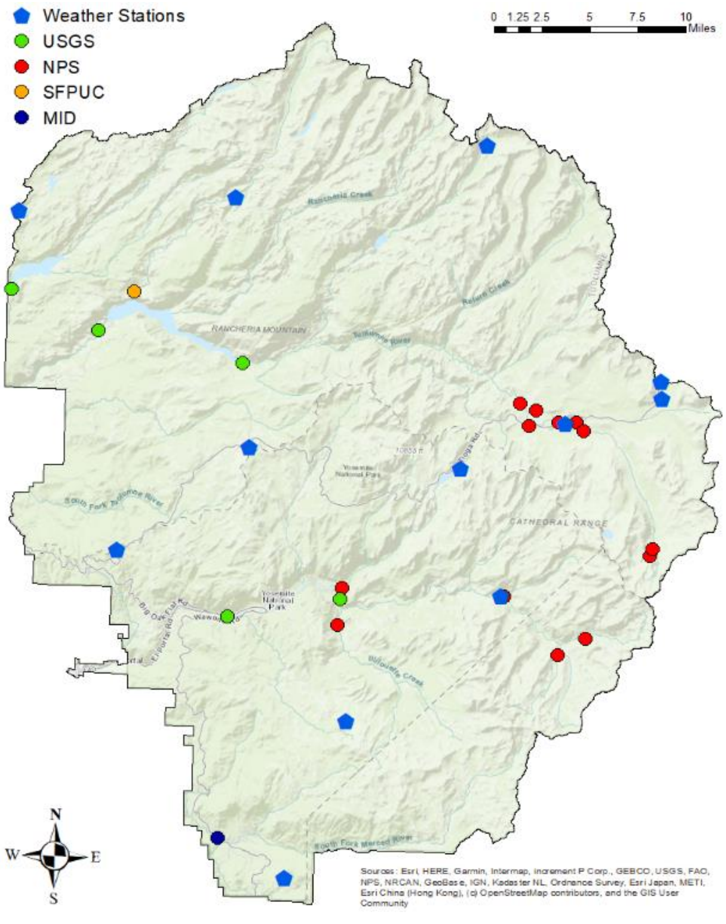
REVIEW OF THE PAST 20 YEARS OF HYDROCLIMATE DATA IN YOSEMITE NATIONAL PARK

Rachel Hallnan[1], Chad Anderson[1], and Catherine Fong[1]

ABSTRACT

The impacts of climate change are projected to be profound in mountainous, snowpack dominated regions of the Sierra Nevada Mountains. Anticipated impacts include a shift in precipitation from snow to rain, increasing snow lines, higher air and stream temperatures, and shifting snowmelt and peak runoff timing earlier in the year. Such changes have implications on natural resources such as vegetation distribution, stream ecosystems and water quality, natural fire regime, wildlife abundance and diversity, and the quantity and distribution of water resources valued and stewarded by the National Park Service. Yosemite National Park, spanning elevations from 640 – 4000 m in the central Sierra Nevada Mountains is equipped with a robust network of snowpack, meteorological, and stream monitoring instrumentation, and provides a unique opportunity to examine water regime shifts over time. Data collection within the park is often a collaborative effort between park resource managers, researchers, and state agencies to satisfy multiple objectives. For park resource managers, these long-term datasets provide an opportunity to examine local weather and climate trends to better understand local climate change impacts and use this knowledge to inform resource management decisions. Presented here are long term trends in temperature and precipitation for the high elevations of the park, and trends in snowpack and streamflow timing over the past twenty years of hydroclimate monitoring within Yosemite. (KEYWORDS: Yosemite, snowmelt, runoff, climate change, Sierra Nevada)

INTRODUCTION AND BACKGROUND



Yosemite National Park is equipped with a robust network of meteorological stations and stream gages for snowpack and runoff monitoring (Lundquist et al. 2016). The California Department of Water Resources installed many of the weather stations with snow pillows in the 1980s, with several additions and upgrades occurring since. In the early 2000s, researchers and park staff completed a substantial expansion of the stream gage network from only a few gages to approximately 18 gages distributed throughout the front and backcountry of the park (Lundquist et al., 2004). As the new installations reach the 20-year mark, it presents a good opportunity to examine the trends produced from these stations and tie them in with existing networks. Here we present and discuss overall temperature and precipitation trends, and snowmelt and runoff timing using data from the distributed hydroclimate network in Yosemite.

Figure 1. Yosemite National Park's hydroclimate monitoring network comprising of weather stations with snow monitoring capabilities and distributed stream gages.

Paper presented Western Snow Conference 2021
[1] Yosemite National Park, 5093 Foresta Yosemite National Park, El Portal, CA, 95318, rachel_hallnan@nps.gov

METHODS

To assess long term changes from historic conditions, temperature data from PRISM (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 20040) for the Tuolumne Meadows 4km grid cell area was analyzed for annual trends in minimum, maximum, and mean temperature change from 1895-2020. To examine if patterns were more recently occurring or were part of longer-term pattern changes, broke the record into four even length groups and used each as current conditions to test against historic patterns based on the preceding period (e.g. 1895-1926 versus 1926-1957, 1926-1957 versus 1957 - 1988, and 1957 - 1988 versus 1998 - 2019). The most recent groups (1988 – 2019) was also tested against the earliest timeframe (1895 – 1926). We used Wilcoxon signed rank tests to assess differences in the means for each timeframe comparison.

To examine trends in snowpack melt timing and relations to spring runoff timing, indices were calculated for both snowpack melt and streamflow timing. Streamflow timing is known to be impacted by annual variations in climate, and thus indices for the distribution of the streamflow record were calculated (Stewart et al. 2005, Moore et al. 2007, Stewart et al. 2009, Clow 2010). Streamflow indices for the date on which 20% of the annual water year flow (Q20), 50% of the flow (Q50), and 80% of the flow (Q80) had passed by the stream gage were calculated (Clow, 2010). These indices represent the general early, middle, and end of the runoff season for snowmelt fed streams. We tested the significance of these trends overtime using Pearson correlation test to evaluation the strength and direction of the observed trends in stream flow indices. In addition to runoff indices, snowmelt indices were calculated based on the annual distribution of SWE. The date and magnitude of peak SWE for the water year, the snowmelt center of mass (SM 50), and duration of the snowmelt were calculated (Clow, 2010). The snowmelt center of mass was defined based on the date of maximum SWE as the date on which half of the snow had melted based on the maximum SWE for the water year.

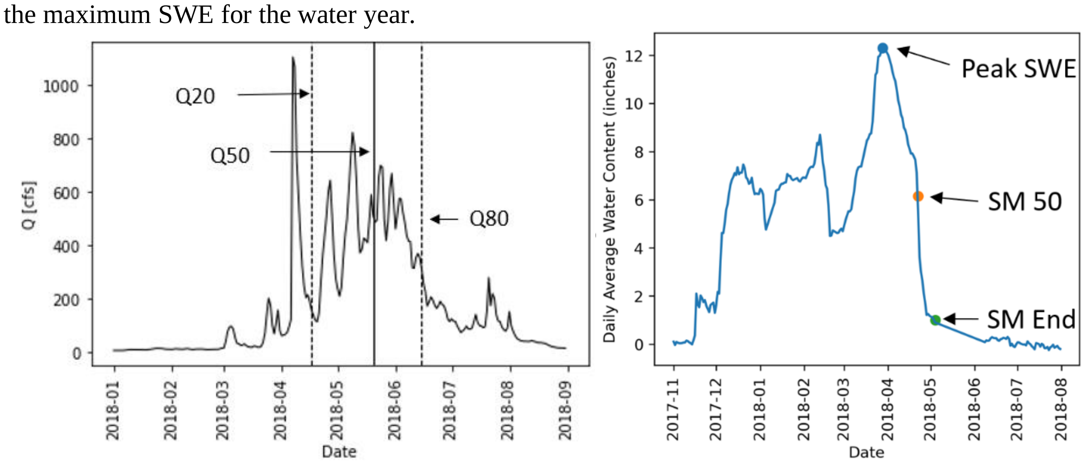


Figure 2. Left – Runoff timing indices highlighted on the hydrograph for Water Year 2018 from the Tuolumne River at Tioga Bridge. Right – Snowmelt timing indices highlighted on daily SWE for Water Year 2018 at the Tuolumne Meadows snow station.

RESULTS AND DISCUSSION

Across all temperature metrics, the largest change was found in mean and maximum temperatures (Table 1). We did not find a significant difference in minimum temperatures or precipitation for any of the time periods evaluated. Similarly, no significant change was found between the 1926 – 1957 period compared to the 1957 – 1988 period. The most significant trends presented in mean annual temperature increases for the most recent two timeframes (Table 1). Maximum monthly air temperatures during the past three decades have increased during the late summer and fall, particularly during the months of July – November (Fig.3). Winter and spring air temperatures show a weaker trend (Figure 3). Increasing temperatures may put more stress on both the amount of water available to park users, and increase stress on plant and animal species that are sensitive to temperature change and late summer water availability. For example, higher air temperatures can increase water use by plants, decreasing the left-over available water for other users, a result amplified in areas of denser vegetation (Cristea et al. 2014).

Table 1. Significance levels of mean changes for FRISM data near Tuolumne meadows for the timeframes tested using Wilcoxon signed rank tests.

Timeframe	Minimum Temperature Increase (˚F)	Maximum Temperature Increase (˚F)	Mean Temperature Increase (˚F)	Precipitation Change (inches)
1895 - 1926 versus 1926 - 1957	ns	ns	<0.05	ns
1926 - 1957 versus 1957 - 1988	ns	ns	ns	ns
1957 - 1988 versus 1998 - 2019	ns	<0.001	<0.001	ns
1895 - 1926 versus 1988 - 2019	ns	<0.01	<0.001	ns

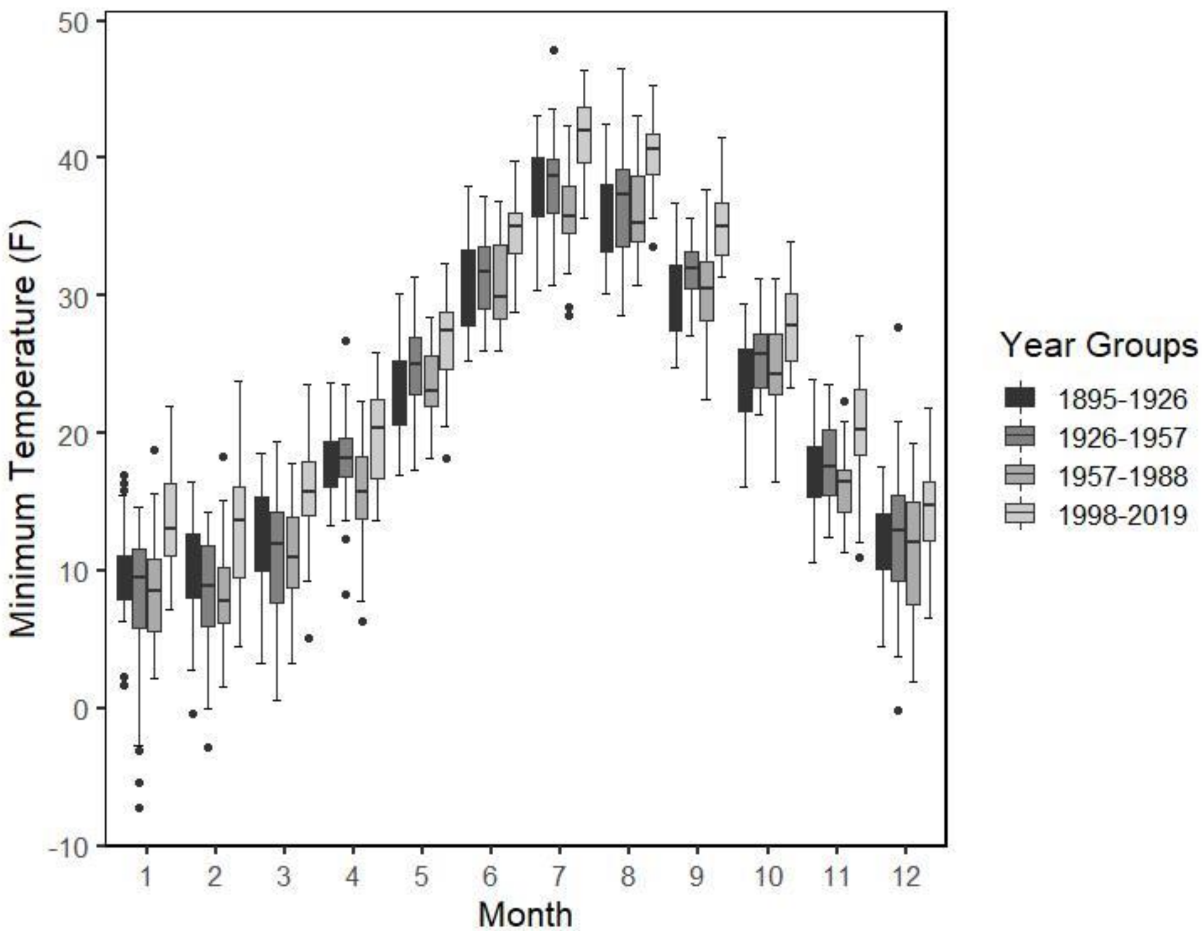


Figure 3. Maximum monthly temperatures from PRISM for the Tuolumne Meadows 4km grid cell area plotted as thirty-year groups beginning in 1895 and extending through 2020.

Snowmelt timing indices suggest a slightly earlier snowmelt in most of the sites across the park, however the significance of this trend was low. Exceptions to this trend were Dana Meadows, White Wolf, and Paradise Meadows. The trend at Dana Meadows was very close to zero, thus suggesting no shift in snowmelt timing over the period. This may be related to topographic effects that hold snow more consistently in that area and/or proximity to the large open Dana Meadow, which may provide a buffer to the effects that annual variations in snowpack size and temperature have on melt timing. White Wolf has had chronic infrastructure and technology issues and has resulted in large periods of missing data. Data record inconsistency and missing data for White Wolf make it difficult to make any statements on trends with confidence, and thus results from that site will not be considered until a more complete data record is available. In general, an earlier snowmelt shifts the timing when water held in the snowpack reservoir would become available to park and downstream users.

The runoff timing indices show little change over time ($p>0.05$), with a slight trend towards earlier in the year. The 20% runoff index, representing the early portion of the snowmelt runoff, showed the most change over time and shifted approximately 1 day earlier per year for the period of record (Fig. 4). However, the 20% runoff timing index trend was not significant ($r2= -0.37$, $p=0.13$). This pattern was also present in the duration of snowmelt calculated from the nearby Tuolumne Meadows Weather Station, which shifted approximately 1 day shorter per year. The 50% and 80% indices show a uniformly descending trend at a lower rate than the 20% index ($r2= -.26$ and $r2=-0.11$, respectively). Both the 50% and 80% did not show a significant trend ($p>0.5$).

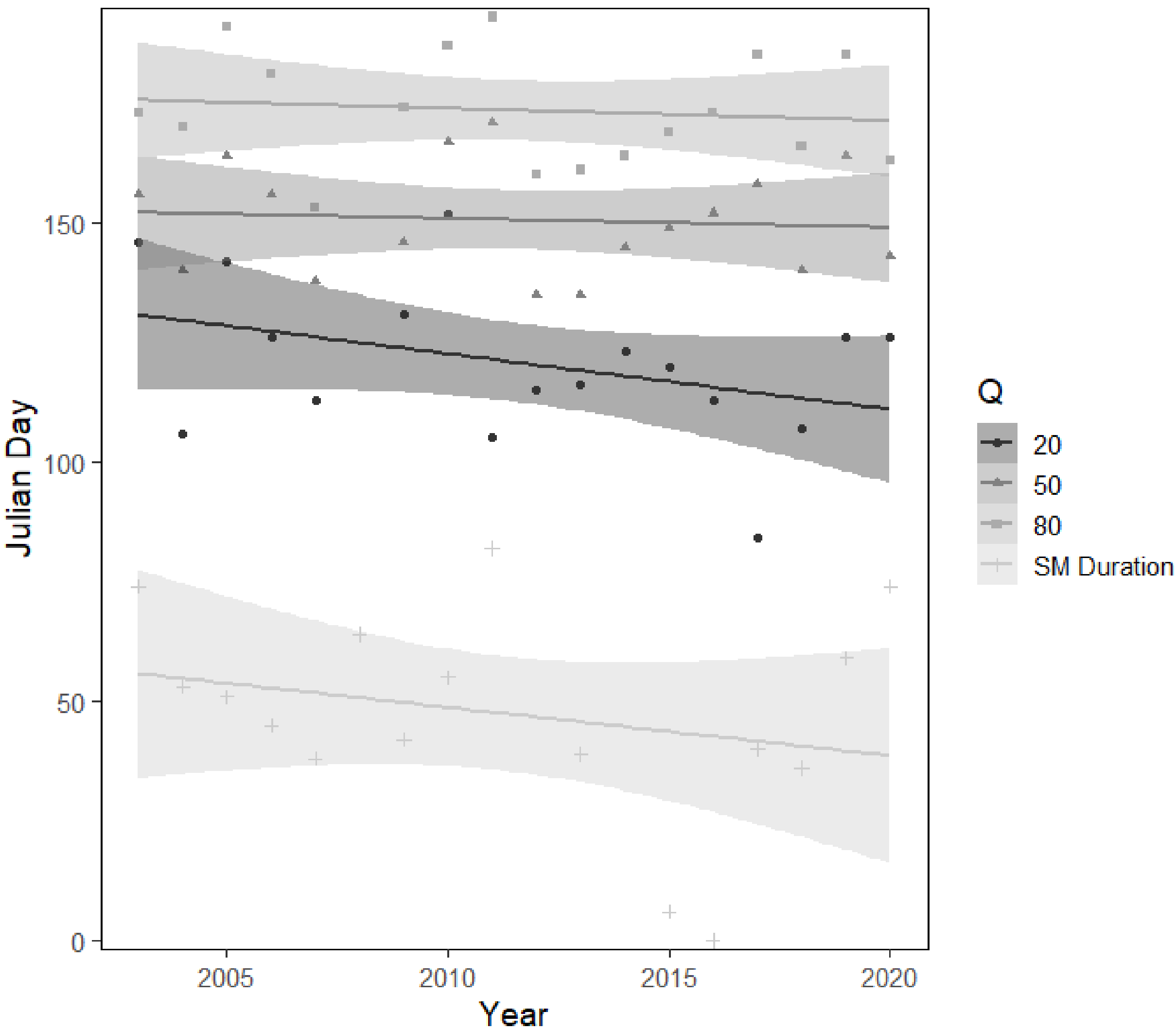


Figure 4. Graph of snowmelt indices for the Julian Day on which 20% (Q20), 50% (Q50), and 80% (Q80) of the total Water Year discharge had passed the stream gage located on the Tuolumne River at Tioga Road. Additionally, the duration of snowmelt (SM Duration) calculated from a nearby meteorological station at Tuolumne Meadows.

CONCLUSIONS AND CONTINUED WORK

Integrating an understanding of hydroclimatic trends into stewardship of park natural resources is critical for park managers to purposefully respond to the continuous climatic changes that are anticipated. Preliminary results indicate that in Yosemite National Park's high country, impacts of climate change on water resources exist in the form of earlier snowmelt and runoff timing, a phenomenon likely tied to the observed increase in air temperatures, and has been observed regionally (Dettinger and Cayan, 1995). Analyses into site specific trends in snowpack and melt timing to understand smaller scale trends within specific regions and areas of the park are ongoing. While a duration metric was not calculated based on the runoff indices, an earlier 20% runoff index coupled with little change in the mid and late season indices would suggests an increasing runoff duration. Conversely, shorter duration of snowmelt implies a shorter runoff season, opposite of what the results here show. A likely explanation is the presence of glaciers and perennial snow and ice in the watershed, which buffer late season runoff and sustain flows even during years of low snowpack (Stock, in progress). As glaciers and perennial snow and ice features shrink, this effect may disappear or change. The projected disappearance of these features in the park may result in reduction of mid- and late-season runoff, and thus may result in an earlier shift for those timing indices, a result not present in the current data. Future work is planned to investigate the contributions of year-round snow and ice fields in the high country to main rivers and tributaries and the extent to which they buffer late season runoff. This preliminary review suggests that climate change impacts are likely underway in Yosemite in the form of shifting snowmelt and runoff timing, but the trends have not yet become significant within the timeframe of observed data that exists from field data from weather and stream gage stations. But, as indicated from the long-term modeled data and previous studies, a long time period would likely demonstrate more statistically detectable changes (Dettinger and Cayan, 1995, Cristea et al., 2014, Stewart et al. 2004). Continued work on this effort by park staff will result in a complete and comprehensive report on recent shifts in hydroclimate data. Examining and understanding the trends presented here and the extent to which climate change currently is impacting park water resources is the first step that is required for any subsequent management actions the park considers in the future to address impacts related to climate change in the park.

REFERENCES

Clow, D. W., 2010. Changes in the Timing of Snowmelt and Streamflow in Colorado: A Response to Recent Warming. *Journal of Climate*, 23, 2293-2306.

Cristea, N.C., Lundquist, J.D., Loheide, S.P., Lowry, C.S. and Moore, C.E., 2014. Modelling how vegetation cover affects climate change impacts on streamflow timing and magnitude in the snowmelt-dominated upper Tuolumne Basin, Sierra Nevada. *Hydrological processes*, *28*(12), pp.3896-3918.

Dettinger, M.D. and Cayan, D.R., 1995. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. *Journal of Climate*, *8*(3), pp.606-623.

Lundquist, J.D., Cayan, D.R. and Dettinger, M.D., 2003. Meteorology and hydrology in Yosemite National Park: A sensor network application. In *Information Processing in Sensor Networks* (pp. 518-528). Springer, Berlin, Heidelberg.

Lundquist, J.D., Roche, J.W., Forrester, H., Moore, C., Keenan, E., Perry, G., Cristea, N., Henn, B., Lapo, K., McGurk, B. and Cayan, D.R., 2016. Yosemite Hydroclimate Network: Distributed stream and atmospheric data for the Tuolumne River watershed and surroundings. *Water Resources Research*, *52*(9), pp.7478-7489.

Moore, J.N., Harper, J.T. and Greenwood, M.C., 2007. Significance of trends toward earlier snowmelt runoff, Columbia and Missouri Basin headwaters, western United States. *Geophysical Research Letters*, *34*(16).

Stewart, I. T., 2009. Changes in snowpack and snowmelt runoff for key mountain regions. *Hydrologic. Processes*, 23, 78–94.