US Army Corps
of Engineers ®
Walla Walla District

SWEETWATER CREEK ECOSYSTEM RESTORATION

Feasibility Report with
Integrated Environmental Assessment

Appendix I

Climate Change Assessment

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List of Acronyms

Acronym	Description
BPA	Bonneville Power Administration
cfs	Cubic feet per second
CHAT	USACE Climate Hydrology Assessment Tool
ESA	Endangered Species Act
EYR	Equivalent Years of Record
GCM	Global Climate Models
HUC	Hydrologic Unit Code
IQR	Inner Quartile Range (25th to 75th percentiles of a distribution)
LOID	Lewiston Orchards Irrigation District
LOP	USBR Lewiston Orchards Project
LSC	Lower Sweetwater Creek (below RM 4.0)
NMFS	National Marine Fisheries Service
PNW	Pacific Northwest
RCP	Representative Concentration Pathway
RMJOC	River Management Joint Operating Committee (BPA, USACE, USBR)
SOL	Soldiers Meadow Reservoir
SWaM	Sweetwater Creek at Mouth. (*Coincides with USGS#13342340*)
SWE	Snow Water Equivalent
Q	Shorthand for hydraulic flow in units of volume per time
TPP	Tribal Partnership Program
TST	USACE Time Series Toolbox
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USGS	US Geological Survey
VIC	Variable Infiltration Capacity

1 Introduction

An assessment of potential climate change vulnerability was completed for the USACE Tribal Partnership Program (TPP) Section 203 Sweetwater Creek Ecosystem Restoration Project basin and region. This assessment was performed to highlight existing and future challenges and risks facing the project due to past and future climatic changes, in accordance with the guidance in Engineering Construction Bulletin (ECB) 2018-14, *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects*, (revised 19 August 2022). As detailed in the main report, this feasibility study (funded under TPP§203) is intended to evaluate and identify a proposed preferred action that will restore the ecological potential of Sweetwater Creek for Endangered Species Act-listed steelhead and culturally significant and Coho salmon by providing complex and suitable instream habitat, restoring culturally significant native riparian plant communities, and establishing sustainable river and floodplain morphology and function.

1.1 Study Background

The project area is located within the lower four miles of Sweetwater Creek (HUC 170603061205), a fifth order stream located in western Idaho with a drainage area of approximately 78 square miles. Despite being located within west-central Idaho, the physiography of Sweetwater Creek is much more similar to the inland Columbia River basin of eastern Washington and is notably distinct from both the Idaho Batholith and Northern Rockies ecoregions to the east (Figure 1-1). Fed by the Craig Mountains between Lewiston and Grangeville Idaho, Sweetwater Creek flows nearly eighteen miles from headwaters at 4,800 feet in the Canyons and Dissected Highlands portion of the Blue Mountains Ecoregion (11f) through the Dissected Loess Uplands of the Columbia Plateau Ecoregion (10f) to the confluence with Lapwai Creek (HUC 1706030612) at 1,100 feet mean sea level.

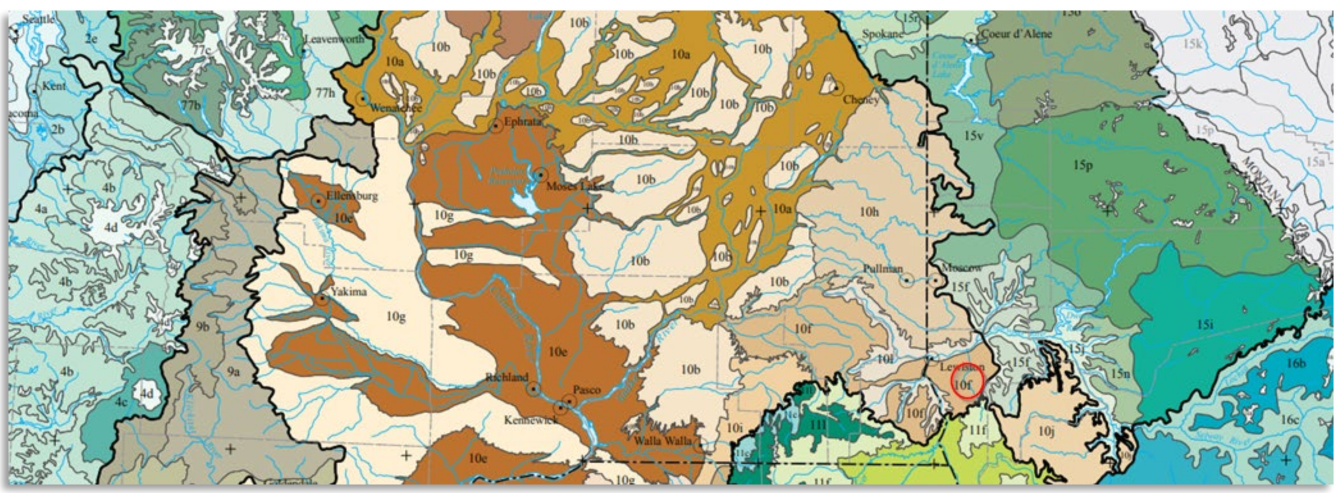


Figure 1-1. Project vicinity and regional ecoregions. (EPA 2016). *Note the Lower Sweetwater Creek watershed is located within unit 10f east of Lewiston, Idaho and highlighted in red.*

The Canyons and Dissected Highlands of the Blue Mountains are volcanic in origin, comprising portions of uplifted Columbia Plateau, and characterized by steep canyon streams draining elevations from 4,000 to over 6,000 feet elevation, relatively dry, though still primarily a snow-driven seasonal maritime climate, and dominated by Douglas fir and ponderosa pine forests. As this region transitions to the Dissected Loess Uplands, the climate is drier, with unforested plateaus also cut by steeper canyon streams cutting through deep loess soils, dominated by agricultural uses due to relatively flat slopes and support of grassland agronomy, though the soils are thinner than in other portions of the Columbia Plateau. Locations with perennial streams can be particularly productive, though many smaller streams are intermittent where connected to groundwater between precipitation or snowmelt events.

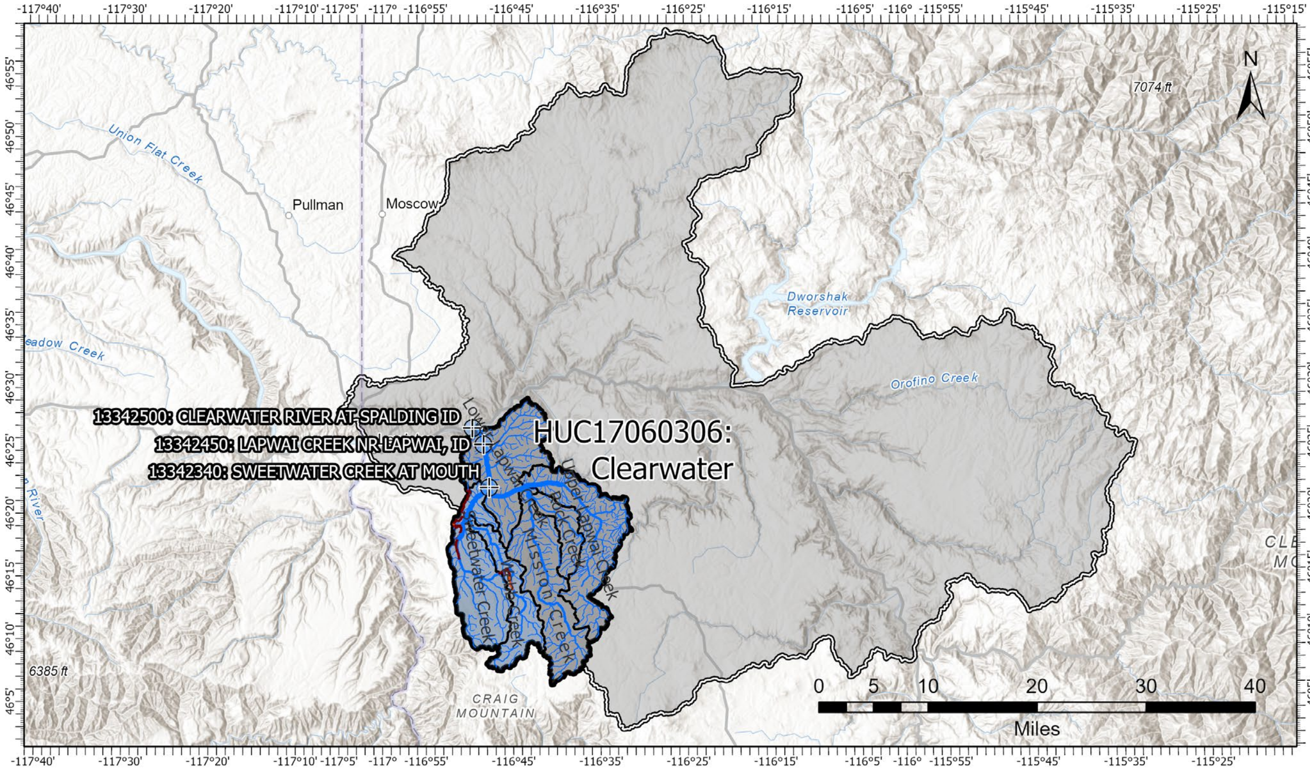


Figure 1-2. Clearwater River HUC8 watershed boundary (17060306) and the HUC10 Lapwai Creek Watershed (HUC 1706030612) which includes the Sweetwater Creek watershed (HUC 170603061205).

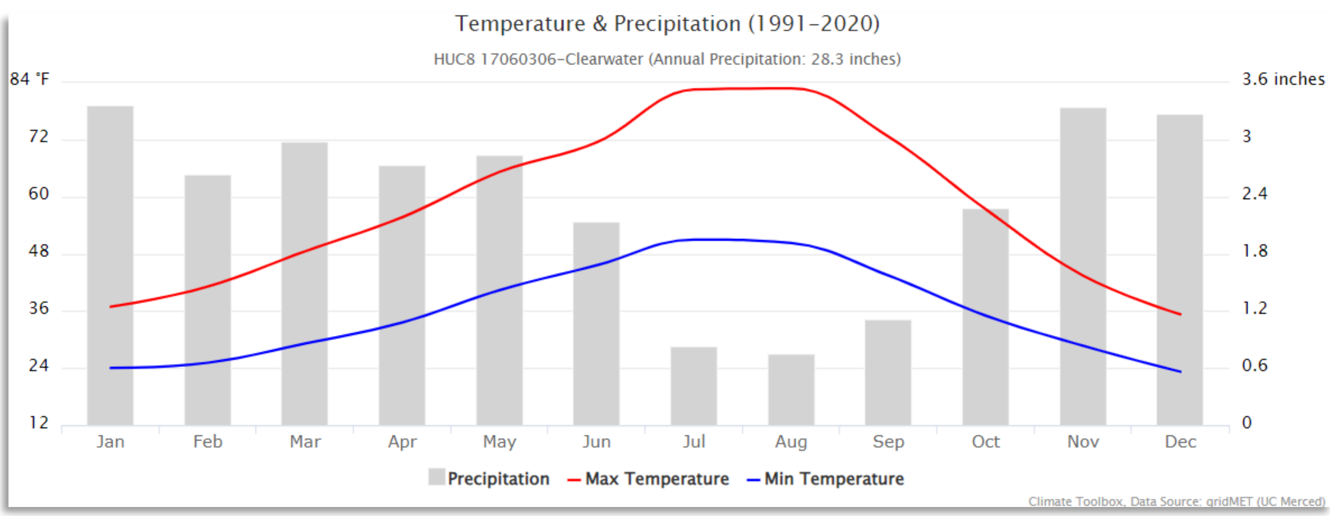


Figure 1-3. Mean monthly Temperature and Precipitation current 30-year normals for the Clearwater River basin (HUC 17060306)

Prior to anthropomorphic changes to the floodplain and hydrology, habitat complexity within Sweetwater Creek was relatively extensive and dynamic with point bars, side channels, backwaters, and braided channels. Large woody debris provided by adjacent riparian overbank would contribute to pool formation and complex cover. Historical accounts indicate that the quality of spawning habitat and quantity of fish species were both greater.

The current ecosystem within lower Sweetwater Creek has been significantly affected by a range of factors including:

- Irrigation diversions that create fish passage barriers and alter the historical natural hydrograph.
- Loss of habitat complexity due to floodplain manipulation and push-up berms and levees that laterally constrain the riparian corridor.
- Loss and degradation of wetland and off-channel habitats due to stream incision and loss of floodplain connectivity at bankfull flow.
- Increased invasive plant species in the riparian has reduced habitat value and the diversity of culturally significant species.

The presence of overbank berms near the channel margin has reduced the frequency of floodplain access for flows less than the two-year return period which has resulted in a narrowing of the historical vegetated riparian corridor. Consequently, there is little potential for natural stream processes such as planform meandering, pool formation, and recruitment of woody debris. Additionally, the upstream LOID diversion affects sediment transport and limits spawning gravel recruitment. The riffle-run-pool structure of Sweetwater Creek is degraded and at risk of being non-functional with long stretches of entrenched uniform plane-bed habitat. These degraded ecologic conditions have negative impacts on species listed under the ESA.

The Recommended Plan is to implement a suite of integrated ecosystem restoration measures within three sub-reaches (sites) to improve degraded aquatic and riparian habitat in lower Sweetwater Creek. Ecosystem restoration is the focus of this climate assessment because the proposed project seeks to improve and create both instream aquatic and overbank riparian habitat through the implementation of multiple integrated measures including riparian preservation and planting, channel realignment, grading and bank stabilization, instream structures, floodplain improvement and reconnection with side channels, and removal/modification of berms. The proposed restoration measures are intended to function together as a composite system to develop a contiguous and sustainable riparian corridor integrated with the hydrologic and geomorphic function of Sweetwater Creek.

The performance of the Recommended Plan habitat restoration measures will be most directly influenced by streamflow (magnitude, seasonality, and duration) and the hydrologic connection with the riparian corridor. As detailed in Appendix A section 2, the hydrology of Sweetwater Creek is characterized by both flashy large floods in the winter and spring followed by low flow summer conditions and hot temperatures. As detailed herein, larger climate drivers could potentially influence the future hydrologic regime in Sweetwater Creek. Sustaining healthy riparian vegetation that remains durable through the hot dry summer months will require careful consideration of current and future projected streamflow responses to climate. One key hydrologic factor that helps to manage the risk of low flows is that Sweetwater Creek has a guaranteed seasonal base flow regime informed by an ESA biologic opinion and decided via a negotiated settlement as detailed in the main report. Flooding on Sweetwater Creek is driven by both snowmelt and precipitation or mixed rain-on-snow events with wide areas experiencing nuisance overbank flooding at frequencies as low as the 20% AEP. A potential future shift in the magnitude, frequency, or duration of flood events in Sweetwater Creek could impact geomorphic function and project performance. Designed as a composite system, the Recommended Plan measures will need to provide stage progressive hydraulic response with sufficient design thresholds for known modes of failure to ensure project durability. Maximizing the duration that riparian vegetation is hydrologically connected to surface and groundwater will be essential to provide the rooting mass necessary for long term project durability.

2 Literature Review

Included in this section are highlights from select publications regarding observed historical climate trends relevant to the inland Pacific Northwest Region and corresponding forecasts of future meteorological and hydrologic conditions. The consensus presented within a wide range of the literature is that observed trends within twentieth century records indicates increased temperature with associated increase in freeze-free season lengths and decreased snowpack or April 1 SWE, with variable hydrologic impacts including variable snowmelt runoff. Delayed runoff of snowmelt is an important process that temporally redistributes winter precipitation to the dries part of the year.

As noted in section 1.1, the Sweetwater Creek project area is located within the western extents of the Clearwater River basin (HUC8: 17060306) and eastern extents of the Lower Snake River basin (HUC4: 1706). Despite being within the state of Idaho, the hydroclimate of the Sweetwater and Lapwai Creek watersheds is notably more similar to those of the inland Northwest than either the Idaho Batholith or Northern Rockies ecoregions to the east. Thus, this literature review focused on the Pacific Northwest region (HUC2: 17), more specifically the inland Columbia River basin of southeastern Washington where possible.

The Fourth National Climate Assessment (NCA4) and the USACE Civil Works Technical Report CWTS-2015-23 are the basis for this literature review. The focus of these references is on summarizing trends in historic, observed meteorological and streamflow data, as well as providing an indication of trends in future climate impacted hydrology based on the outputs from Global Climate Models (GCMs). The NCA4 considers climate change research at both a national and regional scale. Civil Works Technical Report CWTS-2015-23 was published as part of a series of regional summary reports covering peer-reviewed climate literature. The 2015 USACE Technical Reports cover 2-digit, United States Geological Survey (USGS), hydrologic unit code (HUC) watersheds in the United States (U.S). Sweetwater Creek is located within 2-digit HUC 17, the Pacific Northwest Region (USACE 2015).

In many areas, temperature, precipitation, and streamflow have been measured since the early 20th century and provide insight into how the hydrology in the region has changed over the past century. Future climate predictions are derived from GCMs loaded with representative concentration pathways (RCPs) reflecting projected radiative forcings through the end of the 21st century. The radiative forcings encompass the change in net radiative flux due to external drivers of climate change, such as changes in carbon dioxide or land use/land cover.

Projected temperature and precipitation results can be transformed to regional and local scales (a process called downscaling) for use as inputs in precipitation-runoff models (Pytlak, et al. 2016). Downscaling is necessary to add local information (such as terrain elevation, aspect, and slope) to the coarse climate model output to create the higher resolution geospatial datasets to support hydrologic modeling at the subbasin scale. All downscaling methods have relative strengths and weaknesses and inherently introduce uncertainty and error that may require subsequent correction via debias or hybrid methods.

Uncertainty is inherent to projections of temperature and precipitation due to the GCMs, RCPs, downscaling methods, and many assumptions needed to create projections (USGCRP 2017). When applied, precipitation-runoff models introduce an additional layer of uncertainty. However, these methods represent the best available science to predict future hydrologic variables (e.g. precipitation, temperature, & streamflow). Many researchers use multiple GCMs and RCPs in their studies to understand how various model assumptions impact results (Gleckler et al., 2008).

For this assessment, background literature on observed and projected temperature, precipitation and snowpack trends is provided as context for the hydrologic regime and the design/implementation requirements to ensure project viability, reduce risk, maintain durability and extend service life.

2.1 Temperature

2.1.1 Baseline Temperature

In the twentieth century, all areas of the Pacific Northwest Region became warmer, and spring temperatures increased 1 to 3°C between 1970 and 1998 (Spears et al. 2013). MacDonald (2010) noted that average annual temperatures in the Pacific Northwest for the 2001 to 2009 period were up to 2 standard deviations above the 20^{th} century average (1895 – 2000).

Based on observed temperature records, the annual, average air temperature between 1986 and 2016 for the Northwest has increased by 1.54°F from the 1901-1960 annual average temperature baseline (Vose, et al. 2017). Temperatures from 1895–2011 averaged warming of about 1.3 °F. The average present-day (1986–2016) observed coldest daily temperature for the Pacific Northwest Region is 4.78°F warmer than the average for the first half of the last century (1901–1960). The warmest day of this same comparison is 0.17°F cooler. Temperature extremes across the contiguous United States has changed. The frequency of cold waves has decreased since early 1900s, and heat wave frequency has increased since mid-1960s. The number of high temperature records set in past two decades far exceeds the number of low temperature records.

Kunkel et al (2013) reported that temperatures in the Pacific Northwest Region have generally been above the 1901–1960 average for the last 25 years, both annually and for all seasons. The report noted that increases in inland temperature of the northwest US were greater than those near the coast. Freeze-free season lengths during 1991–2010 averaged about 11 days longer than during 1961–1990. Since 1990, freeze temperatures have been occurring later in fall and not occurring earlier in spring. The freeze-free period across much of the Pacific Northwest Region increased by 25–35 days with larger increases for the inland northwest. Kunkel et al. also reported on the frequent occurrence of heat waves in the Pacific Northwest Region in recent years, with five of the top 10 years for intense heat occurring in the last two decades. Cold waves have been generally more infrequent since 1990, with all the top ten years for intense cold occurring prior to 1991. This study also predicted an increase in the number of days hotter than 95°F in the southeast portion of the Pacific Northwest region within which is the Sweetwater and Lapwai Creek basins. The longest string of days with such high temperatures is simulated to increase by up to 10 days per year.

2.1.2 Future Temperature

For future conditions, Kunkel et al (2013) estimated that increases in temperatures will be greater for the inland northwest that those near the cost. The freeze-free period was estimated to increase by 25–35 days across much of the Pacific Northwest Region, with larger increases on the west of the Cascade Mountains. This study also predicts an increase in the number of days hotter than 95°F in the southeast portion of the region. The longest string of days with such high temperatures was simulated to increase by up to 10 days per year.

Mantua et al (2010) reported that rising water temperatures will thermally stress salmon throughout Washington watersheds, becoming increasingly severe later in the twenty-first century. That indicate that while winter and spring warming may benefit parts of the freshwater life cycle of some salmon populations, the combined effects of warming summertime stream temperatures and altered streamflows will likely reduce the quality and extent of freshwater salmon habitat and increase strain to many salmon populations.

For the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), Mote and Salathé (2010) indicate that climate models which generally reproduce the observed seasonal cycle and twentieth century warming trend of 0.8°C (1.5°F) in the Pacific Northwest Region predict a much greater warming for the next century relative to the average from 1970 to 1999. These models project increases in annual temperature of 1.1°C (2.0°F), on average, by the 2020s, 1.8°C (3.2°F) by the 2040s, and 3.0°C (5.3°F) by the 2080s, averaged across all climate models. Predicted rates of warming range from 0.1°C to 0.6°C (0.2°F to 1.0°F) per decade, with some models projecting an enhanced seasonal cycle trending towards wetter autumns and winters, with drier summers.

Mote and Sharp (2016) indicate that for increasing temperature estimates in the Western United States of 2°–5° C over the next century, it is likely that losses in snowpack observed up to 2005 will likely continue and even accelerate, with faster losses in milder climates like much of the Cascades and the slowest losses in the higher altitude Rockies and Sierra Nevada.

Pytlak et al. (2018) report that Columbia Basin warming is expected to be greatest (and more locally variable) within the interior, potentially increasing as much as 3 to 6°F over baseline observations by the 2070s if RCP 4.5 emissions pathways are attained.

2.2 Precipitation and Snowpack

2.2.1 Baseline

Multiple studies have identified increasing trends in average annual precipitation in the Pacific Northwest region for the latter half of the 20th century, especially for the coast areas which are notably distinct from the inland northwest. This precipitation trend is variable depending upon location and season. Within the Sweetwater Creek region, the seasonal hydrologic regime is dominated by winter snowpack with supplemental inputs from "shoulder season" precipitation events that occur primarily in the autumn and spring as the region transitions into and out of winter.

A precipitation trend analysis by McRoberts et al. (2011) identified widespread positive linear trends of 2-5% for the inland northwest and western Idaho over the 20th century average (1895 – 2009) hydroperiod with a negative trend of 2-5% for southeastern Washington. A similar study by MacDonald (2010) noted a decrease in precipitation within the inland Pacific Northwest Region for the 2001 to 2009 period relative to the 20th century average (1895 – 2000).

Wang et al. (2009) analyzed gridded precipitation data for a historical (1950 – 2000) hydroperiod. Within the inland northwest, slight increasing trends were observed during both the spring and fall and no trend during the summer when precipitation is generally lower.

An analysis of 20th century rainfall data by Pryor et al (2009), identified statistically significant nonlinear trends for the pacific northwest, including: an overall increasing trend in total annual precipitation, a decreasing trend in large precipitation events and intensity (exceeding the 90th percentile) and an increase in the number of precipitation days per year.

Soil moisture is a function of both supply (precipitation) and demand (evapotranspiration). Grundstein (2009) found that soil moisture was slightly decreasing in the eastern portion of the Pacific Northwest based on annual data from 1895 to 2006.

In the twentieth century, some areas of the Pacific Northwest Region received more winter precipitation and experienced a general decline in spring snowpack, reduced snowfall to winter precipitation ratios, and earlier snowmelt runoff between the mid- and late twentieth century (Spears et al. 2013).

In the Western United States, from 1950–1999, there was a general decrease in the fraction of precipitation retained in the spring snowpack. Snow cover extent in North America set record lows in 3 of the 5 years preceding 2012. A study by Kapnick and Hall (2010) found that recent snowpack changes are due to regional-scale warming, which implies a possible future loss of late season snowpack and an earlier melt season. Multiple studies estimated 1°C warmer climate results in a 14.8–20 percent decrease in snow water equivalent (SWE).

Mote and Sharp (2016) reported that both winter and spring temperatures have increased in western North America during the twentieth century, coinciding with spring snowmelt shifting earlier in the year and decreased April 1 snowpack. Carelton and Hsiang (2019) noted that increased Increasing temperatures can accelerate snowmelt and lengthen the frost-free season.

2.2.2 Future

Analyses by Beles et al. (2006) suggested both losses in snowpack in lower altitude mountain ranges and high altitude or high latitude cool-season will increase during the twenty-first century.

Kunkel et al (2013) simulated an increase in seasonal mean precipitation for southeast Washington, except for winter, which was projected to experience a 2–4 percent decrease. There is notable uncertainty however associated with the predicted precipitation changes. While the number of wet days (precipitation > 1 in) was forecasted to increase, the changes were found to be statistically significant for only small areas in central Washington and Oregon.

The Washington Climate Change Impacts Assessment (Little et al 2009) projects that April 1 snowpack will decrease by 28 percent across Washington by the 2020s, 40 percent by the 2040s, and 59 percent by the 2080s (relative to the 1916–2006 historical average).

Because global climate models do not have sufficient spatial resolution to represent the atmospheric and land surface processes comprising the unique regional climate of the state of Washington, the regional climate model study by Salathé et al. (2010) is very relevant. The study reports two 100-year regional climate simulations showing large-scale weather patterns simulated by a global model interacting with local terrain. The mesoscale simulations produced regional changes in snow cover, cloudiness, and circulation patterns, which affected temperature and precipitation trends over the region relative to the statistical downscaling of the global model. To illustrate this effect, this study analyzes the changes from the current climate (1970–1999) to the mid-twenty-first century (2030–2059). Main findings from this analysis were (1) projected loss of snowpack; (2) reduced snowpack and earlier snowmelt will alter timing and amount of river runoff in the summer, though changes in annual runoff will depend on annual precipitation changes, which differ from one scenario to another; and (3) extreme precipitation frequency increases over the north Cascades and over eastern Washington.

Miles, et al. (2010) assessed regional impacts and adaptation strategies for potential climate change impacts within Washington State. They indicated that the already highly variable water available would be expected to change in the future as temperature increases of 2–3°F by the 2040s and more basins shift towards rain-dominated by mid-century. Summer and fall low flow season would substantially increase in length, exacerbating direct effects of warmer air temperatures on stream temperature. Rising stream temperatures are expected to reduce freshwater salmon habitat. Based on their analysis, they project greater western and far eastern Washington precipitation, but less precipitation in the lower Columbia River Basin. Similar to multiple other studies reviewed, this study projects decreasing April 1 SWE.

2.3 Hydrology

2.3.1 Baseline

The regional summary from the CWTS-2015-23 reported a mixed consensus of statistically significant decrease in streamflow and April 1 SWE data for the latter half of the twentieth century within the Northwest US. A synthesis of historical climate trends (Spears, et al. 2013) found that stream runoff was characterized by earlier freshet peak flows at most stations between 1950 and 1999, with significant trends toward earlier runoff in the Pacific Northwest Region.

Stewart et al. (2005) found that the center of mass of streamflow has shifted earlier by 1 to 4 weeks in many of the records. Other studies found runoff earlier by 1 to 3 weeks over most of the Mountain West. Fritze et al. (2011) found that warmer temperatures in snowpack dependent watersheds cause reduced snowpack during winter, increased winter month runoff, and earlier spring freshet flows associated with an earlier snowmelt, resulting in decreased inflow to lower elevation reservoirs relative to historical conditions.

Pytlak et al. (2018) present work from the River Management Joint Operating Committee (RMJOC), which includes Bonneville Power Administration, USACE, and the U.S. Bureau of Reclamation. The authors considered data for the Columbia River Basin. The study primarily presents updated sets of naturalized streamflow datasets derived from the Coupled Model Intercomparison Project (CMIP) Phase 5 and projections of future conditions. Under this study, a No Regulation-No Irrigation (NRNI) dataset was developed to best represent streamflows unaffected by human activity in the Columbia River Basin prior to any water resources development for the 1929-2008 hydroperiod. Analysis of the NRNI dataset found that the spatial distribution of identified nonstationarities in annual maximum flows correlated with subbasins where annual peak flows are attributed to spring snowmelt while more rain dominated basins had lower detection rates. In these areas, nonstationarities were also detected in the 30-day maximum flow, due to the spring snowmelt season, which has lower daily peaks than the rainy season, but higher flows for longer durations during snowmelt season. The authors note that snowmelt flooding is more sensitive to warming temperatures, particularly in regions where average winter temperature is close to freezing and at lower latitudes that experience higher rates of spring warming. Nonstationarities were also detected in the annual minimum weekly mean summer flows and were geographically distributed consistent latitude, topography, and snowmelt signature.

2.3.2 Future

Streamflows are predicted to decrease in summer, exacerbating increased temperature effect on aquatic habitat. River hydrograph timing is predicted to continue to shift earlier in the year. The combination of increasing temperature and changing hydrology are predicted to result in loss of freshwater salmon habitat and other ecological mismatches.

A study by Elsner et al (2010), notes that the Pacific Northwest Region hydrology is sensitive to temperature change impact on rain/snow balance because of dependency on snowmelt. April 1 SWE is predicted to decrease by 38–46 percent by the 2040s compared with the mean over water years 1917–2006. By the 2080s, seasonal streamflow timing will shift in both snowmelt dominated and rain-snow mixed watersheds. Annual runoff across the state is projected to increase by 2–3 percent by the 2040s, given an increase in winter precipitation.

Hydrologic simulations by Mantua et al (2010) estimated that by the 2080s, the pacific northwest region would experience a complete loss of snowmelt dominant basins within Washington State, with only about ten transient basins (a mix of direct runoff from cold-season rainfall and springtime snowmelt) remaining in the north Cascades. These transient basins were found to be most sensitive to climate change, with historically transient runoff watersheds (such as Sweetwater and Lapwai Creeks) shifting towards rainfall-dominant behavior, with more severe summer low-flow periods and more frequent days with intense winter flooding that could reduce salmonid egg-to-fry survival rates.

Modeling by USBR (2011) of three Columbia-Snake River subbasins, was used to simulate hydroclimate response from an ensemble of downscaled CMIP3 models that were run through a Variable Infiltration Capacity model (Liang et al., 1994). As enumerated in Table 2-1, the ensemble changes suggest that these basins will experience increasing mean-annual temperature and precipitation during the 21st century, accompanied by decreasing trend in spring SWE, decreasing trend in April - July runoff volume, and increasing trends in December - March and annual runoff volumes.

Table 2-1. Summary of Simulated Changes in Decade-Mean Hydroclimate for Several Subbasins in the Columbia River Basin from an Ensemble of Downscaled CMIP3 Models Run through Variable Infiltration Capacity analysis.

Hydroclimate Metric (Change from 1990s)	**2020s**	**2050s**	**2070s**
Columbia River at The Dalles			
Mean Annual Temperature (°F)	1.4	3.2	4.6
Mean Annual Precipitation (%)	3.4	6.2	8.5
Mean April 1 SWE (%)1	-1.0	-3.1	-6.7
Mean Annual Runoff (%)	2.3	3.7	7.5
Mean December–March Runoff (%)	9.8	18.5	27.3
Mean April–July Runoff (%)	2.2	4.1	2.4
Mean Annual Maximum Week Runoff (%)	3.5	4.0	5.5
Mean Annual Minimum Week Runoff (%)	-1.5	-5.9	-8.5
Snake River at Brownlee Dam			
Mean Annual Temperature (°F)	1.6	3.6	5.0
Mean Annual Precipitation (%)	2.3	3.9	6.6
Mean April 1 SWE (%)1	-5.0	-12.0	-16.0
Mean Annual Runoff (%)	-0.1	1.2	3.4
Mean December–March Runoff (%)	5.6	13.7	21.0
Mean April–July Runoff (%)	-1.3	-2.0	-0.9
Mean Annual Maximum Week Runoff (%)	2.4	3.5	5.8
Mean Annual Minimum Week Runoff (%)	-3.0	-4.3	-5.9
Yakima River at Parker			
Mean Annual Temperature (°F)	1.3	2.9	4.2
Mean Annual Precipitation (%)	3.7	5.7	7.7
Mean April 1 SWE (%)1	-10.3	-19.6	-28.7
Mean Annual Runoff (%)	3.8	3.7	5.6
Mean December–March Runoff (%)	19.6	39.9	56.9
Mean April–July Runoff (%)	-2.0	-9.5	-17.0
Mean Annual Maximum Week Runoff (%)	2.7	4.2	6.7
Mean Annual Minimum Week Runoff (%)	-4.0	-10.6	-14.2

Hydrologic predictions from the River Management Joint Operating Committee (RMJOC) reported by Pytlak et al (2018), indicate that future increases in temperature, with decreases in winter snowpack and summer precipitation will manifest as significantly higher average fall and winter river flows, earlier peak spring runoff, and longer periods of low summer flows starting as early as the 2030s.

2.4 Summary

Within the literature reviewed, there is a weight of evidence that temperature and precipitation have increased, and streamflows decreased over the observed period of record within the inland Northwest regions of the Columbia River basin, with notable departures in recent decades relative to 20th century normals.

Future forecasts of temperature, precipitation, and hydrologic response in the Pacific Northwest are uncertain and variable, but in general can be characterized as wet regions and seasons becoming wetter, dry regions and seasons becoming drier, and reduced snow depth, density and extent. Regional temperatures of the inland northwest are projected to increase by varying amounts, on the order of 3.5–9° F over the next century. An increased freeze-free period and loss of April 1 snowpack follows from this prediction and is also discussed in the literature. Streamflows are predicted to decrease in summer, exacerbating increased temperature effect on aquatic habitat. River hydrograph timing is predicted to continue to shift earlier in the year. The combination of increasing temperature and changing hydrology are predicted to result in loss of freshwater salmon habitat and other ecological mismatches.

Using the most recent data from CMIP5/IPCC-5, two recent climate assessments (USBR 2016 and Department of Energy 2017) reached similar conclusions regarding the future hydroclimate of the Columbia River Basin. More specifically, they agreed that temperatures in the Columbia River Basin will almost certainly continue to rise over the next several decades, which will impact snowpack and subsequent seasonal runoff. Both reports also indicated that a signal may be emerging in the temperature and precipitation datasets produced by the GCMs and their downscaled counterparts that wetter autumns and winters may develop over time in the Columbia Basin, which would correspond to higher annual precipitation despite a possible, partially offsetting emerging trend for already dry summers to turn drier in parts of the basin.

These findings are further supported by the Pacific Northwest region-specific USACE Climate Change Assessment CWTS-2015-23 (USACE 2015), which found that there is a moderate consensus that air temperatures will increase over the next century in the Pacific Northwest Region, and a strong consensus that the region could experience an increase in maximum temperature extremes on the order of 5–15 °F. A strong consensus is also noted that intensity and frequency of extreme storm events will increase. Future minimum temperature, average annual precipitation, and streamflow show varied trends, which may be due to physiographic variability within the greater pacific Northwest Region. Literature review trends from CWTS-2015-23 are summarized in Figure 2-1.

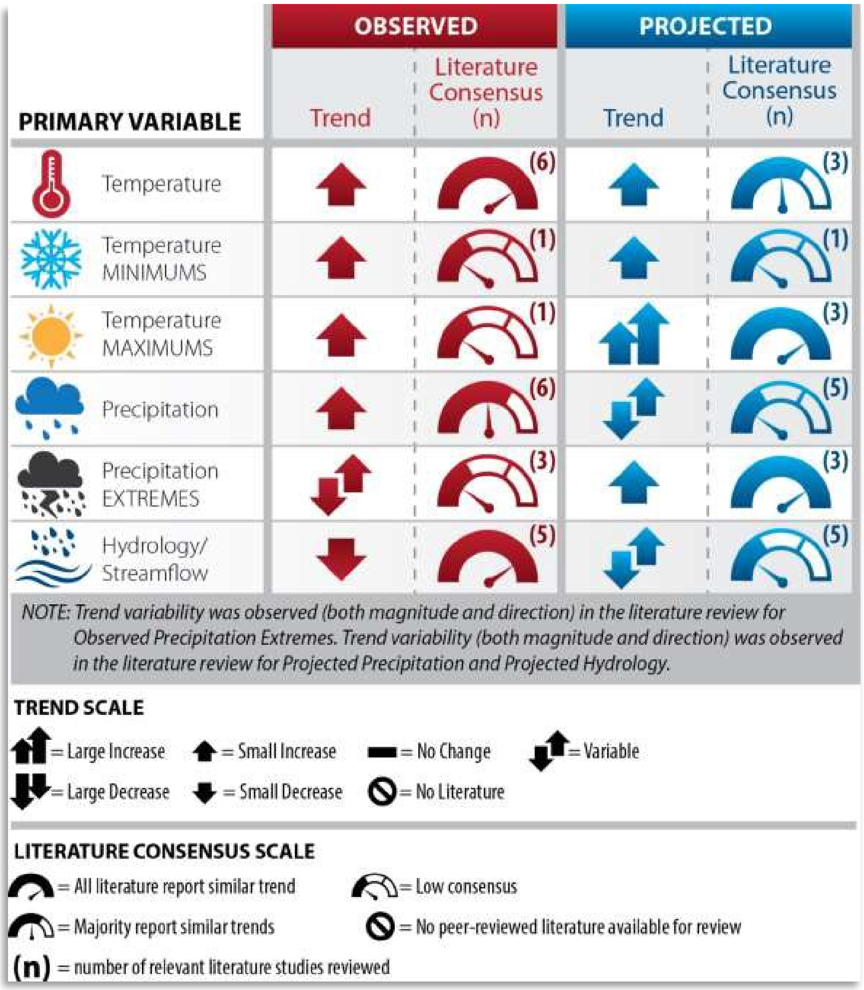


Figure 2-1. Literature review trends from CWTS-2015-23

2.5 Identification of Relevant Climate Variables

The Sweetwater Creek project is intended to restore both aquatic and riparian ecosystem function while balancing multiple constraints and is influenced by multiple climatic variables both under baseline and future conditions. The performance of the Recommended Plan aquatic habitat restoration measures will be most directly influenced by streamflow (magnitude, seasonality, and duration), as well as riparian habitat restoration measures intended to maximize the duration of hydrologic (both surface water and ground water) connectivity with Sweetwater Creek. Establishing and maintaining a contiguous mosaic of riparian vegetation will be critical to improving ecosystem function and quality as well as providing the essential "glue" necessary to improve project durability within the channel system and the resiliency necessary to sustain natural riparian processes over the project service life. Relative to climatic conditions, future changes in temperature, precipitation, snowpack, or streamflow could influence both near-term and long-term ecosystem response in lower Sweetwater Creek.

As the main driver in most GCM models, increases in temperature can influence meteorological metrics such as precipitation and snowpack which subsequently can manifest as a change in system response at the watershed and channel network scale. Within the lower Sweetwater Creek restoration sites, increases in ambient temperature combined with dryer summer conditions would stress riparian vegetation and could increase the risk of vegetation mortality. This would be of significant concern in the post-construction period when newly seeded and/or planted areas are vulnerable and follow a traditional Weibull failure curve. Long term loss of riparian vegetation from increased periods of heat within the Sweetwater Creek watershed would impact the Recommended Plan, potentially leading to an increase in ephemeral sediment loading that could influence geomorphic response within the channel system. An increase in maximum temperatures and heat waves also has the potential to increase stream temperatures, reduce dissolved oxygen concentrations which can impact aquatic life, and may produce harmful algae blooms.

Seasonal increases in precipitation that may occur during warmer shoulder seasons would be expected to improve vegetation in the riparian corridor. During the summer hydroperiod (June to August+) when baseline precipitation in Lower Sweetwater Creek is low and air temperatures are high, even a slight decrease in precipitation would be expected to stress riparian vegetation which could require irrigation to adaptively manage the post-construction period to ensure vegetation establishment and survival. Sweetwater Creek flooding is driven by both snowmelt and precipitation events, and can occur in winter or spring, typically between November and May. The most common month for flooding on Sweetwater Creek is March when mid elevation snowmelt melts quickly with warming seasonal temperatures resulting in a flashy flood response. The lower Sweetwater Creek channel system is relatively high energy, and increased storm intensities or frequencies could influence project performance. A key consideration for the project is that the Recommended Plan measures must be designed to function as an integrated composite system with inset and reconnected floodplains that capture the spring freshet volume and dissipate energy, side channels that reliably route overbank nuisance flows, and in-stream structures that remain stable during intense flooding.

Ecologically relevant components of stream discharge include its magnitude, frequency, and duration, as well as the timing of particular discharges, rate of discharge change, and inter-annual (year-to-year) variability and the corresponding response in stage. An increase in flow magnitude may exacerbate flooding and inundation. More frequent or longer duration flood events could induce geomorphic change and result in ad-hoc flood response from local landowners such as push-up berms and bank hardening with revetment. Low volume runoff years could impact riparian vegetation communities, especially those on overbank terraces.

An increase in annual peak flow derived from either rapid snowmelt or increased storm intensity and frequency could impact existing infrastructure on Sweetwater Creek (such as flood prone structures and undersized bridge crossings) as well as increase bank erosion and sediment loading rates to degraded reaches of the Sweetwater Creek channel system.

Inter-annual variability within typical long-term extremes helps produce the mosaic of habitats found along Sweetwater Creek, however increased year to year variability may affect the establishment of some species of plants and the availability of habitat in the transition zone between channel and riparian overbanks. Departure in the bankfull or channel forming flow regime may alter sediment supply and transport in the channel and influence the health and extent of the riparian corridor. Considering the arid nature of the project area and, a slight flow increase in and longer duration of seasonally frequent events (> 50% change exceedance) could have ecologic benefits as it could increase sediment and nutrient loading to near bank riparian areas and recharge groundwater of the alluvial aquifer, which is necessary to sustain the Sweetwater Creek riparian corridor.

For this assessment, indicator variables within the three categories identified as relevant for assessing potential climate impacts to the Sweetwater Creek restoration project include:

Temperature variables:

- Annual maximum 1-day temperature as an indicator of heat waves
- Annual minimum 1-day temperature as an indicator of winter warming
- Monthly seasonal temperature trends

Precipitation variables:

- Annual accumulated precipitation as indicator of wetter or dryer years.
- Annual maximum 1-day precipitation as indictor of intense storms.
- Annual maximum 3-day precipitation as indicator of extended duration storms
- Monthly seasonal precipitation trends
- Annual maximum of number of consecutive dry days as an indicator of drought conditions.

Hydrologic variables:

- Annual peak streamflow as an indicator of flashy (potentially rain-driven) peaks.
- Annual maximum monthly flow as an indicator of longer duration runoff associated with snowmelt.
- Annual water year volume as an indicator of relatively wetter or dryer years.
- Mean daily streamflow and derived monthly/annual aggregates.
- Minimum monthly and annual streamflows as an indicator of low flow conditions & trends
- Monthly seasonal flow trends

3 Hydrologic Time Series Trends

This portion of the climate assessment focuses on carrying out first order statistical analyses of streamflow records in the study area using the USACE Time Series Toolbox (TST).

3.1 Time Series Data

Observed streamflow records for lower Sweetwater Creek are limited to the period from water years 2003 to 2019 (USGS Gage 13342340) using a gage that was funded by USBR during the prior water exchange negotiation period with NPT. This gage provided ~17 equivalent years of observed record to support the trend analyses and did include some data gaps due to intermittent gage failure. The Sweetwater Creek flow record is influenced by seasonal storage and trans-basin diversions by the Lewiston Orchards Project (LOP) as discussed in Appendix A-2.2 which can result in abrupt changes to the hydrograph. Due to the relatively short record for Sweetwater Creek and variability in upstream inflows, the Lapwai Creek Gage (USGS 13342450) was selected as a surrogate gage representative of regional hydroclimate at the HUC10/12 scale (Figure 3-1). Further, the Lapwai gage period of record is of sufficient length to span nearly 5 decades to support to trends analysis (Figure 3-2). In addition, a third dataset of mean daily flow (and annualized volume) was synthesized by correlating the overlapping periods of record between Sweetwater Creek and Lapwai Creek to estimate a synthetic hindcast composite (SWaM) as detailed in Appendix A-2.2.

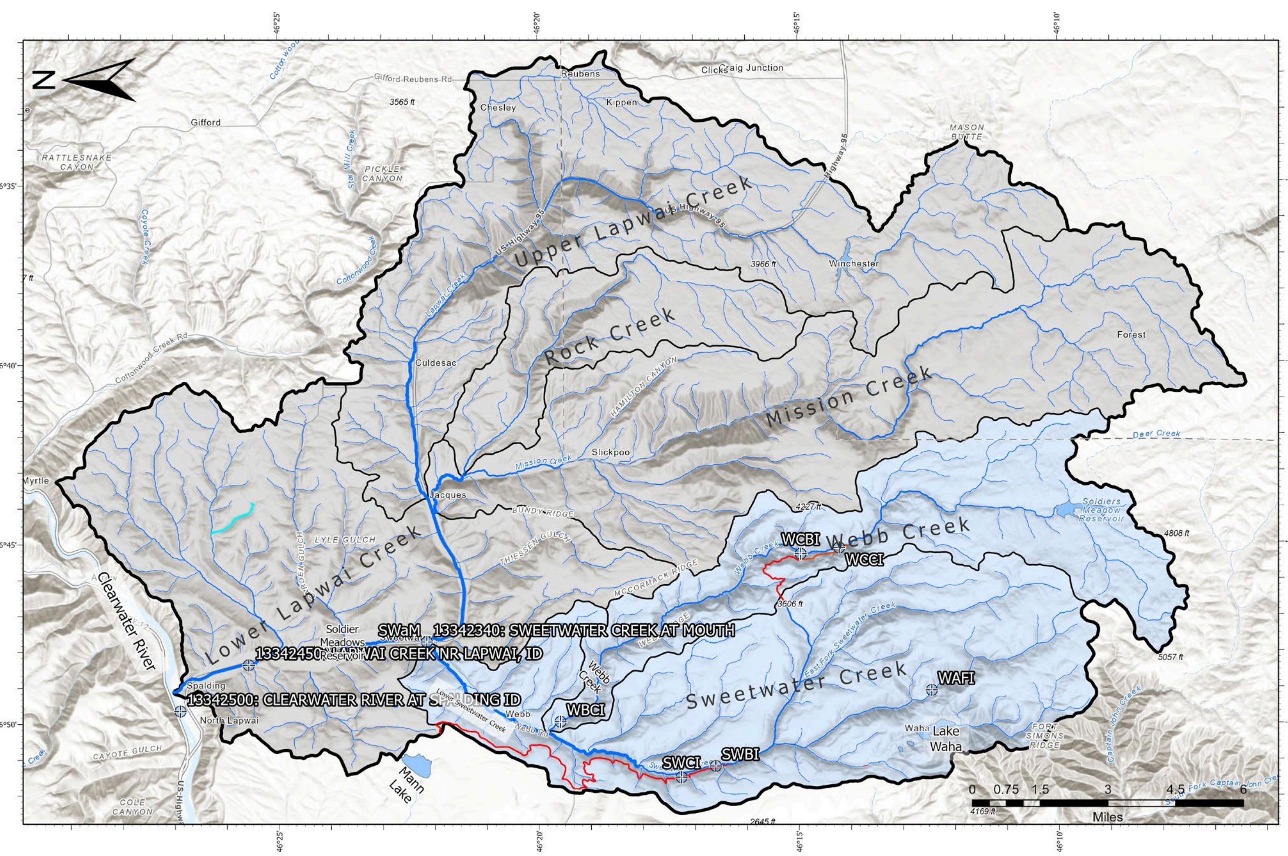


Figure 3-1. Watershed Map of Sweetwater Creek (HUC 170603061205) within encompassing Lapwai Creek (HUC 1706030612) with USGS gage stations of interest. *USBR Hydromet stations for the LOP are also shown. Irrigation conveyances are depicted in red.*

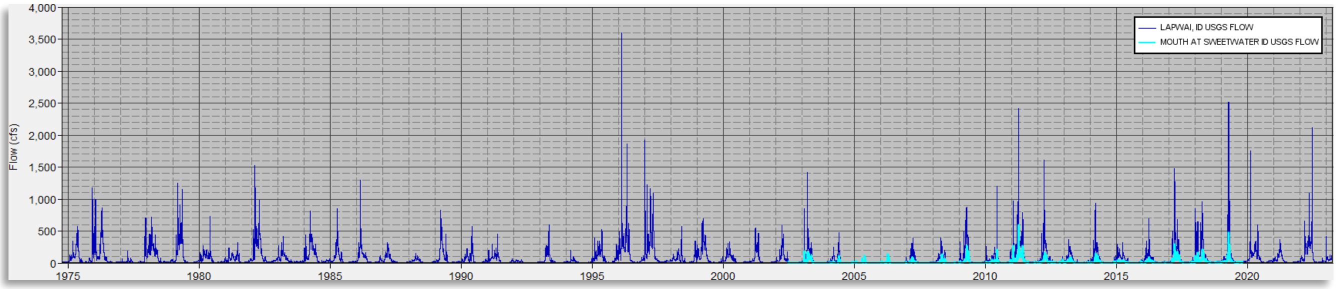


Figure 3-2. Period of Record gaged flows for Sweetwater Creek at Mouth (cyan) and Lapwai Creek (blue).

Table 3-1 below summarizes the hydrologic records of interest selected to inform the feasibility of the Sweetwater Creek ecosystem restoration project and which TST tests were evaluated. Analyses of climate change trends within the Sweetwater Creek study area is complicated by broken streamflow records and historical impacts of land use and subsequent geomorphic change. Streamflow magnitude can be influenced by changes in land-use, channel realignment, and measurement techniques. These factors can make it difficult to determine the role of climate change in affecting the hydrologic signal at the project scale. The relevant question of interest at the project scale is whether there has been, or will be, a change that affects conditions in the study area and how this change would impact the resilience of the Recommended Plan. The selection of the time series datasets considered aligns with the hydrologic records rationale for of relevant climate variables as previously discussed in Section 2.5 above.

Table 3-1. Summary of hydrologic timeseries analyzed in the TST

Dataset	Rationale
Annual Peak Flows and Maximum Flows	The lower Sweetwater Creek study area has experienced repeated overbank nuisance flooding at return periods as low as the 20% AEP, and large flood events have impacted channel stability.
Annual Volumetric Yield	The study area has experienced multi-year periods that cyclically trend wetter and dryer at a nominal decadal scale which has implications for future risk to and performance of the ecosystem restoration project.
Mean Flows	Baseline climate of the study area is characterized by flashy spring flooding followed by hot dry summers and low flows. The seasonality trends in mean daily flow are of interest because reduced summer flows and increased winter flows could potentially impact various measures of the ecosystem restoration Recommended Plan.
Minimum Flows	The study area frequently experiences low flows, especially during the summer months, which could impact project performance.

3.2 TST Methods

Both the Lapwai Creek and SwaM composite (with hindcast) gage records were analyzed using the suite of statistical methods implemented in the USACE Time Series Toolbox (TST). The TST is a web-based tool for computing statistical tests detailed in USACE Engineering Technical Letter (ETL) 1100-2-3, *Guidance for Detection of Nonstationarities* (2017). The toolbox includes three categories of tests that can be used to detect abrupt and gradual changes in the mean, variance, and distribution of time series data.

Five methods in the TST were considered for this analysis:

- Trend analysis to fit trend lines to data and evaluate statistical significance.
- Seasonality to evaluate seasonal trends in data distributions
- Nonstationarity detection to test for nonstationarities using a suite of metrics
- Breakpoint analysis using linear regression.

3.2.1 Trend Detection

Model based trend detection with the TST toolbox was used to evaluate monotonic trends and significance across various hydrologic time series datasets. While the approach uses linear methods to identify long-term increasing/decreasing trends, the trend itself may not necessarily be linear. The tool computes two slope values, the first is the "traditional slope" that uses standard least squares regression, while the second "Sen's Slope" is a nonparametric method that averages the slope between every two points in a timeseries, and is considered more robust for non-normal datasets. Trend significance is evaluated using three metrics: the parametric student's t-test, and two nonparametric test: the Mann-Kendall and Spearman rank-correlation tests. The student's t-test assumes the input data is normally distributed, and was found to erroneously identify significant trends in some datasets where the non-parametric rank-based methods did not.

3.2.2 Breakpoints and Nonstationarity

The assumption that the statistical characteristics of hydrological time series are constant through time (stationarity) has been a foundational assumption for hydrologic assessment and forecasting (Milly et al., 2008). This assumption has enabled the use of well-accepted statistical methods in hydrologic analyses that rely primarily on the observed record and assume that the first and second order statistical moments (i.e. mean and variance) do not vary within a particular time-scale of interest. Over short-term timescales (e.g., daily, monthly, annual), hydrologic timeseries frequently include nonstationarities that can be corrected for such as seasonality or deterministic flow regulation. Over longer timescales however, hydrologic nonstationarity can be present due to random or uncertain processes (such as climatic drivers) that can be difficult to identify without a sufficiently long period of record.

Nonstationarity in hydrologic records can result from multiple spatial and temporal factors. This includes changes in watershed land cover or land use, changes in upstream water supply such as hydroregulation, diversions for water supply or irrigation, and larger scale changes in meteorology and climate. Systemic changes in hydrologic response can be temporally abrupt or gradual and vary by catchment and stream network.

Climate change has the potential to undermine the stationarity assumption by introducing nonstationary into both meteorological trends and hydrologic response. USACE civil works policy guidance includes methodologies for the detection of nonstationarities in streamflow in support of USACE project planning, design, construction, operations, and maintenance (ECB 2016-25, USACE, 2016; ETL 1100-2-3, USACE, 2017).

The TST includes both breakpoint and nonstationarity detection tools. The breakpoint detection utilizes linear regression models of segmented data, while the nonstationary detection tool identifies statistically significant changes in the mean, variance, and distribution of a time series dataset using a suite of both parametric and nonparametric statistical methods. The TST nonstationarity detection approach applies 12 statistical tests to detect trends in the data, five of which are change point models, a Bayesian change point, smooth and abrupt Lombard methods, the energy divisive method, and the Pettitt test. All datasets were analyzed with the default NSD sensitivity parameters enumerated in Table 3-2.

Table 3-2. Default Sensitivity Parameters for TST Tool Nonstationary Detection methods.

NSD Test Method	Applicability	Default Sensitivity Parameters
CPM Methods Burn-In Period		20
CPM Methods Sensitivity		1,000
Bayesian Posterior Threshold		0.5
Energy Divisive Method Sensitivity		0.5
Pettitt Sensitivity		0.05
Bayesian Prior Likelihood		0.2
Lombard Smooth Methods Sensitivity		0.05

3.3 Time Series Toolbox Results

The Time Series Toolbox (TST) was used to analyze four sets of baseline hydrologic data to evaluate the presence of trends in the available period of record. The datasets considered include annual peak and maximum flows, annual volumetric yield, mean flows, and minimum flows as detailed in Section 3.1.

Table 3-3 below, summarizes the trends, breakpoints, and nonstationarity detection results from the TST. In general, no strong trend or nonstationarity signals were identified across the period of record hydrologic datasets considered. Peak and maximum flows indicated a slightly positive but non-significant trend. Monthly extremes in maximum and minimum flows detected multiple nonstationarities that are characteristic of the flashy and regulated nature of the Sweetwater Creek system. The annual minimum flow was characterized by decadal-scale breakpoints where a multi-year dry period abruptly transitioned to a wetter regime. A seasonal-decomposition of the mean daily flow record trend indicated four breakpoints representative of multi-year hydroperiods. Despite this, the trend in water year yield remained consistent across the period of record with neither breakpoints nor nonstationarities.

Table 3-3. Summary of TST results for period of record hydrologic datasets.

Hydrologic Dataset	Trends	Breakpoints	Nonstationarities
Lapwai Creek #13342340			
13342340 – Lapwai Creek annual peak flow	Positive, not significant.	None detected	None detected in observed annual peak flow dataset. One NSD detected for estimated missing data.
Sweetwater at Mouth Composite (SWaM)			
Monthly maximum flow	Near-zero to slightly positive slope. Not significant	None detected	33 abrupt NSD detections in maximum monthly flow dataset corresponding to flashy month-to-month seasonal changes. No NSDs in mean monthly flow detected by gradual tests.
Annual volumetric yield	Near-zero positive slope. Not significant.	None detected	None detected
Mean daily flow seasonal decomposition trend.	Near-zero slope for mean daily flow trend component. Not significant.	*N/A. Unaggregated daily dataset too large for TST to process breakpoints or NSD.*	
Monthly mean flow	Near-zero positive slope. Not significant.	No breakpoints detected in mean monthly flow dataset. Four breakpoints detected in the seasonally decomposed trend in mean monthly flow representative of multi-year hydroperiods.	33 abrupt NSD detections in mean monthly flow dataset corresponding to flashy month-to-month seasonal changes. No NSDs in mean monthly flow detected by gradual tests.
Annual mean flow	Diverging symmetrical mild positive and negative trends. Not significant.	None detected	None detected
Monthly minimum flow	Near-zero positive slope. Not significant.	2 breakpoints detected	30 abrupt NSD detections in minimum monthly flow dataset corresponding to flashy month-to-month seasonal changes. No NSDs in minimum monthly flow detected by gradual tests
Annual minimum flow	Positive slope. Not-significant (except by t-Test)	2 breakpoints & nonstationarities detected. #1 at start of water year 2001 between the hindcast and observed flow data #2 at start of WY 2011, a much wetter year than the prior decade.	

3.3.1 Annual Peak and Maximum Flows

Trends in annual instantaneous peak flows were evaluated using the Lapwai Creek Gage (USGS 13342450) as a surrogate. The flood peak record contains 46 systematic observations compared to less than 20 for the Sweetwater Creek (USGS Gage 13342340). As detailed in Appendix A Section 2.3.1, the magnitude, and timing of observed peak flows on Sweetwater Creek correlated well with Lapwai Creek for the 17 years of coincident records. This suggests that adequate representation of historic peak flow conditions in Sweetwater creek is achieved by using the Lapwai Creek gage data sets in the TST tool to perform Trend analysis and nonstationarity detection. Maximum flows were also considered for comparison (Figure 3-4), and as expected trended similar to annual peak flows.

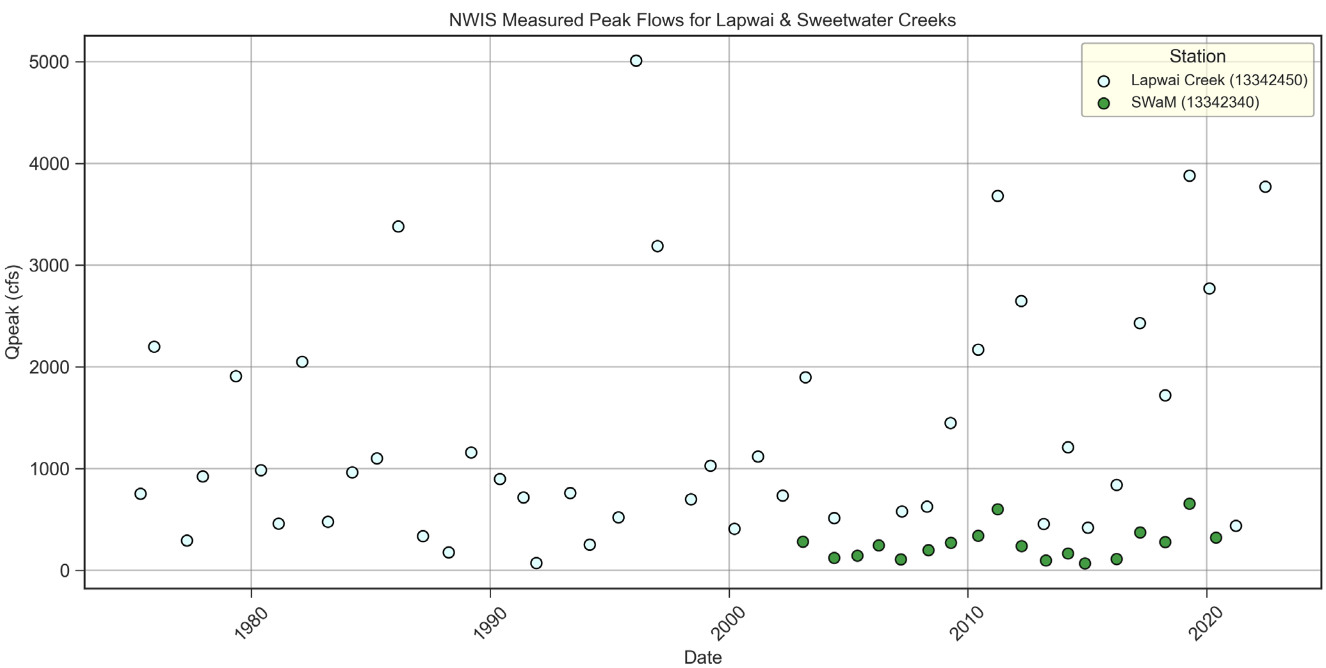


Figure 3-3. Measured peak flows on Lapwai and Sweetwater Creeks. *Note Sweetwater gage was active between water years 2002 and 2020.*

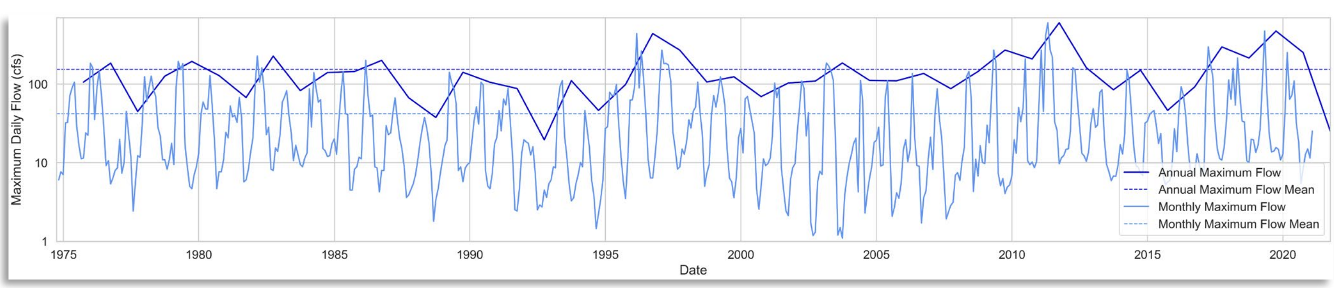


Figure 3-4. SWaM maximum flows.

For the TST trend analysis tests, the significance tests (i.e.: t-test, Mann-Kendall, and Spearman Rank-Order) can be sensitive to datasets with missing values and influence the statistical results. Lapwai Creek gage was out of service during water years 2005 and 2006, and peak flow values for those two years were estimated. Because Lapwai and Sweetwater Creeks occur within a transitional physiographic region of the Lower Clearwater, a representative gage was not available to support a practical gage transfer. As a simplified approach to estimate the representative missing annual peak flow data, a correlation of measured flow on the Clearwater River from upstream and downstream of the confluence with Lapwai Creek was used to interpolate an estimated annual peak value for 2005 and 2006.

As summarized in Table 3-4 and illustrated in Figure 3-5, the annual peak flows had a positive slope trend by both the Traditional and Sen's methods, however, the three hypothesis tests (T-test, Mann-Kendall, and Spearman Rank Order) did not identify this positive trend as significant at the α=0.05 threshold. Similar to the observed dataset, the trend analysis for the revised annual peak flow dataset (with estimated missing values) was also characterized by positive slope and potentially significant at the α=0.10 level. This could suggest that peak streamflow magnitude has been slowly increasing, which would agree with climate literature findings (see section 2.2) that precipitation events are becoming more frequent with higher intensity and could be the result of increasing winter precipitation events.

Maximum monthly flows also did not exhibit any significant trends with near-zero to mildly positive slopes. An interesting comparison is that the maximum monthly TST observed flow trend analysis disagrees with the historical trends for Maximum Mean Monthly Streamflow developed by the Climate Hydrology Assessment Tool (CHAT, section 4.1). While the TST analysis indicates a near-zero mild positive trend in maximum monthly streamflow from 1975 to 2021, the CHAT indicates a decreasing simulated historical trend for the same streamflow from 1951 to 2005. Although the CHAT indicates a historical decrease in maximum monthly average streamflow, the trends were developed using model simulations that spatially discretized mean historical data within a watershed catchment. Considering that the TST trend analysis is based on localized observed flow data rather than a simulated average of historical area trends, the TST analysis is expected to be more indicative of overall local streamflow trends for lower Sweetwater Creek.

Table 3-4. Annual Peak and Maximum Flows TST Summary

Gage - Variable	Trends	Breakpoints	Nonstationarities
Lapwai Creek (#13342340) - Annual Peak Flows observed	Traditional Slope = +19 Sen's Slope = +11 <u>Significance</u> t-test = 0.13 Mann-Kendall = 0.22 Spearman Rank-Order = 0.23	None detected	None detected
Lapwai Creek (#13342340) - Annual Peak Flows with estimated missing values.	Traditional Slope = +23 Sen's Slope = +16 <u>Significance</u> t-test = 0.056 Mann-Kendall = 0.071 Spearman Rank-Order = 0.088	None detected	1 detected between years 2006 and 2007 via the Lombard-Wilson means test.

Gage - Variable	Trends	Breakpoints	Nonstationarities
SWaM - Maximum Monthly Flow	Near-zero mild positive trend. Traditional Slope = +0.29 Sen's Slope = +0.0 <u>Significance</u> t-test = 0.15 Mann-Kendall = 1.00 Spearman Rank-Order = 0.98	None detected	33 abrupt NSD detections in maximum monthly flow dataset corresponding to flashy month-to-month seasonal changes. 28 NSD by distribution tests 13 NSD by means tests 7 NSD by variance tests **0 NSD by smooth tests**

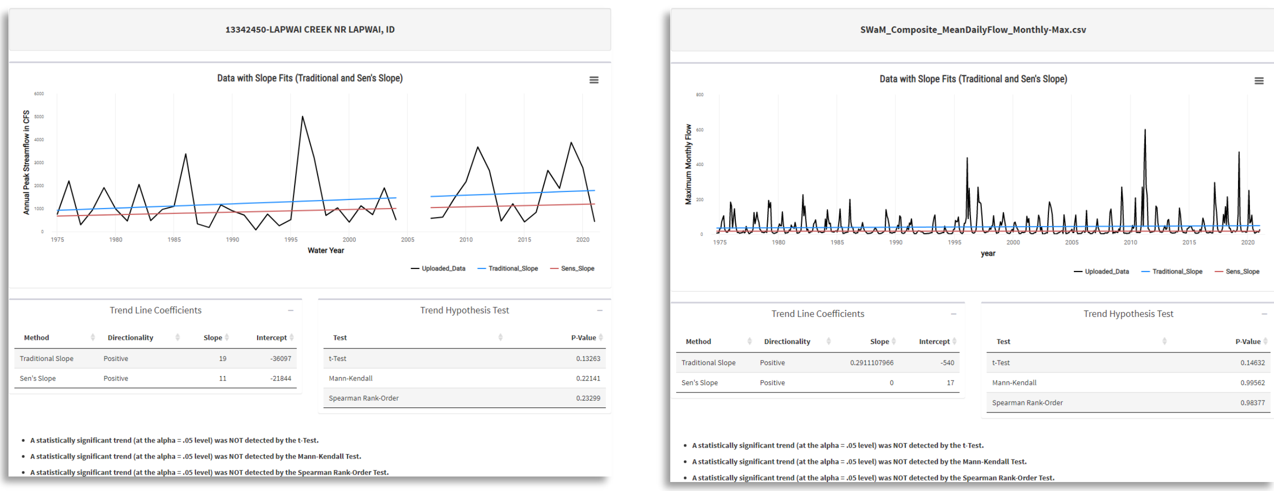


Figure 3-5. Annual Peak and Monthly Maximum Flow Trends for Lapwai Creek (USGS 13342450) and SWaM respectively. *Note – No significant trends.*

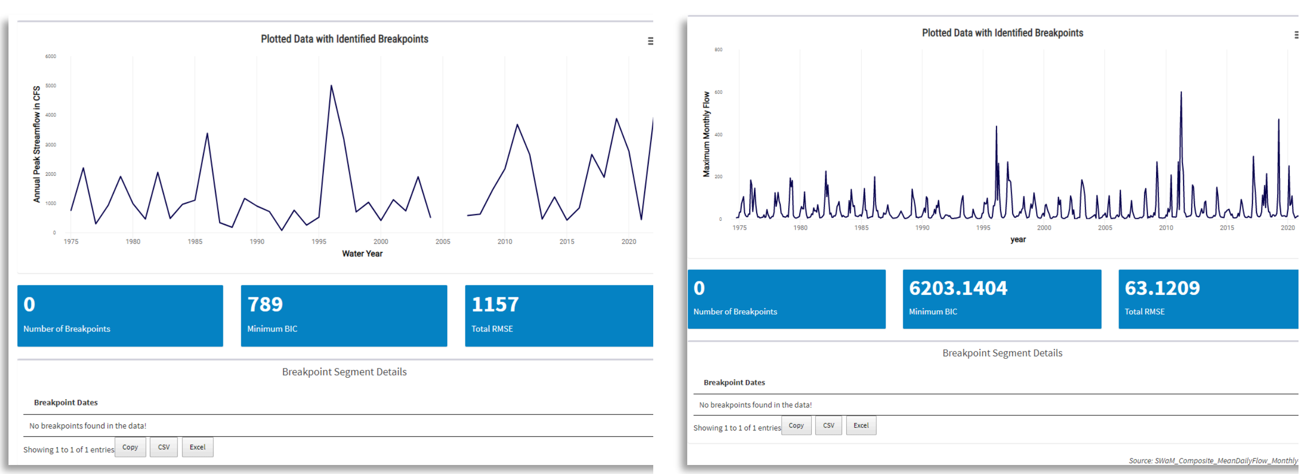


Figure 3-6. Annual Peak and Max Monthly Flow Breakpoints. for Lapwai Creek (USGS 13342450) and SWaM respectively. *Note none detected.*

Results from the NSD analysis detected no significant breakpoints (Figure 3-6) or nonstationarities in the Lapwai Creek observed annual peak flow dataset. NSD analysis of the annual peak flow dataset with estimated missing values detected one nonstationarity between years 2006 and 2007 as illustrated in Figure 3-7. This flagged nonstationarity occurs after the two years of estimated data when the Lapwai Creek gage was returned to operation and was only detected by the Lombard-Wilson Means test. The fact this nonstationarity occurs between estimated and recorded data might be expected. Without actual observed peak flow measurements for 2005 and 2006, this single nonstationarity appears inconsistent with coincident tests and provides limited insight on detected trends.

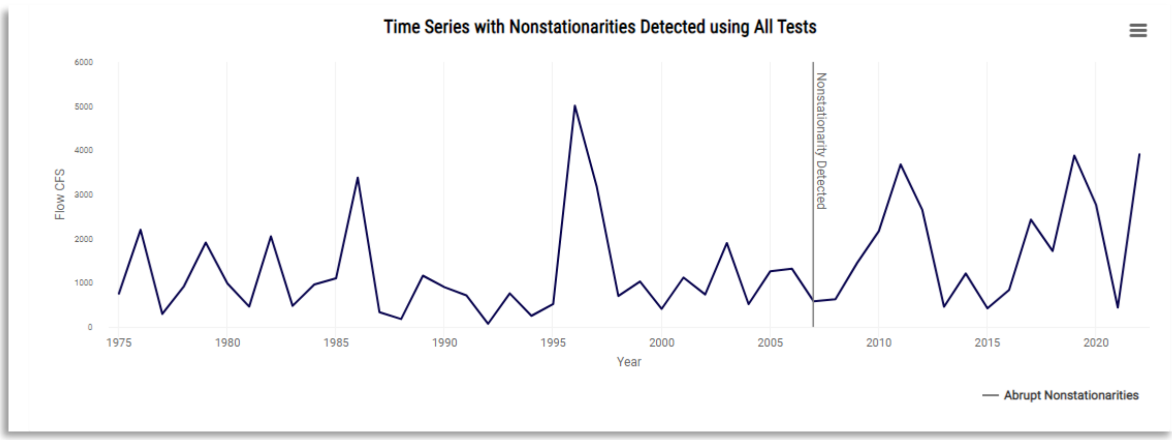


Figure 3-7. Annual Peak Flow Nonstationarity for Lapwai Creek (USGS 13342450) with estimated missing data for water years 2005 and 2006.

3.3.2 <u>Annual Volumetric Yield</u>

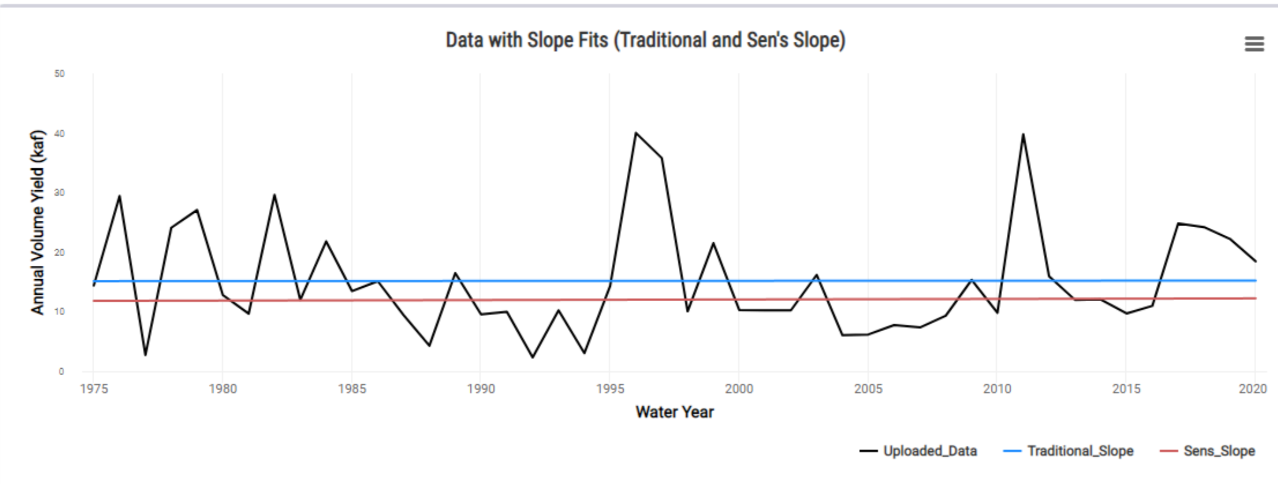
Annual volumetric yield from the SWaM composite record was evaluated in the TST as an indicator of multi-year to decadal length hydroperiods that have trended wetter and dryer. Unlike aggregating flow rate statistics (e.g. maximum and minimum) the volumetric yield is characteristic in that it accumulates each annual water year hydrograph into a total value to identify inter-annual variability and decadal scale trends.

As summarized in Table 3-5, there were no significant trends, breakpoints, or nonstationarities identified in the record of annual runoff volume. Despite historical cycles in volumetric yield indicative of wetter and dryer multi-year hydroperiods as illustrated in Figure 3-8 and Figure 3-9, the inter-annual variability was not sufficient to identify significant breakpoints or nonstationarities.

Table 3-5. Annual Volumetric Yield TST Summary

Sweetwater at Mouth Composite (SWaM)	**Trends**	**Breakpoints**	**Nonstationarities**
Annual volumetric yield	Near-zero positive slope. Not significant. Traditional Slope = +0.002 Sen's Slope = +0.001 <u>Significance</u> t-test = 0.98 Mann-Kendall = 0.89 Spearman Rank-Order = 0.93	None detected	None detected

SWaM_Composite_AnnualWaterYearVolume.csv



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	0.0019091696	11
Sen's Slope	Positive	0.0091641739	-6

Trend Hypothesis Test

Test	P-Value
t-Test	0.98544
Mann-Kendall	0.89455
Spearman Rank-Order	0.92514

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

Figure 3-8. Annual volumetric yield trends for SWaM composite.

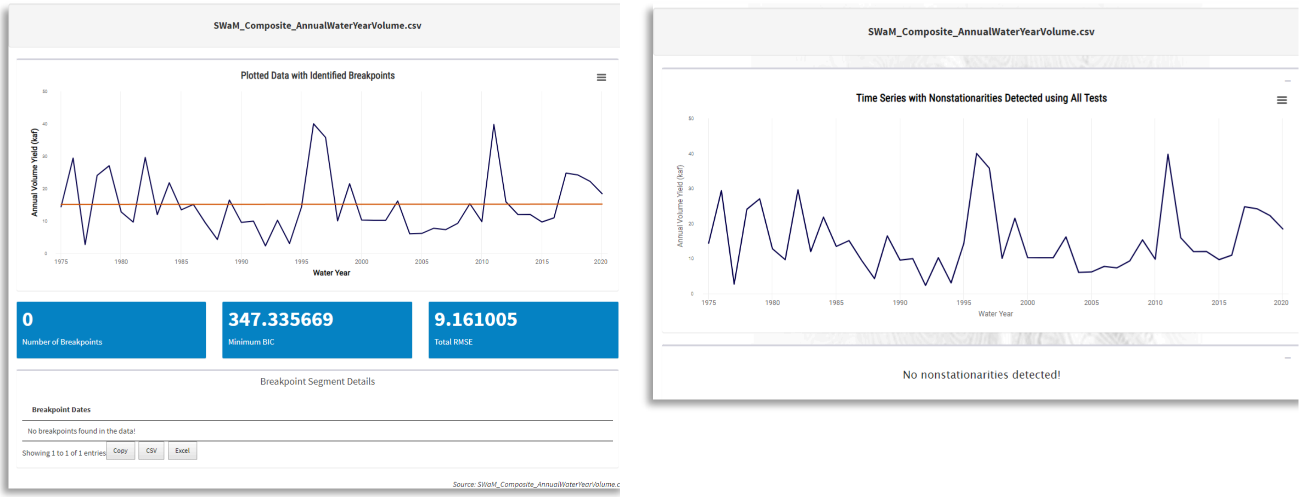


Figure 3-9. Annual volumetric yield Breakpoints and NSD for SWaM composite.

3.3.3 Mean Flow

The TST tools were also used to evaluate mean daily flows for Sweetwater Creek. Because Sweetwater Creek only had measured gage data for water years 2002 to 2019, the record was supplemented with synthetic hindcast data back to 1975 using a correlation to the more extended record from the Lapwai Creek gage (USGS#13342450). The process to develop the SWaM composite flow record with hindcast is detailed in Appendix A Section 2.2.

The SWaM composite record of mean daily flow (Figure 3-10) was evaluated in the TST for general trends. Due to limitations of the TST tool in handling unaggregated timeseries with more than 2500 records, it was only possible to perform a model-based analysis using unaggregated mean daily flow data. The other TST tests for breakpoint and nonstationarity detection were run using monthly and annual aggregates of mean daily flow (Figure 3-11).

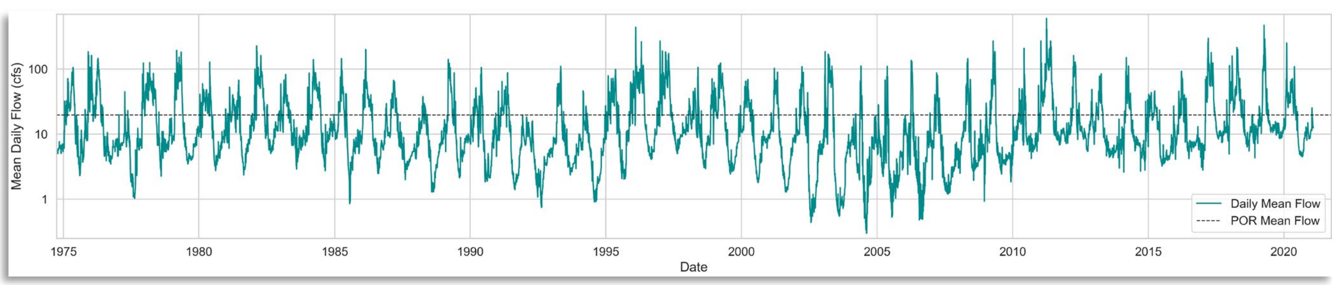


Figure 3-10. Mean Daily Flows for SWaM

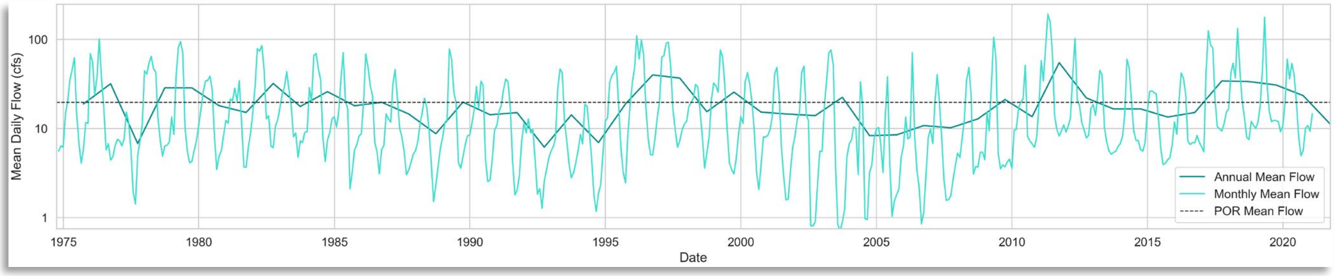


Figure 3-11. Mean monthly and annual flows for SWaM

The seasonality of flow in Sweetwater Creek is characterized by a wetter winter period in the first half of the water year followed by a drastically dryer period in the second half of the water year as illustrated in the TST seasonal cycle graph (Figure 3-12).

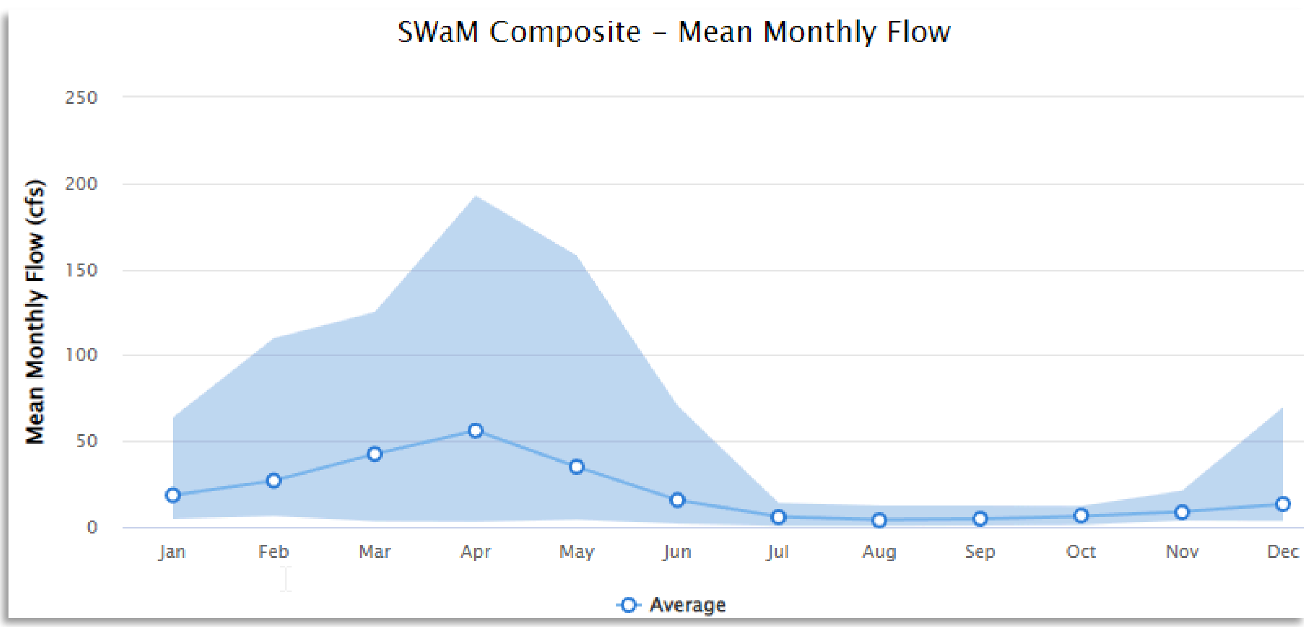


Figure 3-12. Seasonal cycle graph of SWaM mean monthly flow record

To evaluate the underlying trends in mean daily flow, the SWaM composite flow record was seasonally decomposed by partitioning into 3 components (Trend + Seasonality + Remainder) using the TST tool. As illustrated in Figure 3-13, the increasing and decreasing signals in the data are the trend, while the seasonality is a recurring cyclical pattern of equivalent amplitude and wavelength between years. The remainder term represents the LOESS-STL curve fitting residual with a balanced near-zero mean of 0.02cfs and standard deviation of ~21 cfs representing the envelope of variance within the fit.

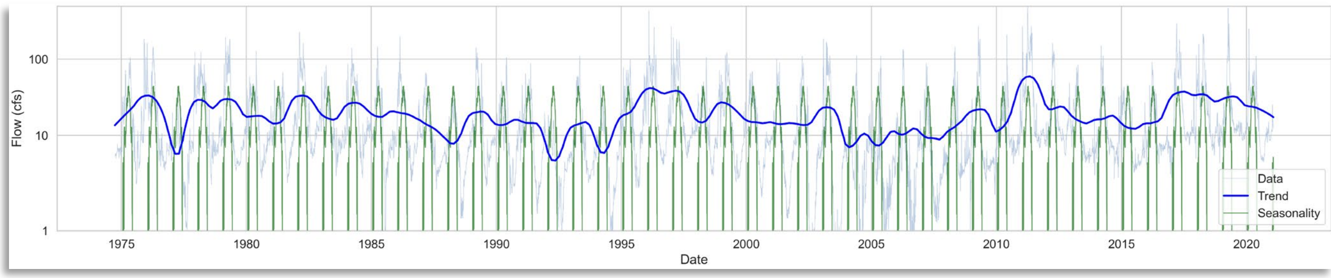


Figure 3-13. Seasonal decomposition of SWaM composite mean daily flow record

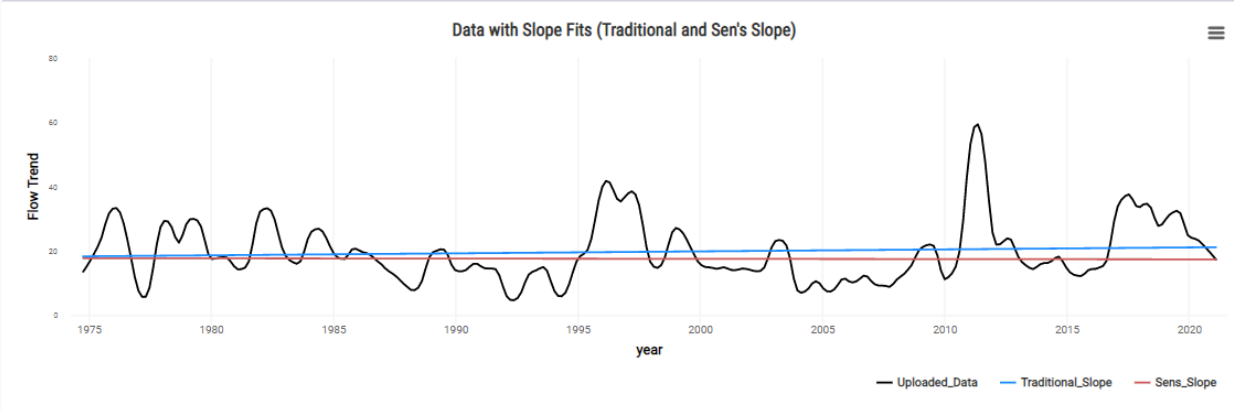
Table 3-6. Mean Flow TST Summary

Sweetwater at Mouth Composite (SWaM)	**Trends**	**Breakpoints**	**Nonstationarities**
Mean daily flow seasonal decomposition trend.	Near-zero slope for mean daily flow trend component. Not significant.	*N/A. Unaggregated daily dataset too large for TST to process breakpoints or NSD.*	
Monthly mean flow	Near-zero positive slope. Not significant. Traditional Slope = +0.053 Sen's Slope = +0.003 <u>Significance</u> t-test = 0.49 Mann-Kendall = 0.92 Spearman Rank-Order = 0.98	No breakpoints detected in mean monthly flow dataset. 4 breakpoints detected in monthly mean flow seasonal decomposition trend representative of multi-year hydroperiods. #1 – September 1986 #2 – October 1994 #3 – September 2001 (between the hindcast and observed flow data) #4 – July 2010	33 abrupt NSD detections in mean monthly flow dataset corresponding to flashy month-to-month seasonal changes. No NSDs in mean monthly flow detected by gradual tests. 26 NSD by distribution tests 9 NSD by means tests 8 NSD by variance tests **0 NSD by smooth tests**

Sweetwater at Mouth Composite (SWaM)	Trends	Breakpoints	Nonstationarities
Annual mean flow	Diverging symmetrical mild positive and negative trends. Traditional Slope = +0.037 Sen's Slope = -0.040 <u>Significance</u> t-test = 0.73 Mann-Kendall = 0.67 Spearman Rank-Order = 0.82	None detected	None detected

Model based analysis trends of slope and significance were performed on the seasonally decomposed mean daily flow dataset. First the daily flow timeseries were seasonally decomposed by partitioning them into 3 components (Trend + Seasonality + Remainder). The linear regression trend analysis of the seasonally decomposed mean daily flow data indicated a near zero positive traditional slope and negative Sen's slope (Figure 3-14). While the parametric student t-Test did indicate that these trends are significant, it requires an assumption of normality, which was invalidated at the α=0.01 threshold based on an omnibus test of normality (D'Agostino, et al. 1971). Further, the nonparametric Mann-Kendall and Spearman Rank-Order tests did not consider the near-zero trends as significant. Annual trends of wetter and dryer years are graphically depicted in Figure 3-3 as deviations above and below the fitted trend intercept of ~ 18 cfs respectively. A similar pattern of near-zero trend slope without significance was also computed for both the mean monthly and mean annual aggregated flows (Figure 3-15).

SWaM-Composite_Flow-MeanDaily_SDecomp-LOESS-STL_TrendComponent.csv



Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	0.000167816	18
Sen's Slope	Negative	-0.0000207147	18

Trend Hypothesis Test

Test	P-Value
t-Test	4.646e-30
Mann-Kendall	0.10846
Spearman Rank-Order	0.022822

- **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 NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 3-14. Mean Daily Trend component for SWaM composite timeseries.

Analysis of both mean monthly and mean annual flows did not detect any significant breakpoints (Figure 3-15). As illustrated in Figure 3-16, a breakpoint analysis on the seasonally decomposed trend of mean monthly flow detected four significant breakpoints: September 1986, October 1994, September 2001, and July 2010. These breakpoints in the mean daily flow trend generally appear to align with year-to-year transitions between dryer and wetter hydroperiods, with two water years (1995 and 2011) characterized by a distinct increase in flow. Numerous abrupt nonstationarities were detected in the mean monthly corresponding to flashy month-to-month seasonal changes (Figure 3-17). No NSDs in mean monthly flow were detected by the gradual methods (smooth Lombard Wilcoxon and Smooth Lombard Mood). Similar to mean monthly flow, the analysis of mean annual flow did not detect any breakpoints or nonstationarities (Figure 3-18).

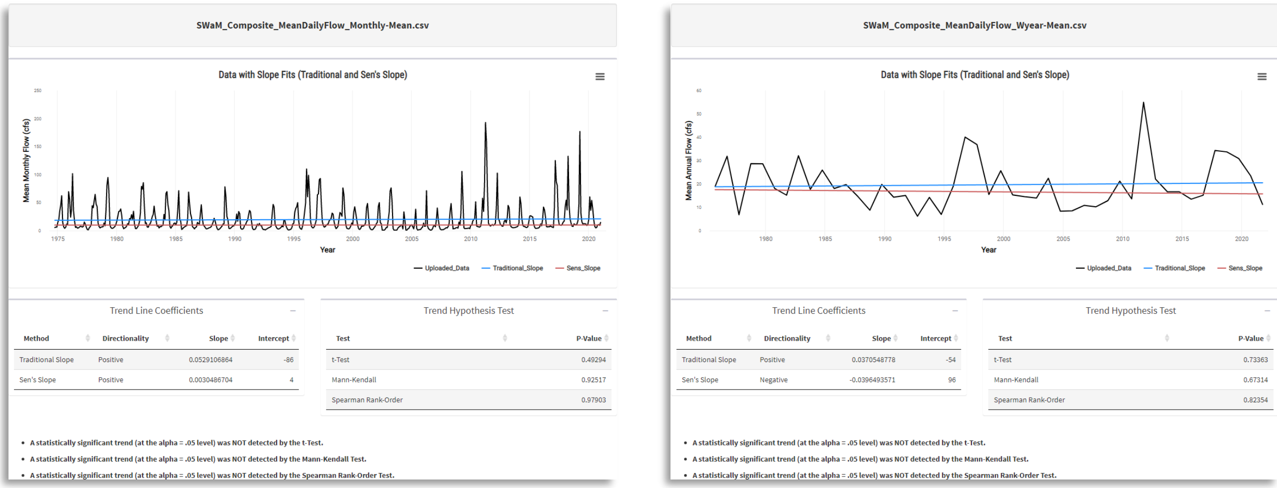


Figure 3-15. SWaM composite. Mean flow trends. *Left plot – monthly mean flow. Right plot: Annual mean flow*

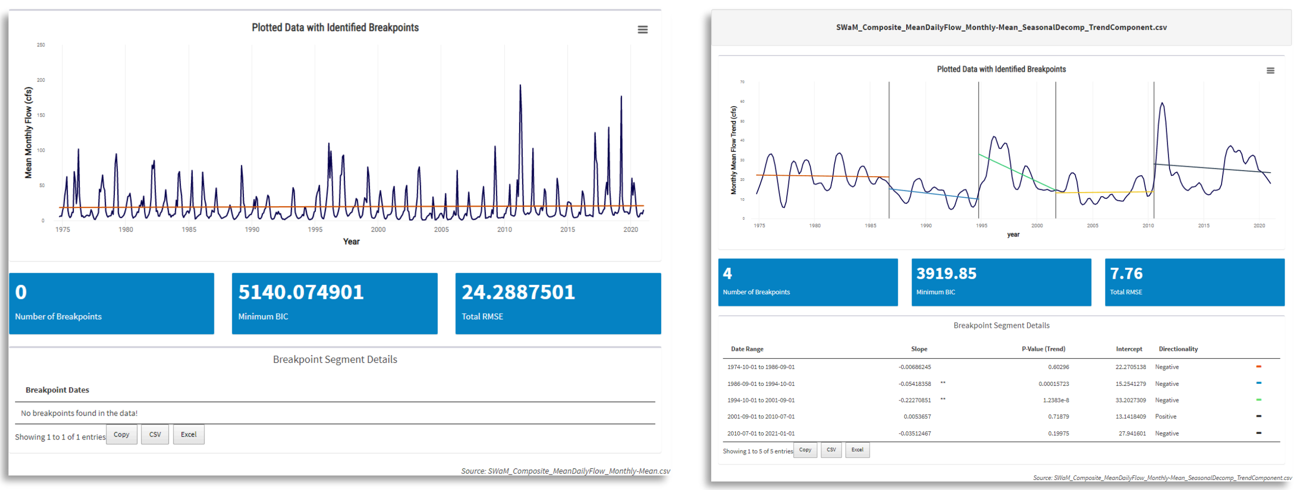


Figure 3-16. Mean flow breakpoints. *Left plot – monthly mean flow. Right plot: seasonally decomposed monthly mean flow trend.*

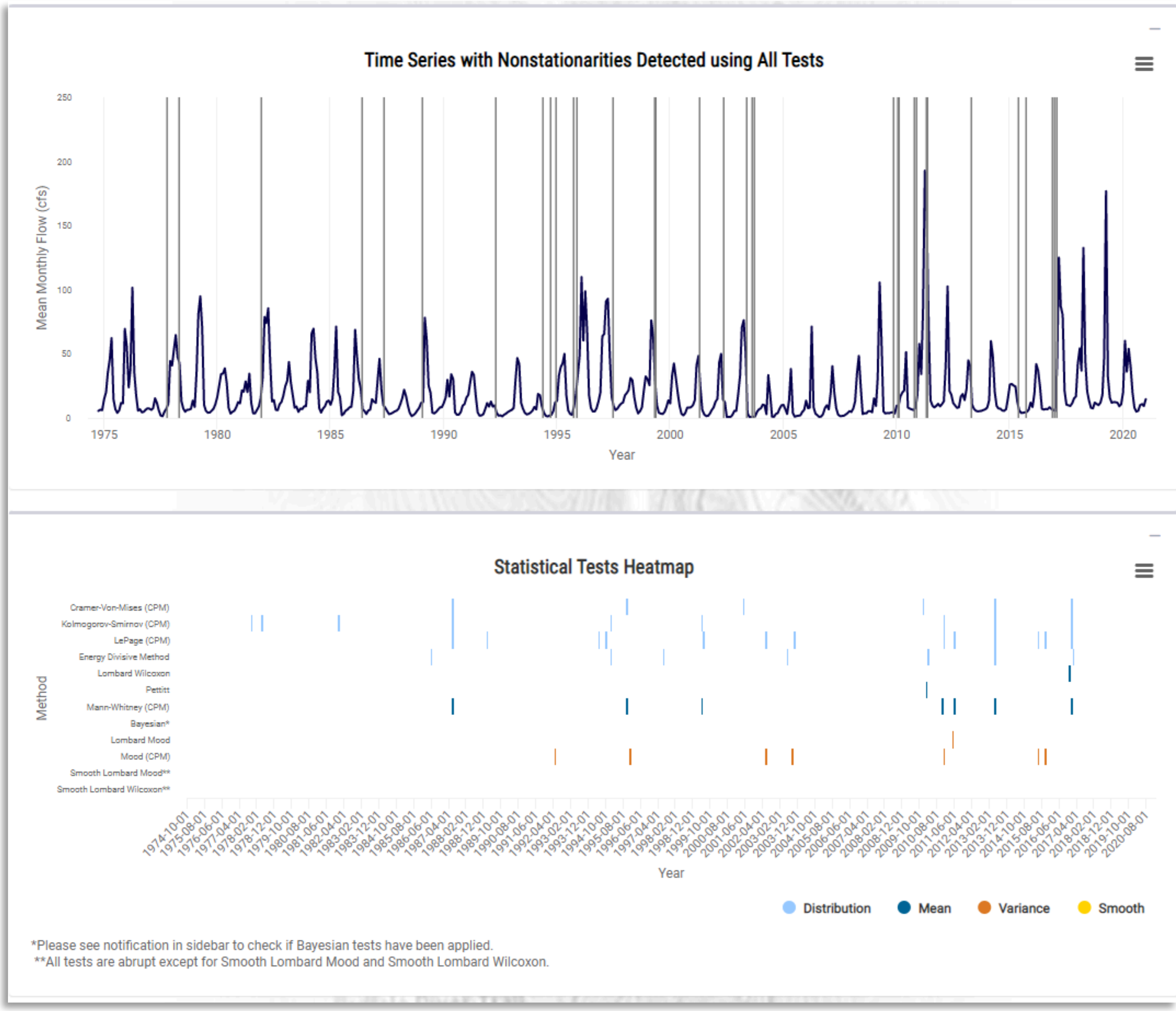


Figure 3-17. SWaM Composite. Mean Monthly Flow NSD.

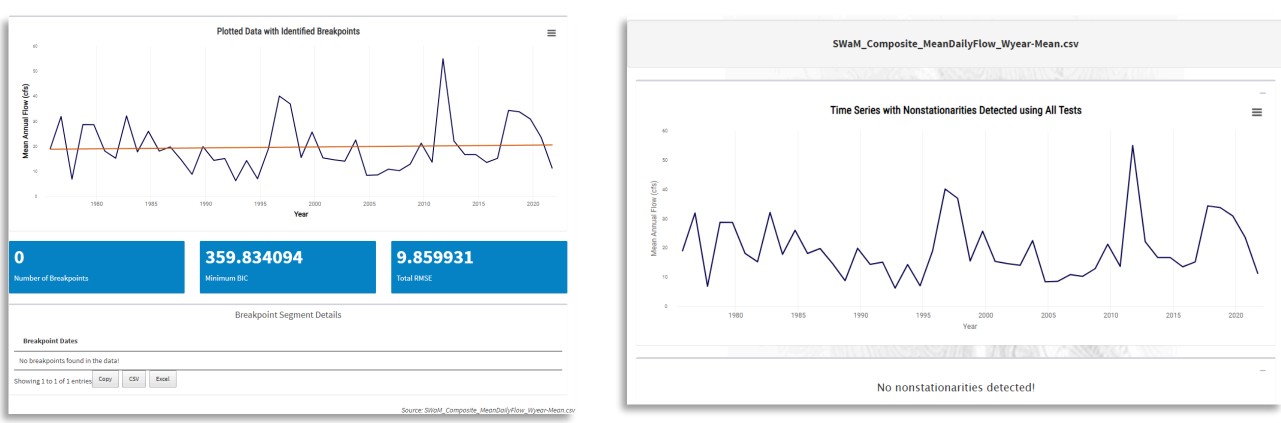


Figure 3-18. SWaM. Mean annual flow breakpoints (left) and nonstationarities (right)

3.3.4 Minimum Flows

The SWaM composite mean daily flow data with historical hindcast was aggregated into annual and monthly minimums to explore low flow trends that my influence performance of the Recommended Plan.

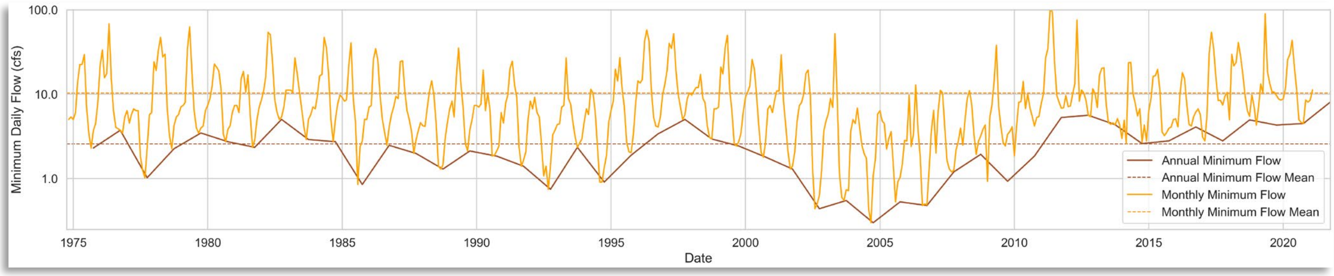


Figure 3-19. SWaM Composite. Minimum Flows

As summarized in Table 3-7 and Figure 3-20, minimum monthly and annual flows did not exhibit any significantly strong trends. Two breakpoints were identified in both the minimum monthly and annual flows (Figure 3-21) that bound a multi-year period of dryer conditions and reduced minimum flows. These breakpoints identify changes in the period of record where linear trends in the data change in slope and direction. Even though the TST identified breakpoints in the data, P values for each segment did not meet the threshold value $P<0.05$ indicating statistical significance. The P values for the three different date ranges indicate a lack of robust statistical significance. Even though there may have been changes detected in the data, the breakpoints did not indicate a significant trend during any of the discretized period of record. This hydroperiod was also identified in the mean flow breakpoint analysis (Figure 3-16).

Table 3-7. Minimum Flow TST Summary

Sweetwater at Mouth Composite (SWaM)	**Trends**	**Breakpoints**	**Nonstationarities**
Monthly minimum flow	Near-zero positive slope. Not significant. Traditional Slope = +0.005 Sen's Slope = +0.0 <u>Significance</u> t-test = 0.90 Mann-Kendall = 0.96 Spearman Rank-Order = 0.98	2 breakpoints detected – #1: May 2001 #2: December 2010.	30 abrupt NSD detections in minimum monthly flow dataset corresponding to flashy month-to-month seasonal changes. 28 NSD by distribution tests 9 NSD by means tests 5 NSD by variance tests **0 NSD by smooth tests**

Sweetwater at Mouth Composite (SWaM)	Trends	Breakpoints	Nonstationarities
Annual minimum flow	Mild positive slope. Traditional Slope = +0.036 Sen's Slope = +0.020 <u>Significance</u> **t-test = 0.04** Mann-Kendall = 0.32 Spearman Rank-Order = 0.17	2 breakpoints & nonstationarities detected. #1 at start of water year 2001 between the hindcast and observed flow data, #2 at start of WY 2011, a much wetter year than the prior decade.	3 NSD detected by abrupt methods that coincide with the identified breakpoints.

Nonstationarity analysis of minimum flows identified 30 abrupt discontinuities corresponding to flashy month-to-month minimum flows.

The minimum-flow nonstationarities detected by the 12 statistical tests are plotted in Figure 3-22

While there are many nonstationarities detected by the distribution tests, the frequent changes and cyclical variation of the monthly streamflow data throughout the season is not indicative of a longer term trend.

The Mean tests reported several nonstationarities and upon further investigation those points coincided with years where the peak minimum flows were significantly lower than surrounding years. The rapid changes in flow values between dry and wet water years could have created a significant change flagged by the statistical tests. While these points are flagged as a nonstationarity, it is very common to have large fluctuations between minimum flows between one year to the next.

The most telling and significant statistical test results are the variance tests as these indicate changes over the period of record that can be identified by broader patterns of monthly minimum streamflow data. Variation in precipitation and streamflow are common year to year, and across the data set one can see the changes from periods of dry years to period of wet years and flood years. These changes were identified by the variance statistical tests. The first two variance statistical test flagged year 1992 where the monthly minimum reached its lowest value from the start of the period of record. The next nonstationarity flagged by the variance tests was in 2002. The period between these two nonstationarities was a period where minimum flows started to increase. At the 2002 flagged nonstationarity, the data seems to change to a trend of lower minimum flows. The peak minimum flow in 2002 was significantly lower than the previous several years of peak minimums. From 2002 until about 2010, minimum flows stayed relatively low compared to the entire period of record. The final two flagged variance test nonstationarities occurred in Nov 2009 and December 2010. This approximate one-year time span is the last low point before several significant higher flow years were recorded.

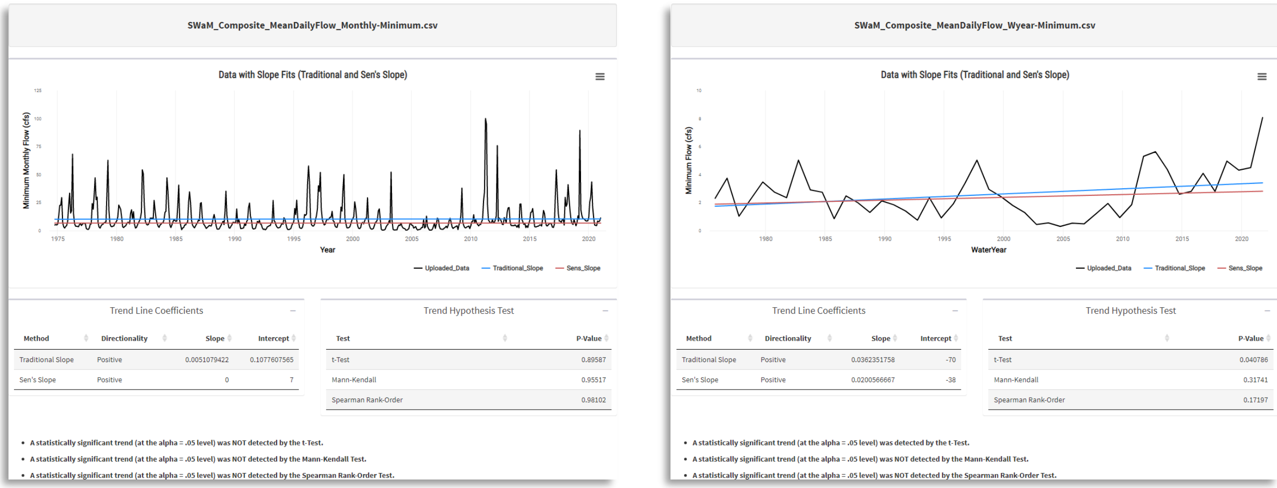


Figure 3-20. SWaM Composite. Minimum flow trends. *Left plot – monthly minimum flow. Right plot: Annual minimum flow*

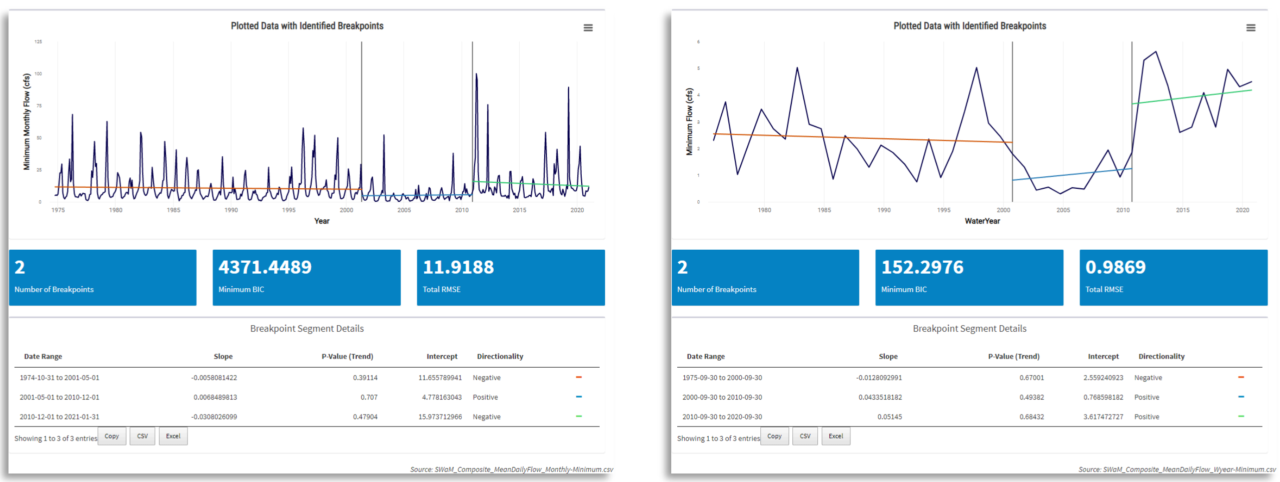


Figure 3-21. SWaM Composite. Minimum flow breakpoints. *Left plot – monthly minimum flow. Right plot: Annual minimum flow*

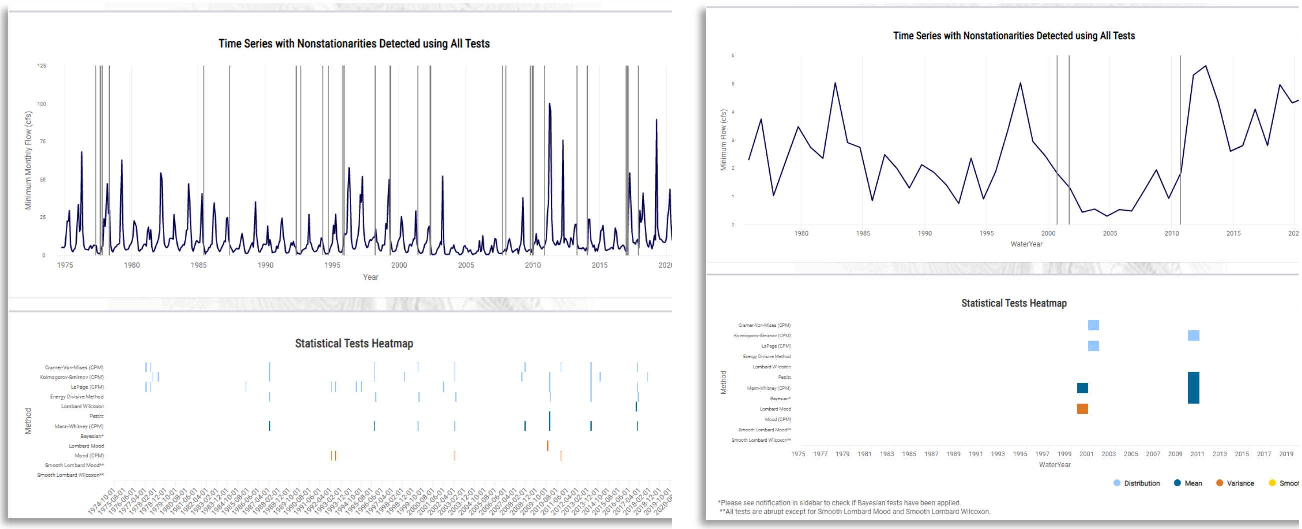


Figure 3-22. SWaM Composite. Minimum flow NSD. *Left plot – monthly minimum flow. Right plot: Annual minimum flow*

4 Climate Hydrology Assessment Tool (CHAT)

This section of the climate change assessment focuses on carrying out first order statistical analysis within HUC 17060306 Clearwater River Basin using the USACE Climate Hydrology Assessment Tool (CHAT). The CHAT displays various simulated historic and future, climate-changed streamflow, temperature, and precipitation outputs derived from 32 Global Climate Models (GCMs). The CHAT uses Coupled Model Intercomparison Project Phase 5 (CMIP5) GCM meteorological data outputs that have been statistically downscaled using the Localized Constructed Analogs (LOCA) method. GCMs rely on scenarios representing different pathways to a given atmospheric concentration of greenhouse gas emissions (GHG) referred to as representative concentration pathways (RCPs). RCPs describe the change in radiative forcing at the end of this century, as compared with pre-industrial conditions. Projected hydroclimate timeseries in CHAT for 2006 to 2099 are produced using two future scenarios: RCP 4.5 (where greenhouse gas emissions stabilized by the end of the century) and RCP 8.5 (where greenhouse gas emission continue to increase throughout the century). Simulated output representing the historic period of 1951 to 2005 is generated using a reconstitution of historic GHG emissions.

To analyze runoff, LOCA-downscaled GCM outputs are used to force an unregulated Variable Infiltration Capacity (VIC) hydrologic model (Liang et al., 1994). Areal runoff from VIC is then routed through a stream network using mizuRoute. Outputs represent the daily in-channel routed runoff (i.e., streamflow) for each stream segment – valid at the stream segment endpoint. Since runoff is routed, the streamflow value associated with each stream segment is a representation of the cumulative flow, including all upstream runoff, as well as the local runoff contributions to that specific segment. For this scenario, the project specific location is within Sweetwater Creek (HUC 170603061205), stream segment 17001827 of the Clearwater Basin. Figure 4-1 below depicts the Clearwater HUC 17001827 shaded in dark gray with the Sweetwater Creek stream segment, highlighted in yellow, and Lower Clearwater River (terminal stream segment of HUC8) highlighted in red.

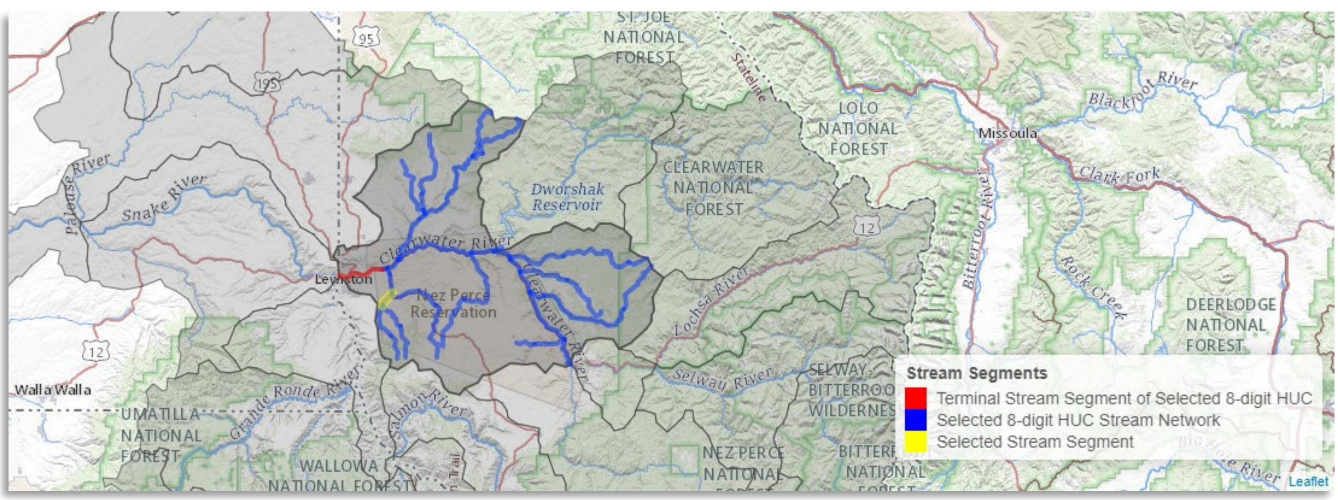


Figure 4-1. CHAT Analysis. Lower Sweetwater Creek (Stream Segment ID#17001827) within Lower Clearwater (HUC17060306)

4.1 CHAT Assessment Summary

The USACE Climate Hydrology Assessment Tool (CHAT) v2.3 was used to investigate historical and potential future trends in: Annual Maximum of Mean Monthly streamflow, Annual Mean 1-day streamflow, Maximum and Minimum 1-day Temperature, Annual/1-Day/3-Day Accumulated Precipitation, and Consecutive Days without Precipitation for HUC 17060306 (Clearwater). Annual Volume was not analyzed in the tool as the volume data included in the CHAT appeared to be erroneous and did not indicate any meaningful data historic or future trends.

Review of baseline and forecast results across multiple metrics from USACE's Climate Hydrology Analysis Tool (CHAT), helps to create a general climate forecast for the Lower Sweetwater Creek project area and inform the hydrometeorological risk to performance and sustainability within the project service life. Based on the climate literature synthesis and significant results from the CHAT projections of future conditions through the end of the 21st century, there is compelling evidence to suggest that summers in the future will be hotter and characterized by longer periods of drought, while winters will be warmer with increased amounts of precipitation.

Monthly temperature extremes are projected to increase for all months, reflected in the change in monthly-maximum temperature box plot. Precipitation is projected to increase for the months November to April with the greatest increases in precipitation changes for the month of April. Interestingly, the month of April is projected to have a decrease in mean-monthly streamflow while precipitation is projected to increase. In reviewing the trends in annual mean-monthly streamflow compared to the change in monthly mean streamflow box plots, there is an overall downward trend in streamflow and a shift to the pattern of when stream flow is at its highest from early spring to late winter with summer and fall flows predicted to be consistently lower.

The CHAT climate projections of having warmer winter temperatures and more winter precipitation events would likely cause a reduction in the amount of snow runoff which could explain the reduction in streamflow projected for the months of April and May. The rising maximum temperatures and longer spans of days without precipitation correlate to the projected decrease in monthly mean streamflow for the typically warmer months of April through October.

As the maximum temperatures consistently rise and consecutive days without precipitation increase through the end of the end of the century, mean monthly streamflow for typically warmer summer months show a projected decrease. The magnitude of CHAT projected decreases in summer streamflow may not necessarily be realized in lower Sweetwater Creek as the system is operated to maintain baseflow levels during key ecologic periods in accordance with a negotiated water exchange as discussed in Appendix A, Section 2.2.

The projected increased precipitation and streamflow during the shoulder seasons and winter months would be expected to beneficial in that it could extend the annual duration of transitional flows up to bankfull discharge which would sustain riparian benefits within the project corridor. The potential for future increase in the maximum 1-day and 3-day precipitation indicated a weak positive trend that was only found to be significant under an RCP 8.5 scenario. The potential for mixed-precipitation and rain-on-snow events is a concern if it was to increase the frequency or magnitude of damaging floods in the channel corridor.

Longer periods of drought and higher temperatures that contribute to lower summer flows could have negative impact to aquatic and riparian habitat from decreased dissolved oxygen due to warmer, lower streamflow.

4.2 CHAT Assessment Results

4.2.1 Temperature

Historical and projected trends from the 32 GCM simulations were analyzed in the CHAT for the annual maximum and minimum 1-day temperature. The temperature range for the projected future (2006-2099) shows significant increase for in both maximum and minimum annual temperatures as illustrated in Figure 4-2. While the RCP 4.5 scenario trends indicate an increase in the projected range of temperatures, they are not as extreme as RCP 8.5.

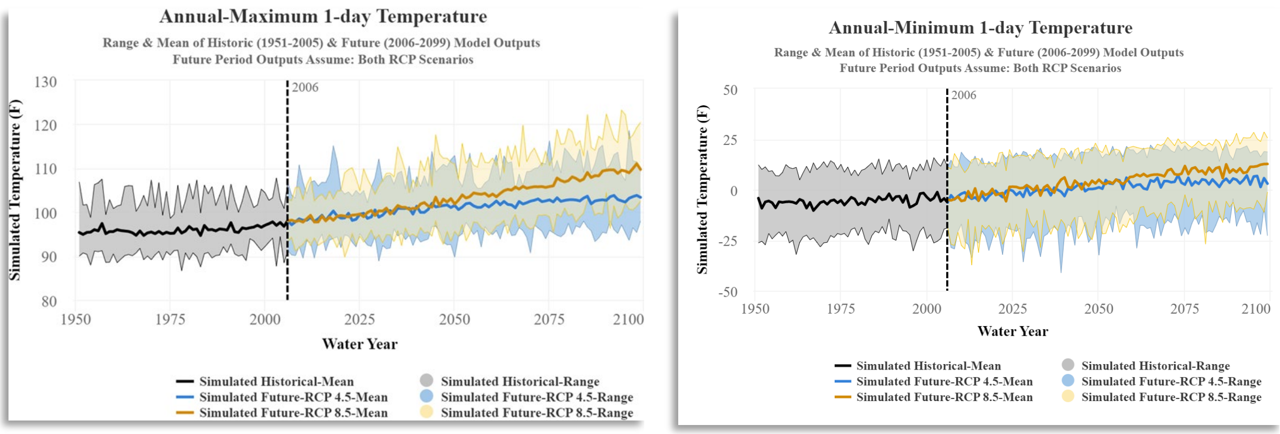


Figure 4-2. CHAT Simulated Annual 1-day maximum and minimum temperature. Lower Sweetwater Creek (HUC170603061205)

As depicted in Figure 4-3, the CHAT analysis indicates that historical temperatures have been increasing during the second half of the 20th century, with future forecasts that indicate a significant positive trend in both maximum and minimum annual temperatures.

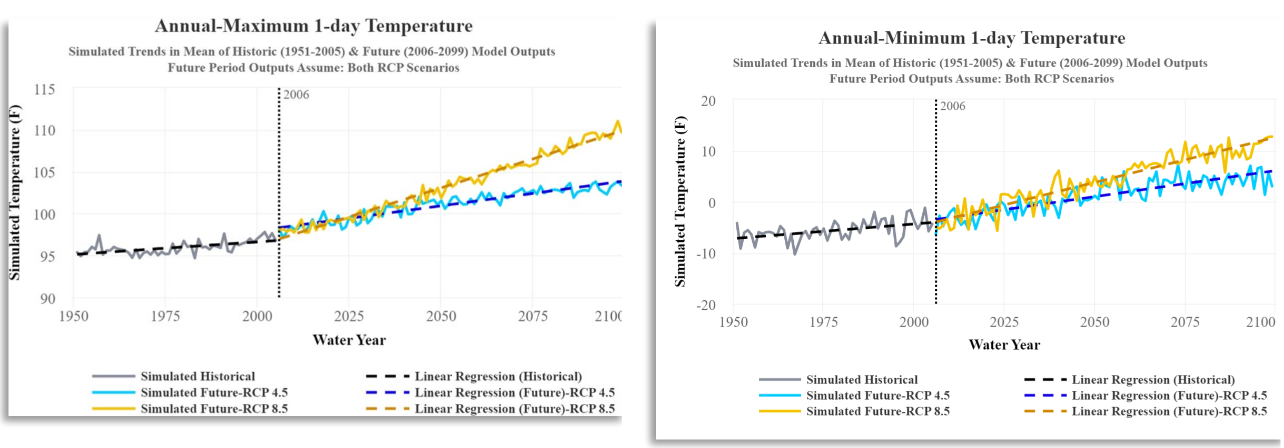


Figure 4-3. CHAT Simulated Annual 1-day maximum and minimum temperature trends. Lower Sweetwater Creek (HUC170603061205)

Increasing temperatures pose an issue for proposed project riparian and aquatic habitat especially if combined with longer periods of drought indicated by the CHAT. As summarized in Table 4-1, the positive trend in both historical and future annual temperatures is significant, based on near-zero P values across both parametric and non-parametric tests. Based on the trend lines all tests indicate a strong level of consensus and exhibit robust statistical significance that historic temperatures have been increasing and the future rate of temperature increase will be larger, especially under the RCP 8.5 scenario. Slope comparison indicates that historical annual minimum temperatures have been rising nearly twice as fast as historical annual maximum temperatures, which is expected to continue under the future RCP 4.5 scenario. For the future RCP 8.5 scenario the rate of change in projected minimum annual temperature is about thirty percent higher than for the maximum temperature.

Table 4-1. CHAT Simulated Annual maximum and minimum 1-day temperature trends. Lower Sweetwater Creek (HUC170603061205)

Trend Analysis	Historic (1951-2005)		Future (2006-2099) RCP 4.5		Future (2006-2099) RCP 8.5	
	Statistically significant	Slope	Statistically significant	Slope	Statistically significant	Slope
t-Test	Yes	0.0301 T_{max} 0.0571 T_{min}	Yes	0.0595 T_{max} 0.1021 T_{min}	Yes	0.1385 T_{max} 0.1769 T_{min}
Mann-Kendall	Yes		Yes		Yes	
Spearman Rank Order	Yes		Yes		Yes	

Box plots depicting the distribution of the change in monthly temperature extremes were included from the CHAT as illustrated in Figure 4-8. RCP 4.5 scenario is represented by red box plots and RCP 8.5 is represented by blue box plots. The figures below show simulated changes in temperature (deg. F) from the Base Epoch (1976-2005) to the Mid-Century Epoch (2035-2064) and from the Base Epoch to End-Century Epoch (2070-2099).

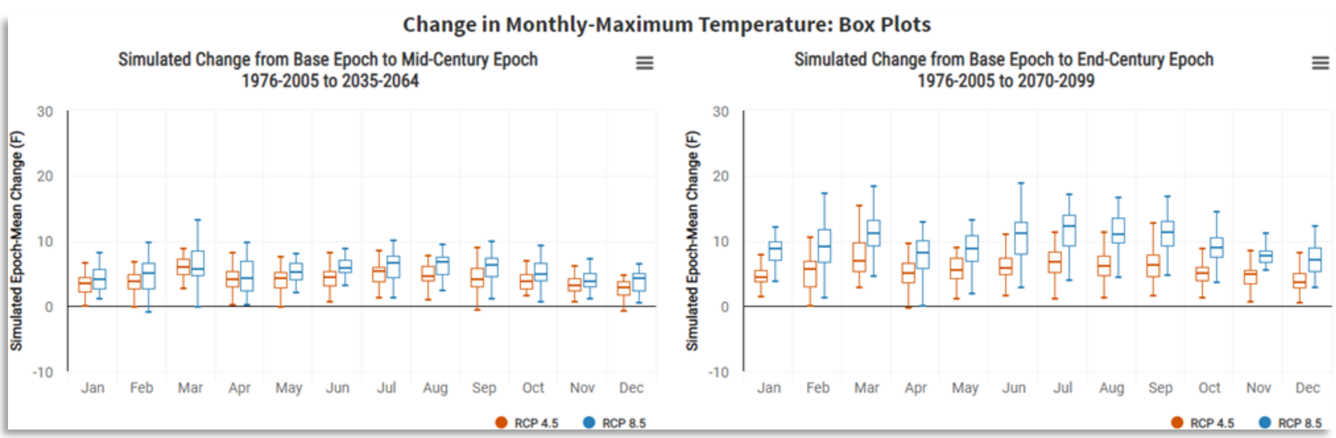


Figure 4-4. CHAT. Seasonal change in monthly-maximum temperature. Lower Sweetwater Creek (HUC170603061205)

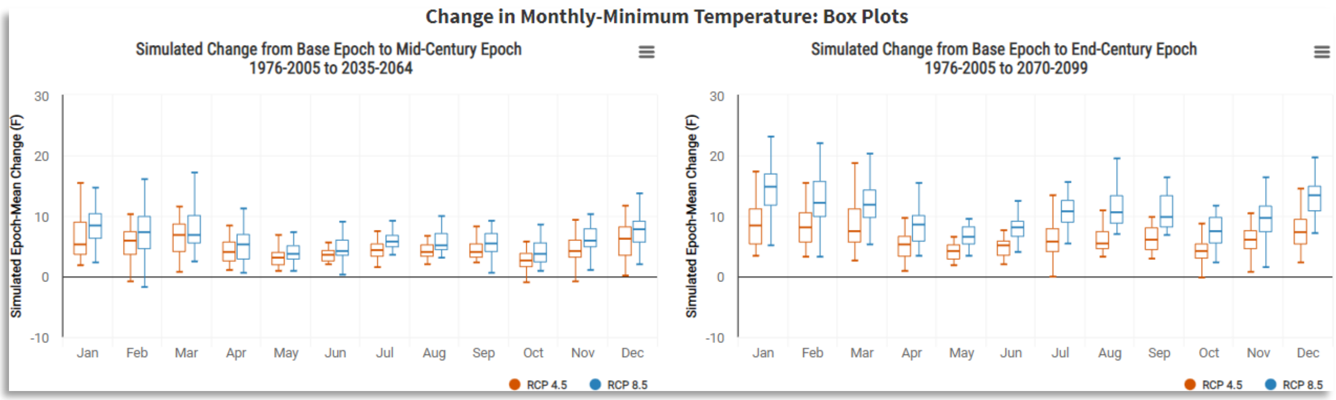


Figure 4-5. CHAT Seasonal change in monthly-minimum temperature. Lower Sweetwater Creek (HUC170603061205)

As illustrated in Figure 4-4 and Figure 4-5, changes in monthly maximum and minimum temperature show increasing trends for all months of the year for both Epochs. For mid-century epoch RCP 4.5 and 8.5 have similar increases in monthly temperatures with median values for RCP 8.5 months typically in line with upper quartile values of RCP 4.5. The spread between upper and lower quartiles for RCP 4.5 and 8.5 for Mid-Century are small with minimal variation. The simulated change from base epoch to end-century epoch has a slightly larger increases in median values for RCP 4.5 from mid-century epoch values and significantly larger medians and larger variability between upper and lower quartiles for RCP 8.5. Minimum monthly temperatures during the winter months are projected to be much larger than during the summer months which tracks with the literature consensus of warmer wetter winters for the inland northwest. The farther into the future the models are projecting temperature changes, the more uncertainty there appears to be, particularly with RCP 8.5 scenario. However, it is consistent across all months that temperature changes are projected to increase through the next century.

4.2.2 Precipitation

Based on the Climate Literature Synthesis, there is a wide agreement that precipitation events will become more frequent and with larger intensities. The CHAT was used to evaluate projected future precipitation conditions forecasted by the GCMs for Sweetwater Creek in the Clearwater Basin (Figure 4-6). The model outputs show a projected rise in annual precipitation for both RCP 4.5 and 8.5 scenarios. The simulated RCP 4.5 shows a more drastic increase and variability in annual precipitation. The amount of precipitation over the project area would have a large variability from year to year between wet and dry years, but an overall trend in increased annual precipitation. The RCP 8.5 scenario also projects an increase in annual precipitation, but not as extreme and slightly less variability between water years as the RCP 4.5 scenario.

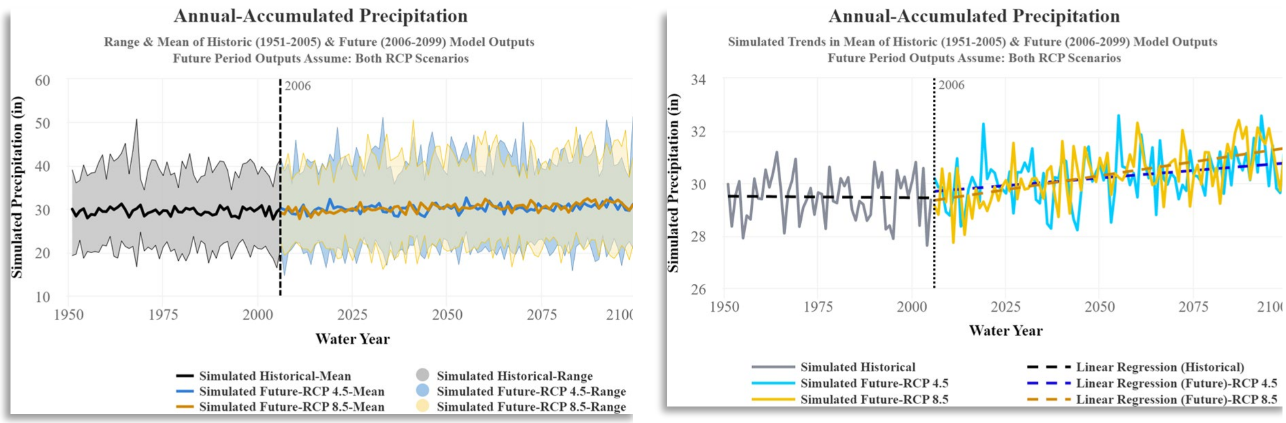


Figure 4-6. CHAT Projected Annual-Accumulated Precipitation. Lower Sweetwater Creek (HUC170603061205)

Table 4-2. CHAT summary for Annual Accumulated Precipitation Trends. Lower Sweetwater Creek (HUC170603061205)

Trend Analysis	Historic (1951-2005)			Future (2006-2099) RCP 4.5			Future (2006-2099) RCP 8.5		
	P Values	Statistically significant	Traditional Slope	P Values	Statistically significant	Slope	P Values	Statistically significant	Slope
t-Test	0.879	No		0.000746	Yes		1.96e-10	Yes	
Mann-Kendall	0.885	No	-0.0012	0.00177	Yes	0.0115	2.2e-16	Yes	0.0213
Spearman Rank Order	0.942	No		0.00103	Yes		2.67e-10	Yes	

Historical trend lines for annual accumulated precipitation did not show a statistical significance (P Values above 0.05) and the trend line slope is approximately equal to zero meaning historical annual precipitation values were not showing increasing or decreasing trends. When evaluating the projected future trend lines, both RCP 4.5 and 8.5 scenarios had all three statistical trend analysis test return P values approximately equal to zero indicating robust statistical significance of the increase. Both scenarios project an increasing trend in annual precipitation. Even though RCP 4.5 seems to have more variability in amount of precipitation from year to year, RCP 8.5 has a steeper trend slope line. Increased annual precipitation could be of benefit for the restoration project providing a greater annual supply of water to the area. However, even though annual precipitation amounts are projected to increase, the timing of these events are not accounted for with an annual accumulation value. More precipitation during months where stream flows are already typically high could become a concern for floodplain exceedance. Reservoirs in the system could be managed to capture the increased precipitation and control the releases and help dampen the variability of flows in the stream system throughout the course of the year to maintain minimum threshold flows for the restoration project viability.

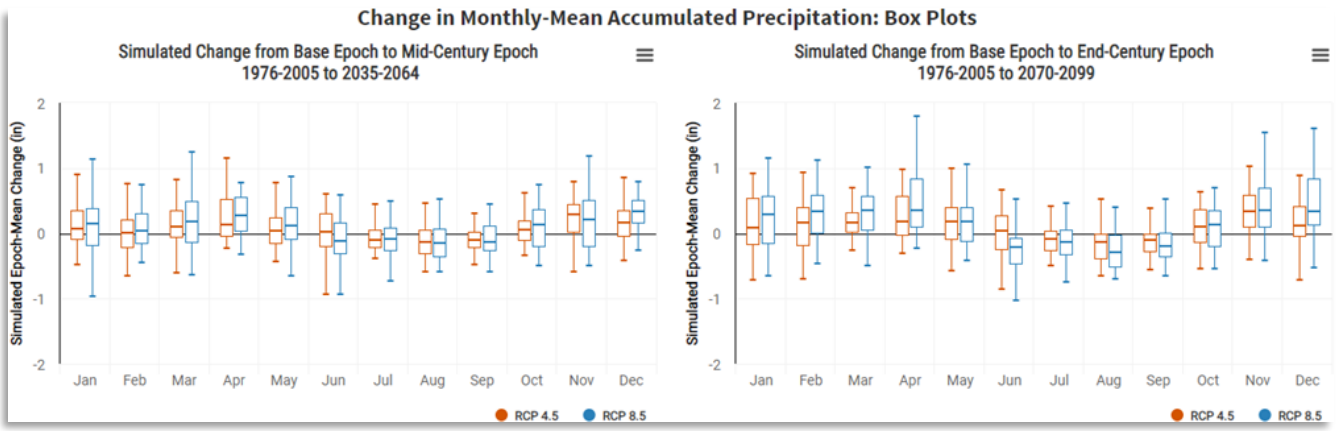


Figure 4-7. CHAT. Mean Monthly Accumulated Precipitation Seasonal change. Lower Sweetwater Creek (HUC170603061205)

Box plots for monthly changes in accumulated precipitation were included from the CHAT. The box plots show simulated changes from the Base Epoch (1976-2005) to the Mid-Century Epoch (2035-2064) and from the Base Epoch to End-Century Epoch (2070-2099). The Mid-Century Epoch changes in monthly accumulated precipitation for both RCP scenarios (4.5 and 8.5) project slight increases for months November through April with February medians even with historical values. Months June through September show upper quartiles even with historical values and median and lower quartiles below historic values. Months May and October have large variations between the upper and lower quartiles with the medians close to historic values. The changes from Base Epoch to End-Century Epoch follow the same trends as Mid-Century Epoch with larger variations between minimums and maximums as well as between upper and lower quartiles. The box plots for the month-mean accumulated precipitation provide another lens to view changes in accumulated precipitation and how it would impact the project area.

Annual maximum 1-day and 3-day precipitation were also evaluated in the CHAT as an indicator of intense and extended duration storms respectively. As summarized in Table 4-3, the historical period from the second half of the 20th century was not characterized by significant trends for either the 1-day or 3-day maximum precipitation. For the future RCP 4.5 scenario, the predicted slope was near-zero for both precipitation metrics and only significant by the Spearman Rank-Order test. A significant positive mild slope was predicted in both the 1-day and 3-day maximum precipitation under the RCP 8.5 scenario. Seasonality of the 1-day and 3-day maximum precipitation indicates only slight seasonal deviation in the monthly distribution from historical baseline with slight increases in the winter and spring, and slight decreases in the summer (Figure 4-8 and Figure 4-9)

Table 4-3. CHAT Simulated maximum 1-day and 3-day precipitation trends. Lower Sweetwater Creek (HUC170603061205)

Trend Analysis	**Historic (1951-2005)**		**Future (2006-2099) RCP 4.5**		**Future (2006-2099) RCP 8.5**	
	Statistically significant	**Slope**	**Statistically significant**	**Slope**	**Statistically significant**	**Slope**
t-Test	No	2e-4 P_{1day} 1.1e-2 P_{3day}	No	3e-4 P_{1day} 6e-4 P_{3day}	Yes	2e-3 P_{1day} 3e-3 P_{3day}
Mann-Kendall	No		No		Yes	
Spearman Rank Order	No		Yes		Yes	

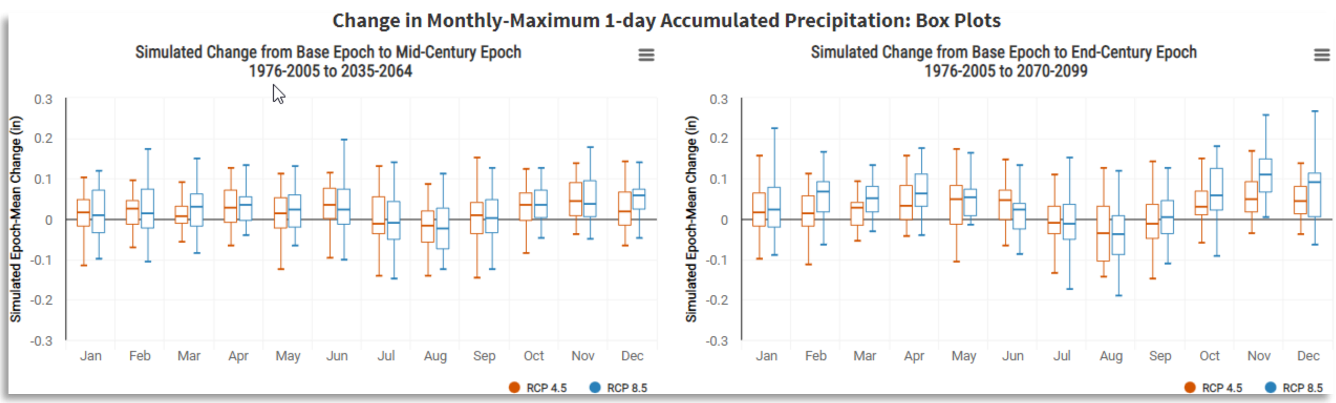


Figure 4-8. CHAT. Monthly-Maximum 1-day precipitation Seasonal change. Lower Sweetwater Creek (HUC170603061205)

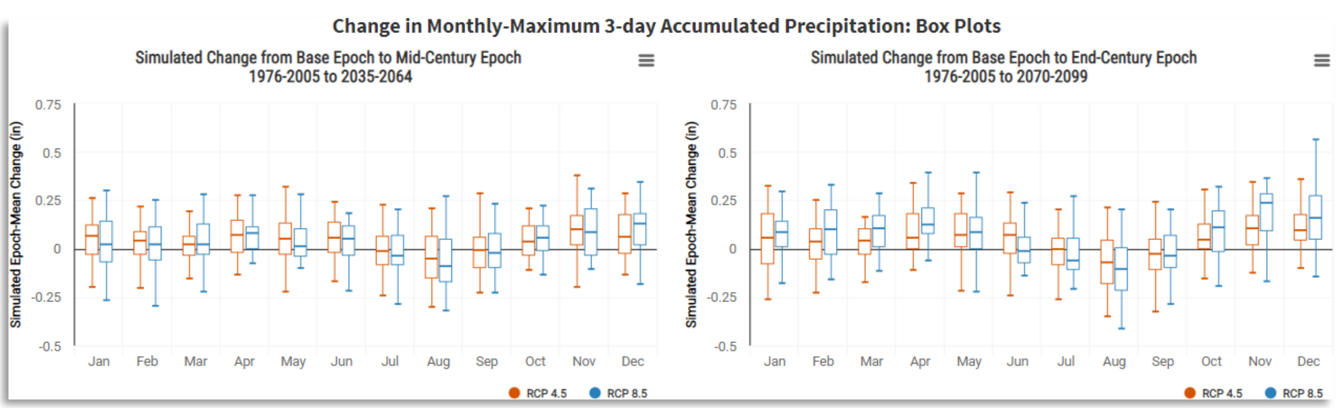


Figure 4-9. CHAT. Monthly-Maximum 3-day precipitation Seasonal change. Lower Sweetwater Creek (HUC170603061205)

Another climate aspect that is relevant to the project in the number of consecutive dry days as this could have a significant impact on aquatic and riparian habitats. The CHAT generated future projections of increasing number or dry days for periods 2006 to 2099 (Figure 4-10). Historically consecutive dry days show a mean span of about 20 days. Future conditions for RCP 4.5 and 8.5 show an increasing trend and considerable increases in range for consecutive days without precipitation with mean spans of approximately 25 days.

All three trend tests returned P values of less than 0.05 for Historic, RCP 4.5, and RCP 8.5 trendlines. This indicates all trends exhibit robust statistical significance. The RCP 8.5 scenario shows a stronger increasing trend in the number of dry days. RCP 4.5 initially projects a higher mean value for dry spans, but by 2025 is surpassed by trends from RCP 8.5 scenario. Typically, this area receives the most amount of consecutive dry days during the summer and longer spans of dry days could have significant impacts to aquatic and riparian habitat.

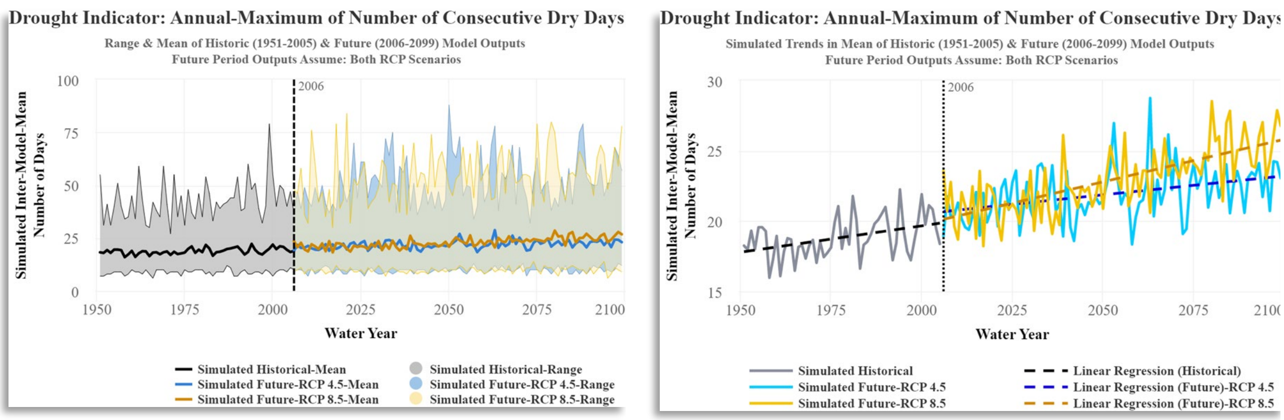


Figure 4-10. CHAT Projected Annual-Accumulated Precipitation. Lower Sweetwater Creek (HUC170603061205)

Table 4-4. CHAT summary for Drought Indicator. Annual Maximum of Number of Dry Days. Lower Sweetwater Creek (HUC170603061205)

Trend Analysis	Historic (1951-2005)			Future (2006-2099) RCP 4.5			Future (2006-2099) RCP 8.5		
	P Values	Statistically significant	Traditional Slope	P Values	Statistically significant	Slope	P Values	Statistically significant	Slope
t-Test	0.00146	Yes	0.0376	7.9e-05	Yes	0.0271	5.53e-16	Yes	0.0605
Mann-Kendall	0.00343	Yes		9.3e-06	Yes		2.2e-16	Yes	
Spearman Rank Order	0.00237	Yes		1.02e-05	Yes		2.25e-16	Yes	

4.2.3 Streamflow

CHAT analysis of historical and projected mean monthly streamflow output from the 32 GCM simulations is illustrated in Figure 4-1 below which depict the range of results and corresponding trendlines for RCP 4.5 and 8.5 scenarios. The RCP 4.5 scenario is represented by blue and RCP 8.5 scenario is represented by yellow in all figures. As expected for this type of analysis, there is considerable, but consistent spread in the projected annual maximum monthly flows. The spread in the projected annual maximum monthly flows is indicative of the high degree of uncertainty associated with projected, climate changed hydrology. The maximum of mean monthly streamflow exhibits a downward trend from 2006 to 2099 but the ranges for both RCP 4.5 and 8.5 have large variabilities. In some instances, for the RCP 4.5 scenario, there is potential for the maximum of monthly mean to exceed historical values.

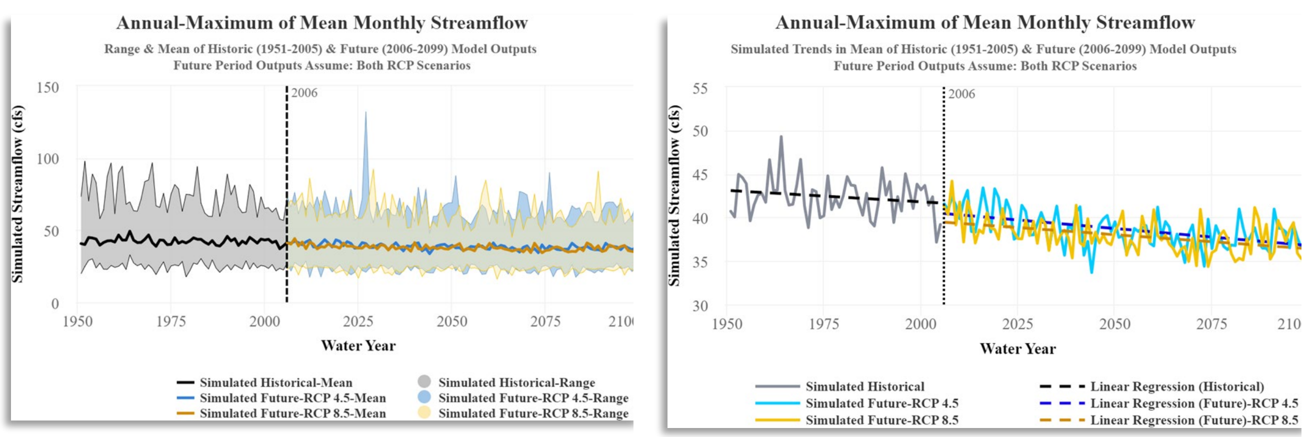


Figure 4-11. CHAT. Mean Projected Annual Maximum of Mean Monthly Streamflow. Lower Sweetwater Creek (Stream Segment ID#17001827) within Lower Clearwater (HUC17060306)

Table 4-5. CHAT summary for Annual Maximum of Mean Monthly Streamflow Trends. Lower Sweetwater Creek (Stream Segment ID#17001827) within Lower Clearwater (HUC17060306)

Trend Analysis	Historic (1951-2005)			Future (2006-2099) RCP 4.5			Future (2006-2099) RCP 8.5		
	P Values	Statistically significant	Slope	P Values	Statistically significant	Slope	P Values	Statistically significant	Slope
t-Test	0.167	No		7.62E-08	Yes		3.58E-06	Yes	
Mann-Kendall	0.316	No	-0.026	3.03E-07	Yes	-0.039	5.45E-06	Yes	-0.033
Spearman Rank Order	0.327	No		1.10E-07	Yes		8.99E-06	Yes	

Trendlines for both historical and future annual maximum streamflow conditions indicate downward direction, however P values for the historical trendline do not indicate a statistical significance. All statistical test for both the RCP 4.5 and RCP 8.5 future trend lines have P values less than 0.05 indicating statistical significance. Qualitatively, the mean estimated decrease in the CHAT maximum mean monthly streamflow change from the breakpoint to 2099 is ~6 cfs. Using the decreasing slope of -0.0325 cfs/year this would accumulate to only about a 2 cfs over the 50-year service life of the project. This small projected drop in flows is not expected to have an overly significant impact within Sweetwater Creek which receives tiered minimum baseflows in accordance with a negotiated water exchange as described in Appendix A, Section 2.2. Nonetheless, considering the arid nature of the project area, regional trends in overall decreased streamflow could result in the Sweetwater exchange operating at the lowest minimum tier.

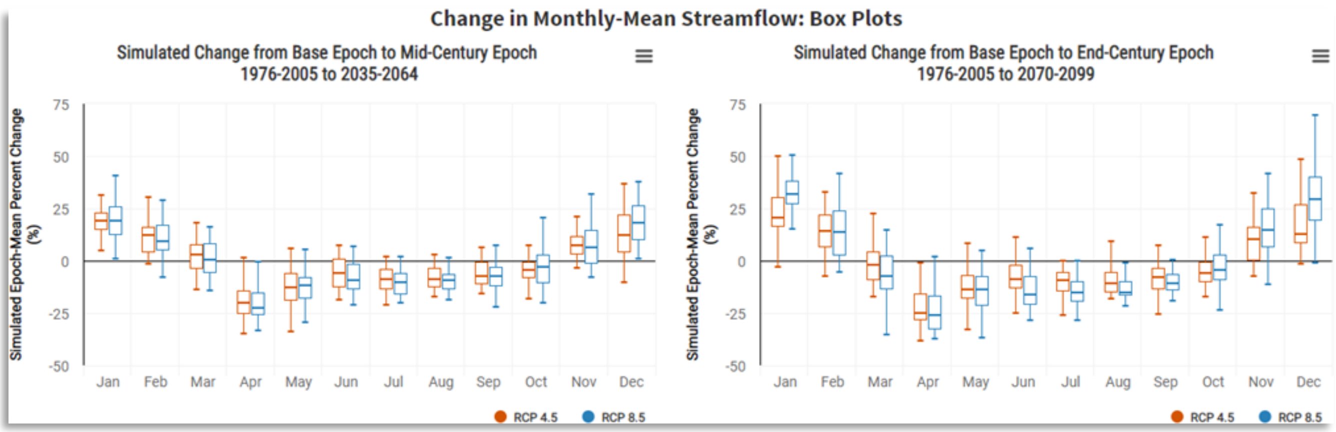


Figure 4-12. CHAT. Mean Monthly Streamflow Seasonal change. Lower Sweetwater Creek (Stream Segment ID#17001827) within Lower Clearwater (HUC17060306)

While the overall trend of Mean of Monthly Streamflow is predicted to decrease, the future seasonal change can be evaluated by comparing boxplots of the distribution as plotted in Figure 4-2. The simulated change from the Base Epoch to Mid Century Epoch (1976-2005 to 2035-2064) for both RCP scenarios shows an increase in streamflow, ranging from 3 to 20 percent, in winter months January through March and a significant decrease in spring stream flows, up to -22 percent, from April and May. The months of June through October show a decrease in percent change, ranging from -3 to -10 percent, from historic mean monthly streamflow for both RCP scenarios while months November and December show increases of 12 to 18 percent of historical monthly streamflow.

Simulated Changes from the Base Epoch to the End-Century Epoch follow the trends described for the Mid-Century Epoch however, the variability between the upper and lower quartiles for each month is greater and more extreme. Both epochs show a significant decrease in flows in the month of April and May and significant increases from November to February. Based in these box plots the projected streamflow conditions are expected to be higher in months November to February and lower than historical for months April to October while the month of March stays fairly similar to historic values.

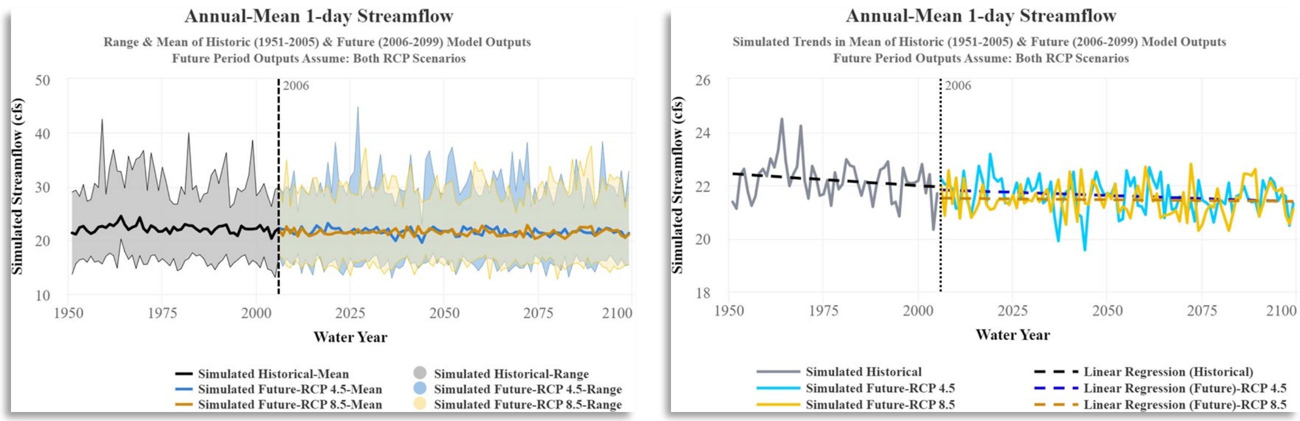


Figure 4-13. CHAT Projected Annual Mean 1-Day Streamflow. Lower Sweetwater Creek (Stream Segment ID#17001827) within Lower Clearwater (HUC17060306)

Table 4-6. CHAT summary for Annual Mean 1-Day Streamflow Trends. Lower Sweetwater Creek (Stream Segment ID#17001827) within Lower Clearwater (HUC17060306)

Trend Analysis	Historic (1951-2005)			Future (2006-2099) RCP 4.5			Future (2006-2099) RCP 8.5		
	P Values	**Statistically significant**	**Traditional Slope**	**P Values**	**Statistically significant**	**Slope**	**P Values**	**Statistically significant**	**Slope**
t-Test	0.153	No		0.0469	Yes		0.579	No	
Mann-Kendall	0.303	No	-0.0091	0.0535	No	-0.0047	0.559	No	-0.0012
Spearman Rank Order	0.295	No		0.0382	Yes		0.539	No	

Figure 4-3 depicts the annual mean 1-day streamflow range and trendlines computed by the CHAT for the period of 1951-2099. Annual mean 1-day streamflow shows a similarly variable range to historical conditions with frequent fluctuations in daily values, particularly with the RCP 4.5. Although these trends seem to have large variabilities, projected daily flows for the Sweetwater Creek are ranging from 15 cfs to 42 cfs in extreme cases. For this restoration project minimum flows are intended to be kept at or above levels prescribed in 2020 Biological Assessment described in Section 2.2.4 of H&H Appendix A. Projected mean daily flows indicate that there might be less risk of maintaining viable streamflow levels for the restoration project Recommended Plan.

Although the entire period of 1951-2099 exhibits a slight downward trend in mean daily streamflow, the projected future (2006 to 2099) after the 2005 breakpoint has almost a flat trendline. Only two statistical tests (t-Test and Spearman Rank Order for RCP 4.5) returned P values of less than 0.05 indicating any significance. The historical trendline and both future trendlines do not indicate a robust statistical significance. Projecting future condition for small daily flows does not provide a strong indication of how the system might change and more value might be placed on annual or monthly flow projections rather than daily flow values.

5 Vulnerability Assessment

The USACE Climate Change Vulnerability Assessment (VA) Tool was used to compare the relative vulnerability of the HUC 1706 Lower Snake watershed to climate change, by comparing with 202 other HUC-4 watersheds across the continental United States (CONUS). The tool facilitates a screening level, comparative assessment of how vulnerable a given HUC-4 watershed is to the impacts of climate change. The tool can be used to assess the vulnerability of a specific USACE business line such as "Ecosystem Restoration" or "Flood Risk Reduction" 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. The tool uses the Weighted Order 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. Indicators considered within the WOWA score for Ecosystem Restoration include: change in sediment load, short-term variability in hydrology, runoff elasticity (ratio of streamflow runoff to precipitation), macroinvertebrate index (sum score of six metrics indicating biotic condition), two indicators of flood magnification (indicator of how much high flows are projected to change overtime), mean annual runoff, change in low runoff, and percent of at risk freshwater plant communities. Ecosystem Restoration and Flood Risk Reduction are the most relevant business lines of interest for the Sweetwater Creek Feasibility Study.

When assessing future risk projected by climate change, the VA tool makes an assessment for two 30-year epochs of analysis centered at 2050 and 2085. These two periods are standardized to be consistent with other national and international analyses. The 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 general climate models (GCMs) and representative concentration pathway (RCPs) resulting in 100 traces per watershed per hydroperiod. The top 50% of the traces are categorized as "wet" and the bottom 50% of the traces are categorized as "dry." Meteorological data projected by the GCMs is translated into runoff using the Variable Infiltration Capacity (VIC) Macroscale hydrologic model. For this vulnerability assessment, the default National Standards Settings were used with the top 20% of HUC-4 watershed WOWA scores flagged as vulnerable.

For the lower Snake River watershed (HUC 1706), the VA tool results of with the National Standard settings indicated that all seven USACE business lines were below the 20% threshold score of 70.0, and thus not considered vulnerable relative to the other 202 HUC-4 CONUS watersheds as detailed in Table 5-1 below.

Table 5-1. HUC 1706 – Lower Snake. VA WOWA Indicator Totals Across USACE business lines.

Business Line	Base	2050 Dry	2050 Wet	2085 Dry	2085 Wet
Ecosystem Restoration	67.72	66.90	67.25	67.48	68.47
Emergency Management	61.65	61.66	60.89	62.29	61.40
Flood Risk Reduction	39.65	37.40	43.27	37.89	41.80
Hydropower	65.93	64.69	68.65	66.25	69.26
Navigation	57.13	57.17	59.25	58.54	60.59
Recreation	61.36	61.71	61.90	62.10	62.98
Regulatory	67.12	66.91	67.45	67.06	67.79

Of interest to this feasibility study, VA Tool ranked Ecosystem Restoration relatively high across business lines for HUC 1706. While Flood Risk Reduction ranked lowest due to the established flow regulation infrastructure in the basin, residual risk may still be present in unregulated and flashy watersheds such as Sweetwater and

Lapwai Creeks. The recreation business line is also of interest to this study as it includes low flow and drought metrics as discussed below.

Vulnerability Assessment scores are comprised of various weighted indicators depending on the USACE business line. For the Ecosystem Restoration business line, sediment is the ratio of the change in sediment load in the future to the present. Monthly COV is a measure of short-term variability in the region's hydrology based on runoff variance and mean. Macroinvertebrate reflects taxonomic diversity and composition. Flood magnification is the estimated future flood runoff (monthly flow exceeded 10 percent of the time) divided by the flood runoff calculated from the base period. Cumulative includes upstream HUC4 watersheds, whereas local restricts the calculation to the study watershed. Low flow reduction is the change in low runoff, or monthly runoff exceeded 90 percent of the time. At risk freshwater plants is the percentage of wetland and riparian plant communities that are at risk of extinction, based on remaining number and condition, remaining acreage, threat severity, etc. Additional indicators for the Flood Risk Reduction business line are the indicator annual runoff COV which represents long-term variability in annual runoff and Urban 500-year floodplain area which represents the acres of urban area within the 500-year floodplain.

Table 5-2. HUC 1706 – Lower Snake. VA WOWA Indicator Scores for select USACE business lines.

Business Line	Indicator	Base	2050 Dry	2050 Wet	2085 Dry	2085 Wet	Avg	Std	CV
Ecosystem Restoration	Sediment	2.01	1.94	2.16	1.97	2.92	2.2	0.41	0.19
	Monthly Runoff CV	13.77	13.04	13.46	12.82	13.44	13.31	0.37	0.03
	Runoff Precipitation	8.5	8.46	8.11	9.22	9.29	8.72	0.52	0.06
	Macroinvertebrate	5.77	5.77	5.72	5.77	5.74	5.75	0.02	0
	Flood Magnification (cum)	1.54	1.38	2.92	1.38	1.63	1.77	0.65	0.37
	Flood Magnification (local)	0.79	0.69	0.87	0.65	0.8	0.76	0.09	0.11
	Mean Annual Runoff	3.85	3.93	3.82	3.95	3.83	3.88	0.06	0.02
	Low Flow Reduction	2.67	2.87	1.6	2.91	2.13	2.44	0.56	0.23
	Freshwater Plants	28.82	28.82	28.59	28.82	28.69	28.75	0.11	0
	Ecosystem Restoration Total	67.72	66.9	67.25	67.48	68.47	67.57	0.59	0.01
Flood Risk Reduction	Annual Runoff CV	2.77	2.9	2.73	2.95	2.81	2.83	0.09	0.03
	Runoff Precipitation	6.12	9.61	5.89	10.47	6.72	7.76	2.12	0.27
	Flood Magnification (cum)	20.35	18.76	23.1	18.69	21.66	20.51	1.9	0.09
	Flood Magnification (local)	10.28	6.01	11.43	5.66	10.49	8.78	2.72	0.31
	Urban Floodplain Area	0.12	0.13	0.12	0.13	0.12	0.12	0	0.01
	Flood Risk Reduction Total	39.64	37.4	43.27	37.89	41.8	40	2.51	0.06
Emergency Management	Floodplain Population	9.35	0.47	0.47	0.22	0.21	2.14	4.03	1.88
	Annual Runoff CV	0.74	0.97	0.93	0.99	0.96	0.92	0.10	0.11
	Runoff Precipitation	1.89	2.42	2.32	2.65	2.66	2.39	0.32	0.13
	Poverty Population	6.63	6.55	5.23	5.99	4.78	5.84	0.82	0.14
	Percent of People Disabled	17.29	17.90	17.76	17.96	17.83	17.75	0.27	0.02
	Past Disaster Experience	3.65	4.70	3.75	4.71	3.76	4.11	0.54	0.13
	Flood Insurance Communities	1.38	1.77	1.76	1.78	1.76	1.69	0.18	0.10
	Flood Magnification (cum)	2.90	3.36	6.53	3.36	6.14	4.46	1.73	0.39
	Low Flow Reduction (cum)	12.70	14.12	13.31	14.37	13.65	13.63	0.66	0.05
	Low Flow Reduction Local	5.13	9.22	8.72	9.84	9.34	8.45	1.90	0.22
	Drought Severity	0.00	0.17	0.11	0.41	0.31	0.20	0.16	0.81
	Emergency Management Total	61.65	61.66	60.89	62.29	61.40	61.58	0.51	0.01

Additional indicators unique to the Emergency Management business line include floodplain population, which is the size of the population within the 500-year floodplain. Key demographic metrics from the US Census Bureau include: the poverty population indicator, the percent of disabled persons, the number of communities with flood insurance, and disaster resilience due to experience. The poverty population indicator represents the number of people below the poverty line and are based on poverty thresholds determined annually by the US Census Bureau. These thresholds are based on the annual amount of cash income required to support families of various sizes. The percent of people disabled is the ratio of disabled individuals as defined by US Census Bureau. The low flow reduction factor represents how low flow represented by the 90% monthly exceedance is predicted to change in the future. Drought severity considers the moisture content of the soil and climate in a region and is calculated using precipitation, evapotranspiration, soil moisture deficit, and runoff data and higher values suggest higher vulnerability relative to other watersheds.

As illustrated in Figure 5-1, for the Ecosystem Restoration business line within HUC 1706, the vulnerability score under the dry scenario decreased by 1.2% and 0.4% for the 2050 and 2085 epochs respectively. The predominant WOWA indicator change was a ~13% reduction in local flood magnification for the 2050 epoch which dropped further to an ~18% reduction for the 2085 epoch. Scores for cumulative flood magnification were equally reduced by ~10% during the 2050 and 2085 dry periods epochs. Similarly, the dry period low flow reduction score increased by 8% and 9% for the 2050 and 2085 epochs. Under the wet scenario, the overall ecosystem restoration WOWA score decreased by 1% in the 2050 epoch, and increased by 1% in the 2085 epoch. The most notable contributors to the 2050 wet scenario score were a 90% increase in cumulative flood magnification during the 2050 epoch and a 40% decrease in the low flow reduction indicator. The 2085 epoch wet scenario score was most strongly influenced by an estimated 45% increase in sediment load and 20% decrease in the low flow reduction indicator.

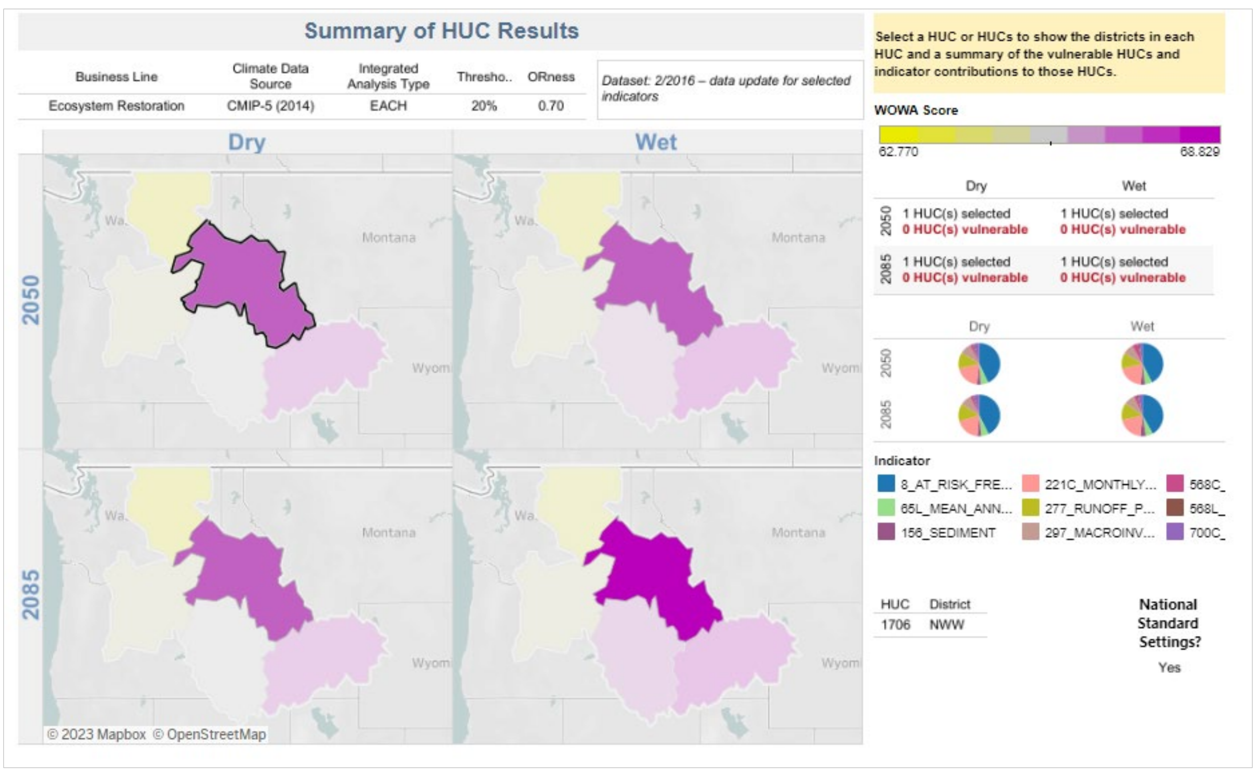


Figure 5-1. Vulnerability Assessment Summary for Ecosystem Restoration in HUC1706 – Lower Snake

The Flood Risk Reduction business line within HUC 1706 (Figure 5-2) estimated a 6% and 4% reduction for the respective 2050 and 2085 dry period epochs. Conversely, the flood risk reduction scores for the wet period scenarios increased by 9% and 5% for the 2050 and 2085 epochs respectively. The primary contributors to the overall scores were increases in the runoff precipitation (57% and 71% for the 2050 & 2085 dry period epochs) which were offset by decreases in local flood magnification indicators (42% and 45%). The increases in wet period scores were driven primarily by increases in both local and cumulative flood magnification during the near period (2050) epoch, which were dampened slightly during the longer term 2085 epoch.

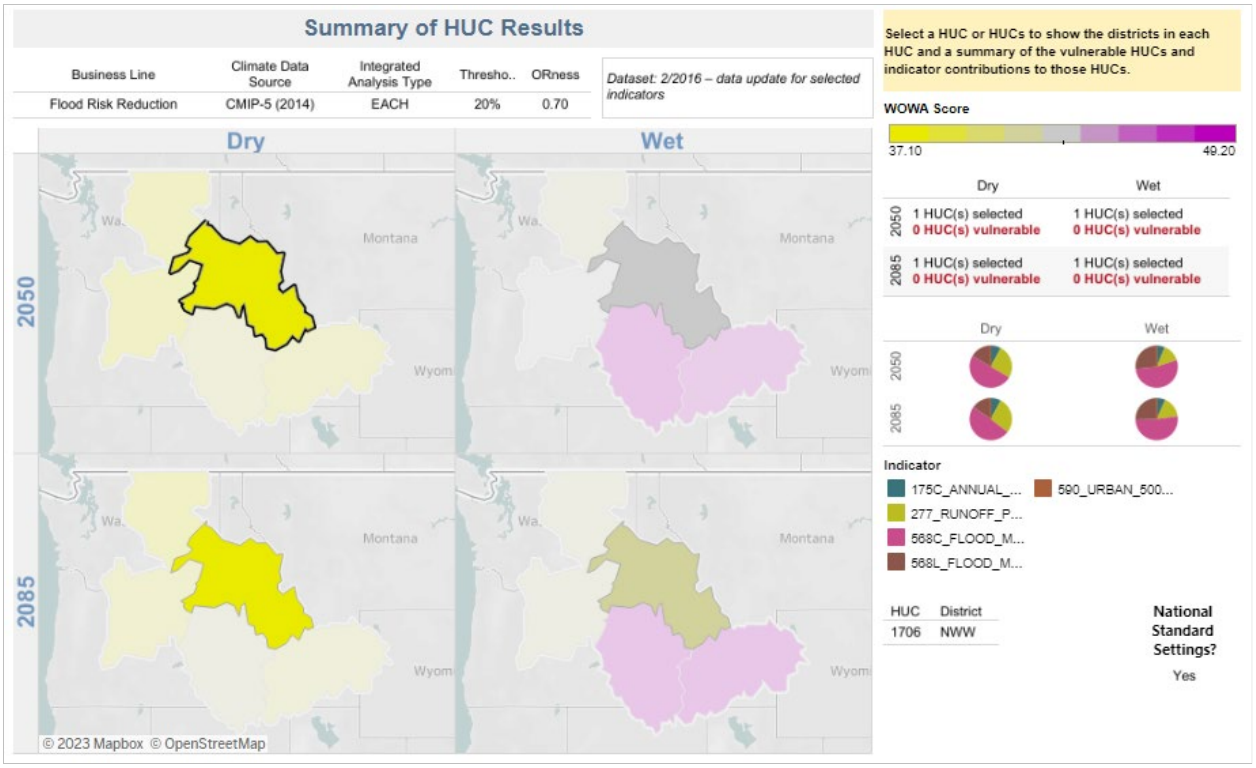


Figure 5-2. Vulnerability Assessment Summary for Flood Risk Reduction in HUC1706 – Lower Snake

Of interest within the HUC1706 emergency management business line was the result that the floodplain population was projected to decrease by nearly 100% for both wet and dry scenarios in both epochs. Annual runoff CV is projected to increase by an average of 29% and 32% in the 2050 and 2085 epochs respectively. Runoff precipitation is also projected to increase across all future scenarios, averaging 26% and 40% by epoch. Cumulative flood magnification is also projected to increase significantly under the wet scenarios, averaging 118% across both epochs. The forecasted poverty population is stable or decreasing slightly while the percent of disabled people is stable or increasing slightly depending upon scenario. The drought severity scour was increasing slightly across all scenarios, with the peak change of ~6% for the 2085 dry scenario, and a corresponding ~5% increase for the 2085 wet scenario.

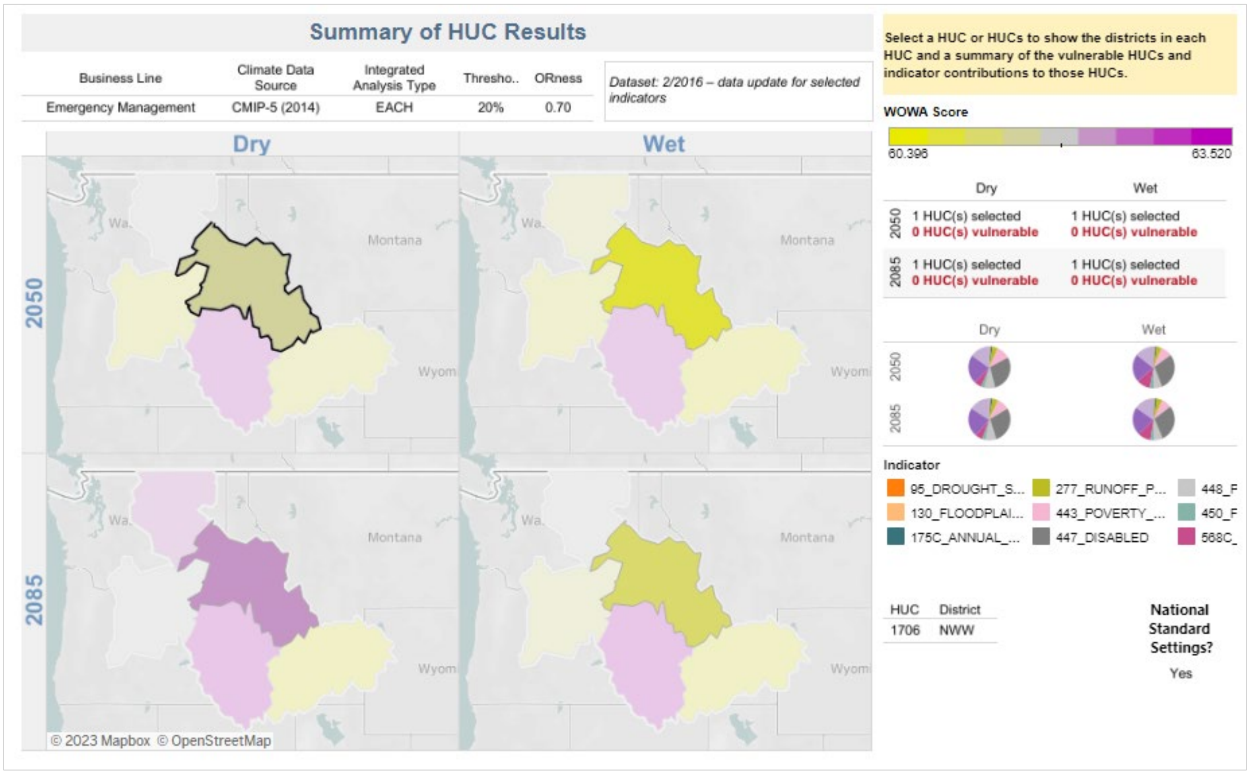


Figure 5-3. Vulnerability Assessment Summary for Emergency Management in HUC1706 – Lower Snake

6 Conclusion

The Recommended Plan is to implement a suite of integrated ecosystem restoration measures within three sub-reaches (sites) to improve degraded aquatic and riparian habitat in lower Sweetwater Creek. The selected plan will implement multiple integrated measures including: riparian preservation and planting, channel realignment, grading and bank stabilization, instream structures, floodplain improvement and reconnection with side channels, and removal/modification of berms. The proposed restoration measures are intended to function together as a composite system to develop a contiguous and sustainable riparian corridor integrated with the hydrologic and geomorphic function of Sweetwater Creek. This climate assessment reviewed baseline literature and evaluated both historic, observed hydrometeorological data and projected, climate-changed hydrometeorological data to identify significant trends that could influence the performance and durability of the proposed restoration plan within the expected fifty-year service life. There is a weight of evidence that climactic change during future epochs would manifest as notable changes in meteorological trends such as temperature and precipitation. This in-turn is expected to influence the hydrologic regime, although how future trends will manifest at the HUC12 project scale is less certain. Residual risk to the Sweetwater Creek ecosystem Recommended Plan due to climate change is summarized in Table 6-1.

Within the literature, baseline trends of the Pacific Northwest region identified strong consensus of observed increases in temperature and low consensus that minimum and maximum temperature extremes have been increasing relative to 20th century normals. There was also strong consensus of notable decreases in observed streamflow and April 1 SWE across the PNW region for the latter half of the 20th century. There was moderate consensus that average annual precipitation has been increasing in the PNW, including some inland regions where the seasonal response varied with location. The frequency of extreme storms during the 20th century has been variable with low consensus of a consistent trend owing in part to the volatility of atmospheric river systems responsible for such events.

Future forecasts of temperature, precipitation, and hydrologic response in the Pacific Northwest are uncertain and variable, but in general can be characterized as wet regions and seasons becoming wetter, dry regions and seasons becoming drier, and reduced snow depth, density, and extent. Continued future reduction of April 1 SWE is also predicted within the literature. Streamflows are predicted to decrease in summer, which could amplify any increased air or water temperature effects on aquatic habitat. River hydrograph timing is predicted to continue to shift earlier in the year in concert with an expansion of the annual frost-free period.

Analysis of select period of record hydrologic datasets for Sweetwater Creek identified no strong trends and limited nonstationarities. Annual peak and maximum flows indicated a slightly positive but non-significant trend. Monthly extremes in maximum and minimum flows detected multiple nonstationarities that are characteristic of the flashy and regulated nature of the Sweetwater Creek system. The annual minimum flow was characterized by decadal-scale breakpoints where a multi-year dry period abruptly transitioned to a wetter regime. A seasonal decomposition of the mean daily flow record trend indicated four breakpoints representative of multi-year hydroperiods. Despite this, the trend in water year yield remained consistent across the period of record with neither breakpoints nor nonstationarities.

Future projections through the end of the 21st century from the CHAT indicate statistically significant increases in temperature and annual precipitation accumulation. Temperature trends were up across all months, while the precipitation signal was characterized by minor seasonal deviations. The CHAT climate projections of having warmer winter temperatures and more winter precipitation events would likely cause a reduction in the amount of spring snowmelt runoff, however vegetation in the riparian corridor would be expected to benefit from milder temperatures and increased precipitation. CHAT Streamflow projections indicate a significant decrease in flows between March and October. Future reduced flows do have the potential to impact the Sweetwater Creek Recommended Plan; however, base flows in the system are managed on a tiered system in accordance with a negotiated settlement informed by an ESA biological opinion, as detailed in the main report. A future reduction in regional water yield could result in Sweetwater baseflows operating a lower tier than in historical wet years.

The National Standard settings of the Vulnerability Assessment indicate that for the lower Snake River watershed (HUC 1706), all seven USACE business lines were below the 20% threshold score of 70.0, and thus not considered vulnerable relative to the other 202 HUC-4 CONUS watersheds. Relative to the Ecosystem Restoration business line, the largest deviation from baseline conditions was a nearly 90% increase in cumulative flood magnification during the 2050 wet epoch. Conversely, this same metric was down about 10% during the 2050 dry epoch. Low flow reduction was projected to be down about 40% in the 2050 wet epoch and half that for the 2085 wet epoch. Sediment production is projected to remain stable in future dry epoch, but could increase by ~7% and 45% in the 2050 and 2085 wet epochs.

Table 6-1. Residual risk due to climate change to Sweetwater Creek Ecosystem Recommended Plan

Triggers	Hazard	Harm	Qualitative Likelihood (Low, Moderate, High)	Qualitative Justification for Likelihood Rating
1. Increased summer air temperatures. 2. Decreased summer precipitation accumulation. 3. Increased duration between precipitation events.	Increases in summer air temperatures combined with decreases in summer precipitation could result in decreased soil moisture and impact essential riparian vegetation	Installed riparian vegetation plantings and seedings will be most susceptible within the early years of the project as they become established. Increased vegetation mortality rates in the post-construction near-term (<5 year period) would be significantly detrimental to the long term benefits of the project.	Low to Moderate	Riparian revegetation will be installed to strategically access near surface groundwater. This includes techniques such as installing to rooting depths at (or below) the adjacent channel baseflow stage as well as integrating subgrade trenches to capture overbank flows of the spring freshet. O&M requirements will include irrigation & invasive species control per the adaptive management plan.
Decreased summer flows.	A decrease in summer flows could reduce residual pool depth and thermal inertia, and increase water temperatures.	Warm water temperatures would be associated with decreased dissolved oxygen levels, and effect other water quality parameters, impacting native aquatic species.	Low	Future base flows in Sweetwater Creek are managed on a tiered system in accordance with a negotiated settlement informed by an ESA biological opinion and project features will be designed to optimize ecologic performance over a wide range of flows. Backwater Alcoves will be constructed where possible to retain water and sustain near bank groundwater levels.

Triggers	Hazard	Harm	Qualitative Likelihood (Low, Moderate, High)	Qualitative Justification for Likelihood Rating
Increased winter temperatures, stream flow, and stage.	Increase in winter stream flow would be beneficial to both channel aquatic habitat, and riparian overbank habitat within stability thresholds.	Increased winter flows could be detrimental to vegetation establishment in newly seeded areas. Increased winter flows are not expected to be detrimental to the stream channel	Low	Stability of the stream channel will be maintained over a wide range of flows regardless of seasonality. Restored overbank floodplains will be graded with stage progressive side channels to route flows and include a mosaic of diverse floodplain roughness features to reduce erosion pathways and trap sediment.
Flood regime.	Continued nuisance flooding at flows <20% AEP are expected although future timing may shift.	An increase in the magnitude or frequency of damaging floods resulting from mixed-precipitation and rain-on-snow events could impact channel stability and accelerate geomorphic response.	Low to Moderate.	The Sweetwater Creek channel system has developed an alluvial cobble-armor layer that sustains a quasi-stable state for flows up to a ~5% AEP event. The Recommended Plan will implement in-stream structures and improve transitions between channel and floodplain routing. Recommended Plan features will be installed to meet no-rise conditions for all flows >20% AEP and remain stable at the 1% AEP expected probability.

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