. Cottage Grove Dam 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. Dorena Dam 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

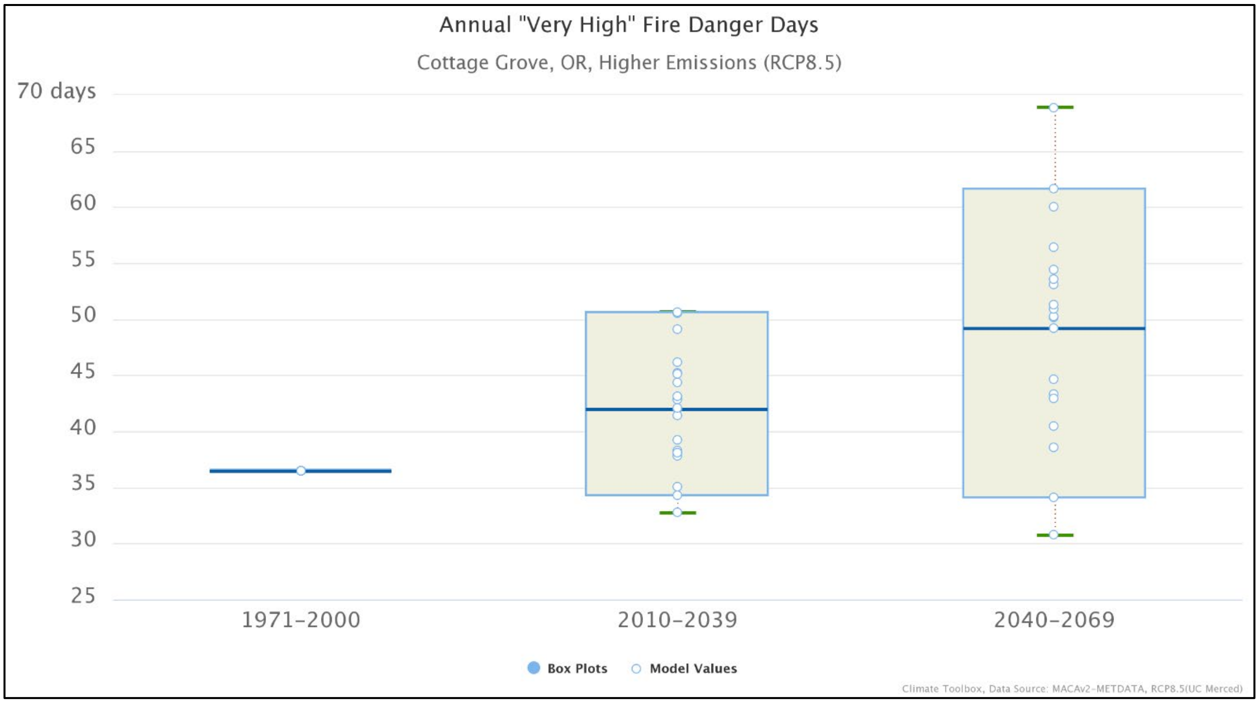

Figure 3-65. Dorena Dam, Oregon Annual Very High Fire Danger Days.

Fire risk at Dorena Dam is representative for the Coast Fork Willamette River Subbasin. The overall trends are the same as for the rest of the subbasins in the Willamette Valley.

3.2.11 Long Tom River Subbasin

The Long Tom River Subbasin is the smallest described subbasin at 392 square miles. The subbasin's topography is milder compared to the others as well. Average elevation is approximately 636 feet (NAVD88), the high point is about 2,095 feet (NAVD88), and the minimum elevation is 275 feet (NAVD88). The subbasin terminates at approximately Monroe, OR. The primary USACE project is Fern Ridge Dam.

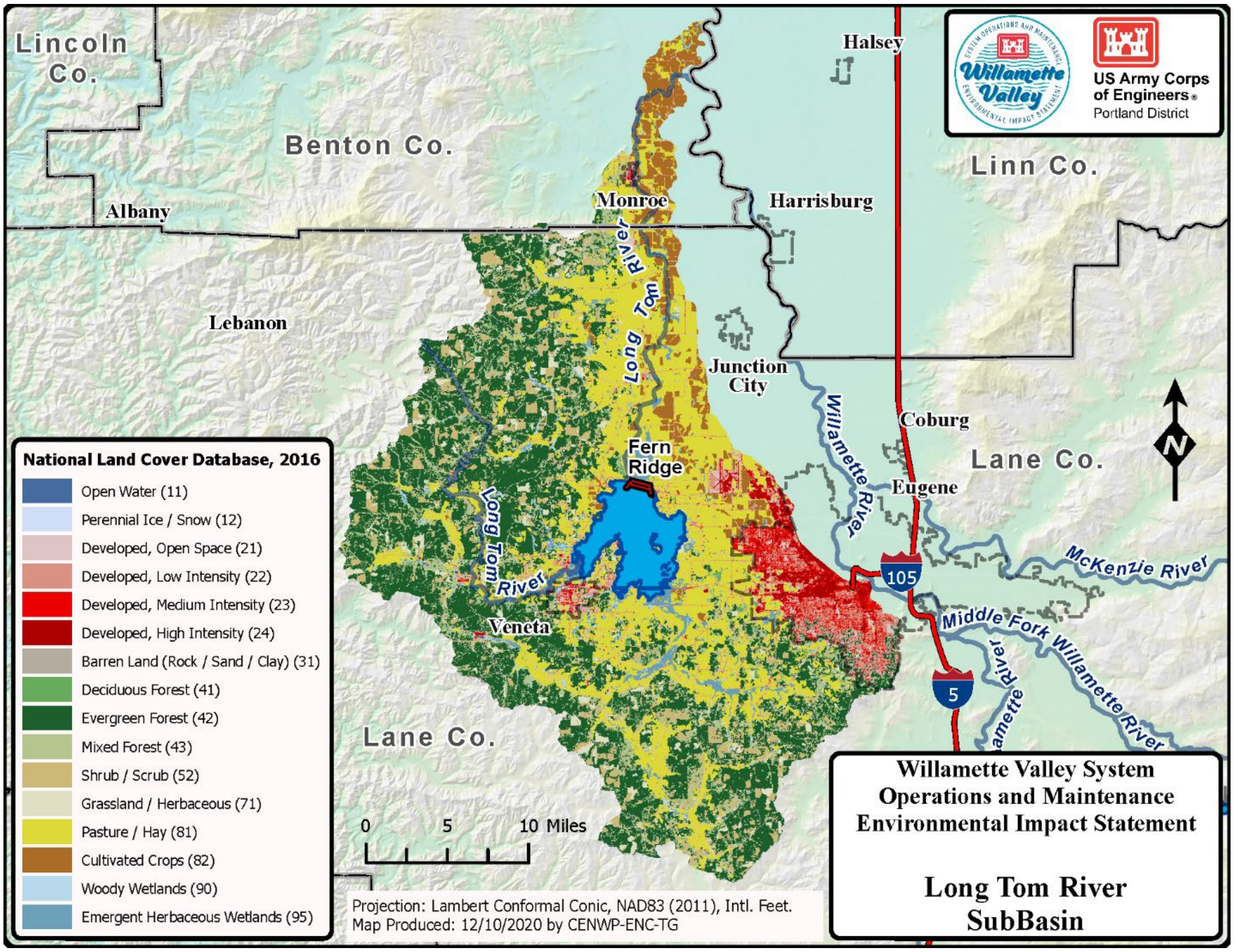

Figure 3-66. Long Tom River Subbasin.

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 multiple purposes, including flood risk management, recreation, irrigation, municipal and industrial water supply, and water quality. This subbasin, like the Coast Fork Willamette River Subbasin, has 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.

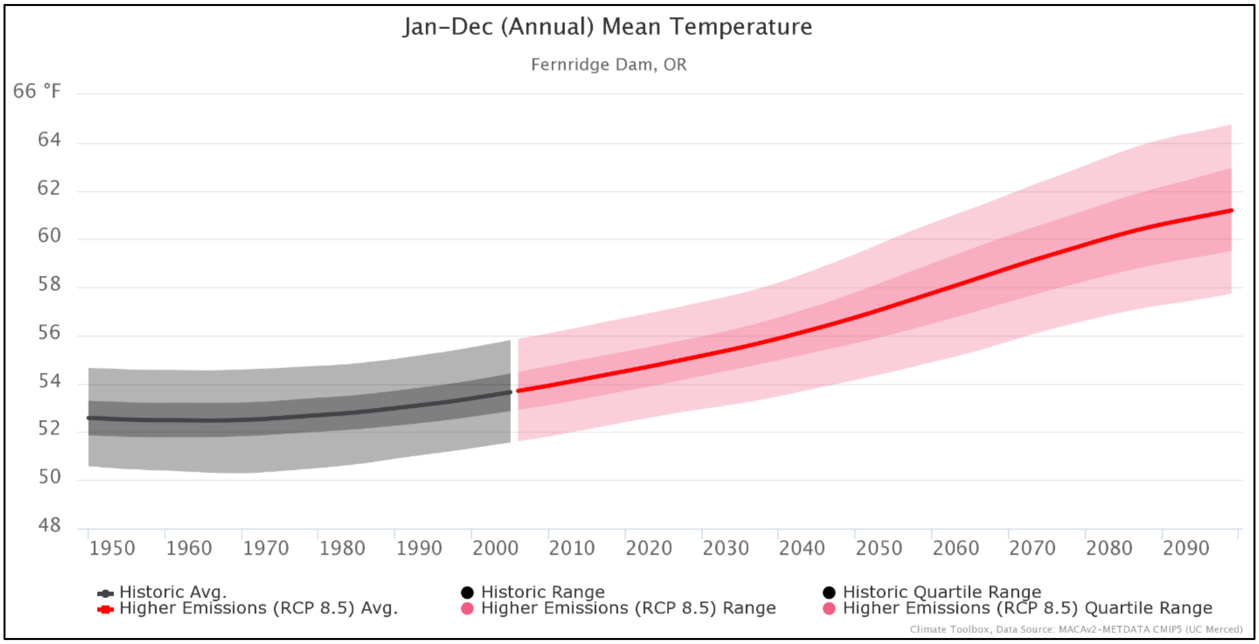

Figure 3-67. Average Annual Temperature Trends at Fern Ridge Dam, Oregon.

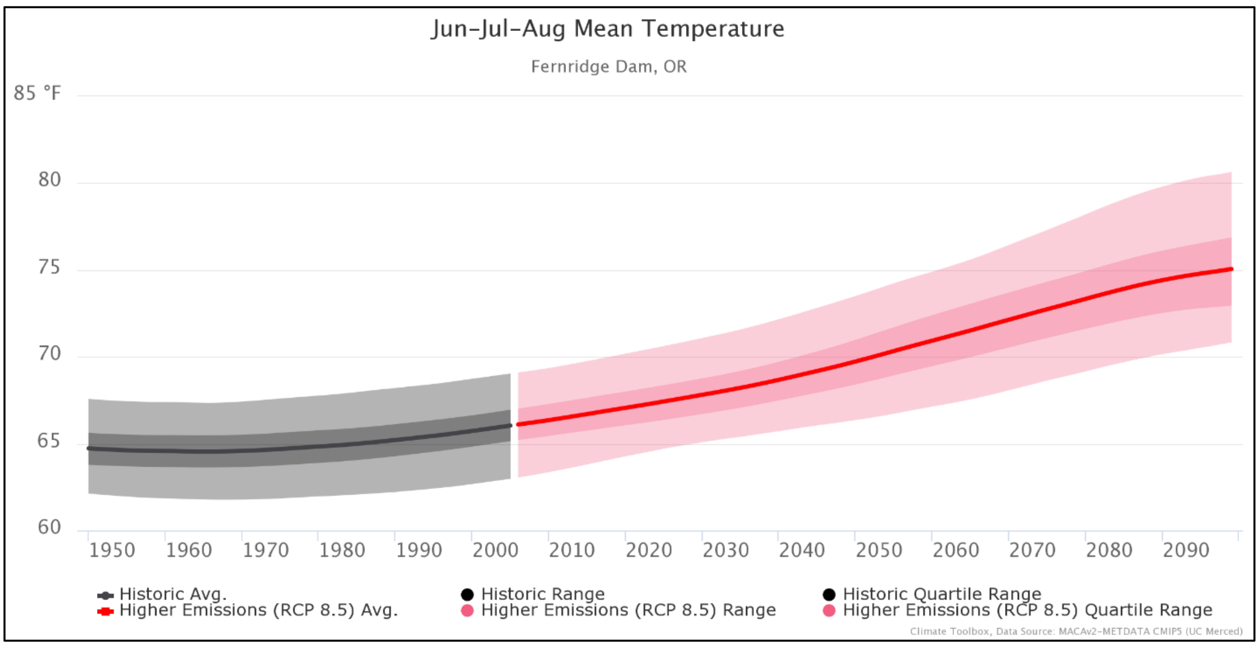

Figure 3-68. Average Annual Summer Temperature Trends at Fern Ridge Dam, Oregon.

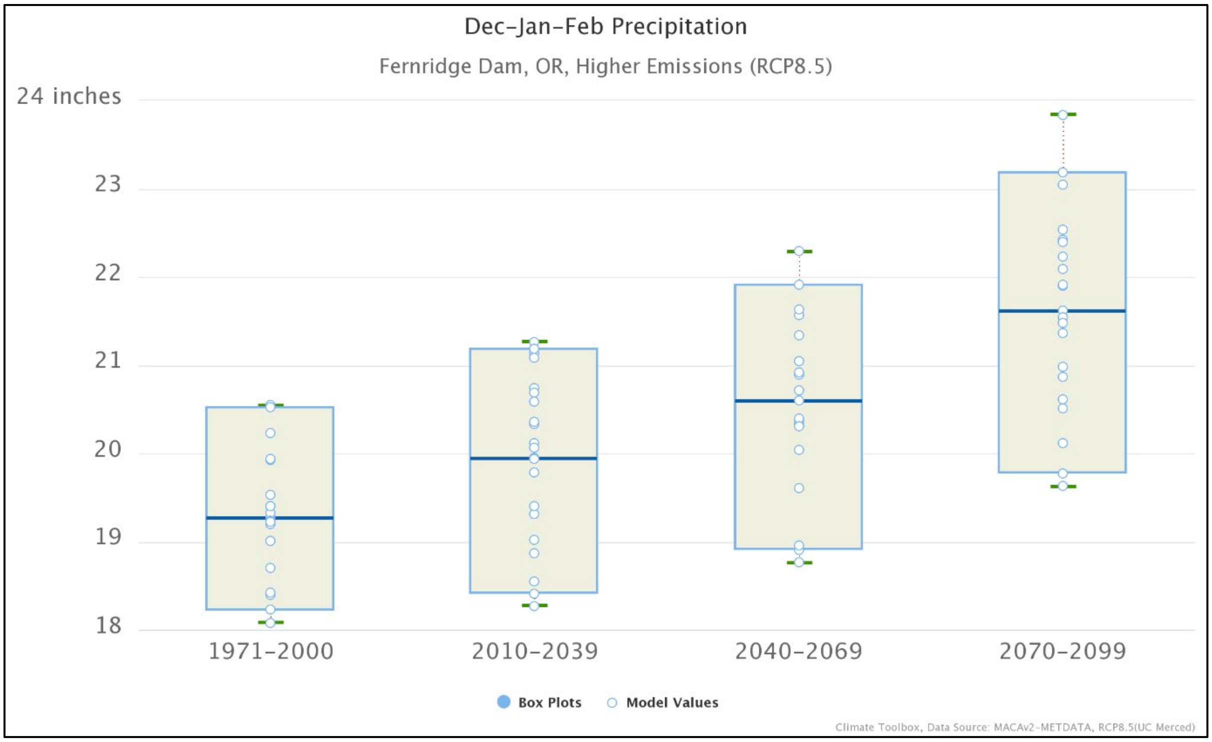

Figure 3-69. Median Winter Precipitation Trends at Fern Ridge Dam, Oregon.

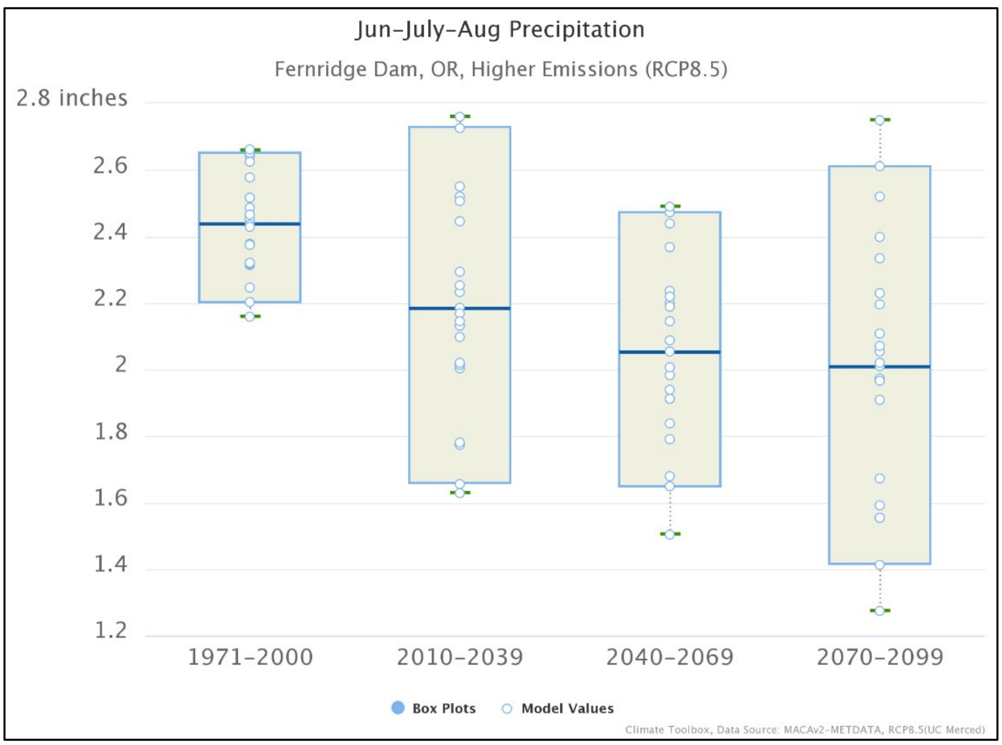

Figure 3-70. Median Summer Precipitation Trends at Fern Ridge Dam, Oregon.

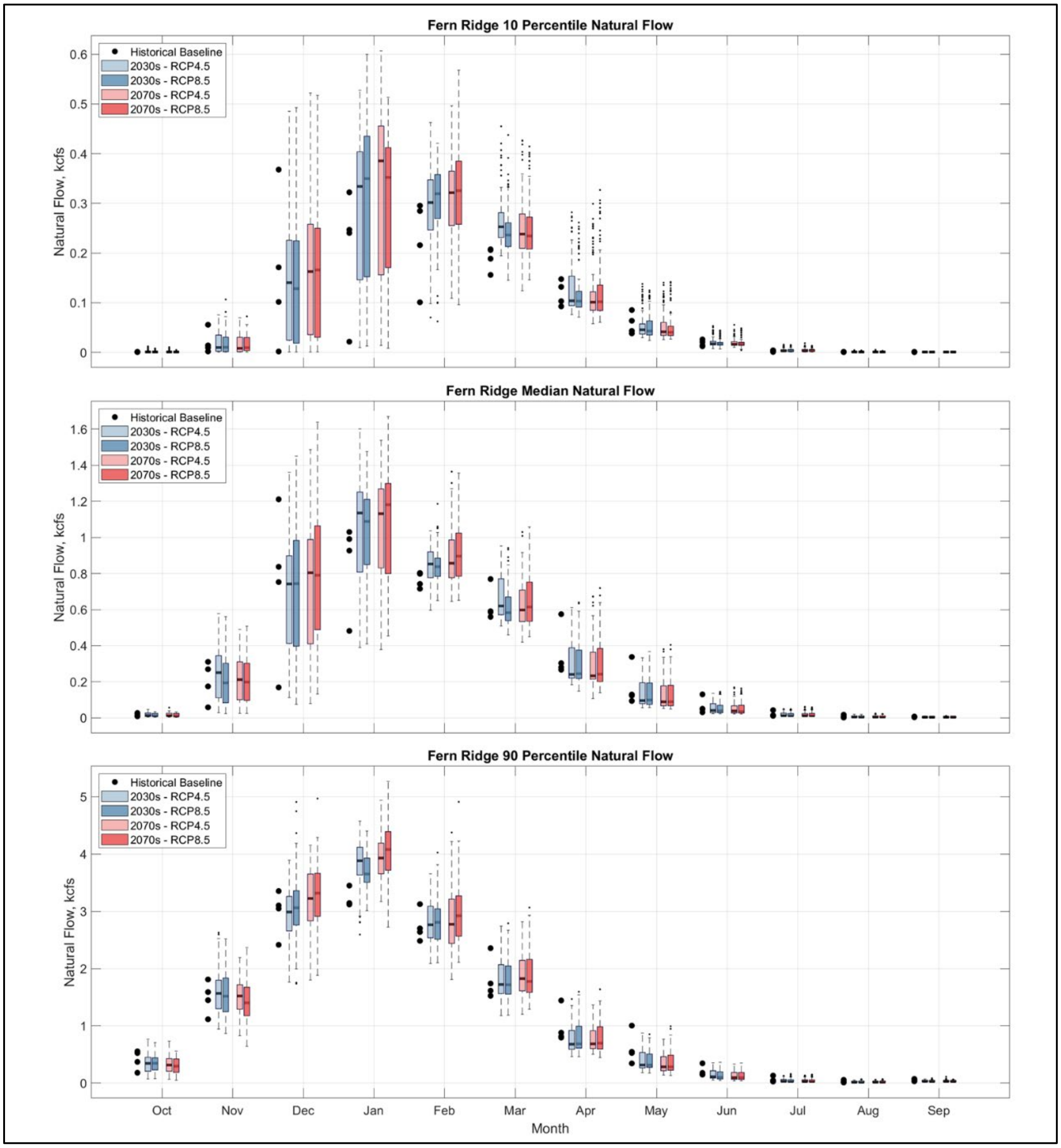

Figure 3-71. Long Tom River at Fern Ridge Dam, Oregon Summary Hydrographs.

Table 3-12. Fern Ridge Dam 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 3-71 and corresponding Table 3-12, Long Tom River 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.

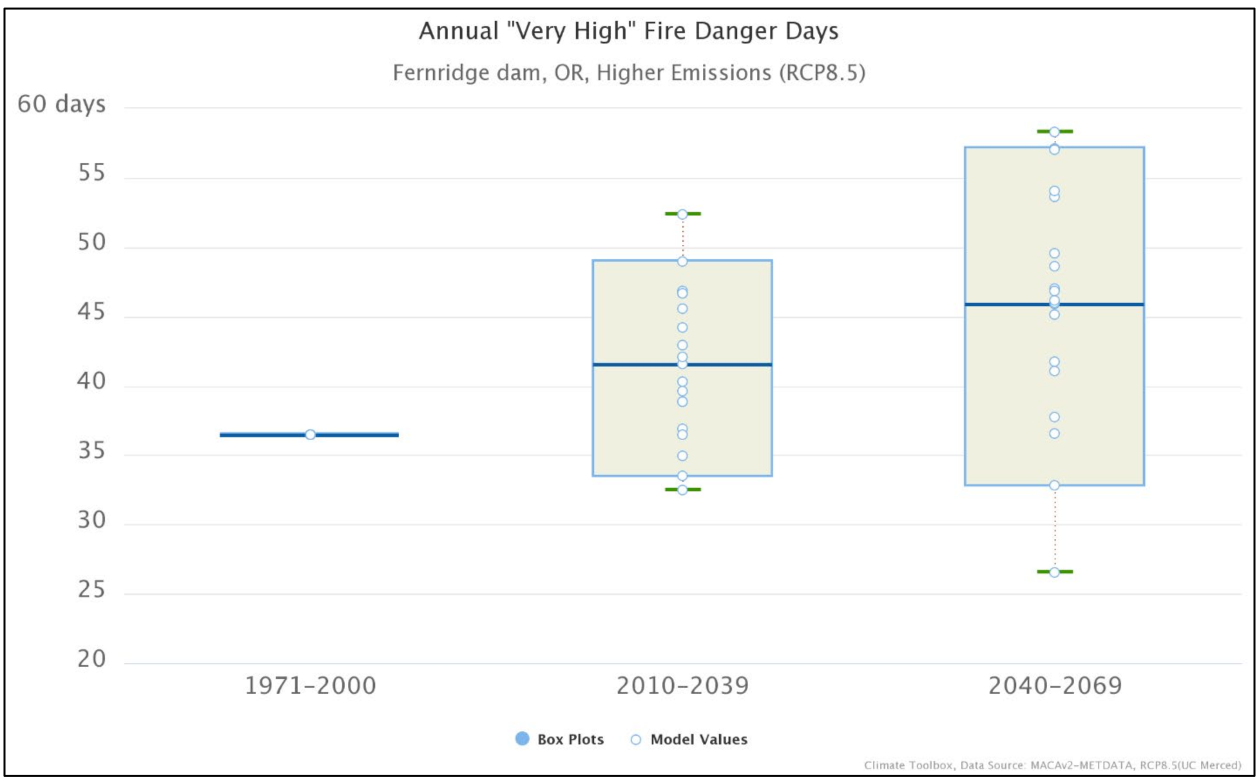

Figure 3-72. Fern Ridge Dam, Oregon Annual Very High Fire Danger Days.
Source: climatetoolbox.org, 2021.

Fire risk in the Long Tom River Subbasin at Fern Ridge Dam, OR is reflective of the similar fire risk in the Upper Willamette River Subbasin 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 River Subbasins, for example. The overall trend is toward higher fire risk in the future.

4. REFERENCES

Abatzoglou, J., D. Rupp, L. O'Neill, and M. Sadegh. 2021. Compound extremes drive the Western Oregon Wildfires of September 2020. Geophysical Research Letters. Volume 48(8). Report #: ARTN e2021GL092520. Retrieved from https://escholarship.org/uc/item/8k03m5mp. http://dx.doi.org/10.1029/2021GL092520

Alden Research Laboratory, Inc. 2021. Alden Research Laboratory, Inc., McKenzie and Santiam Post-wildfire Hydrology and Hydraulics, Draft Literature Review, W9127N-18-D-0002, Task Order No. W9127N21F0199. December 2021.

Bradley, B. A., M. Oppenheimer, and D. S. Wilcove. 2009. Climate change and plant invasions: restoration opportunities ahead? Global Change Biology. Volume 15, pages 1511–1521.

Brummer, T. J., K. T. Taylor, J. Rotella, B. D. Maxwell, L. J. Rew, and M. Lavin. 2016. Drivers of *Bromus tectorum* abundance in the western North American sagebrush steppe. Ecosystems. Volume 19, pages 986–1000.

Chapman, D. S., T. Haynes, S. Beal, F. Essl, and J. M. Bullock. 2014. Phenology predicts the native and invasive range limits of common ragweed. Global Change Biology. Volume 20, pages 192–202.

Climate Impacts Research Consortium (CIRC). 2019. Mooney, A., N. Gilles, K. Hegewisch, J. Abatzoglou, and M. Dalton, presenters. "The Northwest Climate Toolbox Workbook: Discovering and applying your climate data story for climate adaptation planning," Corvallis, Oregon: The Pacific Northwest Climate Impacts Research Consortium (CIRC), College of Earth, Ocean, and Atmospheric Sciences, Oregon State University.

CIRC. 2020. The Climate Toolbox. By the Pacific Northwest Climate Impacts Research Consortium (CIRC), College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, 2019. Website: https://climatetoolbox.org/. Last accessed: September 2020.

Gervais, J.A., R. Kovach, A. Sepulveda, R. K. Al-Chokhachy, J. J. Giersch, and C. C. Muhlfeld. 2020. Climate-induced expansions of invasive species in the Pacific Northwest, North America: a synthesis of observations and projections. Biological Invasions. Volume 22, pages 2163–2183. https://doi.org/10.1007/s10530-020-02244-2

Hegewisch, K.C., V. Laquindanum, E. Fleishman, H. Hartmann, M. and Mills-Novoa 2022. Climate Toolbox Tool Summary series. Accessed: 2022

Intergovernmental Panel on Climate Change (IPCC). 2022a. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/. Last accessed: 2022.

IPCC. 2022b. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar5/wg1/aism-annex-i-atlas-of-global-and-regional-climate-projections-supplementary-material-rcp8-5/. Last accessed: 2022.

McDonald, A., S. Riha, A. DiTommaso, and A. DeGaetano. 2009. Climate change and the geography of weed damage: analysis of US maize systems suggests the potential for significant range transformations. Agriculture, Ecosystems and Environment. Volume 130, pages 131–140. https://doi.org/10.1016/j.agee.2008.12.007

National Oceanic and Atmospheric Administration (NOAA). 2021. May 4, 2021, National Oceanic and Atmospheric Administration, NOAA Delivers New U.S. Climate Normals. https://www.ncei.noaa.gov/news/noaa-delivers-new-us-climate-normals.

Oregon Climate Change Research Institute (OCCRI). 2015. Revised March 2016. Prepared for U.S. Army Corps of Engineers by Oregon Climate Change Research Institute. Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins.

OCCRI. 2023. Sixth Oregon Climate Assessment. E. Fleishman, editor. Oregon Climate Change Research Institute, Oregon State University, Corvallis, Oregon. https://blogs.oregonstate.edu/occri/oregon-climate-assessments.

River Management Joint Operating Committee (RMJOC). 2018. Climate and Hydrology Datasets for RMJOC Long-Term Planning Studies: Second Edition (RMJOC-II), Part I: Hydroclimate Projections and Analyses. https://usace.contentdm.oclc.org/utils/getfile/collection/p266001coll1/id/10562

RMJOC. 2020. Climate and Hydrology Datasets for RMJOC Long-Term Planning Studies: Second Edition (RMJOC-II), Part II: Columbia River Reservoir Regulation and Operations—Modeling and Analyses. https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/9936/rec/1.

U.S. Army Corps of Engineers (USACE). 1997. U.S. Army Corps of Engineers. Portland District. Hydrologic, Coastal, and River Engineering Center. February 1996 Postflood Report: Hydrometeorological Evaluation, USACE, Portland, OR.

USACE. 2012. U.S. Army Corps of Engineers. Portland District. November 2012. Willamette River Basin Operational Measures Evaluation Report.

USACE. 2013. U.S. Army Corps of Engineers. July 2013. Sustainable Rivers Project, Evaluation of E-Flow Implementation and Effects in the Willamette Basin using ResSim Modeling.

USACE. 2016. U.S. Army Corps of Engineers. Portland District. July 2016. Willamette Basin Extreme Storms Report.

USACE. 2019. U.S. Army Corps of Engineers. December 2019. Willamette Basin Review Feasibility, Integrated Feasibility Report and Environmental Assessment.

USACE. 2020. U.S. Army Corps of Engineers. Climate Preparedness and Resilience CoP Applications Portal. https://maps.crrel.usace.army.mil/projects/rcc/portal. Last accessed September 2020.

USACE. 2020. U.S. Army Corps of Engineers. https://www.nwp.usace.army.mil/Locations/Willamette-Valley/. Last accessed September 2020.

USACE. 2019. U.S. Army Corps of Engineers. December 2019. Willamette Basin Year in Review January 1 – December 31, 2019.

U.S. Army Corps of Engineers (USACE), Bureau of Reclamation, and Bonneville Power Administration. 2020. Columbia River System Operations (CRSO) Environmental Impact Statement. https://www.nwd.usace.army.mil/CRSO/Final-EIS/.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I. D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock, eds. U.S. Global Change Research Program, Washington, D.C. Accessed at doi:10.7930/J0J964J6.

USGCRP. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller, D. R., C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pages. doi: 10.7930/NCA4.2018.