FROM SNOW TO FLOW:
ESTIMATING THE TIMING OF PEAK STREAMFLOW USING SNOTEL ABLATION CURVES

Kara J. Ferguson[1], James McNamara[2], Ron Abramovich[3] and Josh Johnston[4]

ABSTRACT

Predictions of peak streamflow timing in snow-dominated river systems are essential for proper water management and recreational availability. This study evaluates historic snow and streamflow data from 11 river basins throughout Idaho to investigate the relationship between snowmelt at SNOw TELemetry (SNOTEL) sites and peak streamflow within each basin. The goal is to provide a simple predictive tool that estimates the probability of peak streamflow occurring within a certain number of days as ablation progresses from 0 to 100%. For individual basins we evaluate melt-out levels in increments of 10% from each SNOTEL site and use a probabilistic modeling approach to develop cumulative distribution function (CDF) curves which illustrate the probability of peak streamflow occurring within a given number of days from the date at which the SNOTEL site reaches each melt-out level. Results from the CDF curves also provide anecdotal indices of peak streamflow timing.
(KEYWORDS: SNOTEL, melt-out timing, peak streamflow, probability)

INTRODUCTION

For snow-dominated river systems, snowmelt driven streamflow provides water for human and agricultural needs. Proper water management and recreational use requires predictions for the timing of peak streamflow. In arid and semi-arid regions, winter snowpacks provide a natural storage reservoir in months when water demand is lowest, while spring and early summer snowmelt runoff provides water to the region when demand is highest and precipitation is nominal. As ablation progresses, water resource and irrigation managers rely on forecasts to make critical decisions concerning water resource allocations for purposes such as crop production, hydropower, ecosystem sustainability, and flood preparedness. Many water sports enthusiasts, particularly kayakers and rafters, also use this information for prime recreation opportunities and safety precaution.

Agencies routinely provide water supply forecasts, however, these forecasts generally focus on volume rather than timing of flow. Currently, the Idaho NRCS generates streamflow-snowmelt comparison charts (NRCS, n.d. a) which gives users an idea of when peak streamflow may occur for several basins throughout Idaho. These charts display the current year's SWE, streamflow, and cumulative precipitation conditions along with an analogous snowpack year. The charts also include observations on half-melt or melt-out date relationships for each SNOTEL/streamgage paired sites (NRCS, n.d. b). A half-melt relationship refers to peak streamflow occurring (on average) when a given SNOTEL site reaches 50% melt-out (when 50% of the seasonal max SWE level remains at the SNOTEL site). A complete melt-out date relationship is when 100% of the snow has melted at the SNOTEL site at the time of peak flow. Though some of these relationships still hold true, many of the analyses are outdated or are not developed for other headwater streams throughout Idaho. Each year water users express the need for predictive tools to easily access and interpret information about peak streamflow timing. Developing these tools requires a more comprehensive knowledge of the relationship between snow melt-out and peak streamflow timing.

The Natural Resources Conservation Service (NRCS) maintains over 850 automated SNOTEL sites throughout the western United States that provide near real-time and historical hydrometeorological data such as air temperature, precipitation, snow depth and snow water equivalent (SWE). The United States Geological Survey (USGS) has an extensive national streamgaging network that provides current and past streamflow conditions. Bringing together historical SWE and peak streamflow data, statistical analyses can determine the relationships between snowmelt and peak streamflow timing within a basin.

Previous half-melt and complete melt-out relationships were explored by Farnes (1984) and Sarantitis and

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[1] Kara Ferguson, Department of Geosciences, Boise State University, Boise, ID, karaferguson@u.boisestate.edu
[2] James McNamara, Department of Geosciences, Boise State University, Boise, ID, jmcnamar@boisestate.edu
[3] Ron Abramovich, USDA – NRCS Snow Survey, Boise, ID, ron.abramovich@id.usda.gov
[4] Josh Johnston, Div. of Research & Economic Development, Boise State Univ, Boise, ID, jjohnston@boisestate.edu

Palmer (1988). Farnes' study developed these relationships for several watersheds in Montana, while Sarantitis and Palmer's study focused on both timing and volume of peak inflow of the North Fork Payette River to Payette Lake in Idaho. Garen (1994) expanded on the work of Farnes and Palmer and Sarantitis by evaluating melt-out levels in increments of 10% up to complete melt-out (100%) at four SNOTEL sites located in the Gallatin River basin, Montana. Garen outlined a forecast procedure to estimate peak streamflow date from simple linear regressions using the date of each of 10 melt-out levels and the date of peak streamflow.

Similar to Garen's analysis, our study relates 10% incremental melt-out levels, from 0% (max SWE) to 100% melt-out (complete snow disappearance), to peak streamflow for each SNOTEL site within a given basin (Figure 1). However, our analysis calculates the lag time between each melt-out percentage to peak streamflow and uses probabilistic modeling to estimate the timing of peak streamflow at any point in the water year once maximum snow accumulation has occurred. The benefit of this approach is that it is based on the probability of occurrence and uses time relative to melt, rather than a calendar date. The goal of this work is to develop a method for users to estimate the probability that peak flow will occur within a time window.

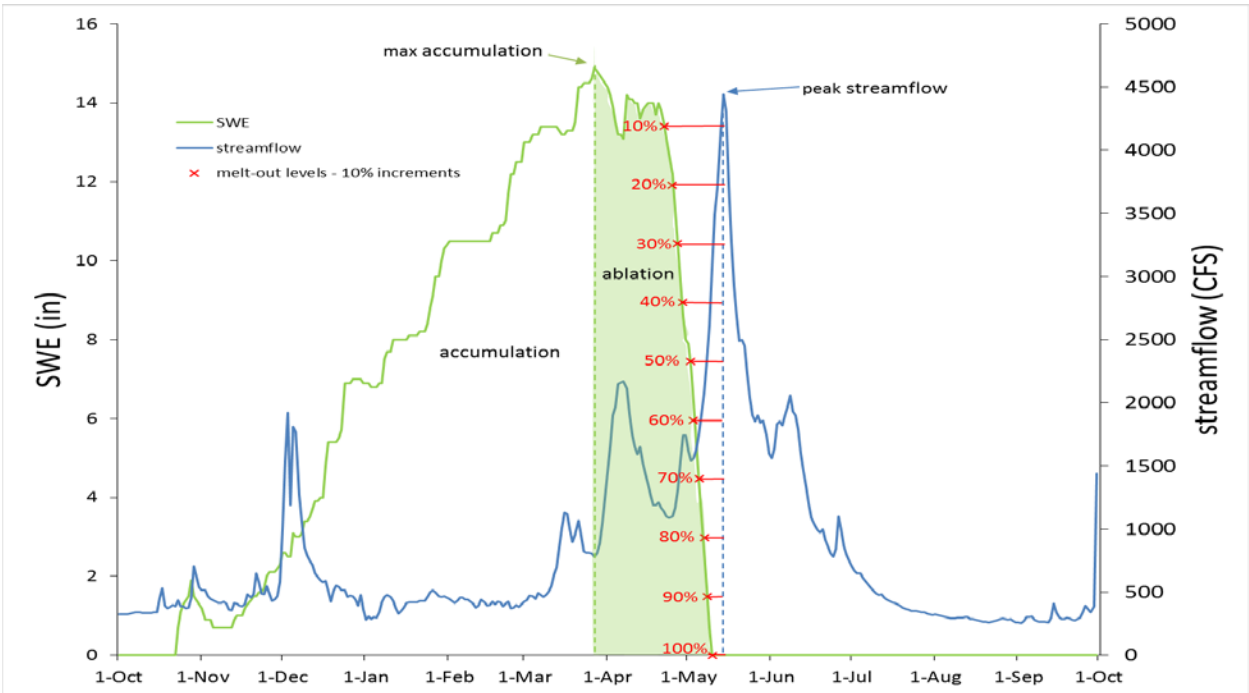

Figure 1. Example of annual hydrograph and snow accumulation/ablation curve. Shaded green area represents active melt period. Red x's mark incremental melt-out percentages. Horizontal red lines indicate time between melt-out and peak streamflow.

METHODS

The study encompasses 11 headwater basins located throughout Idaho and neighboring states, however, this paper focuses on our initial test basin – the Boise River basin (HUC 1705011 – North and Middle Forks). Within the basin are four SNOTEL sites - Atlanta Summit (elev. 7580 ft.), Jackson Peak (elev. 7070 ft.), Mores Creek Summit (elev. 6100 ft.), and Graham Guard Station (elev. 5690 ft.). The streamgaging site is located just downstream of the basin boundary, USGS 13185000 – Boise River near Twin Springs Idaho (elev. 3340 ft.). Historical snow water equivalent and accumulated precipitation records were obtained from the NRCS website www.wcc.nrcs.usda.gov. The length of record varied between 33 and 34 years depending on the SNOTEL site and included only water years with complete records during snow ablation period. Corresponding historical streamflow data was obtained from the USGS website www.waterdata.usgs.gov/nwis.

Our statistical analysis for each SNOTEL/streamgage pair uses the number of days between each incremental melt-out level and peak streamflow for each year of record. To better constrain our analysis to peak streamflow as a result of snowmelt, we limited the date range from 30 days prior to maximum snow accumulation to

the end of the water year (September 30). This removes high flows outside the critical water management period. For each melt-out level, lag times to peak streamflow for each year were sorted in ascending order and non-exceedance probabilities were computed. Figure 2 illustrates the product of this work. The following steps produced similar figures for each SNOTEL/streamgage pairing in 11 basins:

1. Identify max SWE and peak streamflow date and magnitude
2. Compute specific melt-out percentages' dates
3. Calculate time lags between each melt-out percentage date and date of peak flow
4. Using data from steps 1-3 for all years, compute non-exceedance probabilities and plot cumulative distribution functions (Figure 2)

RESULTS AND DISCUSSION

Cumulative distribution function curves for each SNOTEL site within the Boise River basin are shown in Figure 2. These curves are used in two ways. First, the 50% probability level can be used to approximate the average lag times between any melt-out percentage and peak streamflow (blue dotted lines in Figure 2a-d.). For example, on average, peak streamflow for the Boise River basin near Twin Springs occurs:

- 1 day after Atlanta Summit reaches 40% melt-out (Figure 2a)
- 2 days after Jackson Peak reaches 50% melt-out (Figure 2b)
- when Mores Creek reaches 70% melt-out (Figure 2c)
- 22 days after Graham Guard reaches 100% melt-out (Figure 2d)

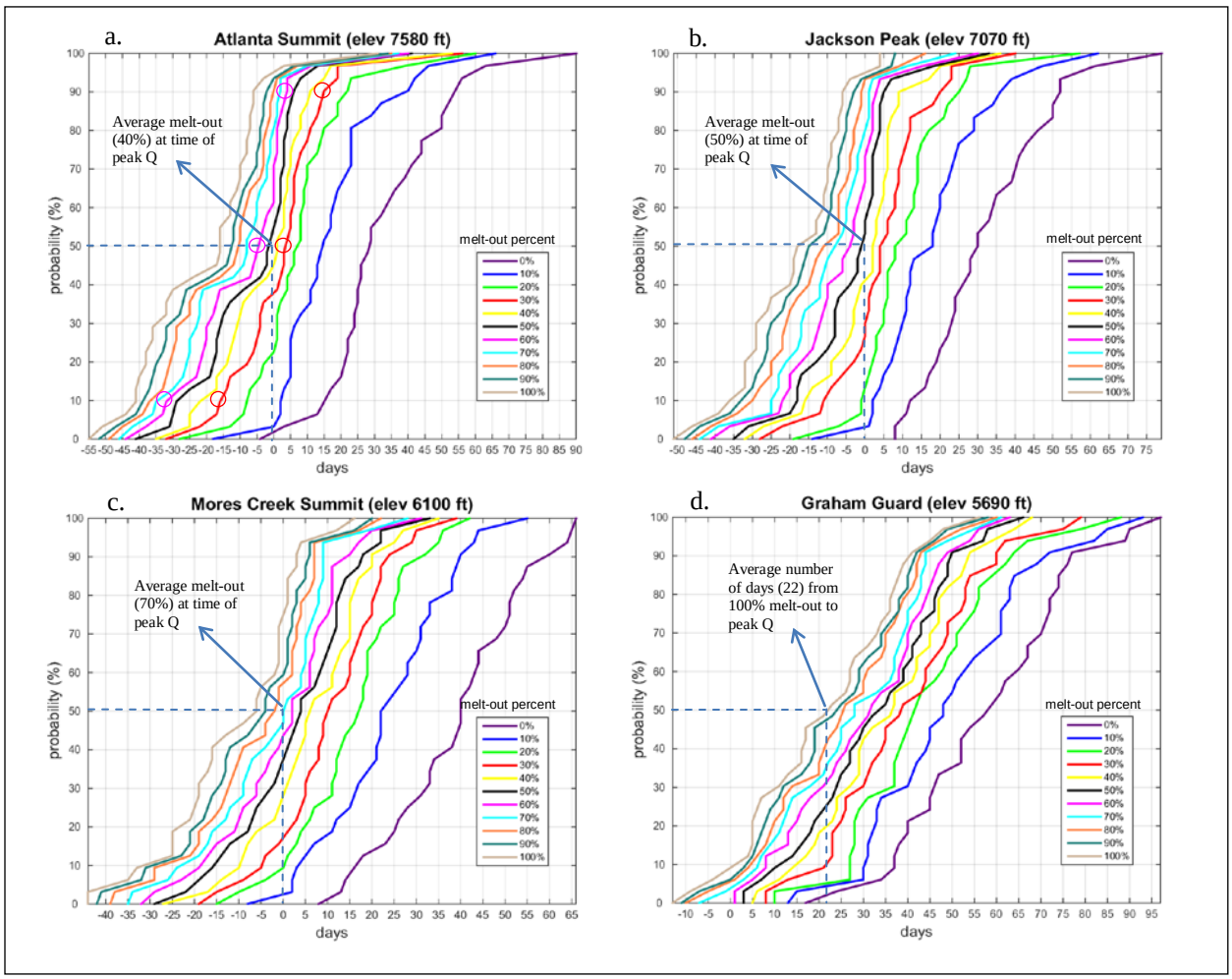

Figure 2a-d. CDF (probability) curves for SNOTEL sites within North and Middle Forks of Boise River basin, estimating the number of days between melt-out percent and peak streamflow. Dotted line intersections indicates average (50% probability) melt-out percentage at time of peak streamflow for each site. Circles mark examples for reading the curves.

Second, during active snowmelt, the probability that peak streamflow will occur within a certain number of days can be estimated. For example, when Atlanta Summit is 30% melted (red line on Figure 2a), there is a 90% chance that peak streamflow will occur within 15 days, a 50% chance within 3 days, and a 10% chance that peak streamflow occurred 16 or more days ago (red circles). Similarly, when Atlanta Summit is 60% melted (magenta line on Figure 2a), there is a 90% chance that peak streamflow will occur within 3 days, a 50% chance that peak flow occurred 5 or more days ago, and a 10% chance that peak streamflow occurred more than 33 days ago (magenta circles).

Each SNOTEL site provides unique probability predictions that can be evaluated individually or in combination. We have yet to fully determine the "best estimate" SNOTEL site and/ or melt-out percentage, however, the higher elevation sites are likely a better representation of "source water" for peak flow since they most often have snow remaining at the time of peak streamflow.

CONCLUSION

Snow-dominated river basins generally experience peak streamflow as a result of seasonal snowmelt. Predictions for the timing of peak streamflow are valuable for water resource and irrigation managers for proper water management and recreational availability. This study investigates a simple, data-driven approach to create an operational tool providing probabilistic predictions for the timing of peak streamflow. It is based on the percent melt-out at SNOTEL sites on any given day after maximum accumulation is reached. Additionally, the analysis provides approximate measures of streamflow timing based on the average (50% probability) melt-out percentage at the time of peak streamflow.

FUTURE WORK

Future goals are to: 1) Incorporate analyses into a user-friendly, web-based visualization tool that includes near real-time USGS streamflow data, NRCS SWE and precipitation data as well as the current melt-out percentage (during ablation) and the corresponding probability curve. 2) Determine melt-out percentage and SNOTEL site that best estimates peak streamflow timing in a basin. 3) Evaluate select streamflow peaks to determine other controls on peak streamflow timing. 4) Develop and test models that predict the timing relationship between low and high elevation SNOTEL sites.

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