Analyzing the Snow Water Equivalent to Discharge Relationship Over Time in the Cascade Range, WA

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Abstract

Throughout the western United States, the melting of snow during spring and summer months provides ~70% of stream discharge. Snow water equivalent (SWE), the amount of water held in snowpack, in the Cascade Range has had an observed decline over the second half of the 20th Century4. Alongside observed declines in SWE, the patterns of stream discharge have had observable changes, most notably an earlier addition of melting snow, causing the magnitude of low flows to decline. This study aims to observe these trends in four drainage basin in the Cascade Range: Klickitat, Entiat, Thunder, and NF Nooksack. These basins were chosen based on availability of SWE and discharge data as well as their similar drainage areas and differing physical locations: two on the western slope and two on the eastern slope. For each water year, peak SWE and peak discharge were analyzed based on magnitude and timing. In analysis, no obvious trends of decreasing SWE and earlier spring melt were observed in the basins. Western basins have a high amount of variability in peak SWE. Entiat basin has a large disconnect between the timing and magnitude of peak SWE and peak discharge. Data sets that go further into the past will be necessary to further this study and analyze if the observed lack of change from 1996-2021 is different than levels further in the past.

Introduction

- In the Pacific Northwest, melting snow during spring and summer months provides 70% of all stream discharge when precipitation is low4
- Snow water equivalent (SWE) is the amount of water in snow, measured in inches
- From 1950-2000, snow water equivalent has decreased across the Cascade Range4
- Across the western US, peak snow accumulation and peak snowmelt has been occurring earlier in the year than historically2
- Earlier spring snowmelt and lower summer discharges have all been observed in the interior Northwest5
- Any change in discharge patterns and magnitudes, affected by winter snowfall and snowmelt timing, will affect water resource management and aquatic and terrestrial ecosystems2

Research Question

- Is the relationship between snow water equivalent and peak discharge changing in the Cascade Range of Washington state?

Study Area

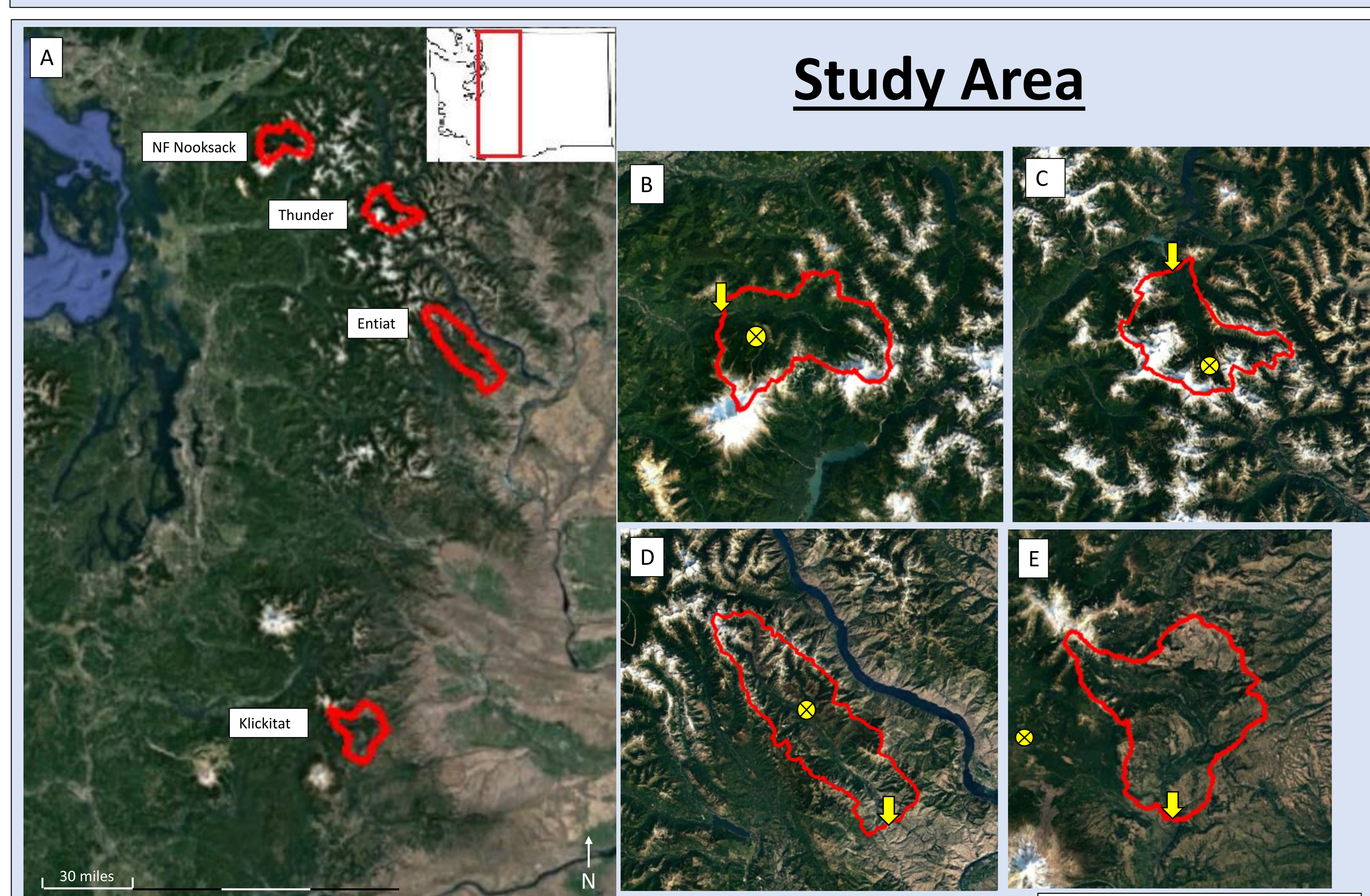

Figure 1: A: overview map of all four basins3, B: NF Nooksack Basin (W), C: Thunder Basin (W), D: Entiat Basin (E), E: Klickitat Basin (E)8

Key
= NWIS USGS discharge gage
= SNOTEL Station

Methods

- Study areas were chosen based on availability of discharge data from the USGS NWIS, snow water equivalent data from the SNOTEL System, similar basin characteristics (average discharge magnitude, basin area, relief, etc.), and location on the eastern and western slopes of the Cascade Range. Two basins were chosen on the western slopes of the Cascades and two basins were chosen on the eastern slopes of the Cascades to provide an overview of the SWE to discharge relationship across the mountain range.
- Yearly peak snow water equivalent (SWE) data was collected from SNOTEL database from USDA.
- Peak discharge data was collected from USGS NWIS database by finding date and magnitude of peak discharge occurring after peak SWE in the water year.
- The number of days into the water year (Oct 1-Sept 30) were calculated to graphically analyze the timing of peak SWE and peak discharge.
- Graphs for peak SWE, peak discharge, timing of peak SWE, timing of peak discharge, time between peak SWE and peak discharge, and the length of the yearly snow season were created. Graphs were visually analyzed.

Results

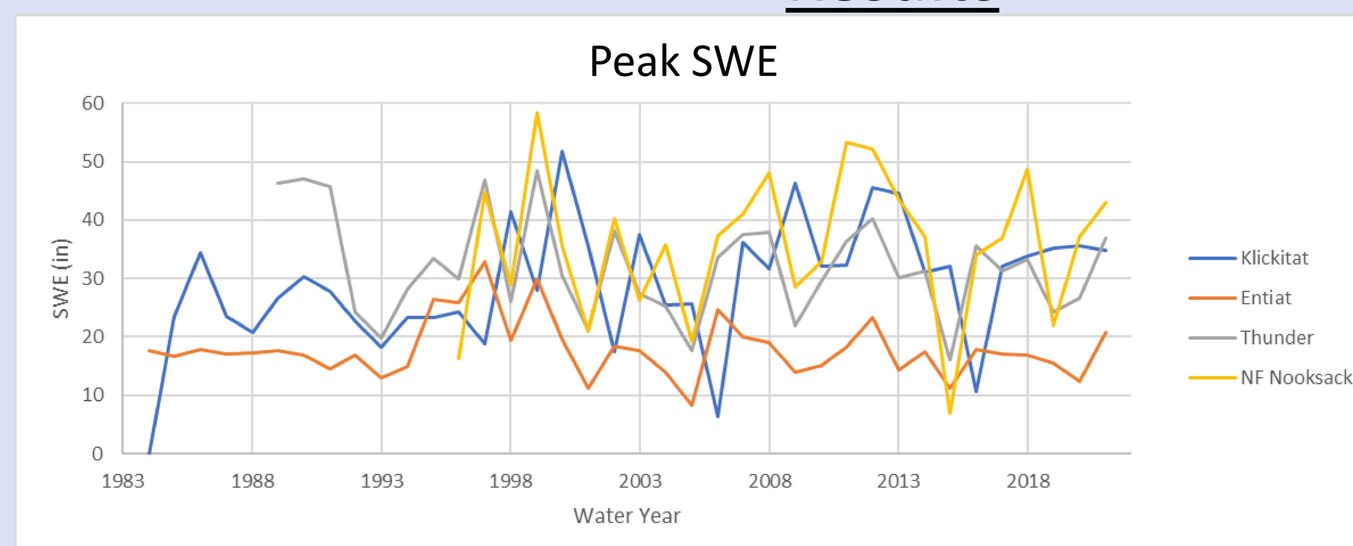

Figure 2: Peak SWE for each basin for years on record from SNOTEL. Entiat basin has the lowest peak SWE year-to-year, while Klickitat, Entiat, and NF Nooksack Basin all follow similar trends of high variability from year-to-year.

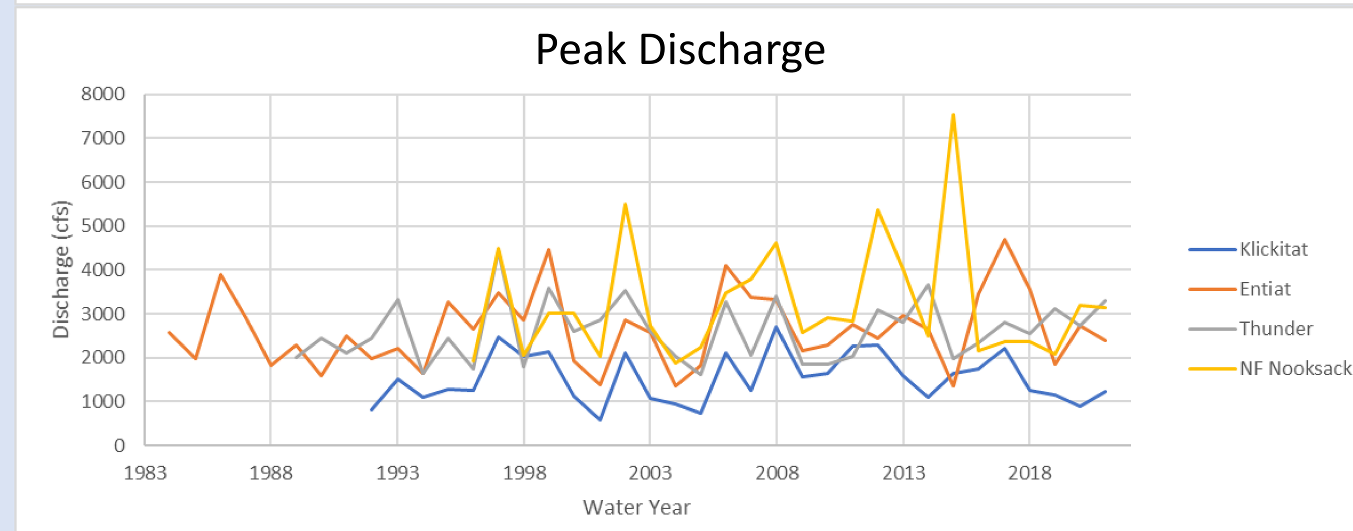

Figure 3: Peak discharge for the time period SWE data is available. Klickitat basin has the lowest peak discharges, NF Nooksack basin has the highest peak discharges and the most variability, and Entiat and Thunder basins have similar peak discharges year-to-year.

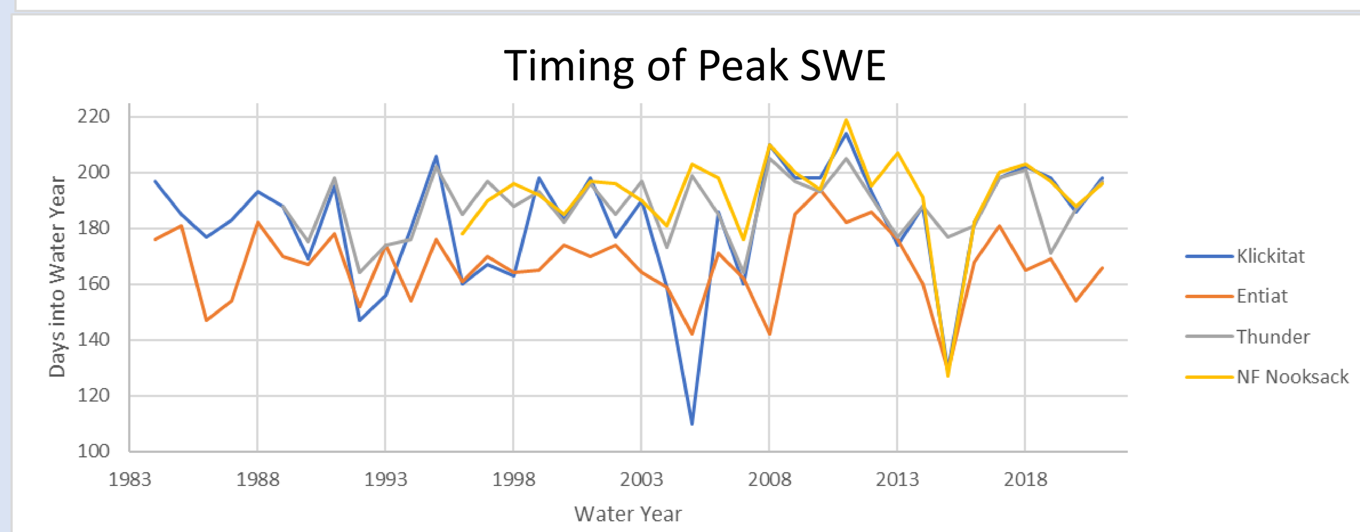

Figure 4: Timing of peak SWE graphed as days into water year (Oct 1-Sept 30) over time. Entiat basin has the earliest peak SWE while the other three basins have similar timing of peak SWE.

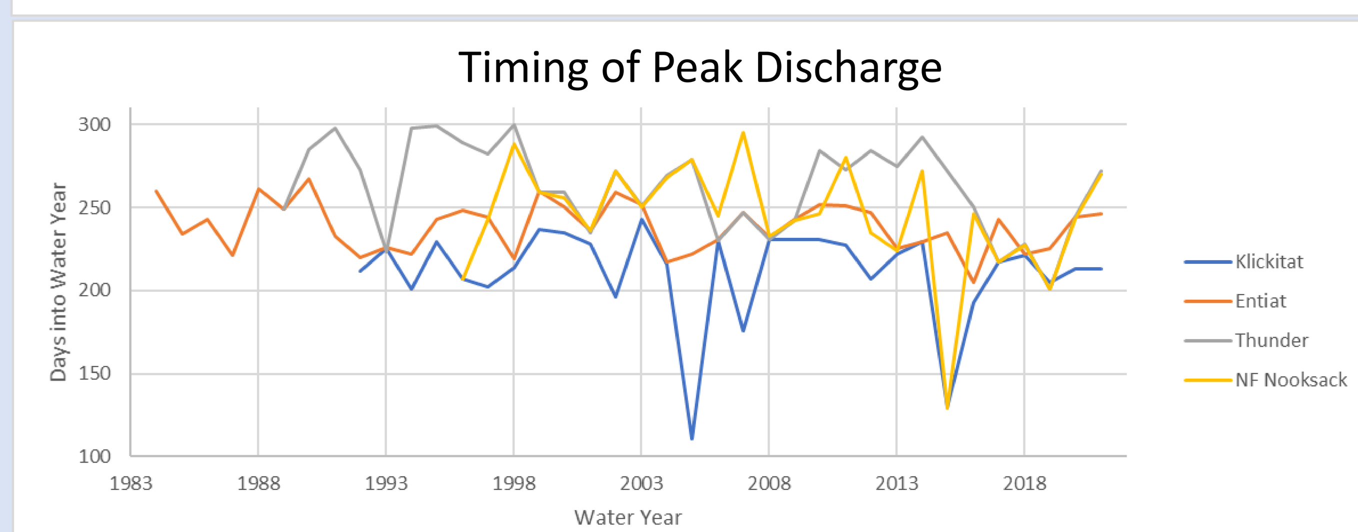

Figure 5: Timing of peak discharge after peak SWE graphed as days into water year (Oct 1-Sept 30) over time. On average, Klickitat basin has the earliest peak discharges and NF Nooksack and Thunder basins have the latest peak discharges.

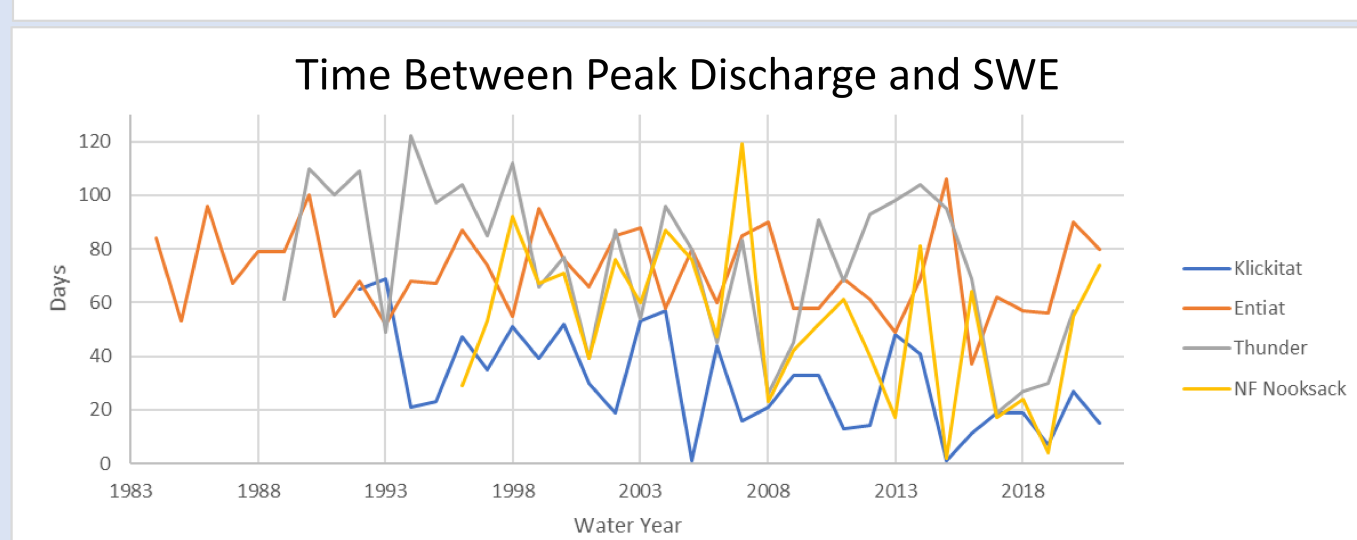

Figure 6: Number of days between peak SWE and peak discharge. Klickitat basin has the lowest amount of time between peak SWE and peak discharge and NF Nooksack and Thunder basins follow similar trends year-to-year.

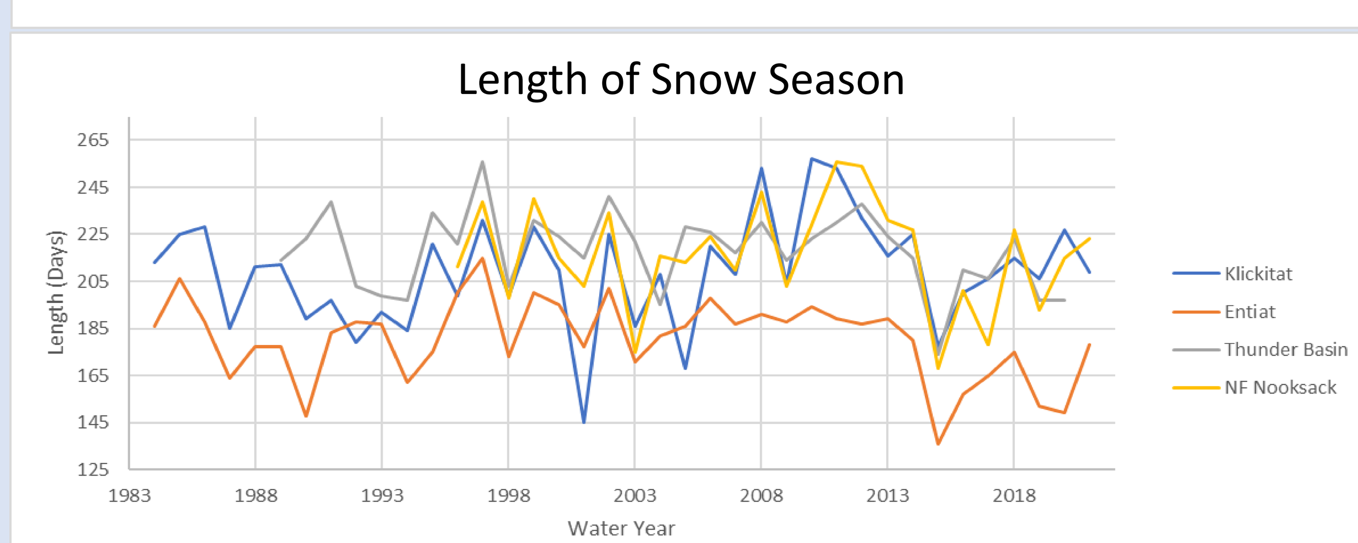

Figure 7: Number of days with snow on the ground. Entiat has the shortest snow season, Klickitat has the largest variability from year-to-year, and all basins follow the same year-to-year trend (when one basin has a shorter snow season, all basins have a shorter snow season, i.e., 2015).

Discussion

- The lack of observable negative trends for the timing and magnitude of peak SWE and discharge could be due to the short timespan of 1996-2021 used for this study. A larger timespan, as used in the Mote, 2004 study, may give us similar results.
- Difference exist between eastern and western basins. Entiat basin has lower peak SWE than NF Nooksack and Thunder basins, the western basins. It also has earlier peak SWE and a shorter snow season than the western basins. However, the peak discharges are not smaller in size or earlier in the year than the western basins. Klickitat basin has lower discharges and earlier peak discharge timing than the western basins yet similar peak SWE magnitude and timing to the western basins.
- Entiat basin has the lowest and earliest peak SWE, yet the magnitude and timing of the peak discharges do not correlate. The peak discharges could be a result of a large precipitation event, yet the consistency of this lag time suggests other processes. Subsurface flow process or climatic processes could be the cause. Slow subsurface flow or an extended period with no snow accumulation or melting could cause this lag time.
- The peak discharge for each water year was determined as the greatest discharge that occurred after the peak SWE. This method did not account for the source of the discharge. Therefore, the peak discharges used for this study could be caused by precipitation events rather than snowmelt. To complete a more accurate analysis of snowmelt caused discharges, precipitation data would need to be included in analysis to determine whether discharge is a product of snowmelt or precipitation.
- Another issue to consider with the data is the fact that the SNOTEL station used for the Klickitat basin lies outside the catchment. This station was used due to its proximity to the basin and drainage to the east, the same direction Klickitat basin drains. This may be why it seems Klickitat basin is behaving like NF Nooksack and Thunder basins regarding SWE data, since the SNOTEL station is close to the divide of the Cascades. The disconnect between the SWE and discharge data may also be a result of this issue, since the discharge magnitude and timing are the lowest and earliest while the SWE magnitude and timing are larger and later.

Conclusions

- Further analysis of the SWE to discharge relationship in the Cascade Range will require larger data sets. For this project, an ~30-year time span was used. The availability of data was a constraint on which basins I was able to study. A project which can allocate more time to study more drainage basins in the Cascades over a greater time span would yield much more insightful results for the SWE to discharge relationship over time.
- Two potential studies could be conducted from the findings of this research:
  - What is driving the variability of SWE and discharge on the western slope of the Northern Cascades (Thunder and NF Nooksack basins)?
  - What role does subsurface flow play in the lag time between peak SWE and peak snowmelt driven discharge in Entiat basin?

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