1. **Introduction:**

The Tolt River was selected as the site of interest because it’s representative of the mountain reservoir system throughout the west coast (Washington, Oregon, California). Snowpack in this mountainous region near a dense population has observed consistent decreases in annual snow levels. This in turn changes the annual timeline of snow levels for the Tolt River. As the snow levels deplete earlier in the spring, the dry season of the summer lengthens. Dry soil increases the risk of forest fires; and early melt increases the risk of flooding. The observations recorded in the Tolt river basin signify the possibility of climate change affecting the region. The verification of these changes in snowpack melt runoff cause for water management personnel to plan for flooding impacts. Understanding how the hydrology of the Tolt river is changing will provide for effective mitigation of these environmental impacts.

1. **Objectives:**

The objective of this project is to assess the frequency, magnitude, and timing of hydrologic impacts in the South Fork Tolt River Basin (SFTRB) associated with rain on snow events, and to further understand the meteorological and snow cover conditions that have led to the occurrence of individual events in the past. Additionally, we will 1) identify decadal trends in the timing and magnitude of peak snowmelt, 2) determine whether there is an increase in rapid snowmelt in the spring, and 3) determine whether the frequency and magnitude of midwinter melt events has been increasing in recent years in the SFTRB. If time permits, we will compare the observed meteorological conditions associated with identified rain on snow events with regional climate models, and quantify the difference in the expected and observed conditions.

1. **Rationale and Scope:**

The South Fork Tolt River Reservoir (SFTRR), which is located 16 miles upstream of the town of Carnation, stores 57900 acre-feet of water and supplies 30% of the drinking water for more than 1.4 million people in the Seattle Metropolitan area (South Fork Tolt Watershed Management Plan, 2011). As in the case for most reservoirs, this resource is largely modulated by snowmelt, with the highest water levels in the reservoir after the spring melt, and lowering levels throughout the summer and early fall. Throughout the winter, water levels in the reservoir vary, and flow through the dam is managed to optimize water storage while also managing flood risks (South Fork Tolt Watershed Management Plan, 2011). Rain-on-snow events in the maritime snow climate of the Cascade Mountains lead to rapid snowmelt events, leading to both a loss of snowmelt for warm-season water storage and increased risk of flooding during the winter months (Marks et al., 1998). Climate models predict that the annual winter precipitation and temperatures are projected to increase in the Snohomish River Basin, with a decrease in precipitation during the warmer seasons (Vano et al., 2009). This motivates understanding the impact, frequency, and magnitude of rain-on-snow events in this region, which will likely increase under these projected meteorological conditions.

This project will consist of a detailed snow hydrology analysis of the Tolt River Basin over the last 25 years (1995-2020) using daily USGS stream discharge data and SNOTEL snow water equivalent measurements, in combination with rain-on-snow event-focussed precipitation and snow cover information. Using these datasets, we will identify annual and decadal patterns in the timing and magnitude of snowmelt throughout the snow year, and characterize the conditions under which rain-on-snow events have happened in this basin in the past. Focussing a detailed analysis on this specific basin will allow us to provide a meaningful dataset for water resource management decisions for the Tolt River Basin and the populations that rely on it.

1. **Research Management Plan:**

To meet the objectives stated for this project, we will visualize and analyze daily time series data of 1) river discharge from a USGS stream gage site and 2) snow water equivalent (SWE) at a SNOTEL pillow in the SF Tolt River Basin to identify significant melting events indicated by dates with high discharge and high melt rates observed at these respective sites. Furthermore, we will use MODIS satellite imagery in combination with temperature and precipitation recordings at the local SNOTEL site to address whether any anomalous melt observations were associated with a rain-on-snow event, and characterize the conditions under which identified events have occurred. Additionally, while analyzing the stream discharge and snow pillow data, we will identify decadal trends in the timing and magnitude of peak snowmelt, along with the frequency of midwinter melting events.

**4.1 Data Acquisition:**

We will use publicly available data from the USGS stream gage site 12147600 which has daily discharge records starting in the 1988 water year. We will use publicly available data from the NRCS Skookum Creek SNOTEL site which has daily snow water equivalent data starting in the 1996 water year. We will acquire MODIS imagery for dates with rapid melt events from the NSIDC site to identify snow-cover distribution. We will use topographic data from the USGS TNM download site to produce maps and identify the elevation of the snow-line during given events. We will acquire temperature and precipitation measurements from the RCS Skookum Creek SNOTEL site to characterize specific events. If time allows, we will compare our observations to a commonly used regional climate model, which has not yet been identified. The tools that we will use include MATLAB, Python, QGIS, ArcGIS, and Google Earth Engine, which are all either provided by the university or publicly available.

**4.2 Data Analysis and immediate results:**

First, we will plot daily discharge and SWE data for the 25 water year study period (1995-2020) and identify typical and anomalous melting events. Second, will also identify if there are trends in the timing and magnitude of snowmelt throughout the year. Third, we will use temperature and precipitation data from the SNOTEL site to determine if identified anomalous melting events were a result of a rain-on-snow event. Fourth, we will use snow cover information, in combination with topographic data, to determine the elevation of snow cover during at least one identified rain-on-snow event. Fifth, we will use a combination of all of these observations to characterize the conditions of at least one rain on snow event. Sixth, if time allows, we will compare the observations from this study with regional climate models and report any differences in the expected and observed conditions. Seventh, we will produce graphics and tables and disseminate our results in a final report.

**4.3 Timeline and progress so far:**

*Week 4 (Jan 26/28):* Draft/revise project proposal, proposal due 1/28/2021

*Week 5 (Feb 2/4):* Acquire data, identify flooding events in streamflow gages

*Week 6 (Feb 9/11):* determine annual snowmelt trends, Midterm report due 2/9/2021

*Week 7 (Feb 16/18):* Identify rain-on-snow event to analyze, download MODIS

*Week 8 (Feb 23/25):* Perform snow cover analysis, perform model comparison

*Week 9 (Mar 2/4):*Draft final report

*Week 10 (Mar 9/11):* Report due 3/12/2021

1. **Future Research:**

This project provides a general understanding of mountain hydrology in the Pacific Northwest. Future research projects will provide additional backing to the findings in this study. The ability to replicate the findings of this research in similar geographical settings will add certainty to the overall trend of snow hydrology. Future research will also explore the specific causes of depleting snow levels. Such projects may focus primarily on temperature change over the time period of interest. Exploring the loss of vegetation in the environment is another topic which may contribute to lower volumes of snow storage in mountainous regions. And if this research proves to display inconsistencies between data collection techniques, future research projects can explore the possibility of improved techniques of remote sensing for snow data.

All of these research topics aim to verify changes in the environment and identify ensuing challenges to water management. Understanding these changes provides the ability to prepare and adjust to the environment accordingly.

1. **References:**

Marks, D., Kimball, J., Tingey, D., Link., T (1998). The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: a case study of the 1996 Pacific Northwest Flood. Hydrological Processes (12) 1569-1587. URL: <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.594.6728&rep=rep1&type=pdf>

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