Application of Remote Sensing Snow Covered Area Data for Streamflow Prediction

Introduction: Seasonal snow water availability and resulting streamflow are critically important for environmental and water resources in the Western United States with over 50% of the streamflow originating from mid to high elevation areas (Hammond *et al.*, 2018). Streamflow predictions are valuable for watershed managers and water users, but modeling tools require information about the spatial and temporal distribution of snowpack conditions. This information is challenging to obtain, as most observations of snow are at low elevations, not representing the spatial variability of snowmelt within a watershed (Rice *et al.*, 2011). Remote sensing-sourced snow data present opportunities to observe high-resolution snow distribution at the watershed scale, which could improve snowmelt and streamflow prediction. In collaboration with the Wood River Water Collaborative (WRWC), the proposed research will assess the application of remote sensing derived snow cover area (SCA) data to improve streamflow prediction.

Background: The WRWC represents seventy-five water users from non-profit and private entities, and both federal and local government agencies, that formed to ensure the long term environmental health and increasing water use demand in the Wood River Watershed, ID. To improve streamflow prediction and water resource management, the WRWC received Bureau of Reclamation funding to develop new tools to help plan and predict water availability. As part of this effort, the WRWC had a Multiple Linear Regression streamflow prediction model developed to predict water curtailment dates before the irrigation season (Kaiser, 2021). The WRWC is seeking to further develop model parameters and additional tools for predicting streamflow and associated curtailment dates.

Knowledge about the distribution of snowmelt across the watershed is necessary to examine and predict the streamflow response to snowmelt. For instance, in the Sierra Nevada, Rice *et al.*, (2011) found high-elevations contributed to about one-third of snowmelt, while middle elevations contributed 40-60% of annual snowmelt. Additionally, aspect and vegetation cover influence snow accumulation and melt rates across the landscape, resulting in spatially heterogeneous snow depth and snowmelt timing (Moeser *et al.*, 2014; Currier and Lundquist, 2018). Despite the spatial variability of snow across watersheds, continuous measurements of snow depth and snow water equivalent (SWE) are generally not feasible at more than a few sites not representing the heterogeneity of the watershed (Rice *et al.*, 2011). Satellite remote sensing derived SCA presents a method to monitor snowmelt at the watershed scale through the snow cover season.

Remotely sensed SCA has been used to derive snow depletion curves, which relate SWE and SCA (Fassnacht *et al.*, 2016), for updating modeled snow cover (Clark *et al.*, 2006), and to forecast spring flood volumes (Marcil *et al.*, 2016). Marcil *et al.*, (2016) correlated SCA with spring runoff entering a reservoir in Nechekao River Basin in British Columbia, Canada. They found the timing of MODIS SCA depletion was highly correlated ($R^2 = 0.87$) with the fraction of flood volume over 14 years. Previously in the Big Wood River Watershed, Harshburger *et al.*, (2010) found MODIS derived snowline combined with and Snotel SWE accurately predicted spatially distributed SWE values. The results of these studies demonstrate empirical relationships between SCA and streamflow are a simple and useful tool for understanding and predicting streamflow in snow dominated watersheds.

Goals and Objectives: The goal of this research is to evaluate, incorporate and communicate the application of snow cover remote sensing data for streamflow prediction in the Big Wood River Watershed, ID. To accomplish this goal, I will complete the following objectives:

1) Extract snow cover metrics from MODIS SCA data.
2) Incorporate and assess metric performance for streamflow prediction.
3) Develop a Google Earth Engine (GEE) GUI to download MODIS SCA metrics.

Research Design: In the proposed research I will collaborate with the WRWC to achieve the three objectives (Fig. 1). To accomplish the first objective I will present the research proposal to WRWC members at their monthly meeting and discuss potential SCA metrics. Following discussion with the WRWC, I will extract currently identified (Table 1) and recommended SCA metrics from MODIS SCA data (MOD09GA, 500 m, 8 day return) using GEE.

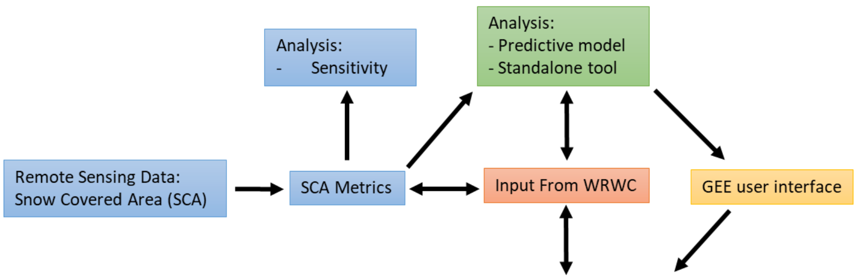

FIGURE 1 Proposal workflow downloading and evaluating SCA metrics (blue), analysis of metrics for streamflow prediction (green), GEE GUI development (yellow) and receiving input from WRWC members through the course of the project (red).

Next, I will evaluate the inter-annual spatial and temporal variability of snow extent depletion and each SCA metric with Snotel SWE and streamflow at gauges (Table 2) on the Big Wood River and tributaries through the previous 10 years. Due to potential changes in the timing and magnitude of snowmelt and streamflow as a result of climate change, I will evaluate how SCA metrics in different water years and preceding landcover changes such as wildfire events. This analysis will identify trends of SCA metrics to changes that may be important when incorporating and evaluating metric effectiveness for forecasting streamflow in different years.

Table 1 Current metrics identified based on a literature review

Snow Metrics
max snow cover extent
rate of snow cover extent depletion
median snow cover
snow cover extent on March 1st
snow cover extent at peak SWE

The second objective is to assess the incorporation of these metrics into a statistical streamflow prediction model developed by Dr. Kaiser and the standalone utility of metrics as an additional tool to help water users. Each metric will be incorporated into the statistical model and model improvement will be assessed by comparing the modeled and measured streamflow and resulting R^2 value. The metric performance will be evaluated based on all the years as well as between wet, dry, and normal snow years and at gauges (Table 2). Analyzing metric performance in different types of water years will provide additional insight into whether different metrics better represent low or high water years and their sensitivity to land cover changes.

The third part of the proposal will be to develop a GUI in GEE to streamline the process for water users to extract real time snow cover metrics and data. The GUI interface will consist of drop down boxes for users to easily identify metrics of interest and download data. The GEE GUI will be written in java syntax, and a manual will be created to explain each step of code underlying the GUI and statistical output. I will lead a session to teach the WRWC how to access and use the GEE interface to visualize, and access snow cover metrics and data.

Table 2 Stream gauges to predict streamflow.

Camas Creek NR Blaine ID
Big Wood River NR Ketchum ID
Big Wood River AT Hailey ID
Big Wood River East Fork
Big Wood River Warm Springs

Stakeholder Engagement: This project will build off current WRWC USBR funding to develop tools for predicting streamflow and water user curtailment dates in the Wood River Watershed. Many members of the WRWC have expressed interest in including remotely sensed snow cover extent in the predictive streamflow model, yet additional time and expertise are needed to incorporate these data sources. I have discussed the proposed deliverables with the WRWC and Dr. Kendra Kaiser to integrate these components into the current modeling efforts. At an initial meeting, I will present the proposed project and will lead a discussion with the WRWC about potential important snow cover metrics. After analyzing the metrics and incorporating different metrics into the snow model, I will present the results at a WRWC meeting. Feedback from the model results will be used to readdress current metrics and analysis. Following the identification of important SCA metrics, I will create a GUI interface in GEE and lead a session to teach the WRWC how to use the interface to automatically download real time snow cover data and metrics. Following this, I will modify the GUI based on input from the WRWC.

Intended Deliverables:

Report of snow cover metrics and metric sensitivity to changes in water and landcover
Report of the evaluation of metric performance in the streamflow forecast model
GEE GUI and manual
Annotated code used in the analysis and developing the GUI

Timeline:

Task	**Fall 2021**	**Winter 2021**	**Spring 2021**	**Summer 2022**
Watershed tour				
Present project to WRWC				
Extract snow cover metrics				
Analysis of metrics				
Incorporate metrics into the model				
Present significant metrics				
Develop GEE GUI				
Teach and modify GUI				
Final Project Presentation				

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