Snowpack Depletion in Tuolumne County, Central Sierra Nevada: Trends of the last century and a look into the future

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Abstract

As California's Mediterranean climate begins to exhibit impacts of climate change, the development of adaptive methods and strategies is at the forefront of the State's water supply challenges. Snowpack from the Sierra Nevada mountain range makes up two-thirds of California's surface water supply, making it a key component of the state's water resources. Due to California's current water management policies and methods, the reduction of snowpack, and as a result changes in water runoff levels, will create a deeper strain on the state's ability to provide water for all uses.

By analyzing the historical and climate change medium and high emission time series data of climate trends of Tuolumne County in the Sierra Nevada, water management operators, water policy makers, and stakeholders will have a historical and predicted climate analysis on which management and policy decisions can be informed. Tuolumne County is the primary water source for the San Francisco region and Central Valley communities. The analysis will serve as a proof of concept which can be duplicated at a larger spatial scale, and across watersheds, counties, and legislative districts.

The historical and future climate change emission scenario time series data for temperature, snow water equivalent, and streamflow data was acquired from Cal-Adapt. The data was analyzed to understand trends in each scenario.

Although the Tuolumne County has been spared from drastic climatic changes in the last 100 years, the trend will not continue into the future. The climate indicators of reduced snowpack, increase temperature, and more volatile precipitation experience variations in the next 100 years.

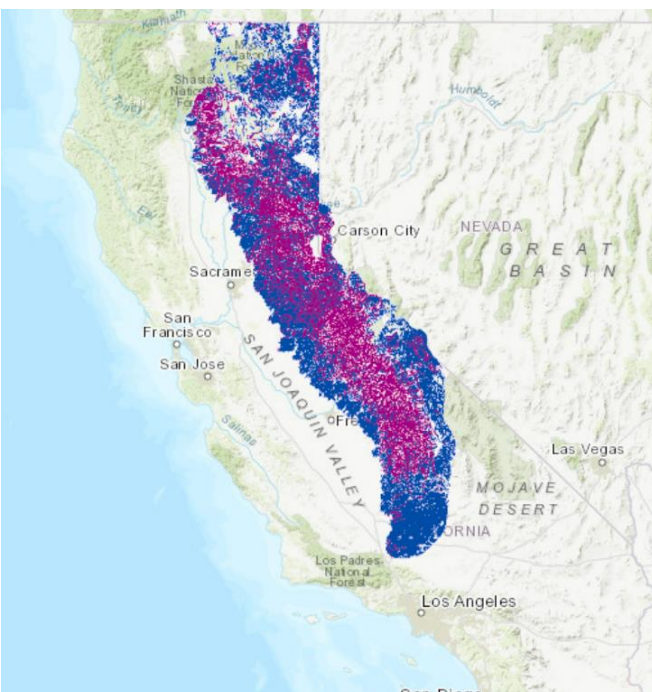


Figure 1: Streams and River sin the Sierra Nevada Zone. The blue depicts intermediate waterways and red depicts perennial waterways. (Source: USGS and Conservation Biology Institute)

Introduction

The Sierra Nevada snowpack will experience a 48% to 65% loss, from the historical April 1 average, by the end of the century due to variations in temperature and precipitation. (7,5) Understanding the variation of snowpack in the Sierra Nevada is critical in the management of the state's water supply. The majority of the state's precipitation falls in the northern portion of the state, of which the snow water runoff makes up two-thirds of the state's surface water supply. However, 60% of the state's inhabitants live in the southern portion of the state. The spatial discrepancy between water resource availability to the location of water supply use creates a logical issue, which has been mitigated by the creation of dams, reservoirs, storage tanks, and other water infrastructure used to store and/or move water from abundant regions to regions of sparse water supply. With the declining snowpack in the Sierras the state's water system will need to be adapted to successfully continue supplying water for all water uses.

The Sierra Nevada extends 250 miles from the Cascade Range of northern California to the Mojave Desert in the south, with peaks ranging from 11,000 to 14,000 feet above sea level, and encompasses rivers such as the Yuba, American, Mokelumne, Stanislaus, Merced, and Kern. (6) The range is located in the mid-latitude region of North America with close proximity to the Pacific Ocean, which serves as a moderating influence on the regions climate. The region has historically received the majority of its precipitation during the wet season, from November to April, which average 33 to 38 feet of snowpack per year in the northern range. (6)

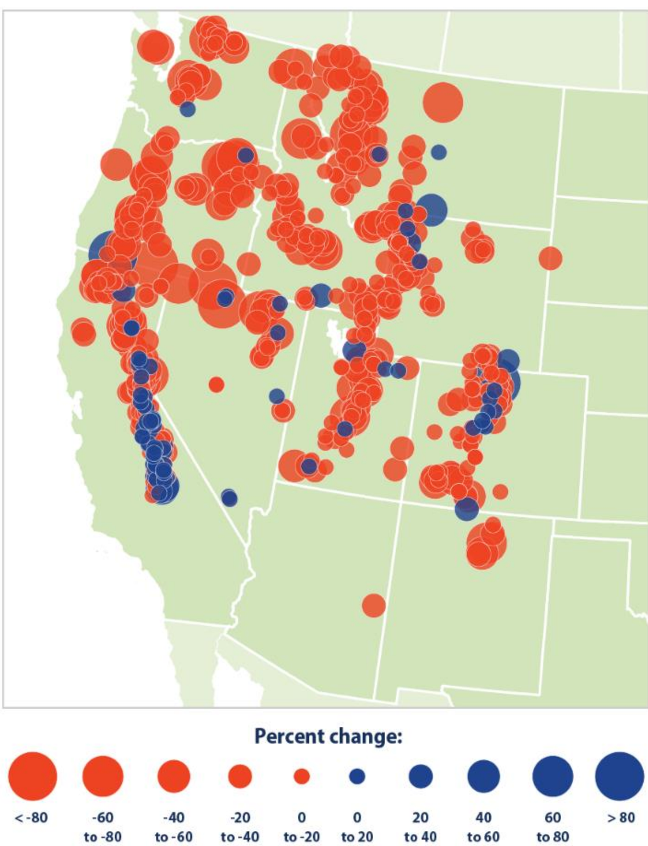


Figure 2: Trends in April snowpack in the Western United States, 1955 - 2020. (Source: EPA)

Historical trends in the April snowpack of the Western United States from 1955 show a decline, with an average 19% reduction across all sites measured. (Figure 2) The decrease in April snowpack has been most prominent in the western states of Washington, Oregon, and northern California. (5)

Objective

The objective of this study is to analyses the time series data of historical snow trends in the Tuolumne County and create a model of future snowpack trends using medium (RCP 4.5) and high (RCP 8.5) climate change emission scenarios. The time series data will include temperature, snow water equivalent (SWE), and streamflow data for the Stanislaus and Tuolumne rivers. The data will be used to analyze 1. the changes in trends of the historical average, and 2. create an average of future snowpack trends using medium and high emission climate change scenarios. The analysis will serve as a tool to educate water management operators, policy makers, and stakeholder when creating management strategies and policy objectives for California's water resources.

Literature Review

The Public Policy Institute of California identifies the five main impacts of climate change affecting water management throughout the State, also called climate pressures, as 1. warming temperatures, 2. shrinking snowpack, 3. shorter and more intense wet seasons, 4. more volatile precipitation, and 5. rising seas. (1) California's climate has experienced an increase amount of above average temperatures since the early 2000s. The above average temperatures effect tangible changes to the state's environment, such as reduced precipitation falling as snow, earlier snowpack melting, rising water temperatures, and more severe droughts and floods. (9) As a result of warming and a more variable climate, predicting the temperature, snow water content of snowpack, and resulting streamflow levels has already become harder which has and will continue to place further strain on California's water supply management. (10) As has been the case when the state "loses water", with the most recent example being in 2022 when the

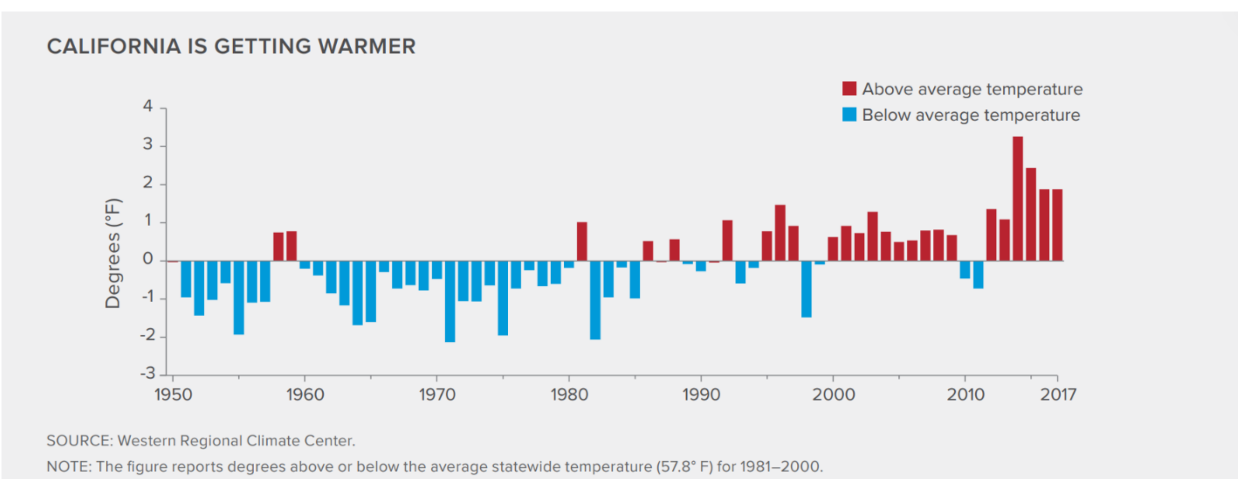


Figure 3: California temperature trends from 1950 to 2017

Department of Water Resources (DWR) and the State Water Control Board miscalculated an estimated 700,000 acre feet of water. (9) The resulted, was a call by Assemblymember Adam Gray for the state auditor to review California's water operations. (9) To combat planning uncertainties, DWR has developed the Climate Action Plan which addresses greenhouse gas emissions reductions, standardizes the departments climate change analysis tools, and assesses asset vulnerabilities. (11)

The Tuolumne region of the Sierra Nevada is of specific importance due to its location and the destination of the water resources. The Tuolumne watershed has two major river systems, the Stanislaus River and the Tuolumne River. The Tuolumne River receives its waters from the peaks above Tuolumne Meadows in the northern portion of Yosemite which cascade toward the western portion of the park into Hetch Hetchy Reservoir. The O'Shaughnessy Dam, the infrastructure holding water in Hetch Hetchy Reservoir, sends water through the Canyon Tunnel toward the Kirkwood Powerhouse ending in Don Pedro Reservoir, and the water is then delivered to San Francisco area. (12) The Stanislaus River originates in the Stanislaus National Forest and forms the boundary between Calaveras and Tuolumne Counties, the waters flow into New Melones Dam where it is stored for summer use or diverted for regional water users, fisheries enhancements, water quality improvement, and electrical generation. (13)

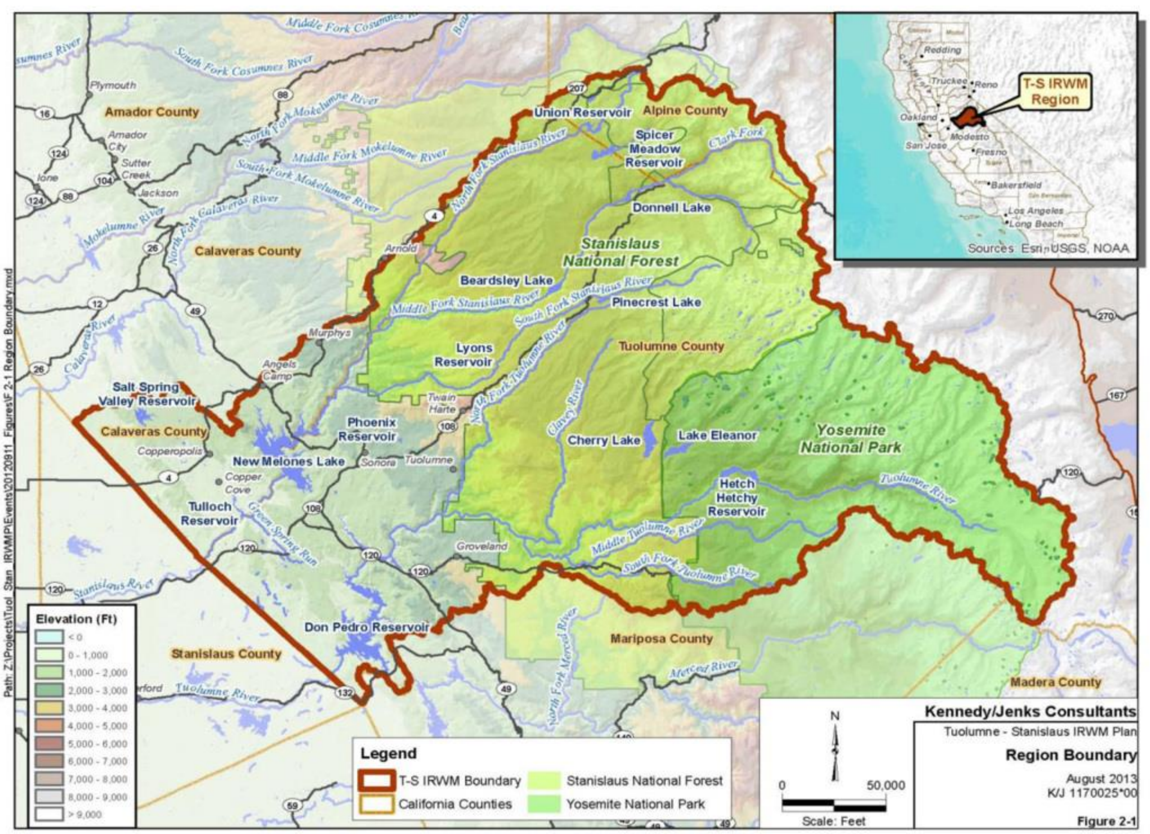


Figure 4: Tuolumne Region Boundary created for the Stanislaus IRWM Plan. (Source: Tuolumne-Stanislaus Integrated Regional Water Management Authority)

Methods

To analyze the statical temperature, snow, and streamflow trends in the Tuolumne County and create future trend model, the historical, medium emission 4.5 climate change scenarios, and high emission 8.5 climate change scenarios time series data of temperature, SWE, and streamflow data was acquired from Cal-Adapt.org.

Using Cal Adapt the following time series data was collected:

- Temperature: Historical annual maximum temperature from 1979 to 2020, Maximum temperature at RCP 4.5 from 2020 to 2100, and Maximum temperature at RCP 8.5 from 2020 to 2100
- Snow Water Equivalent: Historical mean monthly SWE from 1950 to 2020, Mean monthly SWE at RCP 4.5 from 2021 to 2098, Mean monthly SWE at RCP 8.5 from 2021 to 2098
- Stanislaus River Streamflow: Historical mean monthly streamflow data from 1950 to 2020, Mean monthly streamflow at RCP 4.5 from 2021 to 2098, Mean monthly streamflow at RCP 8.5 from 2021 to 2098
- Tuolumne River Streamflow: Historical mean monthly streamflow data from 1950 to 2020, Mean monthly streamflow at RCP 4.5 from 2021 to 2098, Mean monthly streamflow at RCP 8.5 from 2021 to 2098

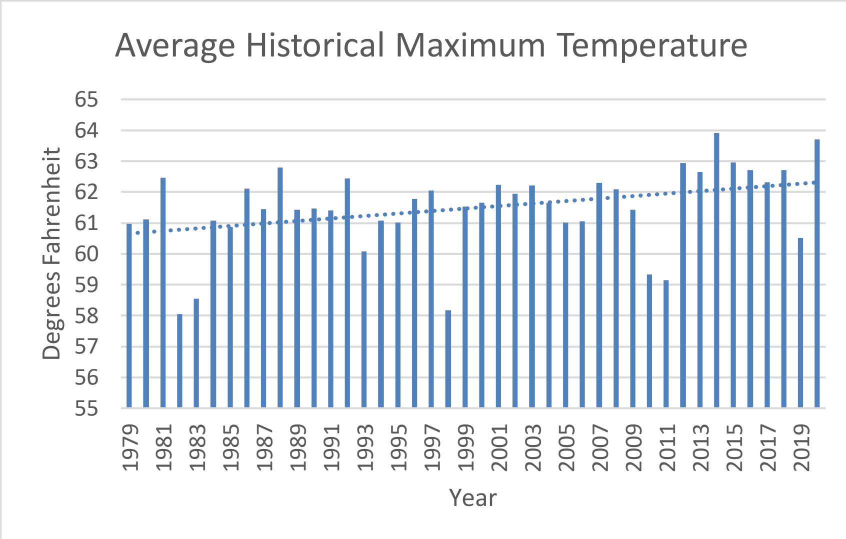
In the first set of calculations all temperature time series data was converted from Kelvin to Fahrenheit. Each of the SWE monthly data, the historical trends and modeled RCP 4.5 and RCP 8.5 emission scenarios, were averaged by year to derive an annual average. The average monthly historical and climate change scenario streamflow data for the Stanislaus River and Tuolumne River were also averaged annually by river. In each category, the historical annual average and both the RCP 4.5 and RCP 8.5 emission scenario data points were used to analyze trends of the last century. The SWE and streamflow data were further analyzed by calculating the median percentiles.

Results

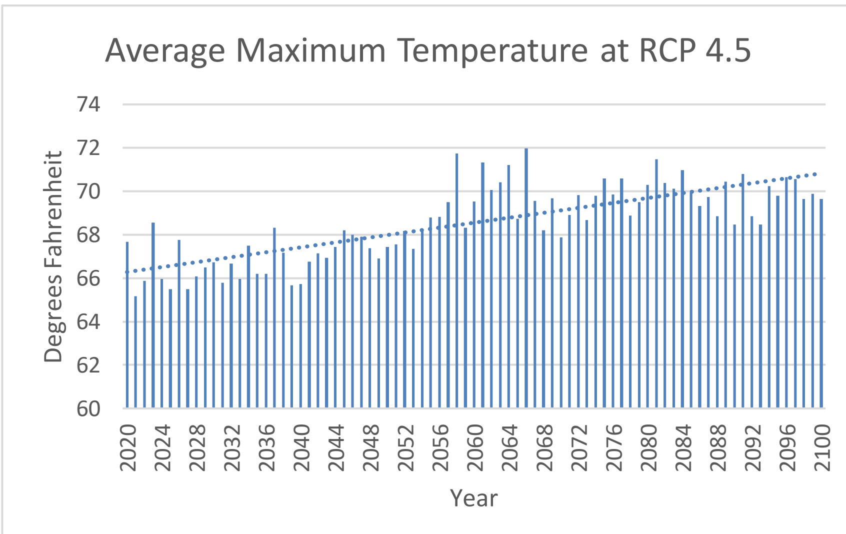
Temperature historical and future trends

Each of the time series data showed an upward trend in temperature.

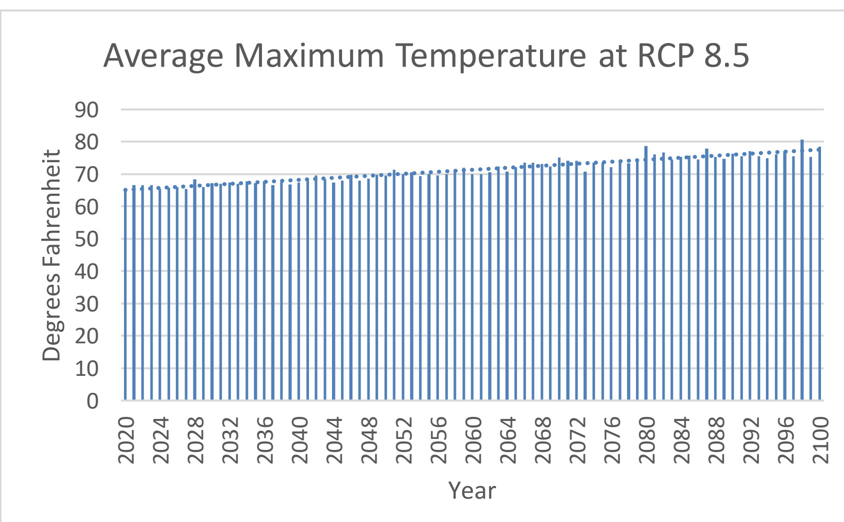
The historical annual maximum average temperature time series data began at an average of 60.75 °F in 1979 and ended at 62.25 °F in 2020, with the maximum average temperatures reaching nearly 64 °F in 2014, and reaching 63.70 °F in 2020. The temperature from the year 1979 to 2020 rose by 1.5 °F.



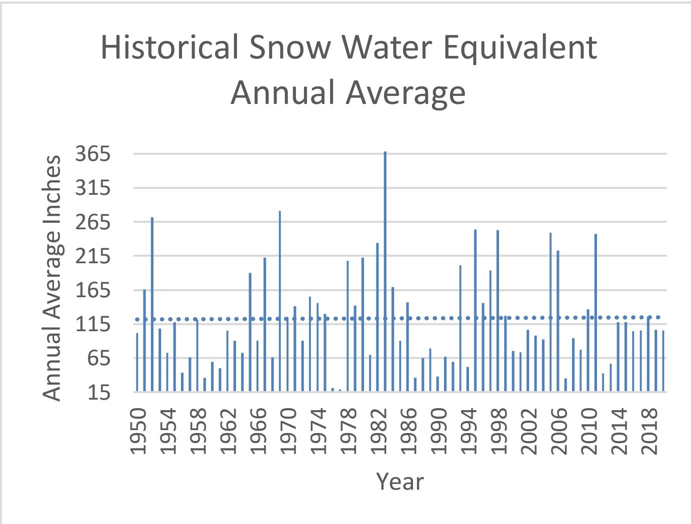
The maximum annual temperature at RCP 4.5, from 2020 to 2100, shows an upward trend in temperature at a medium emission climate scenario, starting at an average annual maximum temperature of 66 °F in 2020 and ending at nearly 70 °F in 2100. The variation in temperature increased about 4 °F.

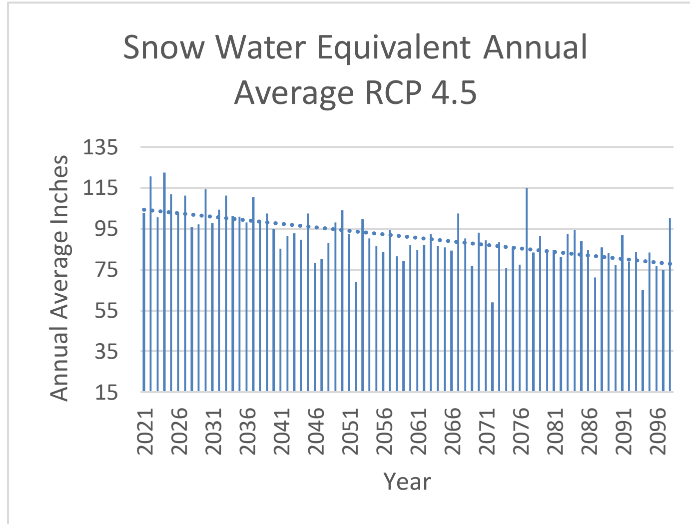


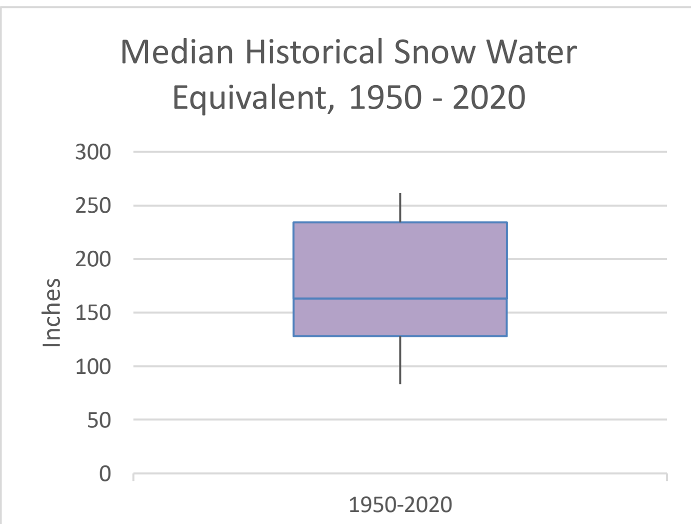
The maximum annual temperature at RCP 8.5 from 2020 to 2100 shows an upward trend in temperature at a high emision climate scenario starting at an average annual maxiumum temperature of 66 °F in 2020 and 80 °F in 2100. The variation in temperature increased about 14 °F.

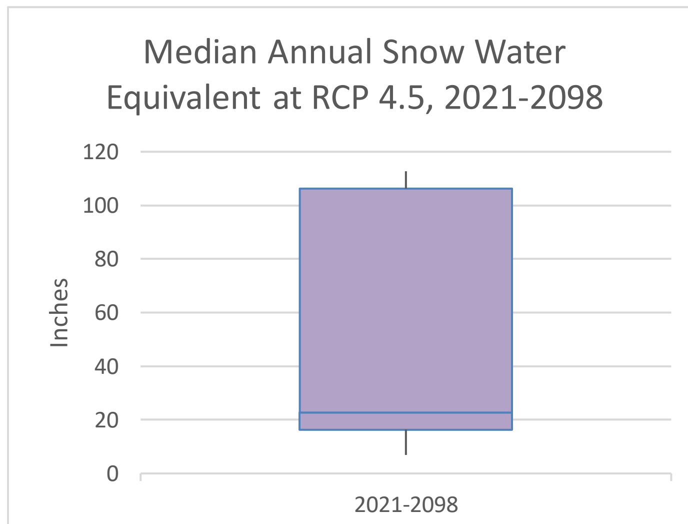


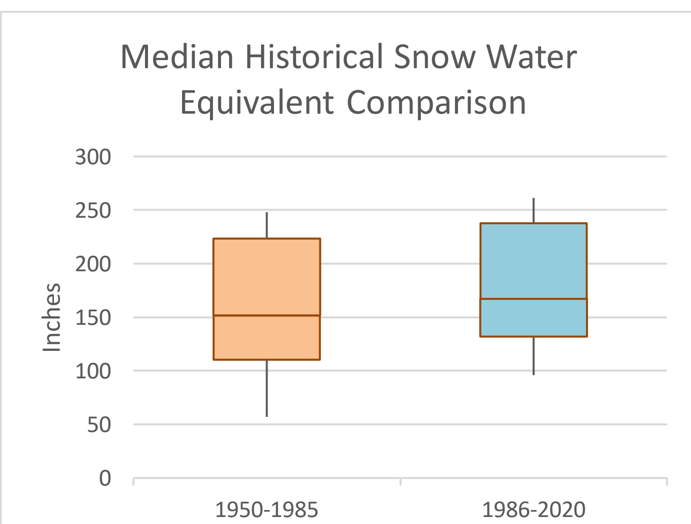
Snow Water Equivalent historical and future trends

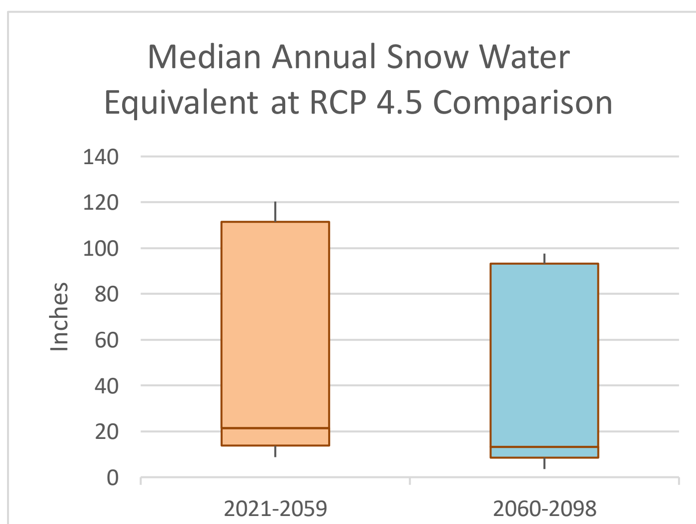


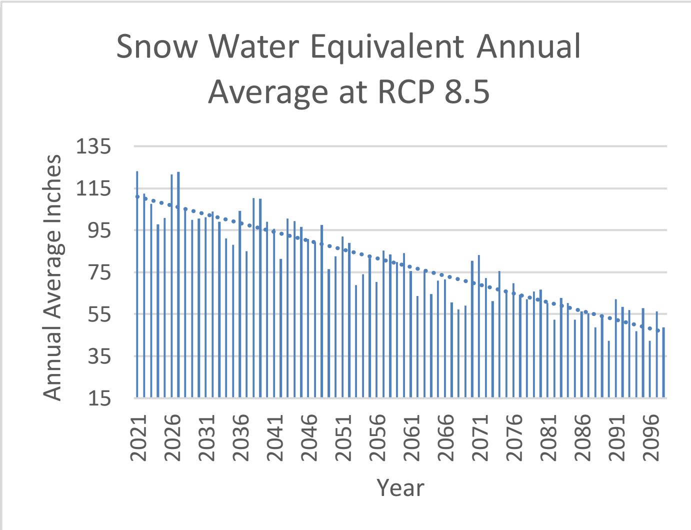


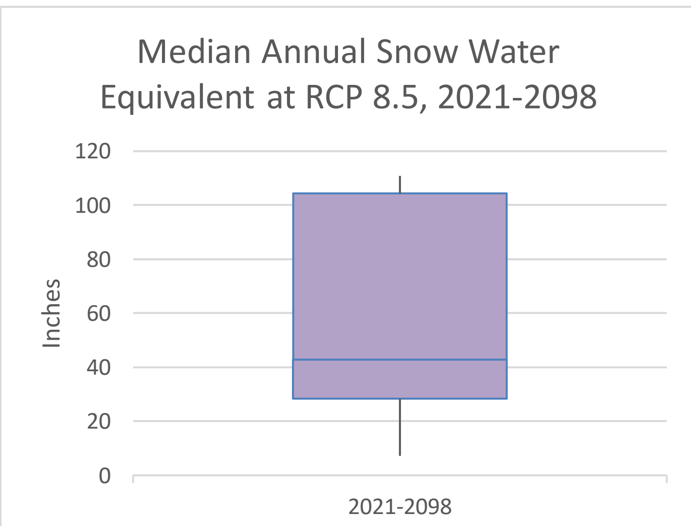


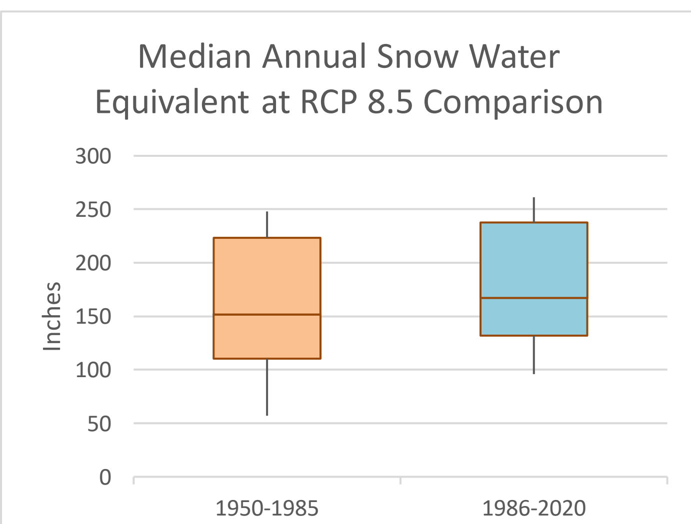










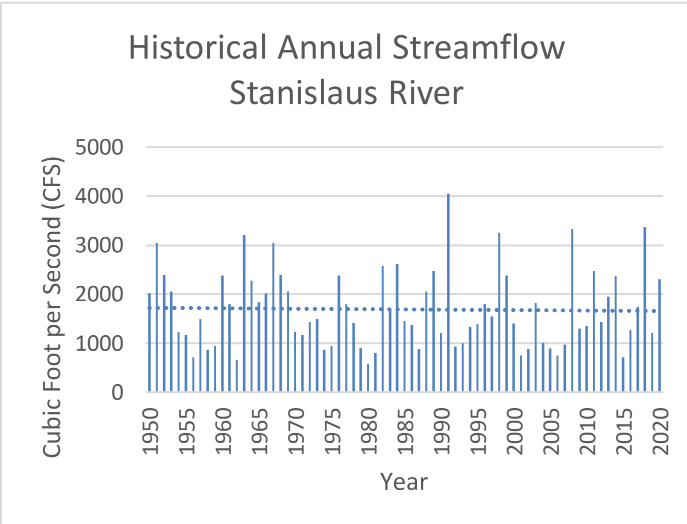


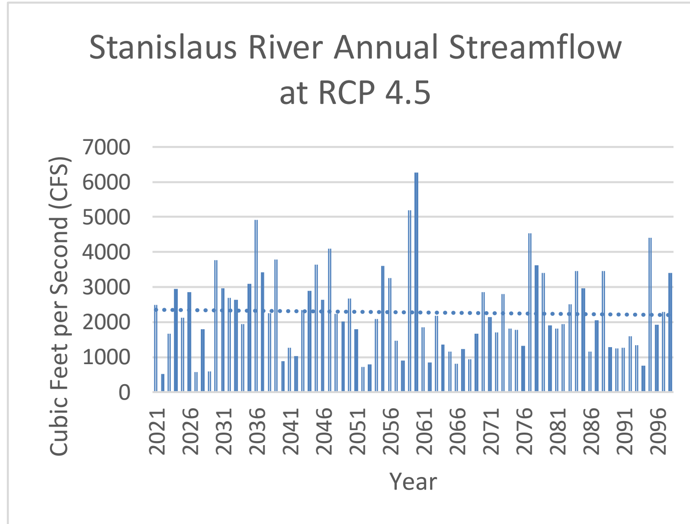
The historical SWE time series data, from 1950 to 2020, shows a slight upward trend in SWE. The SWE began at an average of about 120 inches in 1950 and ended only slightly higher in 2020. The median historical SWE depicts the median variation between 245 and 140 inches. The comparison of the years 1950-1985 and 1986-2020, shows the latter having a higher median SWE.

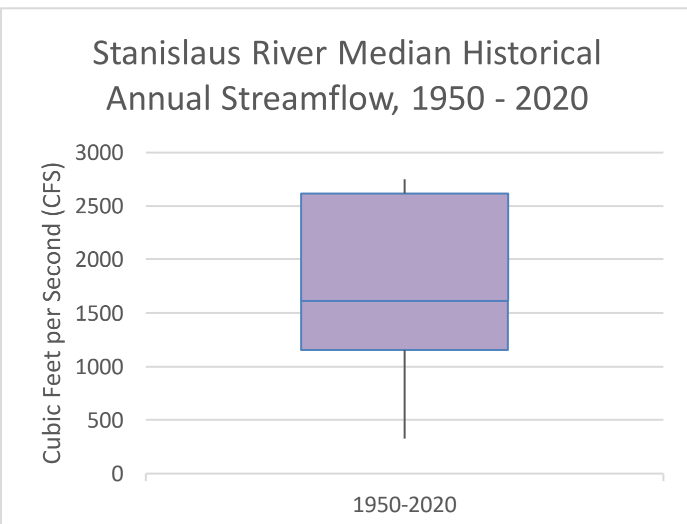
The annual average SWE at RCP 4.5, from 2021 to 2100, shows a downward trend in SWE at a medium emission climate scenario, starting at about 100 average annual inches in 2021 and ending at about 70 average annual inches. The variation of SWE declined by 30 inches. The median annual SWE in the medium emission scenario depicts the median variation between 105 and 118 inches. The comparison of the years 1950-1985 and 1986-2020, shows the latter will have a lower median SWE.

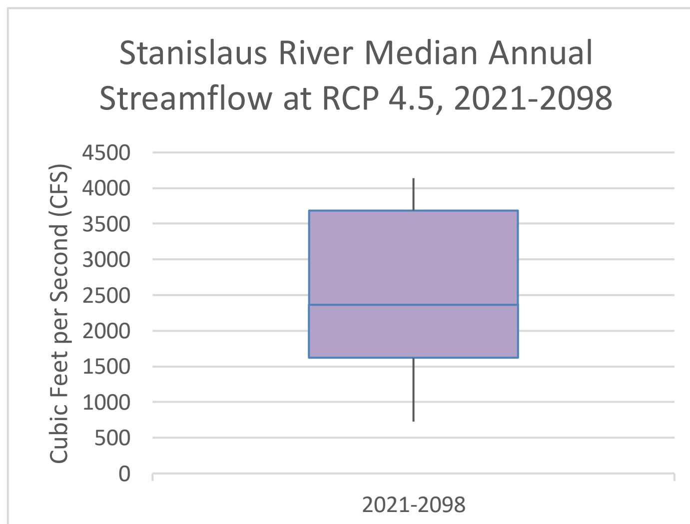
The annual average SWE at RCP 8.5, from 2021 to 2100, shows a downward trend in SWE at a high emission climate scenario, starting at about 100 average annual inches in 2021 and ending at about 50 average annual inches. The variation of SQE declined by 50 inches. The median annual SWE equivalent in the high emission scenario depicts the median variation between 105 and 130 inches. The comparison of the years 1950-1985 and 1986-2020, shows the latter will have a higher median SWE.

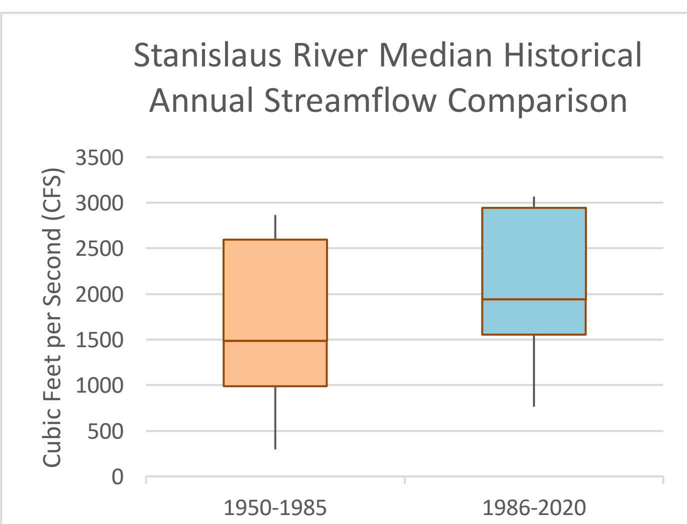
Streamflow historical and future trends: Stanislaus River

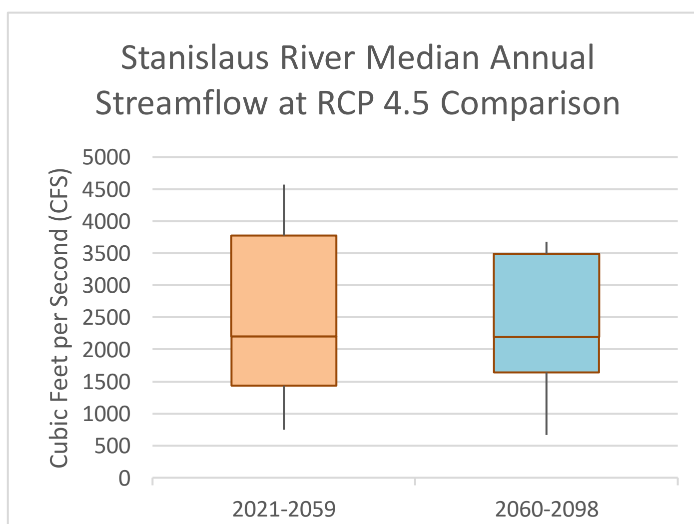


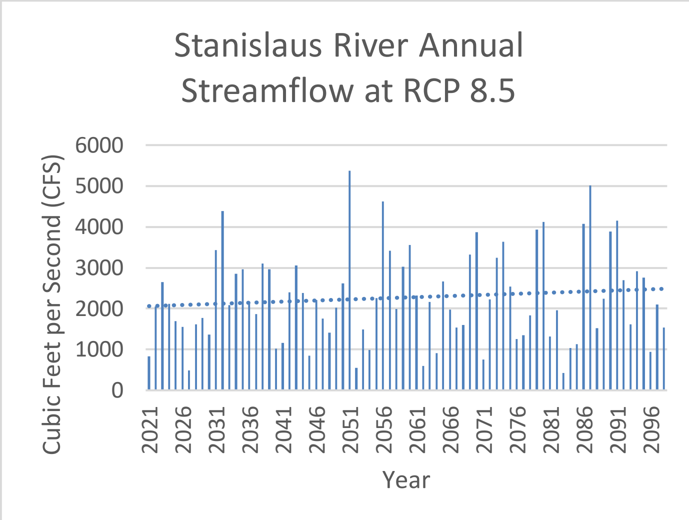


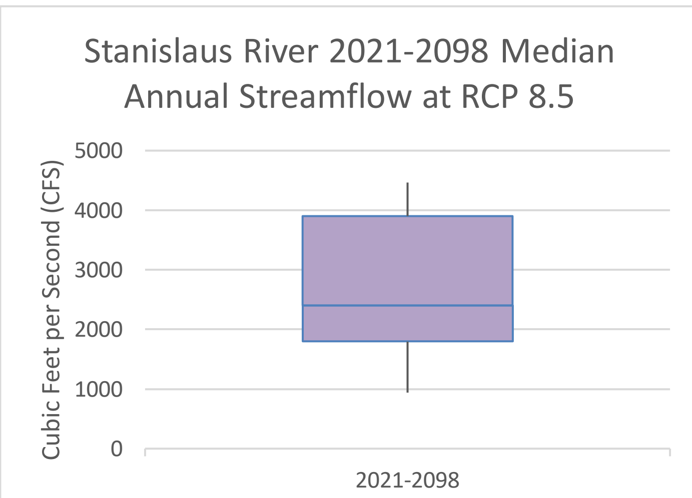


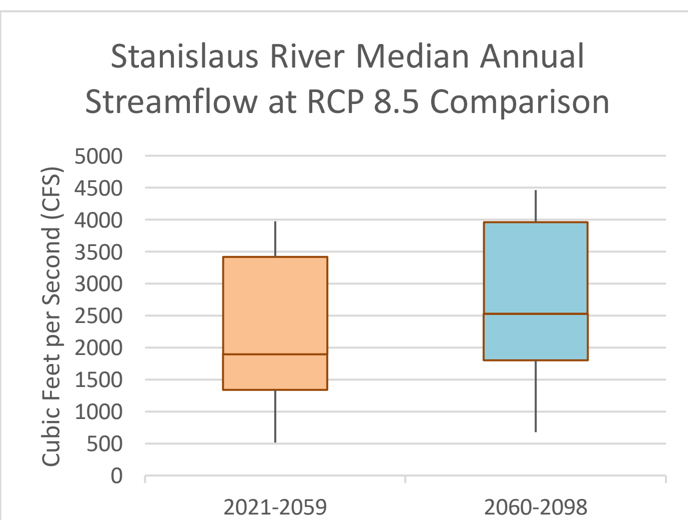










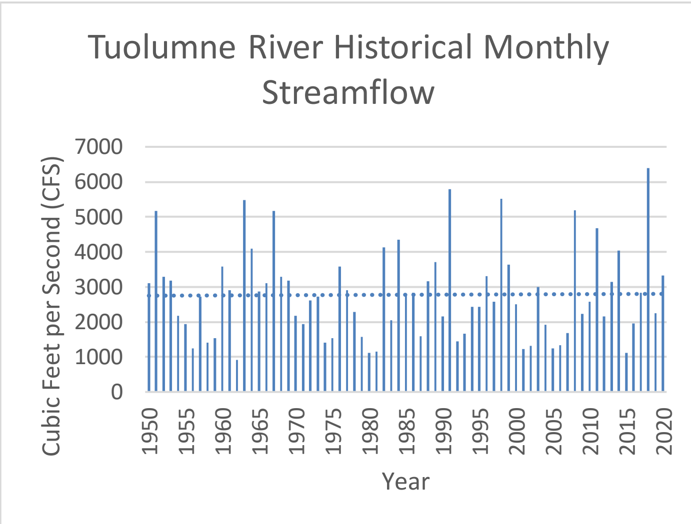


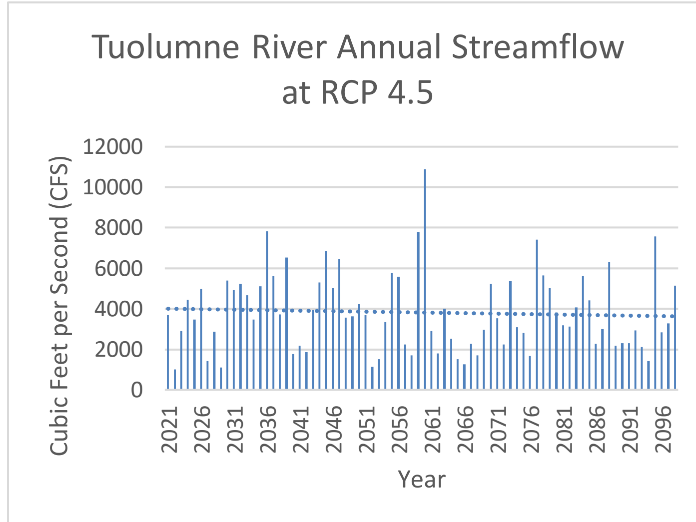
The historical annual streamflow time series data for the Stanislaus River from 1950 to 2020 shows a downward trend in Stanislaus River streamflow. The historical annual streamflow time series data for the Stanislaus River began at an average of about 1800 cubic feet per second (CFS) in 1950 and ended only slightly lower in 2020. The median historical annual streamflow time series data for the Stanislaus River depicts the median variation between 2550 and 1100 CFS. The comparison of the years 1950-1985 and 1986-2020, shows the latter having a higher median annual streamflow.

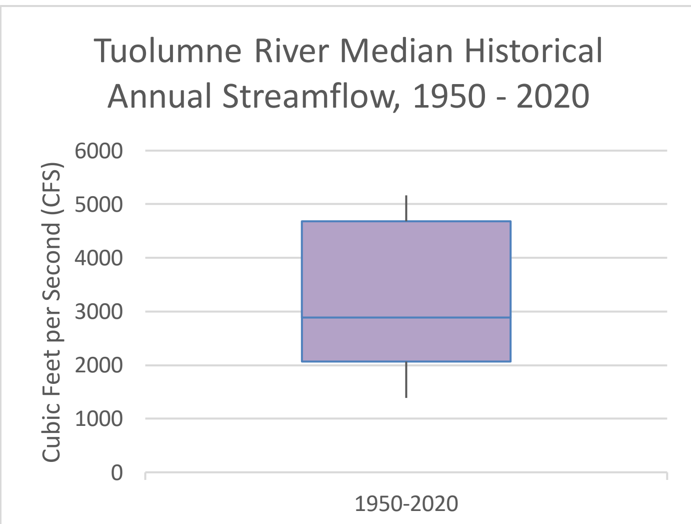
The annual streamflow at RCP 4.5 for the Stanislaus River from 2020 to 2100 shows a downward trend in Stanislaus River streamflow. The annual streamflow for the Stanislaus River at a medium emission climate scenario, starts at an average annual streamflow of 2550 CFS in 2020 and ends at 2100 CFS in 2096. The variation of SWE declined by 450 CFS. The median annual streamflow in the medium emission scenario depicts the median variation between 1550 CFS and 3400 CFS. The comparison of the years 1950-1985 and 1986-2020, shows the latter will have a lower streamflow median and smaller margin.

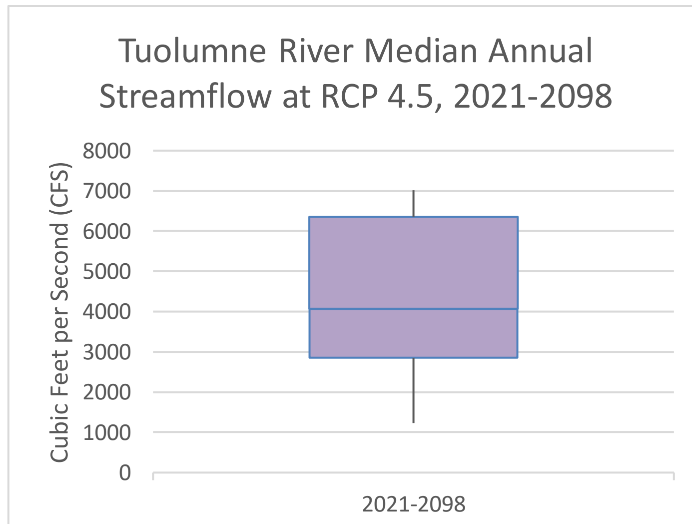
The annual streamflow at RCP 8.5 for the Stanislaus River from 2020 to 2100 shows a upward trend in Stanislaus River streamflow. The annual streamflow for the Stanislaus River at a high emission climate scenario, starts at an average annual streamflow of 2000 CFS in 2020 and ends at 2500 CFS in 2096. The variation of SWE increased by 500 CFS. The median annual streamflow in the medium emission scenario depicts the median variation between 4900 CFS and 1800 CFS. The comparison of the years 1950-1985 and 1986-2020, shows the latter will have a higher streamflow median.

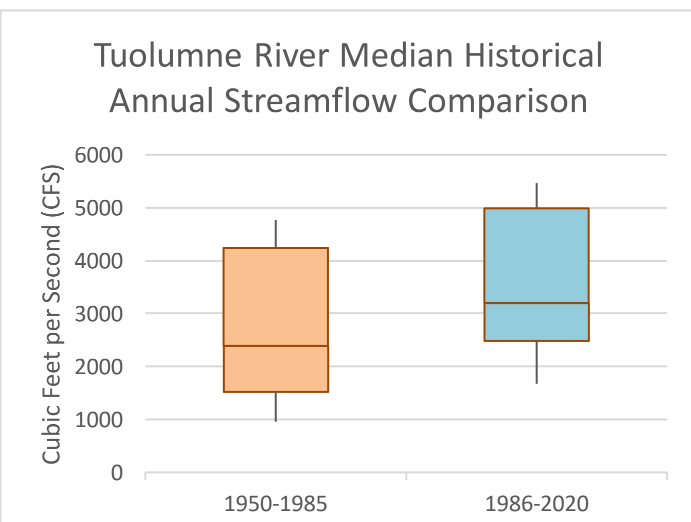
Streamflow historical and future trends: Tuolumne River

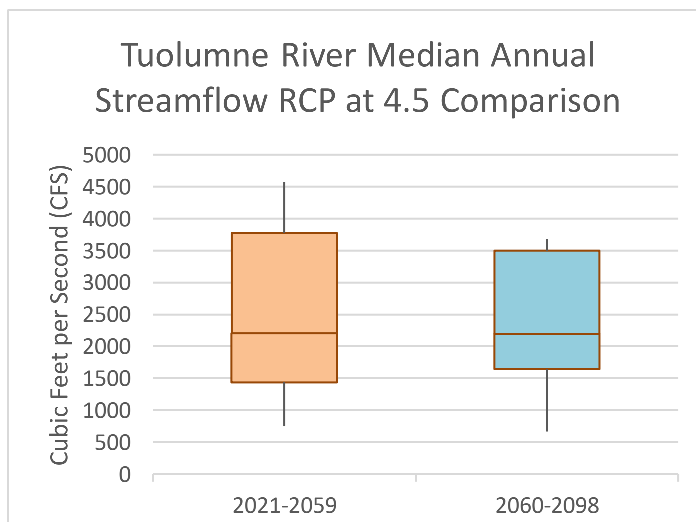


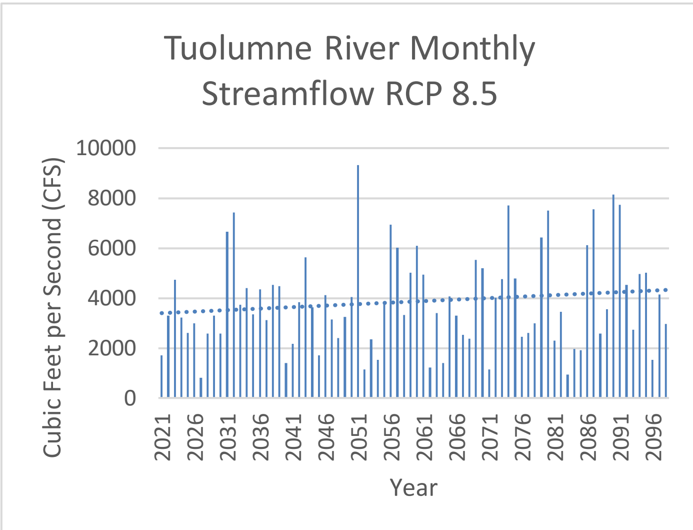


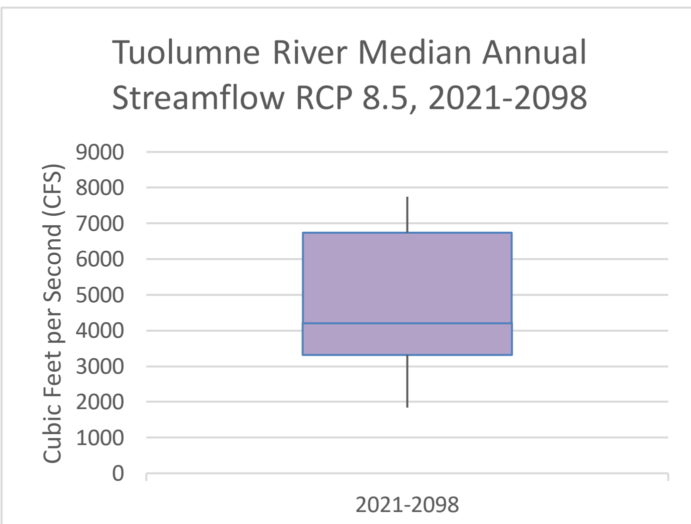


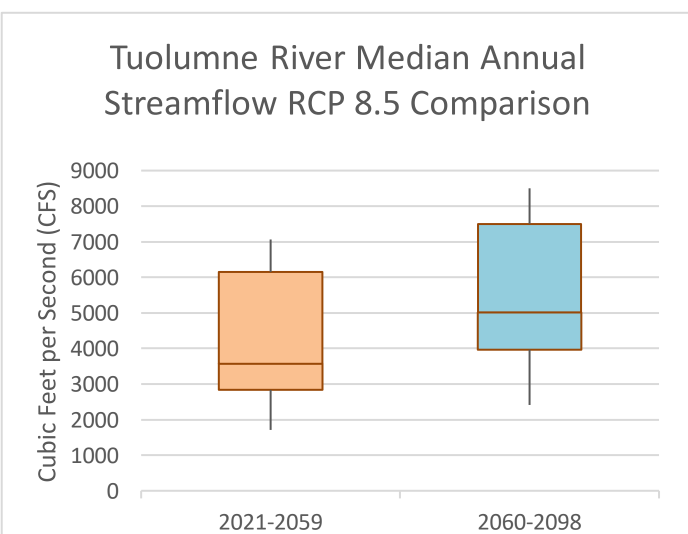












The historical annual streamflow time series data for the Tuolumne River from 1950 to 2020 shows very little variation in the Tuolumne River streamflow. The historical annual streamflow time series data for the Tuolumne River began at an average of about 2800 cubic feet per second (CFS) in 1950 and ended at about the same in 2020. The median historical annual streamflow time series data for the Tuolumne River depicts the median variation between 4800 and 2100 CFS. The comparison of the years 1950-1985 and 1986-2020, shows the latter having a higher median annual streamflow.

The annual streamflow at RCP 4.5 for the Tuolumne River from 2020 to 2100 shows a downward trend in river streamflow. The annual streamflow for the Tuolumne River at a medium emission climate scenario, starts at an average annual streamflow of 4000 CFS in 2021 and ends at 3700 CFS in 2096. The variation of SWE declined by 300 CFS. The median annual streamflow in the medium emission scenario depicts the median variation between 6100 CFS and 2800 CFS. The comparison of the years 1950-1985 and 1986-2020, shows the latter will have a lower streamflow median and smaller margin.

The annual streamflow at RCP 8.5 for the Tuolumne River from 2020 to 2100 shows a upward trend in river streamflow. The annual streamflow for the Tuolumne River at a high emission climate scenario, starts at an average annual streamflow of 3700 CFS in 2020 and ends at 4300 CFS in 2096. The variation of SWE increased by 600 CFS. The median annual streamflow in the medium emission scenario depicts the median variation between 6900 CFS and 3200 CFS. The comparison of the years 1950-1985 and 1986-2020, shows the latter will have a higher streamflow median.

Conclusions

Although the Tuolumne County has been spared from drastic climatic changes in the last 100 years, the trend will not continue into the future. The climate indicators of reduced snowpack, increase temperature, and more volatile precipitation experience variations in the next 100 years.

The current state of Tuolumne County has experienced an average increase of 1.5 °F since 1979. However, the historical SWE has stayed mostly stagnant increasing only slightly. The historical annual streamflow in the Stanislaus and Tuolumne rivers have also stayed mostly stagnant.

In a medium climate change emissions scenario (RCP 4.5) the average maximum temperature beings to rise exponentially, increasing about 4 °F from 2020 to 2100. The average annual SWE will reduce by 30 inches. The annual stream flow for both the Stanislaus and Tuolumne rivers will experience a slight downward trend.

In a high climate change emissions scenario (RCP 8.5) the average maximum temperature rises 14 °F from 2020 to 2100. The average annual SWE will reduce by 50 inches in the same timeframe. The annual streamflow for both the Stanislaus and Tuolumne rivers will increase under the high emission scenario.

This analysis can be conducted across each of California's counties, by watershed, or legislative district boundaries to understand the impacts climate change will have on water resources. By understanding temperature, SWE, and streamflow trends, regional water resources can be managed locally prioritizing the health of the river and riparian ecosystems. The compiled state data may also inform science-based water resource legislation and sustainable cohesive management strategies.

Recommendation/Limitations

Further application: Conduct a similar analysis in all of California's counties to understand regional impacts of climate change across the state.

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