FROM SNOW TO FLOW: EXPLORING RELATIONSHIPS BETWEEN SNOTEL ABLATION CURVES AND PEAK STREAMFLOW TIMING

by

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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 14 river basins throughout Idaho to investigate the relationship between snowmelt timing at SNOw TELemetry (SNOTEL) sites and peak streamflow within each basin. The goal is to provide a simple operational tool that estimates the probability of peak streamflow occurring within a certain number of days as ablation progresses from 0 to 100% melted. For individual basins we evaluate meltout levels in increments of 10% from each SNOTEL site and use a probabilistic modeling approach to create 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 meltout percentage. Results from the CDF probability model graphs also provide basic information about basin specific anecdotal indices or “rules of thumb” for when peak streamflow will occur based on the average percent meltout at the time of peak streamflow. Compiled historical datasets with summary statistics for 54 SNOTEL-streamgage pairs of multiple snowmelt and streamflow metrics add to the body of knowledge of hydrologic processes for basins throughout Idaho. In addition, our analysis reveals how melt timing has a greater influence on the timing of peak streamflow than does the timing or magnitude of maximum accumulation (max SWE) and how the larger snowpack (magnitude of max SWE) often have few lag days between each meltout percentage and peak streamflow.

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ab	above
CDF	Cumulative Distribution Function
CFS	Cubic Feet per Second
Cum.	Cumulative
IQR	Interquartile Range
KAF	1,000 acre-feet
Lat	Latitude
Lon	Longitude
NaN	Not-a-Number
nr	near
NRCS	Natural Resources Conservation Service
SNOTEL	SNOw TELemetry
SWE	Snow Water Equivalent
USGS	United States Geological Survey
WY	Water Year (October 1 – September 30)

INTRODUCTION

For snow-dominated river systems, snowmelt driven streamflow is a vital source of water for human and agricultural needs. Proper water management and recreational use depend on streamflow volume forecasts and knowledge of peak streamflow timing. In the western US, snowmelt accounts for 53% of total runoff (70% for mountainous regions) (Li et al, 2017) and it is estimated that approximately one-sixth of the world's population resides in snow-dominated regions that rely on fresh water supplied by seasonal runoff (Barnett et al, 2005). During spring runoff, water resource and irrigation managers, in regulated basins, must balance the need of capturing water for use in summer months when demand is high and precipitation is nominal with maintaining adequate storage space for peak flows produced by heavy melt and/or spring rainstorms. In unregulated streams, water managers closely monitor streamflow for flood and drought conditions. Information regarding the timing of peak streamflow events can help assist agencies and water users during critical times for 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, as well as river running outfitters also use this information for prime recreation opportunities and safety precaution. This thesis investigates the statistical relationships between the timing of snowmelt and peak streamflow in select river basins throughout Idaho.

The Natural Resources Conservation Service (NRCS) Idaho Snow Survey has outlined an annual timeline of water users' needs (Figure 1). Of importance is the need for operational products, which include critical threshold forecasts, timing of snowmelt peak flow, and low flow forecasts. Volume and critical threshold forecasts are routinely prepared by each state NRCS agency through their Water Supply Outlook Reports. These forecasts are based on techniques established by Garen (1992), which employ principle component regression-based relationship models that utilize several predictor variables – known at the time of forecasting – such as SWE from select SNOTEL and snow course measurements, cumulative precipitation values, and antecedent streamflow. These forecasts provide essential information needed for water and irrigation managers, farmers, and recreationist; however, these reports generally only provide forecasted volume of water (1,000 acre-feet KAF) during specific time periods and do not provide outlooks for timing of peak streamflow. Few operational products focus on the timing of when the snowmelt peak supply of water will arrive.

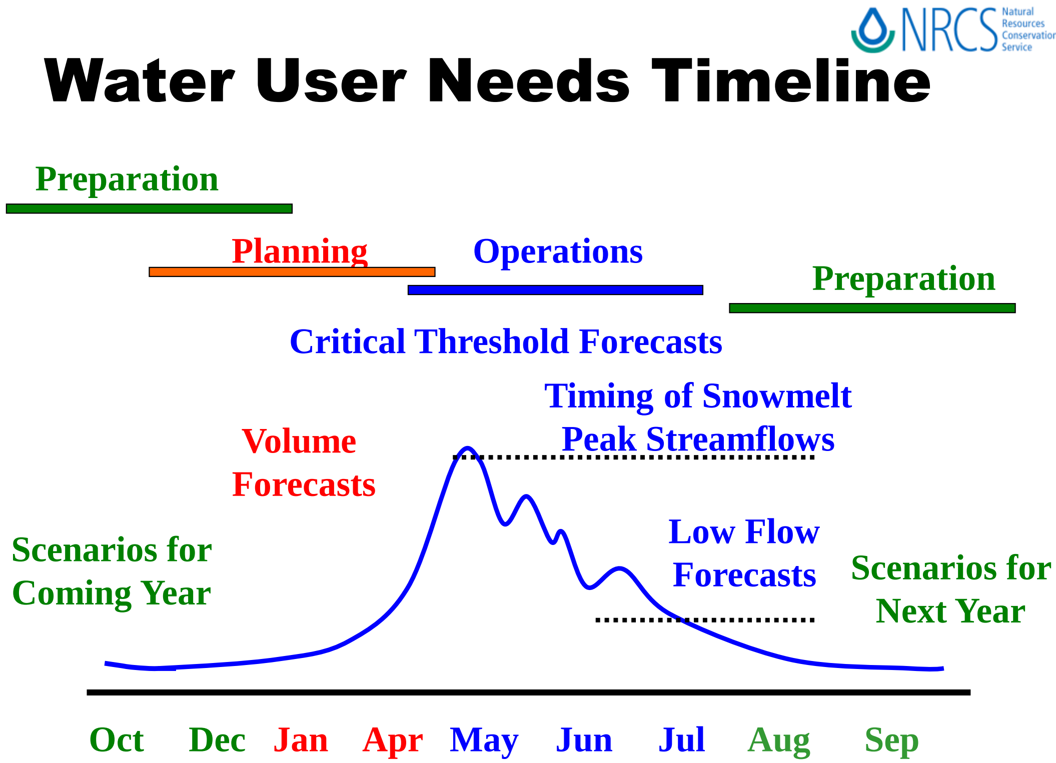

Figure 1. Annual timeline of water user needs (Abramovich, 2007).

The Department of Agriculture's Natural Resources Conservation Service (NRCS) is responsible for tracking snow accumulation and ablation each season in mountainous regions throughout the western United States and Alaska, through their automated SNOw TELemetry (SNOTEL) sites and snow course measurements. There are over 850 automated SNOTEL sites 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 daily SWE and peak streamflow data, statistical analyses can determine the relationship between snowmelt and peak streamflow timing within a given basin.

Currently, the Idaho Snow Survey generates a limited number of snow–stream comparison charts (Figure 2), which provide a visual estimate of when peak streamflow may occur based on historical averages of the percent of maximum SWE accumulation that has melted at the time of peak streamflow (percent meltout). These charts display the current year's SWE, streamflow, and cumulative precipitation conditions along with an analogous snowpack year. The average percent of maximum SWE that has melted at the time of peak flow is often observed as having a half-melt or complete meltout relationship between 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% meltout (when 50% of the seasonal max SWE level remains at the SNOTEL site). A complete meltout relationship refers to peak streamflow occurring when 100% of the snow has melted at a given SNOTEL site or within a certain number of days of complete melt. Though some of these relationships still hold true, many of the analyses are outdated or have not been developed for headwater streams of interest throughout Idaho; each spring the NRCS Idaho Snow Survey routinely inquiries about the time of peak snowmelt runoff and the potential for additional, secondary peaks from the mountain snowpack. Additionally, these products are based strictly on averages, do not consider uncertainty, and lack provisions for when, i.e., a time frame, peak flow will occur.

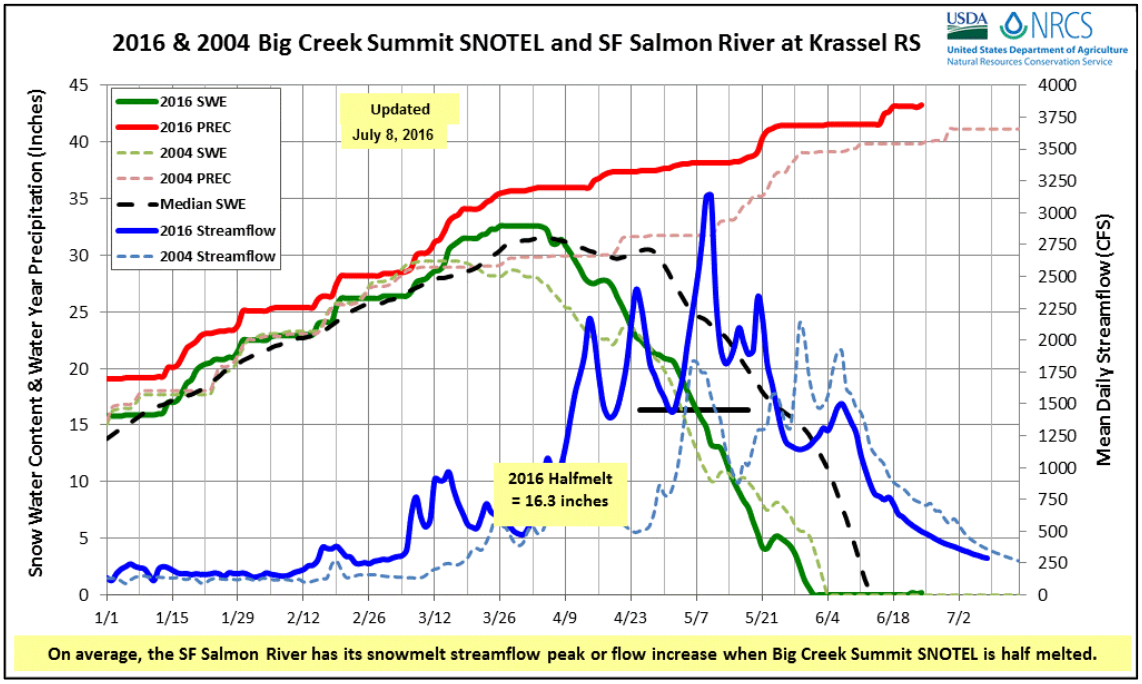

Figure 2. **Example Snow-Stream Comparison chart generated by the NRCS Idaho Snow Survey (NRCS, n.d. a).**

This thesis introduces a probabilistic framework to estimate peak streamflow timing based on the relationships between the timing of snowmelt and the timing of peak flow. Cumulative distribution functions (CDFs) are created for select SNOTEL-streamgage pairs that, for specified meltout percentages, describe the probability that peak flow occurs within a certain time (Figure 3). CDF's describe historical data, but can be used in a forecasting sense if it is assumed that the probability of current events can be described by past events. This method is similar to the statistical approach currently used by the NRCS (described above); however, this approach provides an estimate for when peak streamflow will occur based the percent meltout at the time of inquiry and allows for statistical uncertainty by providing the full range of probabilities as opposed to just the average (0.5 probability).

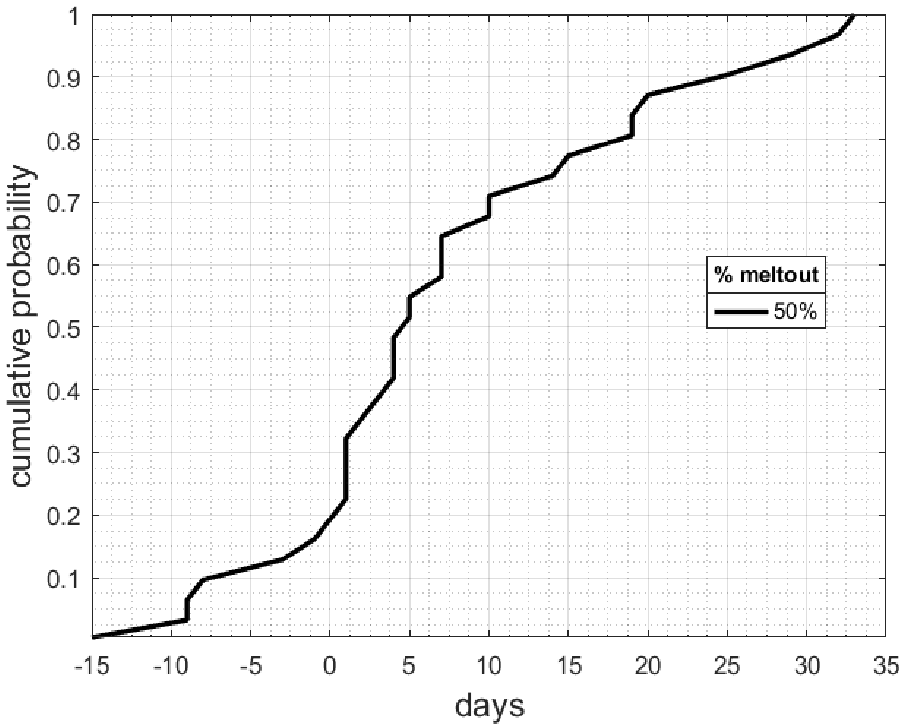

Figure 3. Cumulative distribution function (CDF) probability model example. Black line expresses current meltout percentage (50%) at a given SNOTEL site with corresponding number of lag days (until) peak streamflow at each probability.

Paired SNOTEL-streamgage CDF probability models are created by first assessing historical SWE data to find the date on which specific incremental meltout percentages occurred (Figure 4). Meltout percentages are defined in increments of 10%, from 0% meltout (maximum SWE accumulation) to 100% meltout (first reported zero SWE value). Next, lag days are calculated by subtracting incremental meltout dates from the date on which peak streamflow occurred for the year. For each meltout percentage the probability of occurrence for each numbered lag days are calculated based on the Weibull plotting position. The CDF probability models are graphical representations of the computed probability that, for a given meltout percentage, peak flow will occur within a certain number of days, or less.

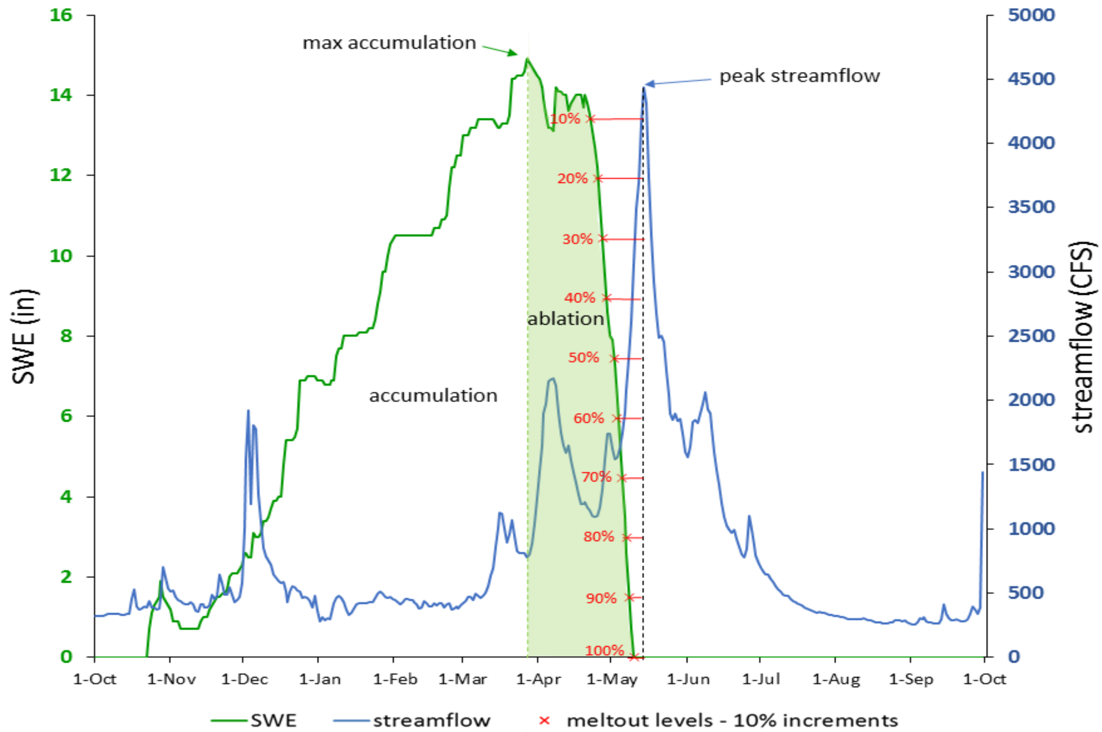

Figure 4. Graph of snow accumulation/ablation curve from SNOTEL data (green) and streamflow hydrograph (blue). Red x's mark meltout levels for each 10% increment (calculated from percentage of max accumulation). Red lines illustrate the lag time between each meltout level and peak streamflow.

To assess the functionality of the CDF probability model, we first establish that a significant relationship exists between snowpack and streamflow properties for Idaho basins. This is accomplished by evaluating the correlations between:

- Date of each incremental percent meltout (including 0% [max SWE]) and date of peak streamflow
- Magnitude max SWE and date of peak streamflow
- Magnitude max SWE and lag days for each incremental percent meltout
- Magnitude max SWE and peak streamflow rate

These correlations not only provide evidence the CDF models are a valid approach, they also provide insight to processes that govern peak streamflow. Specifically, the influence of the magnitude and timing of max SWE vs melt timing on the timing of peak flow.

The goal of this study is to add to the body of knowledge for SNOTEL-streamgage pairs and develop an operational tool to guide peak streamflow forecasts for 14 headwater basins located throughout Idaho and neighboring states.

The objectives are:

- Construct historical datasets and summary statistics of multiple snowmelt/streamflow metrics for 54 SNOTEL-streamflow pairs
- Determine correlations between snowpack and streamflow properties
- Create CDF probability models based on the relationship between meltout timing (in increments of 10%) and peak streamflow

BACKGROUND

Farnes (1984) explored relationships between SNOTEL snow pillow data records and peak streamflow and discovered that, for basins in Montana, the date of peak flow did not coincide with maximum melt rates or certain snow water equivalent levels but related to the date snow pillows melted to either one-half of their annual maximum snow water equivalent or reached complete meltout. In general, the relationship between the date of one-half melt was strongest for higher elevations sites and the date of meltout for related best the lower elevation sites. Farnes used these relationships to forecast peak flow date by projecting when each SNOTEL site within the basin would reach one-half melt and meltout based on their annual maximum SWE and average daily melt rates during specific periods (May 1-15, May 15-June 1, and June 1-June 15).

Sarantitis and Palmer (1988) also used SNOTEL half-melt and meltout date relationships to peak flow to predict timing of peak inflow to Payette Lake from the North Fork Payette River in Idaho. They determined the relationship of each SNOTEL site to peak inflow by calculating the average number of days of offset from half-melt and meltout to peak inflow. Instead of using average melt rates during specific periods, Sarantitis and Palmer used current melt rates and extended weather forecasts to extrapolate short term future melt rates to predict the date of half-melt and meltout at SNOTEL sites that correlated best to the peak inflow date. Their procedure provides an approximate two-week advanced forecast of peak inflow into the lake. Additionally, they used SWE data and fall precipitation data, from a nearby climatological station, to generate a multiple linear regression equation to forecast the April-July volume inflow to Payette Lake.

Garen (1994) expanded on Farnes' study incorporating additional meltout levels (ten levels in increments of 10%, including day of melt out) to improve the procedure for predicting the date of peak streamflow for the Gallatin River in Montana using SWE data from four SNOTEL sites located within the basin. Using sequential day numbers from October 1 (water year day number), he developed simple linear regressions to model the relationship between the dates of each meltout level (independent variable) to the date of peak streamflow (dependent variable). Garen developed the following forecast procedure that can be used after one or more SNOTEL sites are in their ablation period:

1. For all sites being used, obtain the current year's peak snow water equivalent and the current day's values.
2. Calculate the percent melt out for each site.
3. For each site, calculate the peak flow date prediction using the equation for the melt out level nearest to the current day's level.
4. Compare the predictions from each site's equations.
5. The final prediction can either be a subjective blending of the several predictions or simply the single predications that has the smallest standard error.

By evaluating increments of 10%, Garen eliminates the need to predict one-half and meltout dates which are themselves predictor variables.

Similar to Garen's analysis, our study relates 10% incremental meltout levels, from 0% (max SWE) to 100% meltout (complete snow disappearance), to peak streamflow for each SNOTEL site within a given basin (Figure 4). However, our analysis calculates the lag time between each meltout 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 and does not require calculations other than the percent meltout on the day of inquiry.

STUDY AREAS

Fourteen basins located throughout Idaho and surrounding states were selected for this study (Figure 5, Table 1). Basin selections were based on 1) need, e.g. past requests received by the NRCS Idaho Snow Survey regarding peak streamflow and 2) contained a gaged, natural, unregulated headwater stream with one or more SNOTEL sites located within the basin or within close proximity of basin boundaries and considered to be representative of snow accumulation and melt within the study basin. Requests from the NRCS include 14 basins delineated from the following USGS streamgaging forecast points.

The initial test basin was the Boise River basin delineated from the Twin Springs streamgage station (pour point). CDF probability models results and summary statistics for the historical datasets for each SNOTEL pair are contained in the main body of this thesis. CDF probability model results for the other 13 basins appear in Appendix A. Historical datasets and summary statistics for all 14 basins (54 SNOTEL-streamflow pairs) can be downloaded from “Additional Files” attached to this thesis.

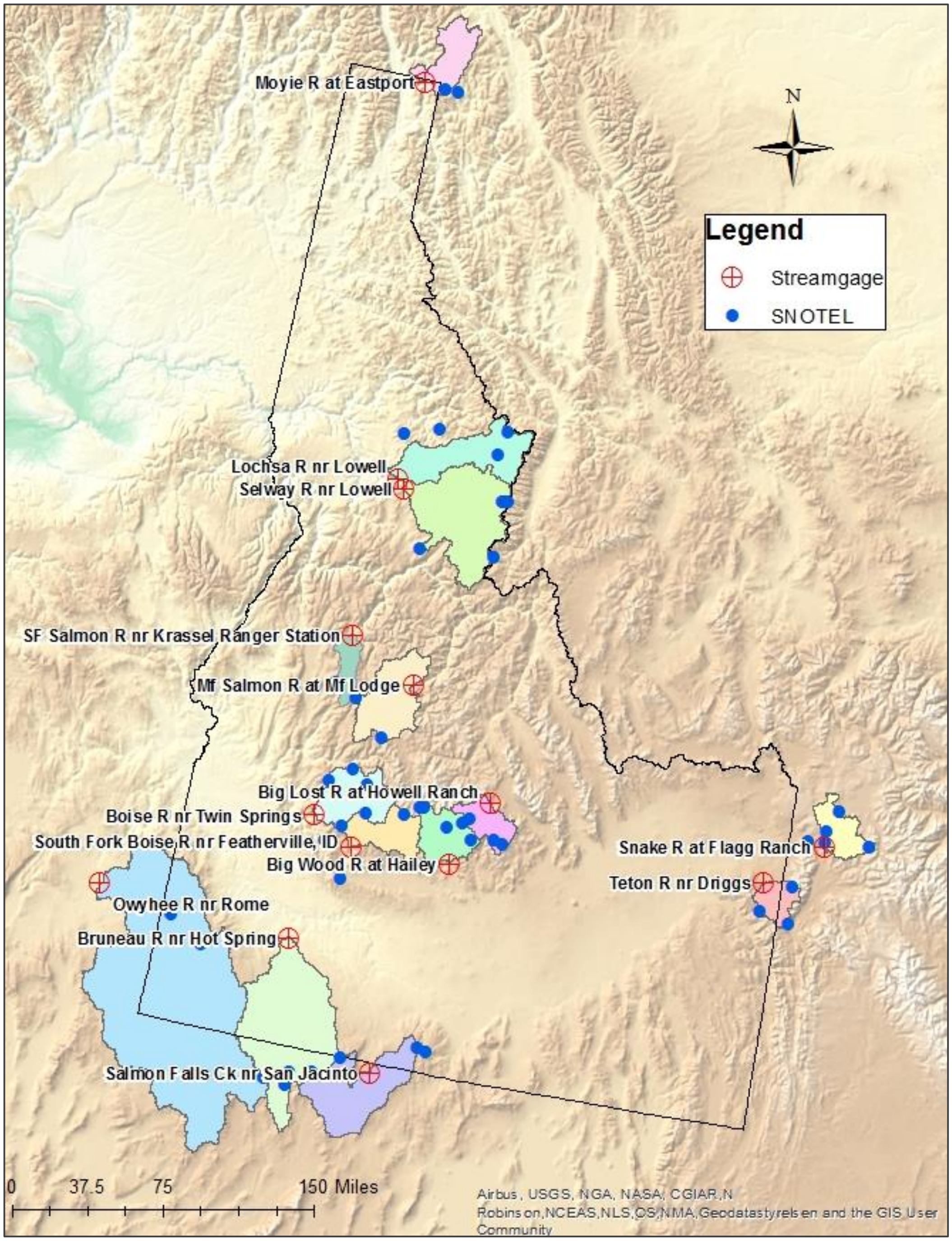

Figure 5. Study area basins

Table 1. Study area basin information. Note, SNOTEL sites for each basin are listed in descending order by site elevation.

Streamgage Station (delineated drainage area)	SNOTEL Site	Station/ Site #	State	Station/ Site Elevation (ft)	Lat.	Lon.	Paired SNOTEL - Streamflow Dataset (WY)
			Boise River Basin				
Boise River nr Twin Springs ID (832 sq miles)		13185000	ID	3340	43.67	-115.73	
	Trinity Mtn.	380	ID	7770	43.63	-115.44	1981-1989, 1991-2015
	Atlanta Summit	306	ID	7580	43.76	-115.24	1981, 1984-2015
	Jackson Peak	550	ID	7070	44.05	-115.44	1982-1983, 1985-1988, 1990-2015
	Mores Creek Summit	637	ID	6100	43.93	-115.67	1982-2015
	Graham Guard Station	496	ID	5690	43.95	-115.27	1981-2015
SF Boise River nr Featherville ID (640 sq miles)		13186000	ID	4219	43.50	-115.31	
	Vienna Mine	845	ID	8960	43.80	-114.85	1982-1983, 1985-2015
	Trinity Mtn.	380	ID	7770	43.63	-115.44	1981-1989, 1991-2015
	Atlanta Summit	306	ID	7580	43.76	-115.24	1981, 1984-2015
	Camas Creek Divide	382	ID	5710	43.27	-115.35	1993-2015
	Prairie	704	ID	4800	43.51	-115.57	1987-2015
			Big Lost River Basin				
Big Lost River at Howell Ranch nr Chilly ID (442 sq miles)		13120500	ID	6622	44.00	-114.02	
	Smiley Mountain	926	ID	9520	43.73	-113.83	2002-2015
	Bear Canyon	320	ID	7900	43.74	-113.94	1981-2015
	Lost-Wood Divide	601	ID	7900	43.82	-114.26	1982, 1984-2015
	Stickney Mill	792	ID	7430	43.86	-114.21	1981-2015
			Big Wood River Basin				
Big Wood River at Hailey ID (628 sq miles)		13139510	ID	5295	43.52	-114.32	
	Vienna Mine	845	ID	8960	43.80	-114.85	1982, 1983, 1985-2015
	Galena Summit	490	ID	8780	43.87	-114.71	1982,1983, 1986-2015
	Lost-Wood Divide	601	ID	7900	43.82	-114.26	1982, 1984-2015
	Galena	489	ID	7470	43.88	-114.67	1983-2015
	Hyndman	537	ID	7620	43.71	-114.16	1981-2015
	Chocolate Gulch	895	ID	6310	43.77	-114.42	1994-2015
			Bruneau River Basin				
Bruneau River nr Hot Springs ID (2686 sq miles)		13168500	ID	2599	42.77	-115.72	
	Pole Creek R.S.	698	NV	8360	41.87	-115.25	1981-2015
	Bear Creek	321	NV	8040	41.83	-115.45	1979-1980, 1982-2015
	Wilson Creek	871	ID	7120	42.01	-115.00	1991-2015
	Seventysix Creek	746	NV	7350	41.74	-115.47	1979-2015
	Big Bend	336	NV	6898	41.76	-115.69	1979-2015
			Loschsa River Basin				
Lochsa River nr Lowell ID (1178 sq miles)		13337000	ID	1453	46.15	-115.59	
	Savage Pass	735	ID	6190	46.47	-114.63	1984-2015
	Crater Meadows	425	ID	5960	46.56	-115.29	1985-2015
	Hemlock Butte	520	ID	5810	46.48	-115.63	1984-2015
	Lolo Pass	588	ID	5240	46.63	-114.58	1984-2015
			Moyie River Basin				
Moyie River at Eastport ID (614 sq miles)		12306500	ID	2620	49.00	-116.18	
	Hawkins Lake	516	MT	6450	48.97	-115.95	1969-2015
	Garver Creek	918	MT	4250	48.98	-115.82	1969-2015

Table 1. Continued

Owyhee River Basin							
Owhyee River nr Rome ID (7690 sq miles)		13181000	OR	3344	42.87	-117.65	
	South Mtn.	774	ID	6500	42.76	-116.90	1982-2015
	Mud Flat	654	ID	5730	42.60	-116.56	1982, 1985-2015
Salmon Falls Creek Basin							
Salmon Falls Creek nr San Jacinto NV (1401 sq miles)		13105000	NV	5120	41.94	-114.69	
	Pole Creek R.S.	698	NV	8360	41.87	-115.25	1981-2015
	Bear Creek	321	NV	8040	41.83	-115.45	1979, 1982-2015
	Bostetter R.S.	359	ID	7500	42.16	-114.19	1982-2015
	Wilson Creek	871	ID	7120	42.01	-115.00	1991-2015
	Magic Mountain	610	ID	6880	42.18	-114.29	1981-2015
Salmon River Basin							
MF Salmon River at MF Lodge nr Yellow Pine ID (1041 sq miles)		13309220	ID	4421	44.72	-115.01	
	Banner Summit	312	ID	7040	44.30	-115.23	1999-2016
	Deadwood Summit	439	ID	6860	44.54	-115.56	1999-2016
SF Salmon River nr Krassel Ranger Station ID (329 sq miles)		13310700	ID	3750	44.99	-115.73	
	Deadwood Summit	439	ID	6860	44.54	-115.56	1981,1982, 1986, 1990-2015
	Big Creek Summit	338	ID	6580	44.63	-115.80	1982, 1986, 1990-2015
Selway River Basin							
Selway River nr Lowell ID (1914 sq miles)		13336500	ID	1540	46.09	-115.51	
	Twin Lakes	836	MT	6400	46.14	-114.51	1968-2015
	Mountain Meadows	650	ID	6320	45.70	-115.23	1981-2015
	Nez Perce Camp	662	MT	5650	45.73	-114.48	1977-2015
	Twelvemile Creek	835	MT	5600	46.14	-114.45	1968-2015
Upper Snake River Basin							
Snake River ab Jackson Lake at Flagg Ranch WY (490 sq miles)		13010065	WY	6802	44.10	-110.67	
	Two Ocean Plateau	837	WY	9240	44.15	-110.22	1984-2015
	Thumb Divide	816	WY	7980	44.37	-110.58	1988-2015
	Lewis Lake Divide	577	WY	7850	44.21	-110.67	1984-2015
	Grassy Lake	499	WY	7265	44.13	-110.83	1984-2015
	Snake River Station	764	WY	6920	44.13	-110.67	1990-2015
Teton River Basin							
Teton River ab South Leigh Creek nr Driggs ID (341 sq miles)		13052200	ID	5953	43.78	-111.21	
	Grand Targhee	1082	WY	9260	43.78	-110.93	2007-2015
	Phillips Bench	689	WY	8200	43.52	-110.91	1981-2015
	Pine Creek Pass	695	ID	6720	43.57	-111.21	1989-2015

METHODS

An automated metadata retrieval code was developed in MATLAB utilizing web service tools available from each federal agency. For each SNOTEL station historic, daily time-step SWE (inches) and cumulative and incremental precipitation (inches) data were acquired from http://www.wcc.nrcs.usda.gov/awdbWebService/services?WSDL for each period of record. Years with extensive missing data were omitted from the analysis. Historic daily average streamflow data (CFS) for the same period of record as the paired SNOTEL site were obtained from the USGS http://waterservices.usgs.gov/nwis/dv/?format=rdb&parameterCd=00060&sites. Generally, SNOTEL data were the limiting data source mostly due to SNOTEL sites superseding installation of streamgaging sites. Historical records were extracted and analyzed by water year – October 1 to September 31. Basin boundaries were determined by delineation from each of the 14 USGS streamgage locations (Table 1).

Each basin analysis consists of one natural headwater streamgage station, typically located in the lower reaches of the basin prior to natural and manmade diversions or reservoirs, paired with select SNOTEL sites located within the basin or within close proximity of the basin boundaries and considered to representative of accumulation within the study basin. The number of paired SNOTEL-streamgage sites for each basin analysis varied between two and six pairs. For each SNOTEL-streamgage pair several annual metrics were determined based on the historical period of record for the pair. For time and computational efficiency and consistency a MATLAB code was developed to automatically create SNOTEL-streamgage pair historical dataset tables of the following metrics: date (day water year [WY]) of peak streamflow, maximum SWE, and meltout (first day of reported zero SWE value); peak streamflow flow rate (CFS); magnitude maximum SWE (inches) (if maximum SWE was sustained for more than one day or occurred on more than one date, the date of the last occurrence was selected); and percent of maximum SWE melted on the day of peak streamflow, calculated from the following equation:

$$\%MO = \frac{magnitude\ SWE\ at\ time\ of\ peak\ Q}{magnitude\ \max SWE} * 100$$

Additionally, the dataset tables include: number of days melt occurred in the ablation period (number of day from max accumulation to complete meltout where the daily change in SWE was >0); average daily melt rate (inches per day); maximum melt rate (inches per day); date of maximum melt rate (day WY); cumulative 3-day melt (inches) (summed total of: melt on day of peak flow, one day prior to peak flow, and two days prior to peak flow); the cumulative 3-day precipitation (inches) (summed total of: precipitation on day of peak flow, one day prior to peak flow, and two days prior to peak flow), and cumulative fall (October 1 to November 30) precipitation (inches).

Using the acquired SWE data, the day of the water year each incremental percent meltout occurred (in increments of 10%, from 0% meltout [maximum SWE accumulation] to 100% meltout [no SWE remaining on the SNOTEL snow pillow]) were determined. This was achieved by first calculating incremental SWE values by multiplying the maximum SWE, for each water year, by each fractional percent of SWE remaining. This is the same as determining the meltout percentage. For example, 10% meltout is the same as 90% remaining. The corresponding date (or day closest to the calculated SWE) for each incremental SWE were then determined for each water year. Lag times (days) between each incremental meltout percentage and peak streamflow were calculated by subtracting the meltout percentage date of occurrence from the peak streamflow date.

Correlation analysis were conducted by calculating the Spearman's rho correlation coefficients for each SNOTEL-streamflow pair, between the following variables: date (day of WY) of max SWE and date (day of WY) of each incremental meltout level (10% increments from 0% [max SWE] to 100%); magnitude of max SWE and date (day of WY) of peak streamflow; magnitude of max SWE and the number of lag days between each incremental meltout level and peak streamflow; magnitude max SWE and peak streamflow rate. Results for each SNOTEL-streamflow pair were combined and the total number of statistically significant ($\alpha < 0.05$) pairs were tallied to determine if relationships are present across Idaho basins.

The CDF probability model was created from the historic record of number of lag days between each incremental meltout percent and peak streamflow and graphically displayed as cumulative distribution function using the Weibull plotting position formula:

$$P_i = \frac{(i)}{(n+1)}$$

where i is the rank of the event (number of days between the meltout percentage and peak streamflow [lag days]), n is the sample size (number of years) and P_i values give the non-exceedance probability for the event with rank i (McCuen, 1998). The calculated probability is the probability that, for a given meltout percentage, peak flow occurs within a certain number of days, or less.

RESULTS

Historical Datasets and Summary Statistics

Historical water year datasets for derived metrics (as outlined in Methods and Table E.1) for each SNOTEL site paired with the Boise River nr Twin Springs streamgaging station are in available in Additional Files; Table 2 provides summary statistics for each of the historical datasets for each SNOTEL site. Note, conversion tables for WY day to calendar date can be found in Appendix C. Also, years whose peak flow occurred prior to maximum accumulation are listed as NaN (Not-a-Number) within the datasets and are not included in the summary statistics calculation. While, years whose peak flow occurred after complete meltout are listed as 100% no matter the number of days after meltout the peak occurred and are included in summary statistic calculations.

Table 2. Summary Statistics for paired SNOTEL sites with Boise River at Twin Springs streamgage

	Date Peak Q (day WY)	Date Max SWE (day WY)	Date Meltout (day WY)	Peak Q (CFS)	Max SWE (in)	SWE Day Peak Q (in)	Percent Melted Day Peak Q (%)	Number of Melt Days	Average Melt Rate (in/day)	Max Melt Rate (in/day)	Date Max Melt Rate (day WY)	3-Day Cum. Melt (in)	3-Day Cum. Precip (in)	Cum. Oct-Nov Precip (in)
Trinity Mtn SNOTEL														
median	232	205	266	6255	37.9	30.4	25	52	-0.7	-1.8	261	2.5	0.1	11.2
mean	229	205	264	6650	39.4	30.1	29	50	-0.7	-1.9	258	2.4	0.8	10.1
25th %-ile	225	196	254	3738	29.0	17.6	12	40	-0.8	-2.1	248	1.8	0.0	6.1
75th %-ile	240	218	277	9273	48.9	42.2	43	56	-0.6	-1.7	269	3.2	1.5	12.4
min	133	182	228	2300	20.7	1.7	3	25	-1.1	-3.5	214	0.0	0.0	3.1
max	255	227	300	12500	71.5	60.8	94	80	-0.5	-1.1	290	4.6	3.2	18.1
range	122	45	72	10200	50.8	59.1	91	55	0.6	2.4	76	4.6	3.2	15.0
Atlanta Summit SNOTEL														
median	229	196	251	6130	27.7	18.7	45	43	-0.6	-1.7	240	3.2	0.1	8.6
mean	227	198	251	6410	29.6	17.6	47	41	-0.6	-1.7	241	2.9	0.7	8.2
25th %-ile	223	189	240	3685	22.0	8.0	21	35	-0.8	-2.0	228	1.7	0.0	5.3
75th %-ile	240	206	262	9120	37.9	28.1	66	47	-0.5	-1.6	252	4.5	1.5	10.1
min	133	160	219	2300	17.8	0.0	10	26	-0.9	-2.5	214	0.0	0.0	2.7
max	255	226	278	12500	46.8	36.9	100	58	-0.4	-1.0	270	5.7	2.7	14.8
range	122	66	59	10200	29.0	36.9	90	32	0.5	1.5	56	5.7	2.7	12.1
Jackson Peak SNOTEL														
median	232	199	251	6255	27.5	15.4	50	44	-0.6	-1.7	244	3.0	0.1	9.2
mean	228	198	250	6509	28.5	16.1	48	42	-0.6	-1.7	242	2.8	0.7	8.4
25th %-ile	225	187	242	3633	20.4	7.8	30	34	-0.8	-1.9	229	1.7	0.0	6.2
75th %-ile	240	206	259	9150	36.4	25.5	66	48	-0.5	-1.4	251	3.8	1.4	10.6
min	133	159	224	2300	16.1	0.0	5	23	-1.1	-2.5	218	0.0	0.0	2.4
max	255	229	273	12500	44.0	32.1	100	58	-0.4	-1.0	271	6.5	3.1	14.7
range	122	70	49	10200	27.9	32.1	95	35	0.7	1.5	53	6.5	3.1	12.3
Mores Creek Summit SNOTEL														
median	231	191	242	6255	31.8	12.6	71	41	-0.7	-1.8	232	3.2	0.1	8.9
mean	227	190	241	6582	31.8	12.8	66	41	-0.7	-2.0	234	3.1	0.6	9.1
25th %-ile	224	183	233	3738	22.6	0.0	37	35	-0.8	-2.2	224	0.9	0.0	6.7
75th %-ile	239	198	248	9273	41.6	23.6	100	47	-0.5	-1.5	243	4.8	0.9	11.8
min	133	139	218	2300	14.9	0.0	8	26	-1.0	-4.8	213	0.0	0.0	2.8
max	255	220	262	12500	55.9	36.3	100	56	-0.4	-1.0	259	8.9	2.7	15.9
range	122	81	44	10200	41.0	36.3	92	30	0.6	3.8	46	8.9	2.7	13.1
Graham Guard Station SNOTEL														
median	232	173	210	6140	13.4	0.0	100	28	-0.4	-1.2	203	0.0	0.1	6.4
mean	228	172	209	6569	13.5	0.6	95	27	-0.4	-1.3	202	0.4	0.6	6.5
25th %-ile	225	161	201	3790	9.8	0.0	100	23	-0.5	-1.6	191	0.0	0.0	5.0
75th %-ile	240	183	218	9180	16.5	0.0	100	30	-0.4	-1.1	212	0.0	1.2	8.4
min	133	129	176	2300	5.7	0.0	11	13	-0.8	-2.0	173	0.0	0.0	2.0
max	255	197	235	12500	24.8	8.3	100	42	-0.3	-0.6	229	4.2	2.3	11.0
range	122	68	59	10200	19.1	8.3	89	29	0.5	1.4	56	4.2	2.3	9.0

Correlation Analysis

Correlation Between the Date of Maximum Swe, Date of Each Meltout Percent and the Date Peak Streamflow

Surprisingly, the date of maximum SWE (0% meltout) is not well correlated to the date of peak streamflow. Only 12 (of 54) SNOTEL-streamgage pairs (Figure 11, Table B.1) are significantly correlated (at 0.05 significance level). However, if the timing of melt (date of specific meltout percentages) is considered instead of the timing of maximum accumulation, the number of correlations greatly improves. In early melt (0 to 20% meltout), the number of SNOTEL-streamgage pairs with significant correlation increases rapidly from 12 to 37 SNOTEL-streamgage pairs. The number of correlated SNOTEL-streamgage pairs continue to increase to a maximum of 44 for the date of 50% meltout and then declines slightly to 38 pairs at 100% meltout.

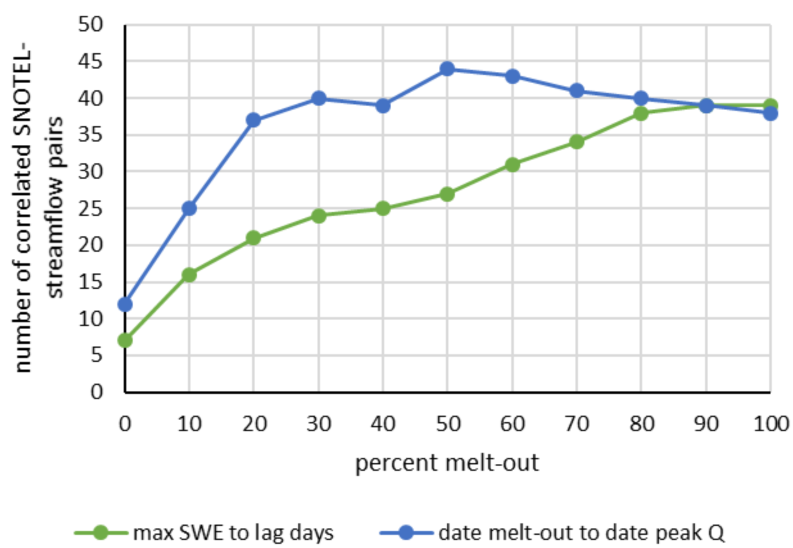

Figure 6. Number of significantly correlated SNOTEL-streamflow pairs for 14 basins throughout Idaho. Blue line indicates the correlation between date of meltout percent and date of peak streamflow, green line is the correlation between magnitude of max SWE and lag days.

Correlation Between Magnitude Max Swe and Date of Peak Streamflow

The magnitude of max SWE is also not well correlated to the date of peak streamflow for many SNOTEL-streamgage pairs (Table B.1). Only 15 (of 54) SNOTEL-streamgage pairs have significant correlations (at 0.05 significance level) and of the 14 basins analyzed, 6 basins do not have any correlated pairs. Only 3 basins have more than one SNOTEL-streamgage pair with significant correlations.

Correlation Between Magnitude of Max Swe and the Number of Lag Days Between Each Percent Meltout and Peak Streamflow

The lag time (days) between the date of max SWE (0% meltout) and the date of peak streamflow is significantly correlated (inverse correlation) to the magnitude of max SWE for 7 (of 54) SNOTEL-streamgage pairs (at 0.05 significance level) (Figure 11, Table B.2). The number of significantly correlated SNOTEL-streamgage pairs increases as the percent of meltout grows, up to a maximum of 39 pairs for both 90 and 100% meltout. The inverse correlations indicate that as the magnitude of max SWE increases, the number of days between meltout percentages and peak streamflow gets smaller. Many of these lag times, especially for greater meltout percentages, are negative values. A negative value occurs when the date of peak streamflow occurs prior to the meltout percent date. In years when peak streamflow occurs in winter, due to a warming event and/or rain-on-snow event, the lag time may be negative for all meltout percentages.

The Bruneau River basin was the only basin that had all SNOTEL-streamgage pairs at all meltout levels significantly correlated, while the Teton and Owyhee River basins have no significant relationships. Across all basins the Spearman's rho value generally increased as meltout percentage increased.

CDF Probability Model

Relationships between snowmelt and peak streamflow timing are displayed visually as cumulative distribution function (CDF) probability curves for all 5 SNOTEL sites located within the delineated drainage basin for the Boise River nr Twin Springs gaging station (Figures 6-10). The CDFs are non-exceedance probability curves that show the historical lag time, in days, between each incremental meltout percentage at individual SNOTEL sites and peak streamflow within a basin and are used in three ways. First, the 0.5 probability level can be used to approximate the percent of maximum accumulation that has melted, at each SNOTEL site, at the time of peak streamflow (blue dotted lines in Figures 6 through 10). For example, on average, peak streamflow for the Boise River basin near Twin Springs occurs:

- ~when Trinity Mtn reaches 20% meltout (Figure 6)
- ~ 1 day after Atlanta Summit reaches 40% meltout (Figure 7)
- ~ 2 days after Jackson Peak reaches 40% meltout (Figure 8)
- ~when Mores Creek reaches 70% meltout (Figure 9)
- ~21 days after Graham Guard reached 100% meltout (Figure 10)

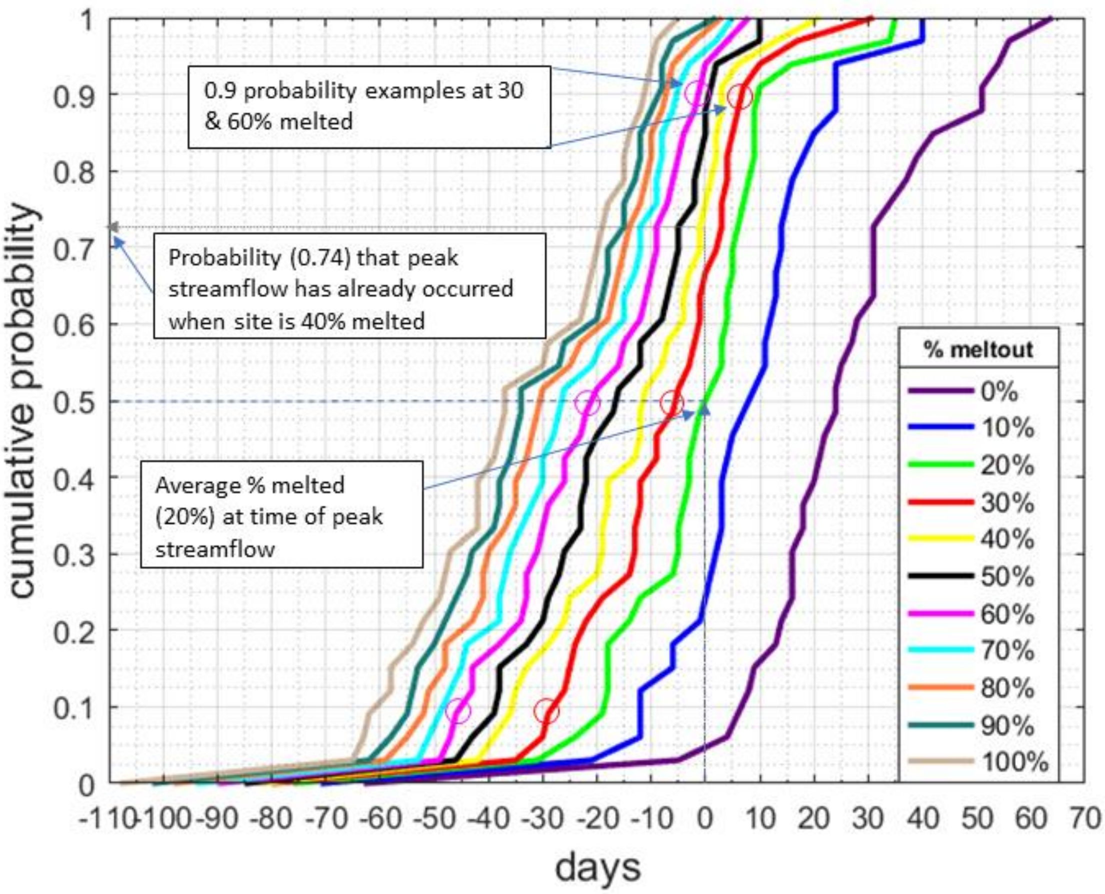

Figure 7. **Trinity Mtn SNOTEL CDF probability model. Blue dotted line indicates the average percent (20%) melted at the time of peak streamflow at Twin Springs streamgage. Red and magenta circles express example probabilities at 30 and 60% melted (respectively). Grey solid line indicates the probability of peak streamflow having already occurred if the site was 40% melted.**

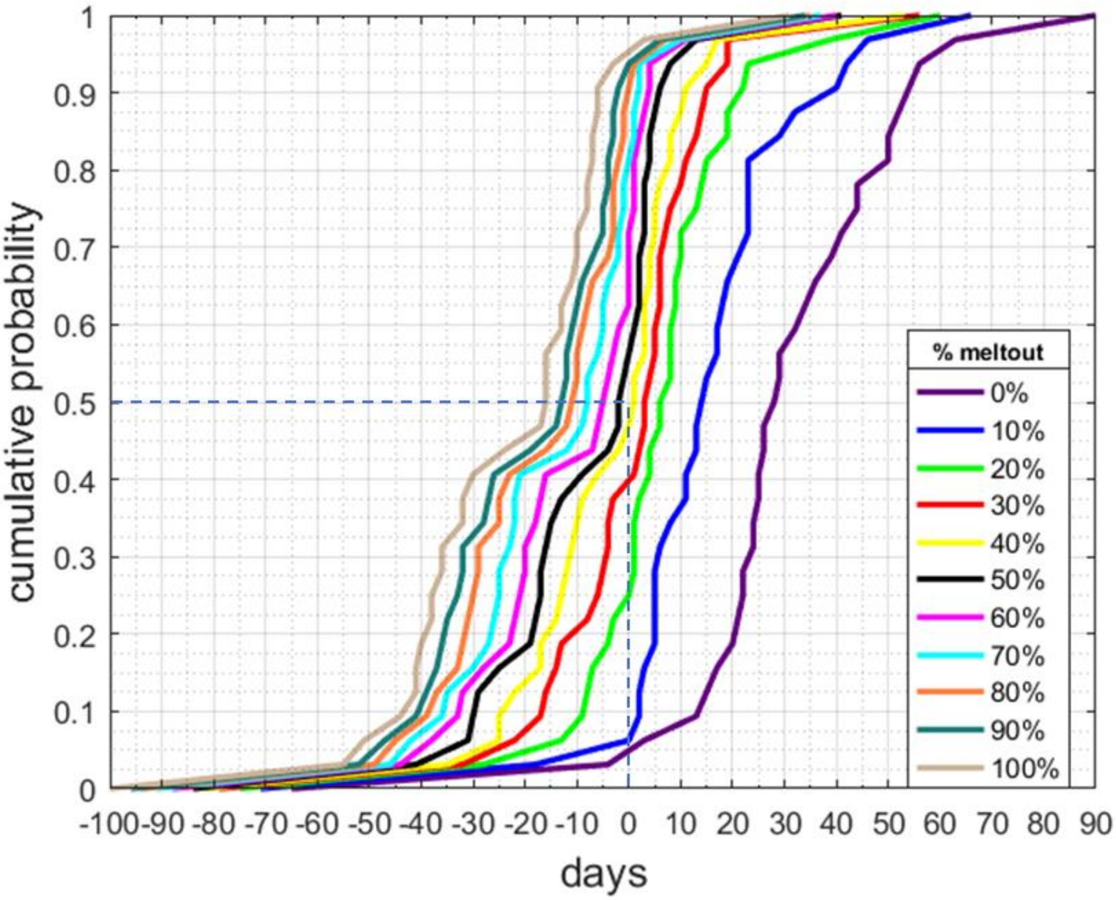

Figure 8. Atlanta Summit SNOTEL CDF probability model. Blue dotted line indicates the average percent melted (1 day after 40%) at the time of peak streamflow at Twin Springs streamgage.

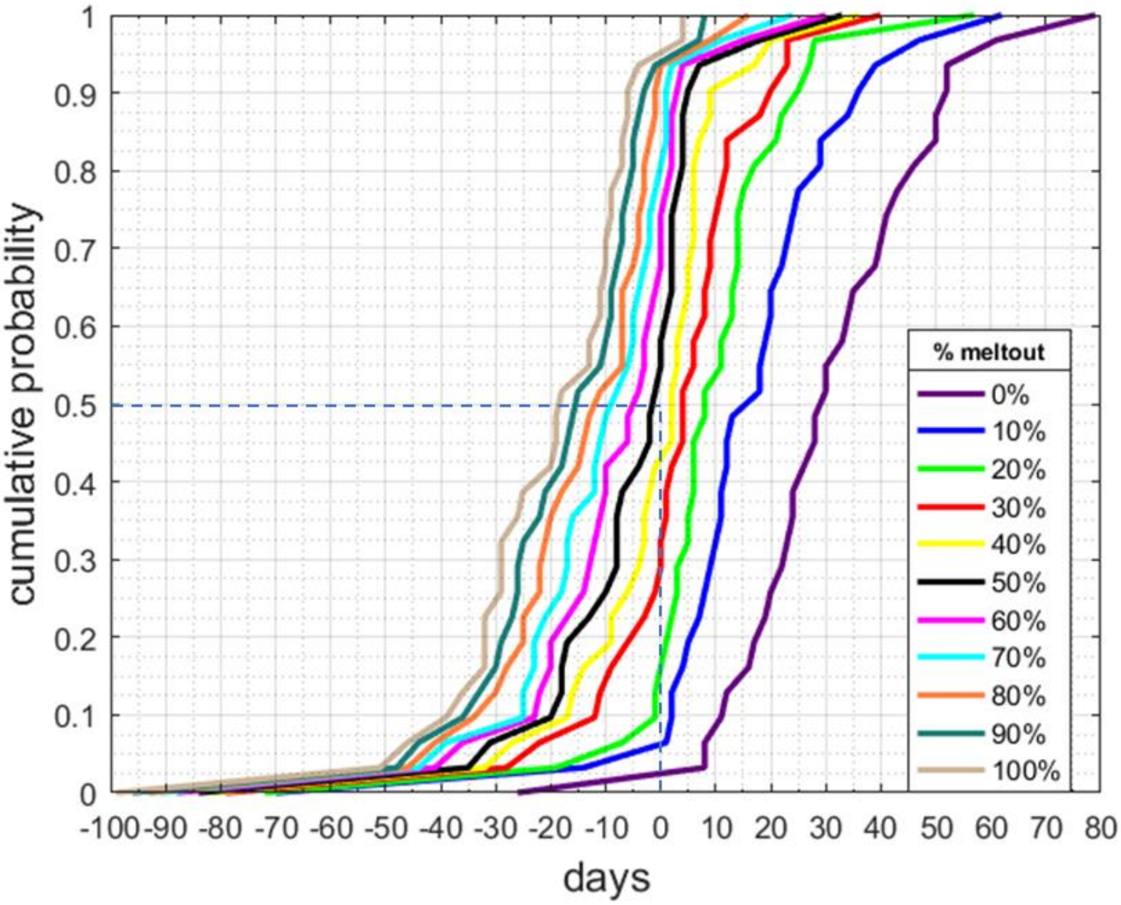

Figure 9. Jackson Peak SNOTEL CDF probability model. Blue dotted line indicates the average percent (2 day after 40%) melted at the time of peak streamflow at Twin Springs streamgage.

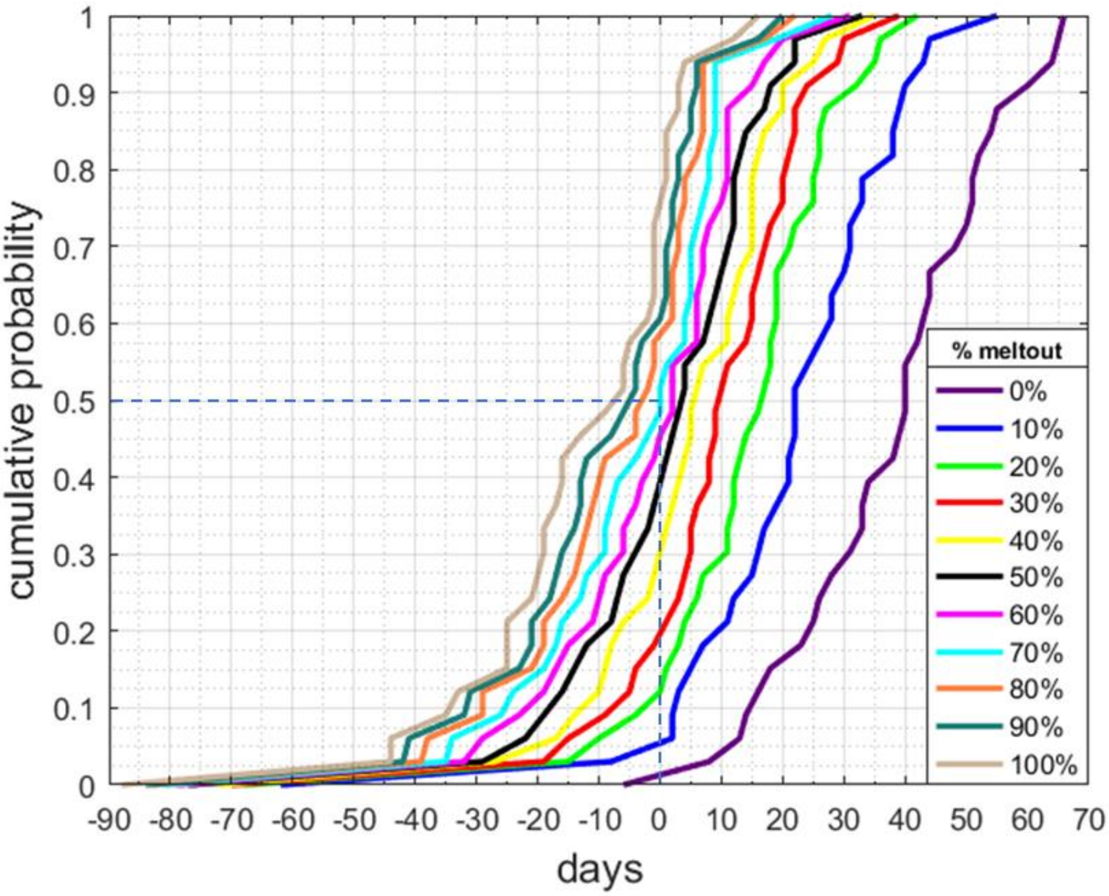

Figure 10. **Mores Creek Summit SNOTEL CDF probability model. Blue dotted line indicates the average percent (70%) melted at the time of peak streamflow at Twin Springs streamgage.**

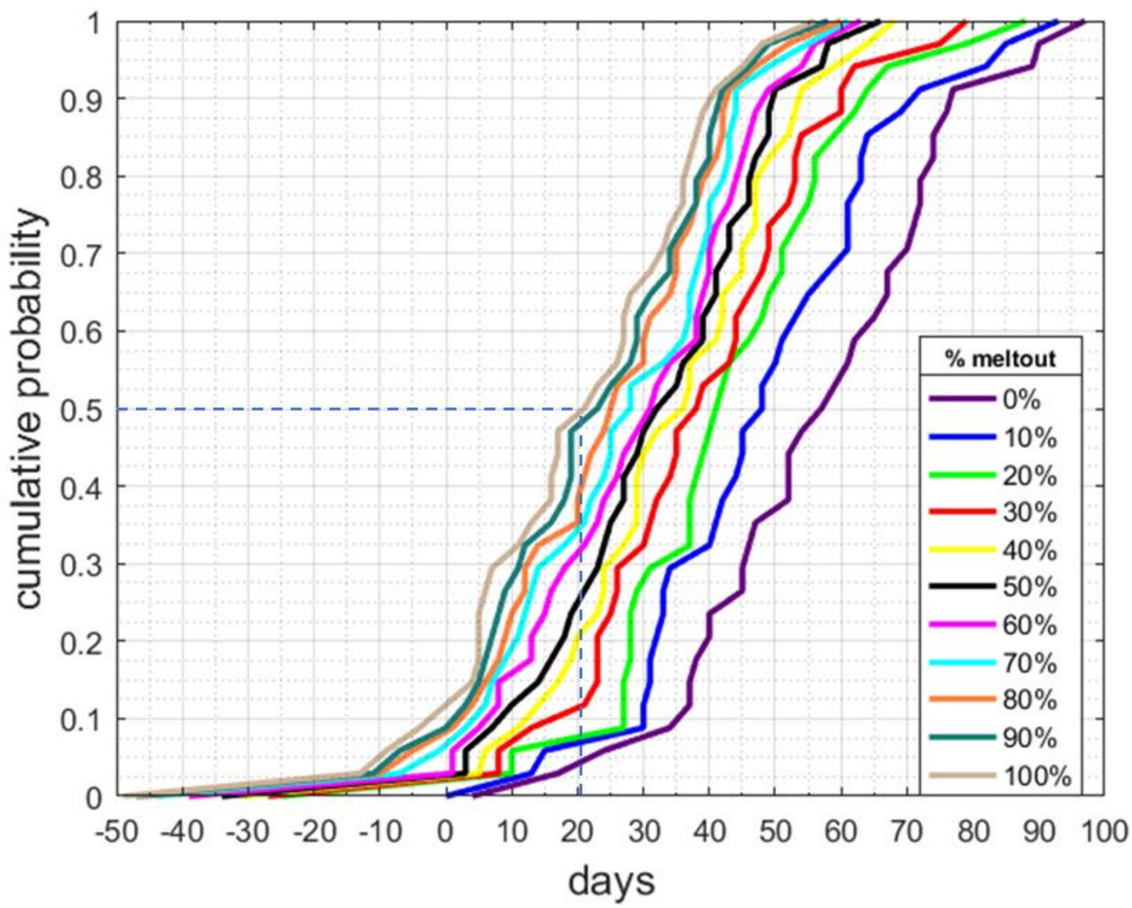

Figure 11. Graham Guard SNOTEL CDF probability model. Blue dotted line indicates the average percent melted (21 days after 100% meltout) at the time of peak streamflow at Twin Springs streamgage.

Second, during active snowmelt, the probability that peak streamflow will occur within a certain number of days can be estimated for each of the 11 meltout percentages (10% increments, from 0 to 100%). The figures can be used as an operational tool to help estimate, based on probability, when peak streamflow will occur depending on the SWE level and corresponding meltout percent at the time of inquiry. For example, if Trinity Mtn is 30% melted (red line on Figure 6), there is a 90% chance that peak streamflow has already occurred or will occur within 9 days, a 50% chance it occurred 6 or more days ago, and a 10% chance that peak streamflow occurred 30 or more days ago (red circles). Similarly, if Trinity Mtn is 60% melted (magenta line on Figure 6), there is a 90% chance that peak streamflow is currently occurring or has already occurred, a 50% chance that peak flow occurred 21 or more days ago, and a 10% chance that peak streamflow occurred more than 47 days ago (magenta circles).

Third, the probability curves can be used during ablation to assess the likelihood that peak streamflow has already occurred or the probability it is yet to come. This is similar to the above technique but instead of calculating the window of lag days to peak streamflow at specific probabilities this method calculates the probability of peak streamflow occurring at lag day zero; essentially reading the graph in reverse. For example, if on the day of inquiry, Trinity Mtn SNOTEL is 40% melted (Figure 6, yellow line), the probability that peak streamflow has already occurred is 0.74 or there is a 0.26 chance peak streamflow is yet to come. This can be valuable in determining if a peak that has already occurred is likely the absolute peak and the chances of an additional peak occurring.

DISCUSSION

Correlation Analysis

Correlation analysis between multiple metrics were conducted for two purposes: one, to establish that relationships exist between snowmelt and peak streamflow which serves to validate the functionality of the CDF probability model and two, to help assess the influence of magnitude and timing of maximum SWE accumulation vs. melt timing on the peak streamflow timing. Though significant correlations were not present throughout all basins between some metrics, the analysis establishes reasonable verification that relationships are present and therefore statistical models can be developed. As discussed below, individual basin properties, regional climate, as well as study design, e.g. selection of peak flow, likely effect the strength of these relationships.

Correlation Between the Date of Maximum Swe, Date of Each Meltout Percent and the Date Peak Streamflow

The difference in the number of significantly correlated SNOTEL-streamflow pairs between the date of max SWE and the date of peak streamflow (12 out of 54) compared to number of correlated pairs (25 to 44 out of 54) between the date of each meltout percent and the date of peak streamflow indicates that the timing of melt is more important than when maximum accumulation is reached (Figure 11, Table B.1). The fewer correlations between max SWE and peak streamflow are likely due to greater variability in the timing of max accumulation than in melt timing, which is likely due to local and/or regional temperature and weather patterns that occur during the transition from accumulation to melt. It is not uncommon for a snowpack to experience multiple melt/freeze/precipitation cycles before ablation is in full effect. Variability in the date of maximum accumulation can also be a result of max SWE being maintained for several days or occurring on more than one date. For this study, only a single date for annual max SWE was used and was defined as the date of last occurrence. Large variances also occur in early melt (up to ~20% meltout) often due to late season accumulation that essentially resets melt timing. The variability in melt timing dates tends to decrease as the melt period progresses which strengthens the correlations between the dates of meltout percentages and peak streamflow timing.

Despite the increase in the number of correlated pairs, there are still several SNOTEL-streamflow pairs that lack correlation even in for greater meltout percentages. For two such pairs (Smiley Mountain SNOTEL – Big Lost River at Howell Ranch streamgage and Grand Targhee SNOTEL – Teton River nr Driggs streamgage) the lack of correlation is likely due to small sample sizes, 14 and 9 respectively. For other pairs, the lack of correlation may be due to some SNOTEL sites, usually lower elevation sites, being completely melted out at the time of peak streamflow. The lack of correlations may also be due to the point source nature of relating melt at an individual SNOTEL site to the peak streamflow. Snowpack properties within individual basins and the processes controlling snow accumulation distribution and melt are both spatially and temporally variable (Anderson et al, 2014; Deems et al, 2006; Elder et al, 1991). Also, this study selects absolute peak streamflow that has occurred at any time during the water year. Some basins may be more sensitive to or more likely to have winter or summer precipitations events that produce the absolute peak streamflow for the year. Streamflow peaks produced outside the typical melt periods increase the variability of the date of peak streamflow and can affect correlations. It is possible that implementation of different criteria for the selection of streamflow peaks, e.g., streamflow peaks that only occurred during a specific time frame or under melt conditions (as addressed in 'Challenges to the probability model' section), the number of correlated SNOTEL-streamflow pairs would increase.

Correlation Between Magnitude Max Swe and Date of Peak Streamflow

The relatively small number of correlated SNOTEL-streamflow pairs (15 out of 54) indicates that the magnitude of max SWE does not impact the timing of peak streamflow, except in a small number of basins. This is similar to Farnes' (1984) findings for the Gallatin River basin in Montana. The lack of correlation between the magnitude of max SWE and the date of peak streamflow may again be in part due to the study design which selects peak streamflow occurring at any time during the water year not just during active melt. Notably, all 54 pairs have significant correlations between magnitude of max SWE to magnitude of peak streamflow.

Correlation Between Magnitude of Max Swe and the Number of Days Between (Lag) Each Percent Meltout and Peak Streamflow

Similar to correlations between the date of max SWE and the date of incremental meltout percentages, the number of significantly correlated SNOTEL-streamflow pairs between the magnitude of max SWE and the number of lag days between meltout percentages and peak streamflow are fewer for the timing of max accumulation (7 of 54 pairs) and 10% meltout (16 of 54 pairs) and increase as melt progress. However, despite the similar tendencies, the rise in the number of significantly correlated sites is more gradual and the actual correlated SNOTEL-streamflow pairs themselves are not the same.

The inverse relationship between the magnitude of max SWE and the number of days between each incremental meltout level and peak streamflow indicates that for larger snowpack, the lag days to peak streamflow will be smaller. This may be due to greater melt-rates with increased solar radiation from longer daylight hours, as larger snowpack are generally reached later in the year as it takes more time for a greater amount of snow to accumulate. Garen (1994) reported the lag time between meltout levels and peak flow were dependent on when in the season the meltout level was reached – larger lag times were estimated if a meltout level was reached early or smaller lag times if a meltout level was reached later in the season. Garen explains this follows "physical reasoning" in that snowmelt initiated early in season will generally be a longer, slower process and melt that begins later in the season progresses more rapidly.

In a separate analysis, a similar inverse relationship was seen between the magnitude of maximum SWE and the average meltout percent at the time of peak streamflow. Fifty-four percent (29 out of 54 basins) had significant correlations between magnitude max SWE and the average percent melted at the time of peak streamflow. In some basins, the inverse relationship can also be observed when max SWE is grouped into below-average (1st quartile), average (interquartile range), and above-average (4th quartile) snowpack years. For example, for the Atlanta Summit SNOTEL – Boise River nr Twin Springs pair the average percentage of max accumulation melted at the time of peak streamflow increases as max SWE decreases (Table 3), meaning that years with above-average max SWE experiences peak streamflow at lower meltout percentages than years at average or below-average max SWE levels. Perhaps simple reasoning is that smaller snowpack require a greater amount of snow to melt (i.e. a larger percentage) to produce peak streamflow and for larger snowpack a smaller amount (percentage) is needed.

Table 3. Atlanta Summit SNOTEL – Boise River at Twin Springs streamgage pair average percent melted at the time of peak streamflow grouped by below average, average, and above average, max SWE years.

Max SWE category	Magnitude max SWE (inches)	Number of Years in Analysis	Average percent melted at time of peak streamflow
Below average	<22.7	8	62
Average	22.7 - 37.6	17	43
Above average	>37.6	8	22

In general, the correlation coefficients (rho values) for each significantly correlated SNOTEL-streamflow pair increase (and p-values decrease) as the percentage of meltout increases. This suggests that the snowmelt process is more consistent as ablation progresses.

Note, evaluating correlations between the date of max SWE and the number of lag days between each meltout percentage and peak streamflow was not conducted due to the implicate relationship between the date of max SWE and the date of each meltout percentage – meltout dates are dependent on when the melt is initiated, i.e., date max SWE.

CDF Probability Model

Guidelines for Use of CDF Probability Model:

1. The CDF probability model can be used in three ways:

a. During active melt to estimate the probability that, for a given meltout percentage, peak streamflow will occur within a certain number of days or less.

b. During active melt to assess the likelihood that peak streamflow has already occurred, or the likelihood it is yet to occur, based on the probability at the time of inquiry (lag days zero).

c. At any point in the water year, the average (0.5 probability) percent meltout, at a given SNOTEL site, at the time of peak streamflow provides anecdotal indices or "rules of thumb" for peak streamflow timing.

2. Active melt refers to the ablation period which occurs after a SNOTEL site has reached maximum SWE accumulation and SWE values begin to decrease.
3. During active melt accumulation events may occur which may "reset" the percent meltout observed.
4. Lower elevation SNOTEL sites can generally be used first, in early melt, often before high elevation sites have reached maximum SWE accumulation. However, for many basins, lower elevation sites have weak or no correlations between the date of each 10% meltout and the date of peak streamflow. Estimates for the timing of peak streamflow from low elevation sites, especially in early melt, will often have large variability and should be used conservatively.

5. Once a SNOTEL site has reached complete (100%) meltout use of the CDF curves should be limited to avoid assumptions of a linear relationship existing past meltout. Assessments should only be based off the date of complete meltout. Use of other SNOTEL sites, in active melt, is preferred or maybe used in conjunction.
6. As the season progresses, melt occurs at higher and higher elevations and more SNOTEL sites can be used to estimate timing of peak streamflow. Use of high elevation SNOTEL sites is often the most practical since higher elevation sites usually receive more precipitation as snow than lower elevation sites and the snow remains longer (Lundquist et al, 2004). High elevation sites generally have less melt variability, likely due to the topographic controls on accumulation and melt, such as elevation, slope and aspect (DeWalle and Rango, 2008), and therefore have a stronger relationship to peak streamflow timing.
7. If a snow pillow or significant portions of a basin are affected by fire, or other significant alterations to the landscape occurs, use of the probability model should be discontinued as alterations can affect many components of the hydrologic cycle (Anderson et al, 1976; Neary et al, 2005).

Advantages to the Probability Approach

One of the main advantages to using a data-driven probability model to estimate the timing of peak streamflow is that it is a simple approach that does not require a lot of oversight or calibration. It is based on easily accessible historical data, which for many SNOTEL-streamgage pairs throughout Idaho have over 30 years of data. The probability models can be utilized in multiple ways, depending on the time of inquiry and only require knowledge of current and maximum SWE magnitude values. These are often attractive features for agencies since many physically based models generally require management by a full-time hydrologist.

Another advantage of the CDF probability model is that it can provide important basic information about various hydrologic properties of each basin based on the shape, extent, and range of percent meltout curves. For example, the range between 0 and 10% meltout illustrates how quickly a SNOTEL site progresses into active melt. For the Galena Summit SNOTEL-Big Wood River at Hailey streamgage pair, the range between 0 and 10% meltout extends to almost 20 days (Figure 12). While, each water year does not always match up at the same probability level for given meltout percentages, it is likely that, for this SNOTEL sites, it often takes the snowpack several days to get into active melt. The reasons can vary from a large snowpack taking time to ripen and prime the system or dependence on elevation and temperature.

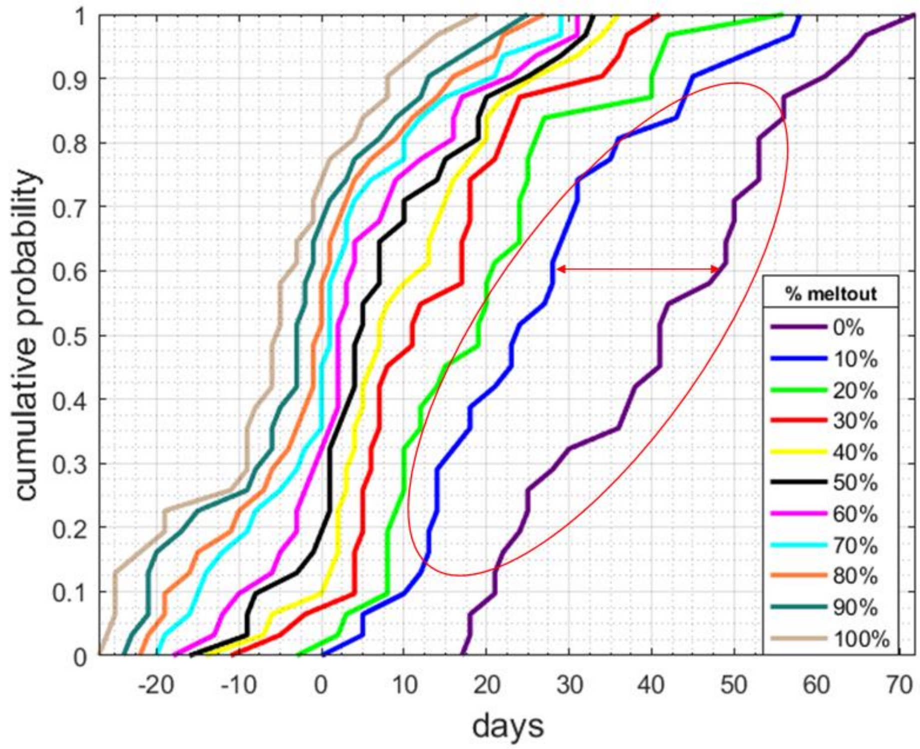

Figure 12. CDF probability model for Galena Summit SNOTEL and Big Wood at Hailey streamgage. The red ellipse highlights the days between 0 and 10% meltout. The red double arrow line indicated the possible extent (~ 20 days).

The CDF probability graphs can also provide quick reference information about whether a SNOTEL site is usually completely melted out at the time of peak streamflow. For example, the Chocolate Gulch SNOTEL-Big Lost River at Howell streamgage pair (Figure 13) shows only positive numbers for the lag days. Even at 100% meltout (tan line), there is only 0.5 probability that peak streamflow occurs at zero lag days.

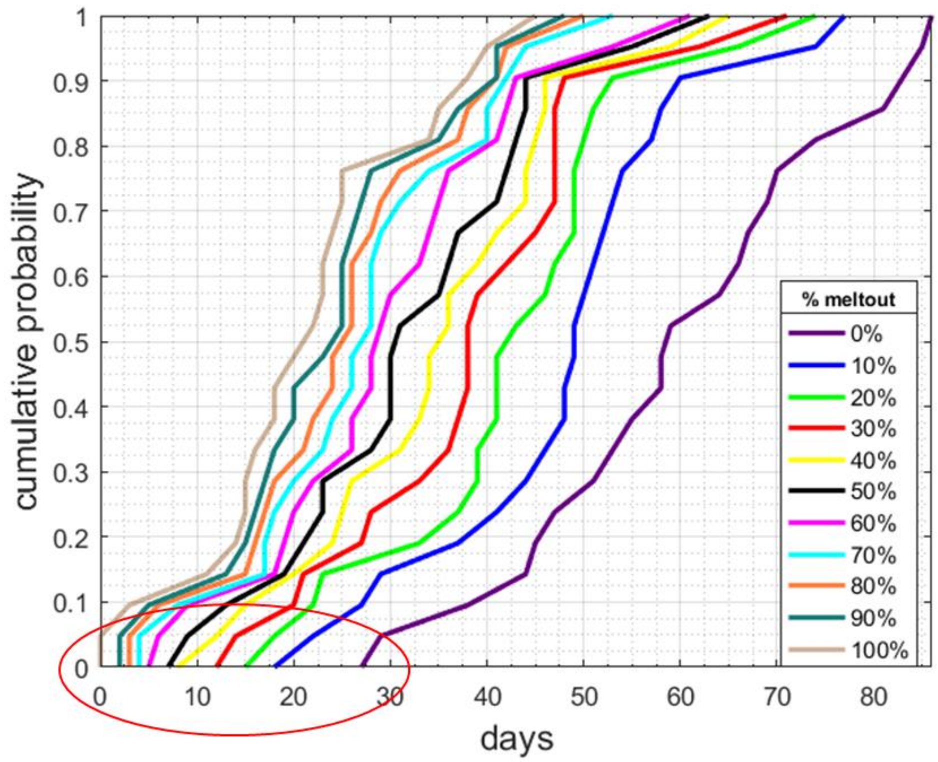

Figure 13. CDF probability model for Chocolate Gulch SNOTEL and Big Wood River at Hailey. Red ellipse highlights only positive numbers for all meltout percentages, indicating this site has always been completely melted at the time of peak flow.

Extreme outliers can also be determined from the CDF probability graphs. For example, for the Savage Pass SNOTEL-Lochsa River nr Lowell streamgage pair, the long, left tail in the CDF probability model (Figure 14) represents two peaks that occurred in early in the water year, during the accumulation phase, likely due to rain-on-snow events. Calculations confirm the date of peak streamflow for these two years were "extreme" outliers (events that fall more than 3 x IQR above the third quartile or below the first quartile). If the two years in which these early peaks occurred are removed the CDF the long tails are no longer displayed and the probabilities are slightly different (Figure 15). Though, it doesn't alter the probability a great deal, elimination of the outliers, provides a better model for estimating the time of the snowmelt peak.

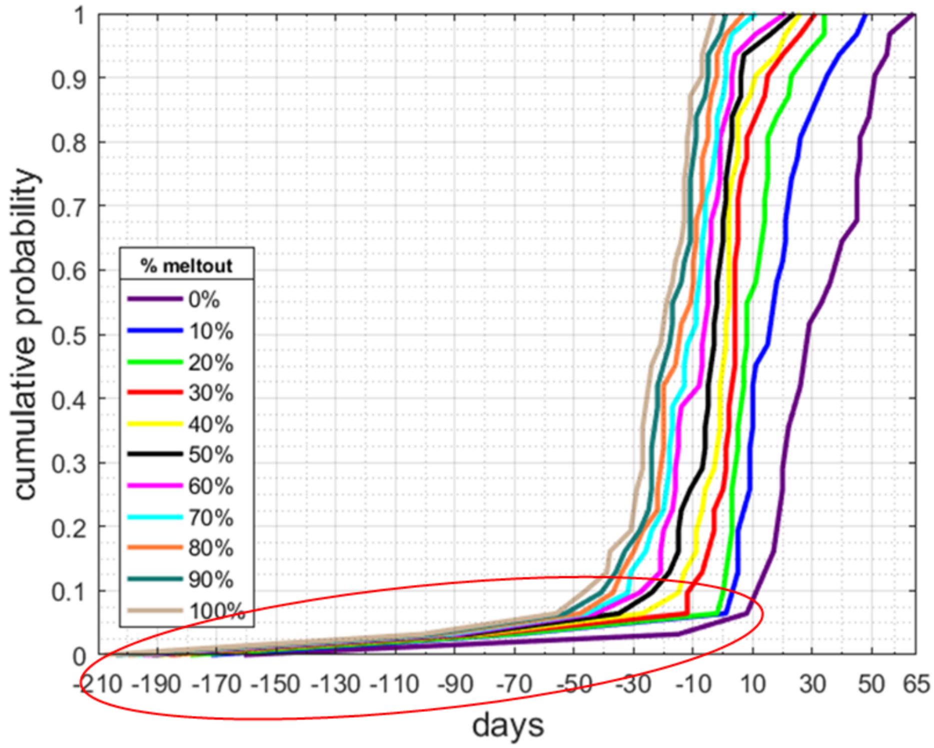

Figure 14. **CDF probability model for Savage Pass SNOTEL and Lochsa River nr Lowell. Red ellipse denotes the effects of two extreme outliers.**

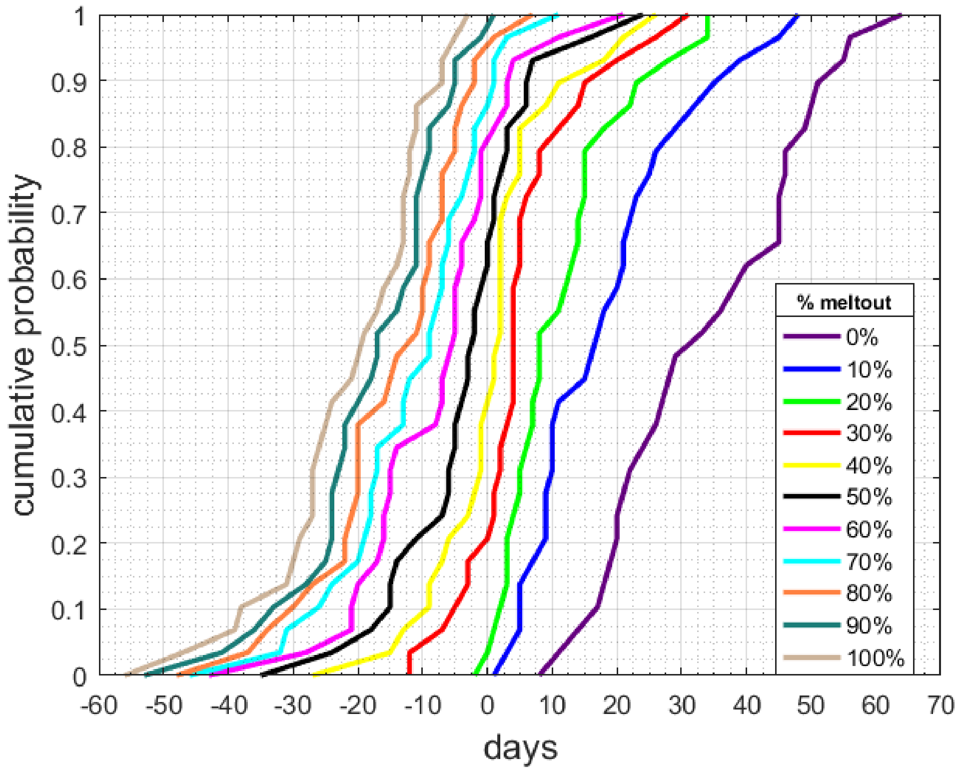

Figure 15. CDF probability model for Savage Pass SNOTEL and Lochsa River nr Lowell with extreme date of peak streamflow outlier years (1996 and 2015) removed, note the absence of the long tail.

There are some basins that historically experience multiple peaks within a year, often one in mid-winter due to rain-on-snow or weather patterns that bring warm temperatures and one (or more) in spring from snowmelt. When the mid-winter peaks are larger than the snowmelt peaks and occur often enough, they are not considered outliers. The pattern for these basins can often be seen in the CDF probability figures. For example, the CDF probability model for the Pole Creek R.S. SNOTEL-Bruneau River nr Hot Springs, ID streamflow pair (Figure 16), shows a slight inflection in the curves at the lower probabilities (red ellipse). The lag day values for all meltout percentages below the inflection point are mostly negative values, indicating peak streamflow occurred before those meltout levels were reached or even before maximum accumulation occurred. Knowledge of basins that are sensitive to early peaks can be beneficial for water managers and possible help identify basins whose rain-snow transition zone make up a large portion of the basin. This is especially important in a changing climate where the rain-snow transition areas are projected to move to higher elevations (Klos et al, 2014).

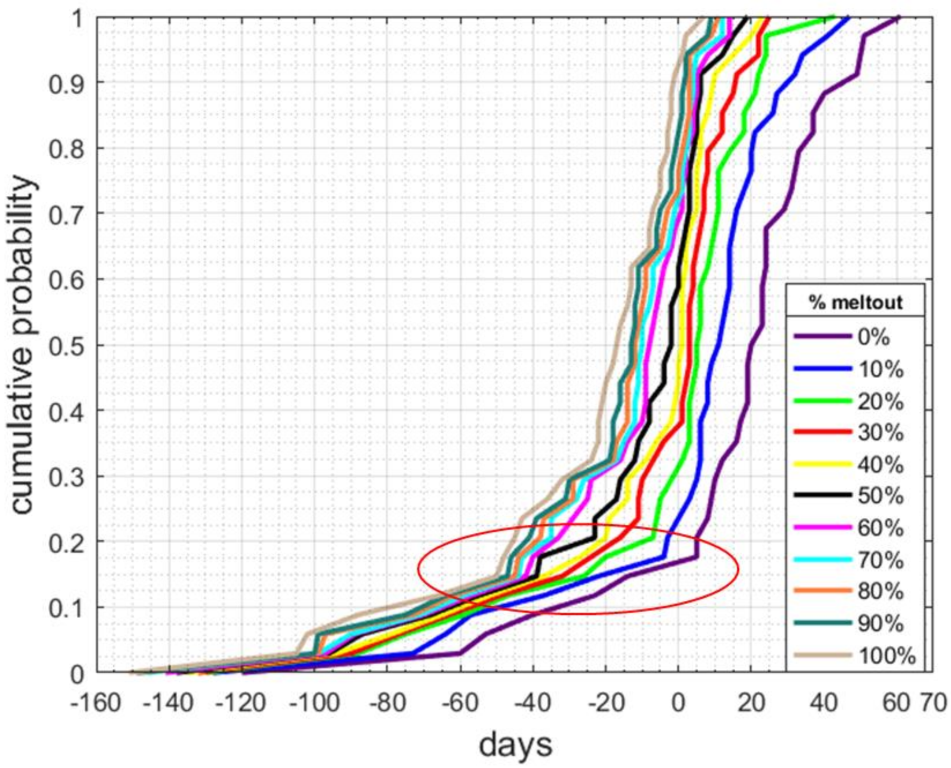

Figure 16. CDF probability model for Pole Creek R.S. SNOTEL and Bruneau River nr Hot Springs, ID. Red ellipse highlights inflection point.

Analysis of the shape of the CDF curves can also indicate how quickly and/or consistently an individual SNOTEL tends to melt. Sites that often melt more quickly can be seen in meltout percentage curves that are close together. More consistent year-to-year melt is indicated by curves that are close to vertical. Both rapid and consistent melt are indicated in the CDF probability model curves for the Graver Creek SNOTEL – Moyie River nr Eastport streamgage pair (Figure 17). Note the smaller range of lag days and the minimal spacing between meltout percentages as well as a steep vertical gradient for many of the meltout percentages. In contrast, Figure 18, the CDF model for the Bostetter

R.S. SNOTEL and Salmon Falls Creek nr San Jacinto streamgage pair shows a larger variance in lag days, indicating more year-to-year variability which is likely due to multiple process contributing to peak streamflow (e.g. rain-on-snow events, local weather patterns, or site-specific conditions).

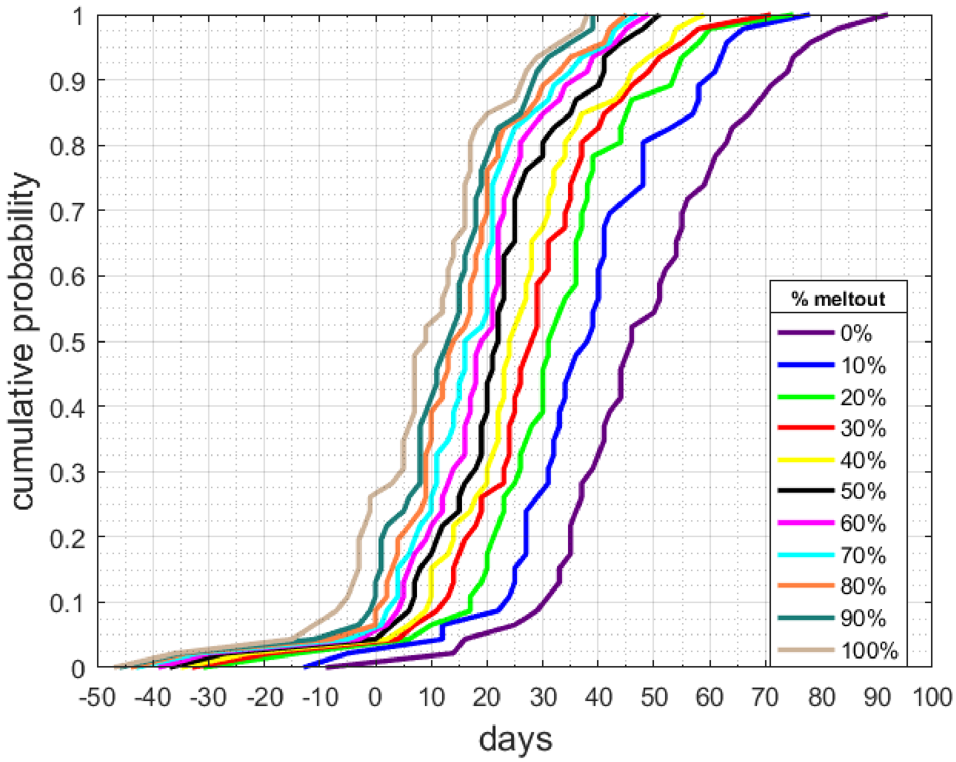

Figure 17. CDF probability model for Graver Creek SNOTEL and Moyie River at Eastport. The minimal spacing between each meltout percentage indicates fairly rapid melt and the verticalness of the individual meltout percentages indicates fairly consistent melt from year-to-year.

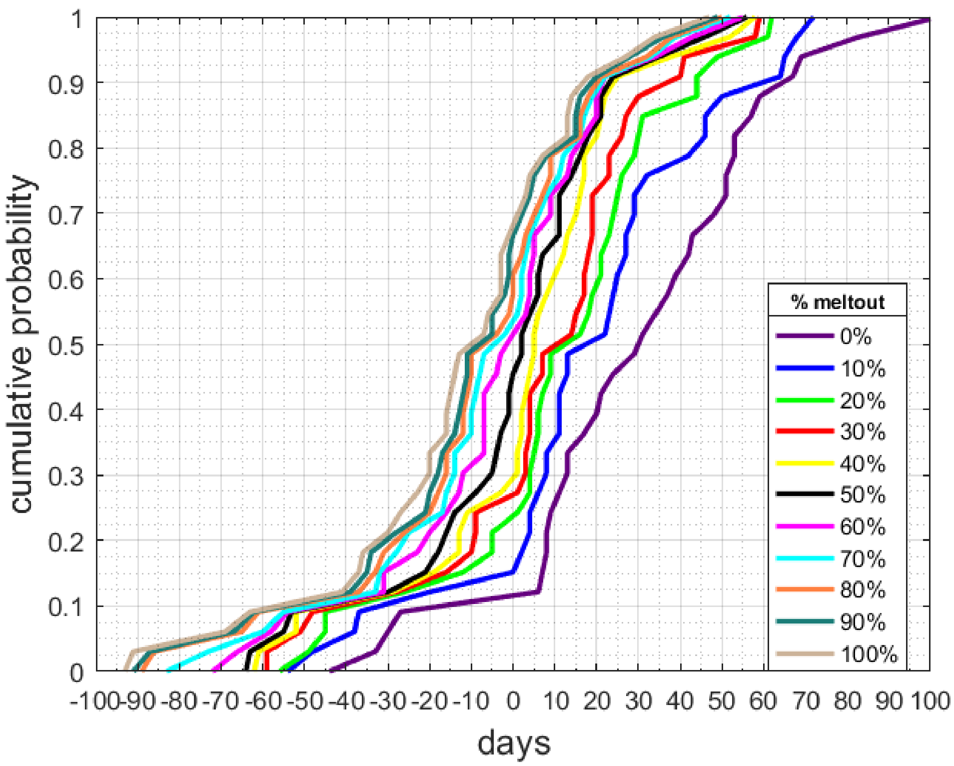

Figure 18. CDF probability model for Bostetter R.S. SNOTEL and Salmon Falls Creek nr San Jacinto. The large variance in lag days indicates possible multiple process contributing to peak streamflow.

Challenges to the Probability Approach

Despite many of its attractive features, the probability models bring some inherent challenges including: assuming stationarity, determination of the true timing of maximum accumulation, criteria for peak streamflow selection, and ease of use. In addition, use of the probability model does not consider the current year's snowpack conditions, such as the magnitude of maximum SWE being below average, average, or above average for the site.

Like many stochastic hydrologic forecasting models, this approach assumes stationarity – meaning that statistical properties (of peak streamflow) do not change over time. However, trend analysis studies indicate changes in precipitation and temperature are impacting snowmelt hydrology throughout the Western US. Changes in the timing and magnitude of snow accumulation and runoff throughout the western US (Barnett et al, 2008; Cayan et al, 2001; Clark, 2010; McCabe and Clark, 2005; Mote et al, 2005; Mote et al, 2018; Regonda et al, 2005; Stewart et al, 2005) suggest that the assumption of stationary it no longer valid (Milly et al, 2008). Specific to Idaho, Kunkel and Pierce (2010) used reconstructed final snowmelt dates to show that in recent decades (~1985-2007) snow has melted early and become more variable compared to previous decades (~1940s-1970s). As the climate continues to change, it is possible the snowmelt-streamflow relationships for many of the study basins will also change. This could be especially true for date based regression models, however; the design of the probability approach may potentially guard against stationarity. This is possible since the probability models use the number of lag days between the date each meltout percent and date of peak streamflow as opposed to a singular date. Trend analysis performed for each SNOTEL-streamflow pair partly support this hypothesis. Mann-Kendall trend test results in Appendix D, Tables D.1 and D.2 indicate that the date-based analysis are more sensitive to trends. Though the number of statistically significant trends were minimal (2 to 4 out of 54 pairs) for the date-based evaluations (date of each meltout percentage and date of peak streamflow), there were zero significant trends for the lag-based analysis. Despite the reassuring initial trend analysis results, it is advised that for use with the CDF models the lag day metric be re-evaluated with each update (~ every 5 years) to determine if trends are evident and if the use of the complete period of record for each SNOTEL-streamgage pair is still appropriate. If a different method for selecting the peak streamflow (as addressed below) is used it is advised that a new trend be conducted prior to development of the CDF probability models.

One of the drawbacks of using the probability model as an operational tool is that it is primarily intended to be used during active melt, after peak accumulation has occurred, yet determination of peak accumulation in real time is challenging. Due to variability in seasonal conditions, primarily weather patterns, melt periods may be followed by periods of accumulation or melt may cease for extended periods of time causing fluctuations in SWE which can make it difficult to determine if and when maximum accumulation has occurred, therefore the use of the probability model in the early melt period (0 to 20% meltout) should be used with caution. This can be especially challenging in basins whose meltout relationship to peak streamflow occurs, on average, during early melt periods. This early melt relationship is often seen with high-elevation SNOTEL sites.

Another possible drawback is the consequences from the criteria for selection for peak flow. For this study, there were no conditional selections; peak streamflow was determined from daily time step values of mean daily streamflow and daily SWE values examined over the entire water year – October 1 to September 30. This allows for selection of peak flow occurring at any point in the water year including non-seasonal snowmelt generated peaks, such as peaks that occurs in fall or early winter prior to peak SWE accumulation, yet the tool for estimating the timing of peak flow was intended to be based on the relationship of seasonal snowmelt timing to peak streamflow. Having the selection window over the entire water year can, for some basins, produces large variability in the number of days from each percent meltout to peak streamflow. This is seen in the shape and spread (tails) of many of the CDFs analysis. Peak streamflow that occurs early in the water year prior to peak accumulation, often caused by a warming event and/or heavy rain, will result in large, negative, number of days lag (Figure 14). Large, positive number of days lag are also seen for peaks in streamflow likely caused by late spring and summer rain storms that occur after complete meltout. Large variability in the number of lag days between meltout percentages and peak streamflow will likely result in weak relationships due to the influence of other factors and may produce skewed probability models especially if fit to specific distribution models. Perhaps, more appropriate would be to allow for conditional selection, i.e., limit the window of time in which to select peak streamflow, such as April 1 to June 30 or only during the ablation period, however, conditional selections can be problematic as well. Conditional selections based on a specified time frame may be an issue (or become an issue in the future) since trend analyses are showing the timing of snowmelt and seasonal streamflow are shifting toward earlier in the year (Fritze et al, 2011; McCabe and Clark, 2005; Regonda et al, 2005; Stewart et al, 2005). Selecting a longer window of time may help, however, the potential for selecting non-snowmelt peaks could remain. Selection for peaks that occur only during ablation would reduce the potential for selecting non-snowmelt peaks, however, the ablation period for each SNOTEL site within a basin is different – lower elevation site's melt begins and end much earlier than higher elevation sites. Having different peaks selected for a given year would be less than optimal especially if the data were to be used for intra-basin SNOTEL comparisons. Possibly, a combination approach would be more ideal, where ablation data from all SNOTEL within the basin were combined and the conditional selection window was the entire ablation period across all sites. Another approach could be evaluating Idaho basin for "spring pulses" as described by Cayan et al (2001) and used by Peterson et al (2008).

Another approach could be to keep the selection process the same – across the entire water year, but to eliminate extreme outliers. It should be noted that implementing conditional selection does not ensure capturing the true snowmelt; peak streamflow relationship in that precipitation events that occur during ablation may influence the timing of peak streamflow. Despite identifying some of the consequences of not implementing a conditional selection of peak streamflow we felt the maintaining the study design that selects the absolute peak streamflow occurring at any point in the water eliminated any potential bias of precipitation events that occur either before, during, and/or after the melt period. Selection for peak streamflow over the entire water year also allowed for updating historical annual (from mean daily) records and summary statistics. This method also provided some unanticipated insights into some of the various hydrologic responses of basins throughout Idaho as discussed in the "Advantages to the probability approach" section above.

Another drawback of the probability model CDF curves is the ease of use as an operational tool; reading and interpreting can be difficult for some users. It is advised that the final product provide clear explanations and instructions on how cumulative distribution functions and the probability of occurrence work. For example, if the current meltout percent is 30%, from the graph the user may interpret there is an 80% probability peak streamflow will occur in the next 5 days, however, more accurately it should be read as there is an 80% probability peak streamflow will occur within the next 5 days OR ANY TIME BEFORE which may be a rather large window of time. If the user feels confident the peak has yet to occur the 5-day window can be useful, however, it is often difficult to know especially if streamflow has been gradually increasing through the season but has not yet experienced a peak and subsequent drop.

One final drawback to the probability model approach is that it doesn't allow for current conditions to be utilized. The cumulative distribution function combines data available for all years for each SNOTEL-streamgage site regardless of each year's unique conditions – e.g. magnitude maximum SWE, date of maximum SWE, or date of each percent meltout. However, some SNOTEL-streamflow pairs show significant negative correlations between magnitude maximum SWE and the number of days lag between each meltout percent and peak streamflow (Table B.2) which implies years (data points) with greater magnitudes of maximum SWE will generally plot on the probability model curves at lower lag days (to the left) and therefore have lower probabilities. The opposite is true form smaller magnitudes of maximum SWE – they will generally plot at higher lag days (to the right) and have higher probabilities of occurrence. This concept can be seen in the CDF probability model for the Atlanta Summit SNOTEL – Boise River at Twin Springs streamgage pair (Figure 19). On the 40% meltout curve, blue triangles mark the years with the above average max SWE (75^{th} percentile) and red triangle mark years with below average max SWE (25^{th} percentile). Though there is some overlap, there is a clear distinction in the range of probabilities for each group. Since not all SNOTEL-streamflow pairs have significant correlations or are not correlated for all meltout percentages, implementing current magnitude max SWE in the current operational product is uncertain and suggestions as to which probability a user should consider generally considered improper, however, users may want to adjust accordingly based on the information provided.

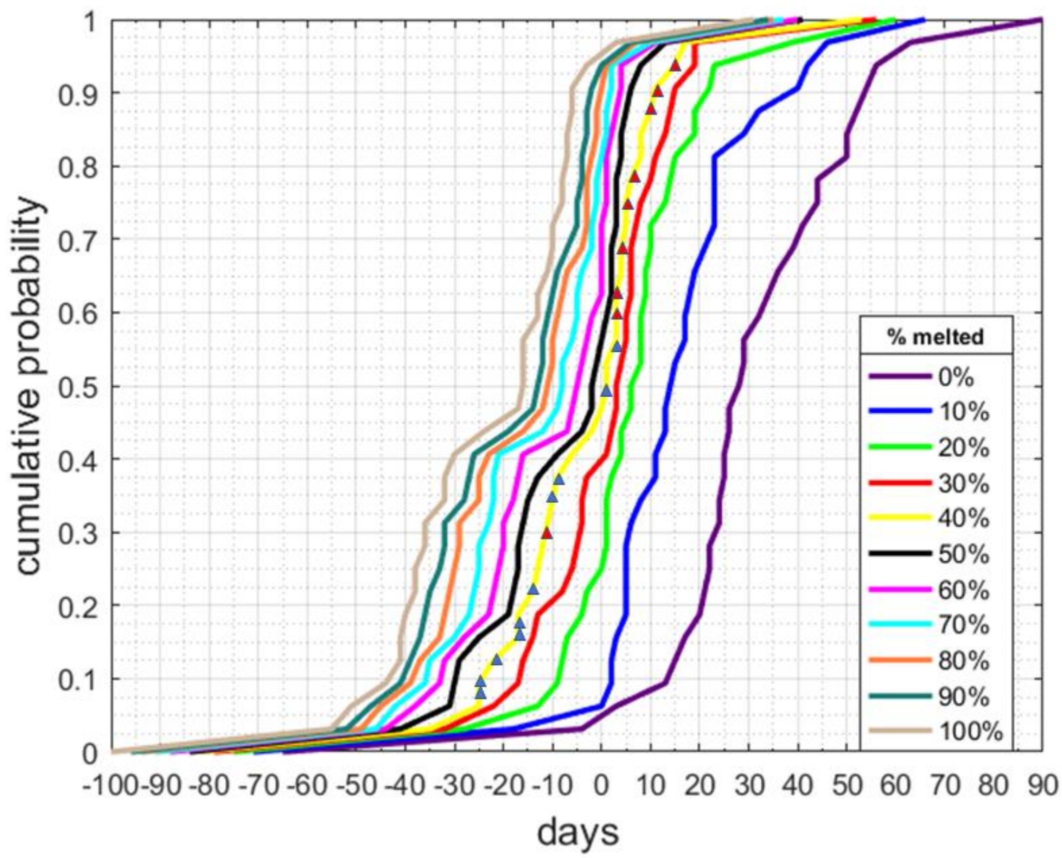

Figure 19. CDF probability model for the Atlanta Summit SNOTEL-Twin Springs streamgage pair. Triangles on the 40% meltout curve highlight years with above average (blue triangles) and below average (red triangles) SWE.

CONCLUSION

The goal of this research was to evaluate the relationships between snowmelt and peak streamflow for basins throughout Idaho to determine if simple relationships can be used to estimate the timing of peak streamflow. Historical dataset tables of snowmelt-streamflow metrics for 54 SNOTEL-streamflow pairs add to the body of knowledge for basin dynamics throughout Idaho. These tables not only provided the metrics required for this study they can also be the basis for future research on basins in Idaho.

Correlation analysis between both the timing and magnitude of max SWE and peak streamflow as well as the number of lag days establish significant relationships exist between snowmelt and streamflow processes. These correlations also reveal that the timing of snowmelt may impact the timing of peak streamflow more than the timing of max SWE accumulation. The magnitude of max SWE is also shown to be inversely correlated to the number of lags days between each incremental meltout and peak streamflow, especially at higher meltout percentages.

The most effective use of the probability curves is during active melt, after peak SWE accumulation. The melt percentage (of maximum accumulation) can be calculated from the SWE value reported at the time of inquiry and the corresponding percent meltout curve shows the probability of peak streamflow occurring within a certain number of days or the likelihood the peak has past. During non-melt periods the relationship between snowmelt and peak streamflow is evaluated based on the average (50% probability) percentage of meltout occurring at the time of peak streamflow. The

CDF curves can also be used after a peak in streamflow has occurred to assess the likelihood the peak was the absolute annual peak based on the percentage meltout at the time the peak occurred and corresponding probability on day zero (0 days lag). Evaluation of the shape and distribution of individual CDF probability models can also provide basic insight to hydrologic processes within each basin.

FUTURE WORK

Fit Data to Normal Distribution

The current method to create the probability model employs the Weibull plotting position to plot the number of days between each percent meltout and peak streamflow (lag days). For ease of use, utilizing a normal distribution model may be advantageous. Fitting the data to a normal distribution was dismissed as part of the original study design after determining some of sample datasets were not from a distribution in the normal family (by use of MATLAB's lillietest function). It is likely the non-normality for the date of peak streamflow (day of the water year), for some basins, is due to the selection of peak flow over the entire water year. In a preliminary analysis conducted on the Trinity Mtn SNOTEL – Twin Springs streamgage pair shows removal of extreme outliers solved the issue of non-normality for date (day of WY) of peak streamflow. Implementation of other conditional selection for peaks may also resolve this issue but have not been tested.

Investigate Multiple Linear Regression for Predictions of Peak Streamflow Timing

Similar to early work conducted by Farnes, Sarantitis and Palmer, and Garen, the use of multiple linear regression models may be explored. Preliminary analysis of Trinity Mtn SNOTEL – Boise River at Twin Springs streamgage using simple linear regression between the date of each meltout percent and date of peak streamflow resulted in R^2 values ranging between 0.075 and 0.156 (note: extreme outlier year 2015 was excluded). Exploring additional snowpack condition variables such as magnitude max SWE, date of max SWE, and melt-rate (average rate up to the date of inquiry or monthly rates) may improve R-squared values. Utilizing a stepwise backward regression approach or use of principal component regression can help select the most informative variables to include in a multiple linear regression model and eliminate collinearity of variables. The regression analysis should be conducted on each SNOTEL-streamgage site pair and each model based accordingly. Conditional selection of peak streamflow should help ensure all model assumptions are met (normality, homoscedasticity, collinearity). Implementation into an automated operational tool could be a welcome addition for many water managers and users.

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APPENDIX A

South Fork Boise River Near Featherville, Idaho CDF Probability Models

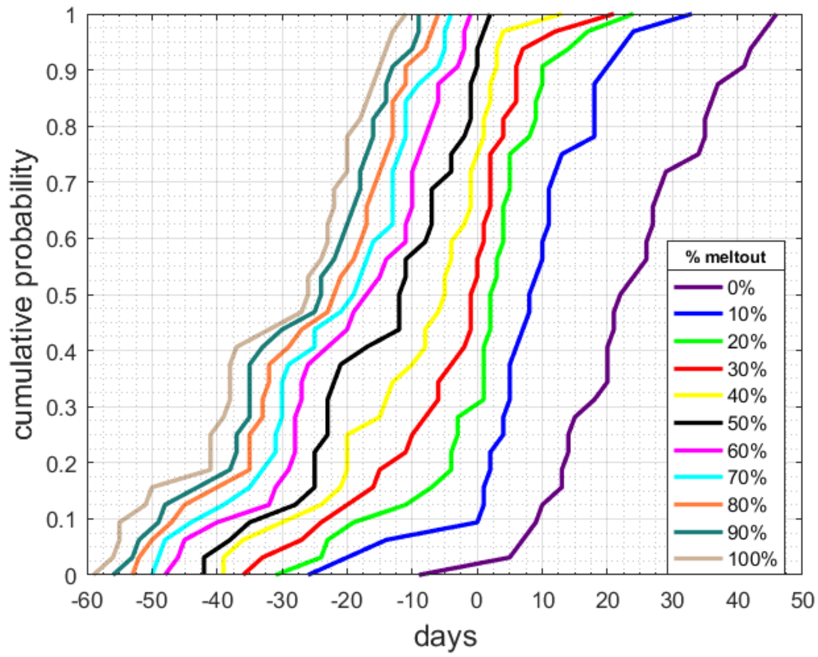

Figure A.1 CDF probability model estimating the number of days from each meltout percentage at Vienna Mine SNOTEL to peak streamflow at SF Boise River near Featherville, Idaho.

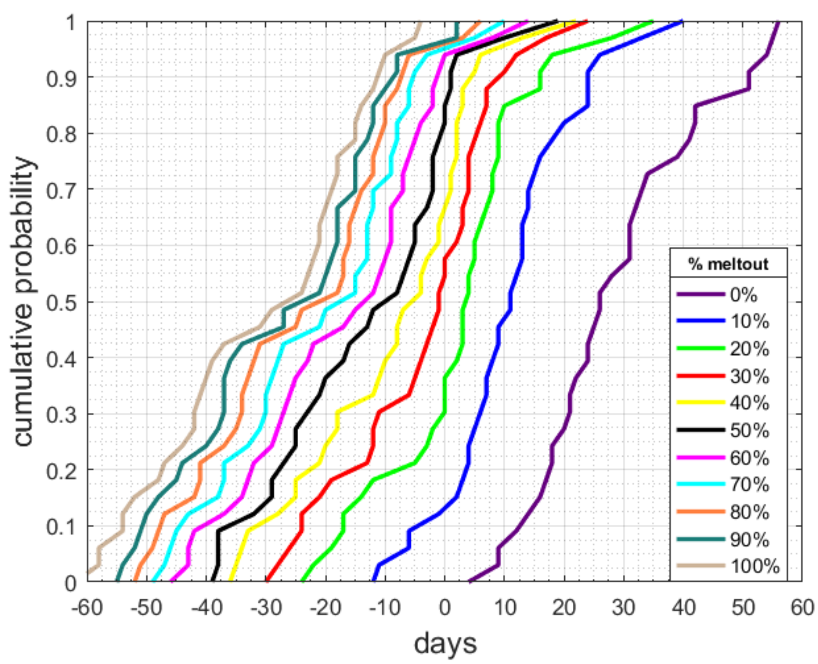

Figure A.2 CDF probability model estimating the number of days from each meltout percentage at Trinity Mtn SNOTEL to peak streamflow at SF Boise River near Featherville, Idaho.

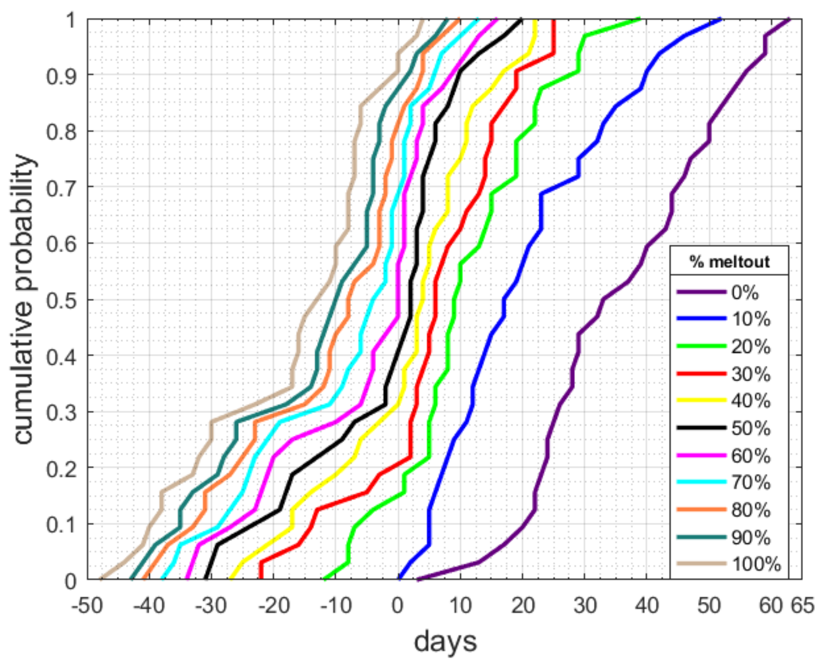

Figure A.3 CDF probability model estimating the number of days from each meltout percentage at Atlanta Summit SNOTEL to peak streamflow at SF Boise River near Featherville, Idaho.

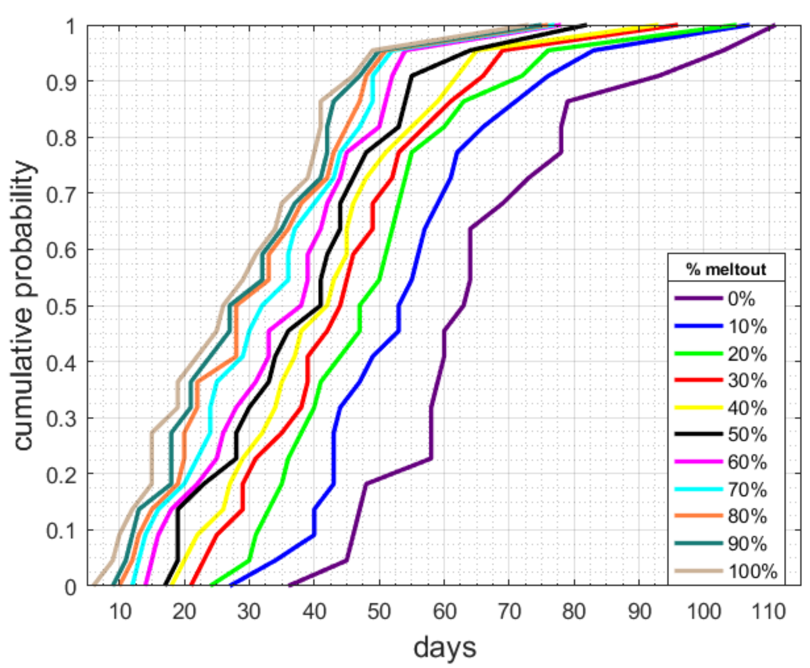

Figure A.4 CDF probability model estimating the number of days from each meltout percentage at Camas Creek Divide SNOTEL to peak streamflow at SF Boise River near Featherville, Idaho.

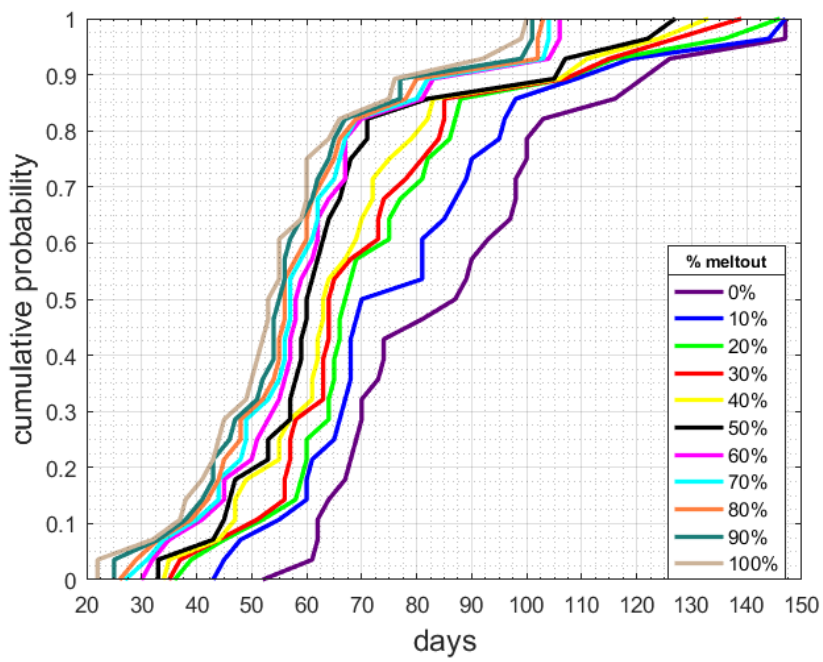

Figure A.5 CDF probability model estimating the number of days from each meltout percentage at Prairie SNOTEL to peak streamflow at SF Boise River near Featherville, Idaho.

Big Lost River at Howell Ranch near Chilly, Idaho CDF Probability Models

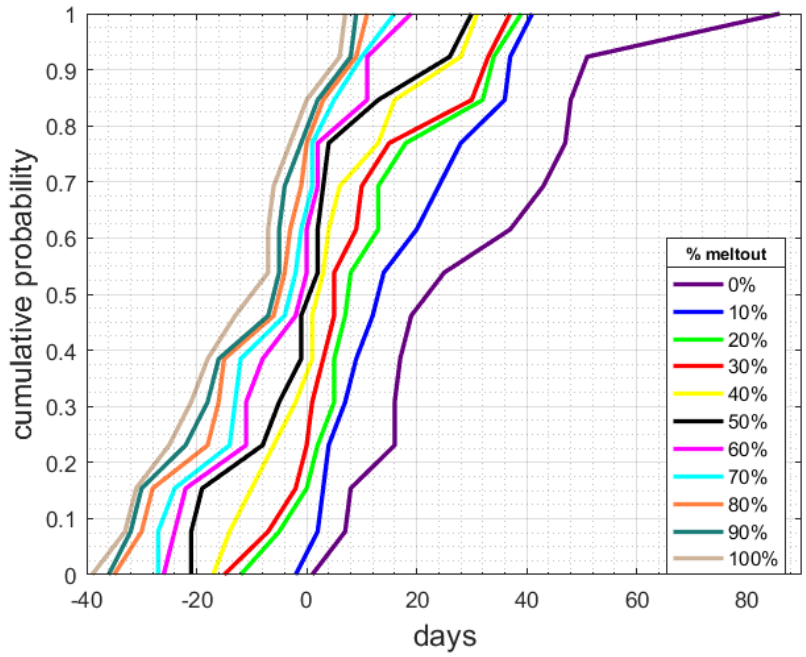

Figure A.6 CDF probability model estimating the number of days from each meltout percentage at Smiley Mtn SNOTEL to peak streamflow at Big Lost River at Howell Ranch near Chilly, Idaho.

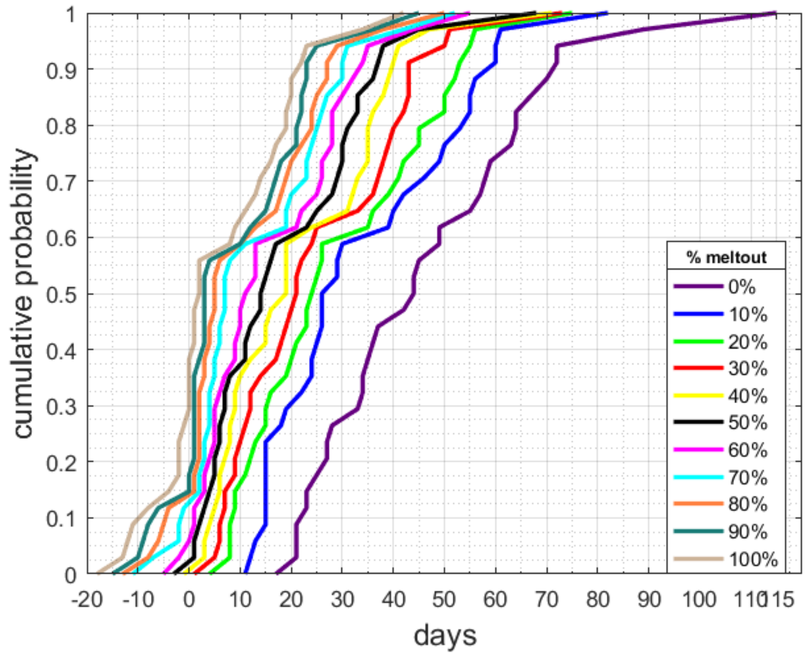

Figure A.7 CDF probability model estimating the number of days from each meltout percentage at Bear Canyon SNOTEL to peak streamflow at Big Lost River at Howell Ranch near Chilly, Idaho.

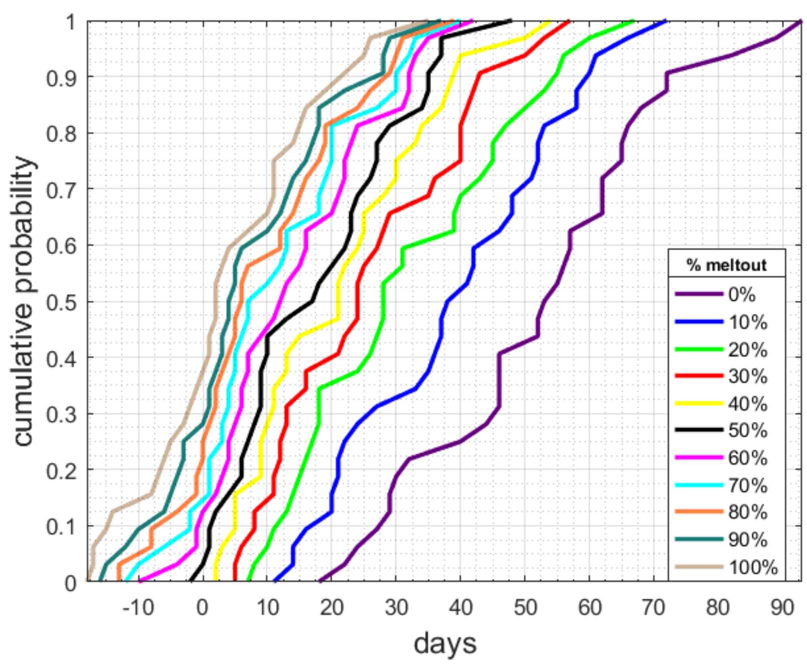

Figure A.8 CDF probability model estimating the number of days from each meltout percentage at Lost-Wood Divide SNOTEL to peak streamflow at Big Lost River at Howell Ranch near Chilly, Idaho.

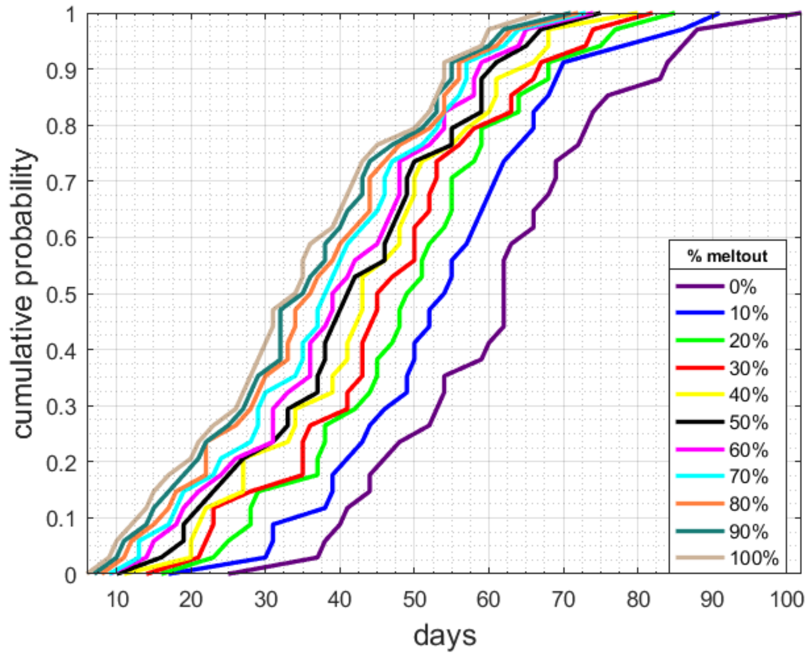

Figure A.9 CDF probability model estimating the number of days from each meltout percentage at Stickney Mills SNOTEL to peak streamflow at Big Lost River at Howell Ranch near Chilly, Idaho.

Big Wood River near Hailey, Idaho CDF Probability Models

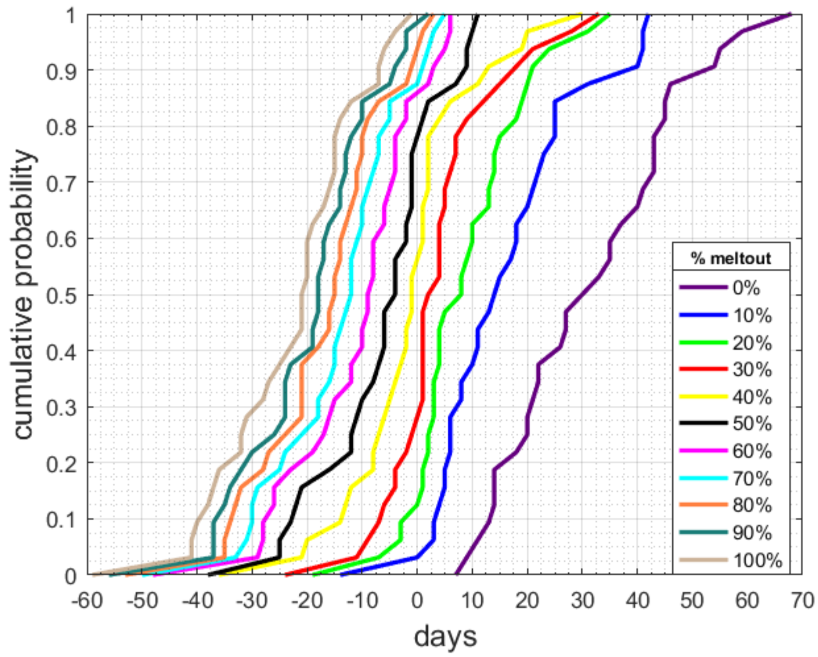

Figure A.10 CDF probability model estimating the number of days from each meltout percentage at Vienna Mine SNOTEL to peak streamflow at Big Wood River near Hailey, Idaho.

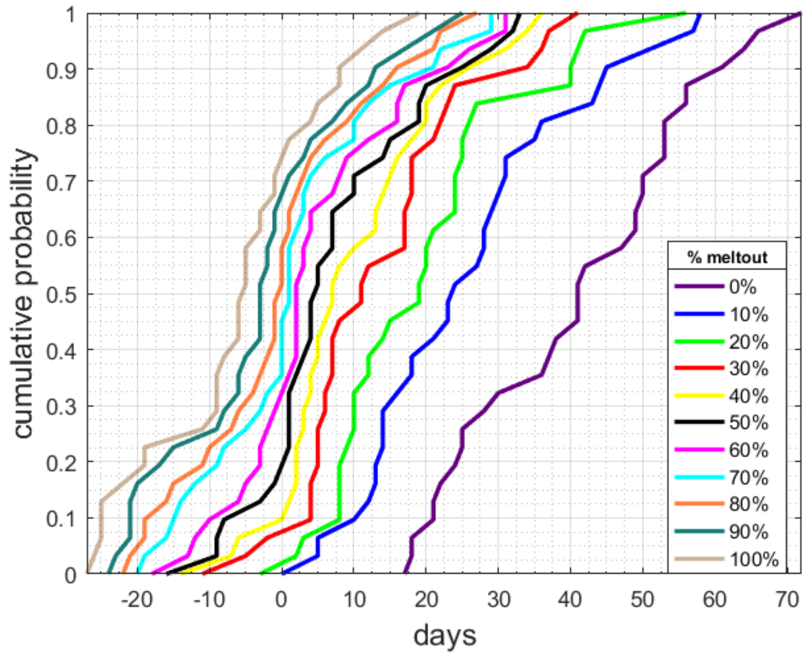

Figure A.11 CDF probability model estimating the number of days from each meltout percentage at Galena Summit SNOTEL to peak streamflow at Big Wood River near Hailey, Idaho.

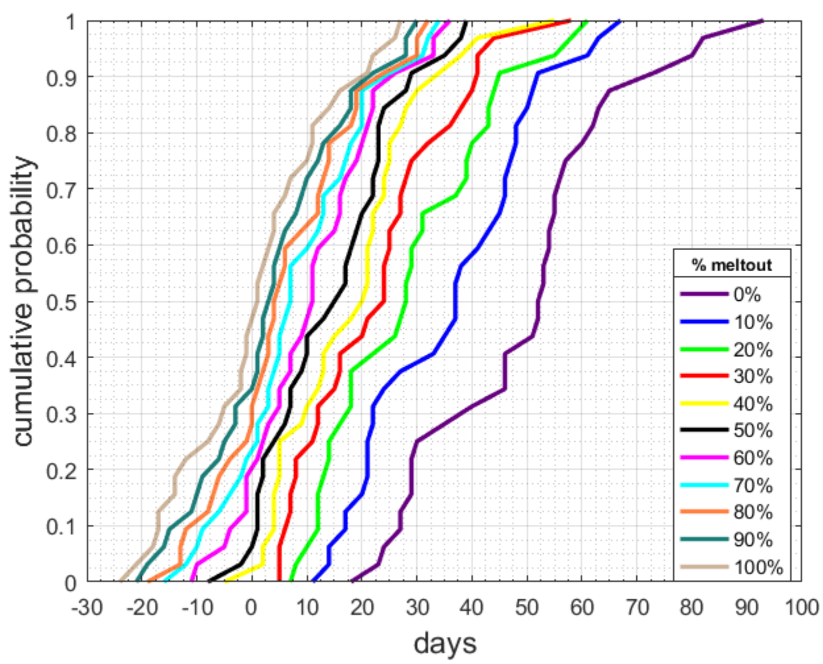

Figure A.12 CDF probability model estimating the number of days from each meltout percentage at Lost-Wood Divide SNOTEL to peak streamflow at Big Wood River near Hailey, Idaho.

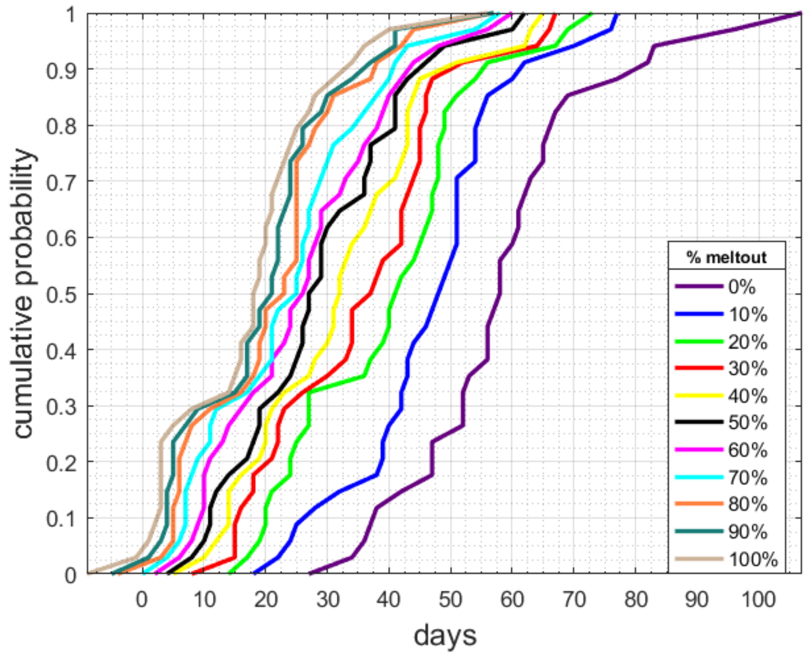

Figure A.13 CDF probability model estimating the number of days from each meltout percentage at Hyndman SNOTEL to peak streamflow at Big Wood River near Hailey, Idaho.

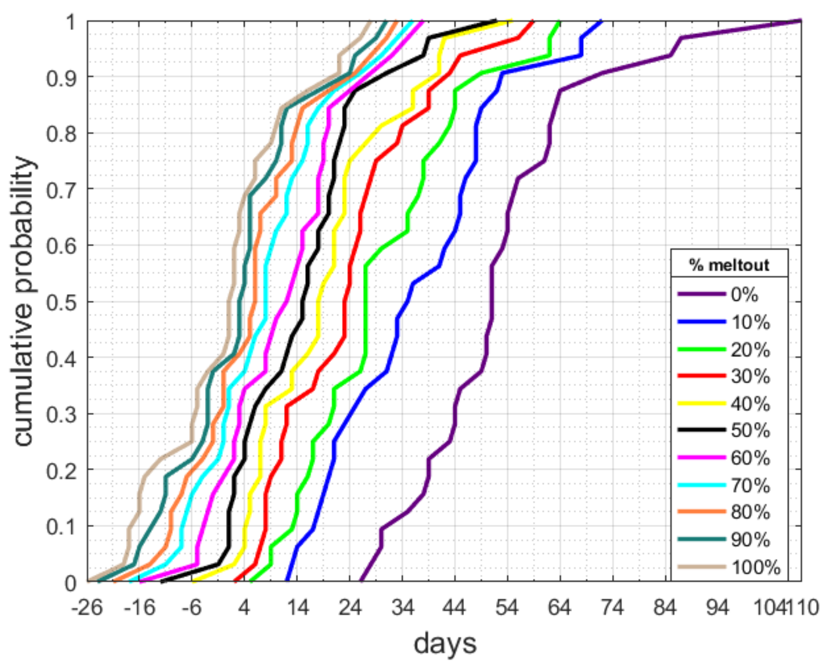

Figure A.14 CDF probability model estimating the number of days from each meltout percentage at Galena SNOTEL to peak streamflow at Big Wood River near Hailey, Idaho.

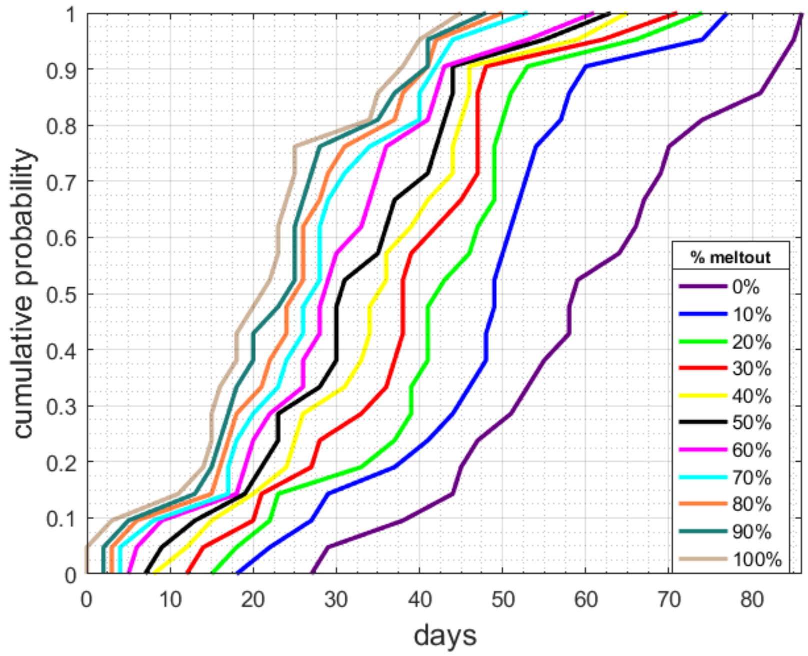

Figure A.15 CDF probability model estimating the number of days from each meltout percentage at Chocolate Gulch SNOTEL to peak streamflow at Big Wood River near Hailey, Idaho.

Bruneau River near Hot Springs, Idaho CDF Probability Models

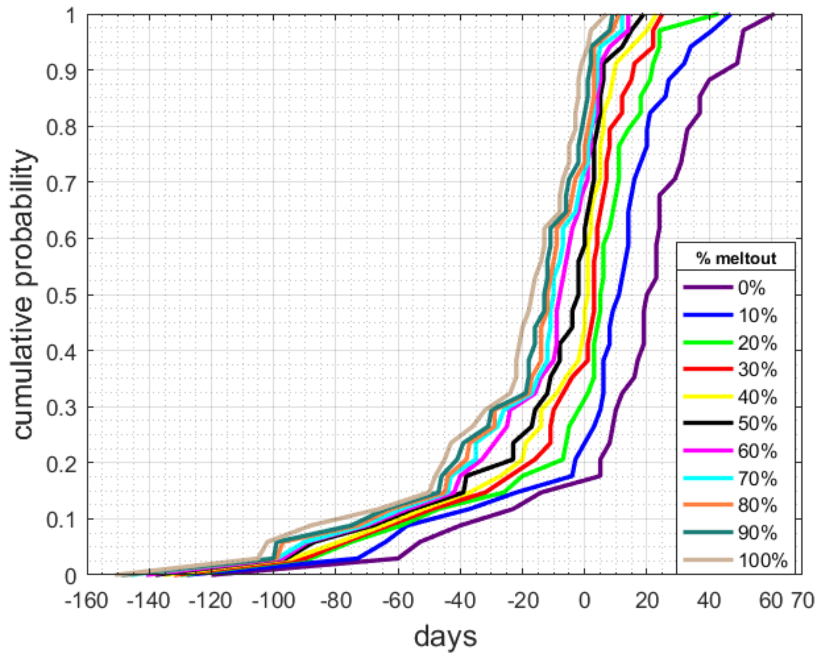

Figure A.16 CDF probability model estimating the number of days from each meltout percentage at Pole Creek R.S. SNOTEL to peak streamflow at Bruneau River at Hot Springs, Idaho.

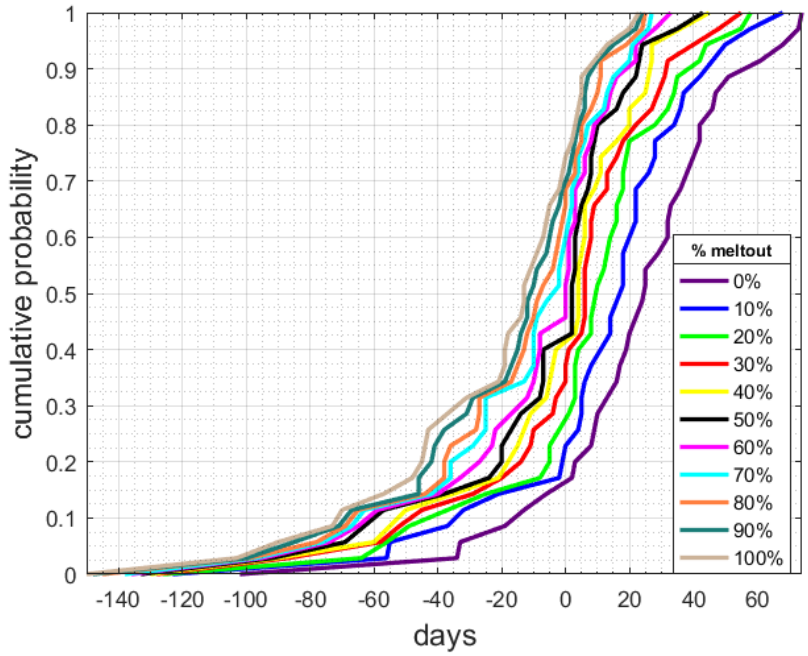

Figure A.17 CDF probability model estimating the number of days from each meltout percentage at Bear Creek SNOTEL to peak streamflow at Bruneau River at Hot Springs, Idaho.

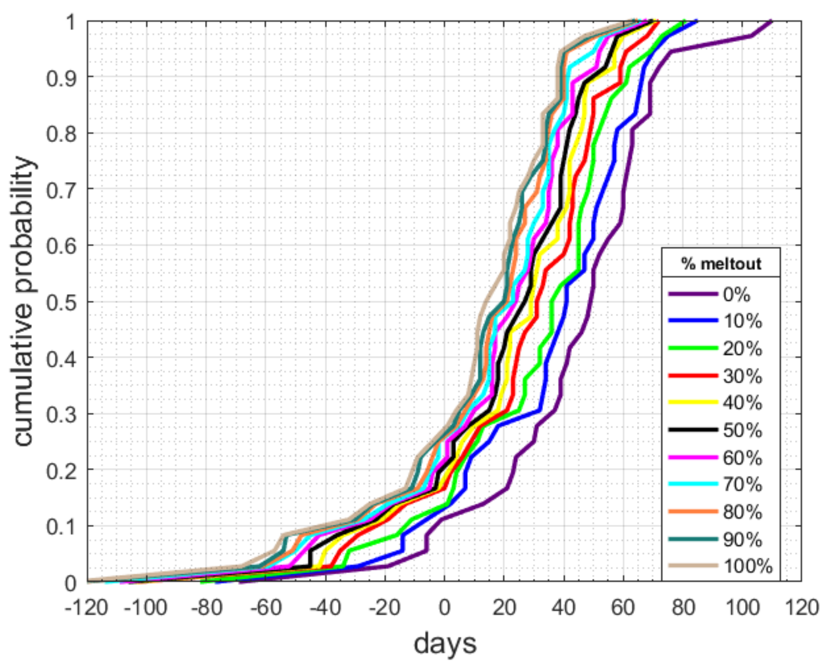

Figure A.18 CDF probability model estimating the number of days from each meltout percentage at Seventysix Creek SNOTEL to peak streamflow at Bruneau River at Hot Springs, Idaho.

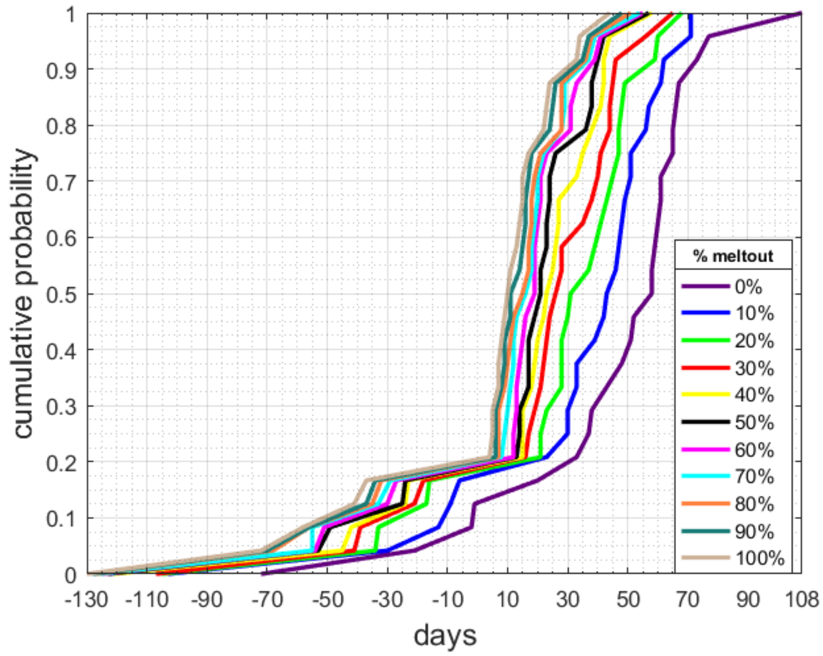

Figure A.19 CDF probability model estimating the number of days from each meltout percentage at Wilson Creek SNOTEL to peak streamflow at Bruneau River at Hot Springs, Idaho.

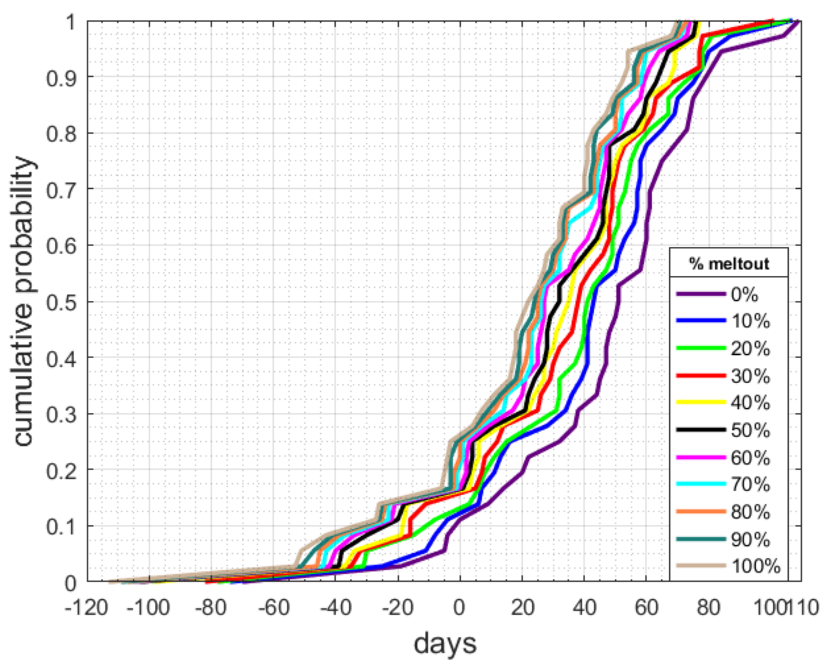

Figure A.20 CDF probability model estimating the number of days from each meltout percentage at Big Bend Creek SNOTEL to peak streamflow at Bruneau River at Hot Springs, Idaho.

Lochsa River near Lowell, Idaho CDF Probability Models

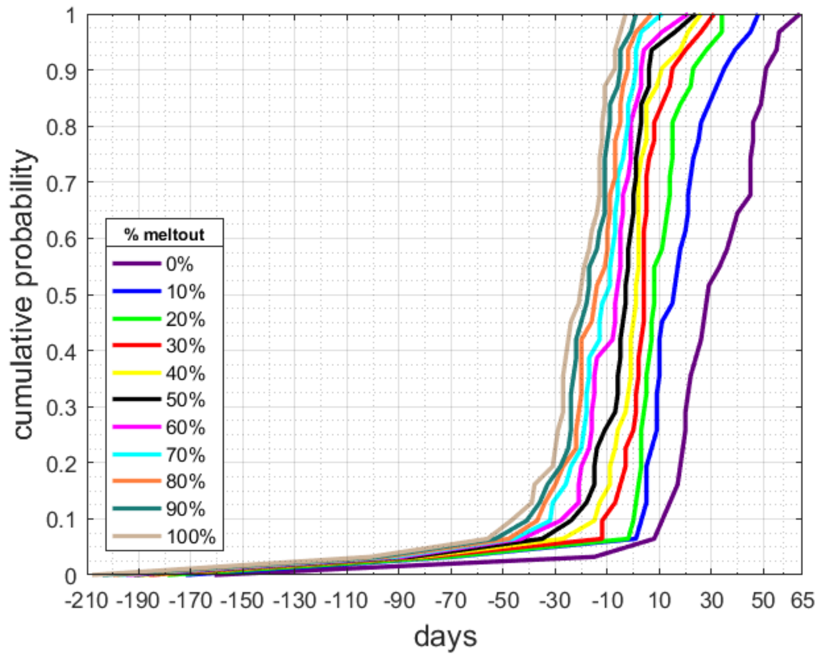

Figure A.21 CDF probability model estimating the number of days from each meltout percentage at Savage Pass SNOTEL to peak streamflow at Lochsa River near Lowell, Idaho.

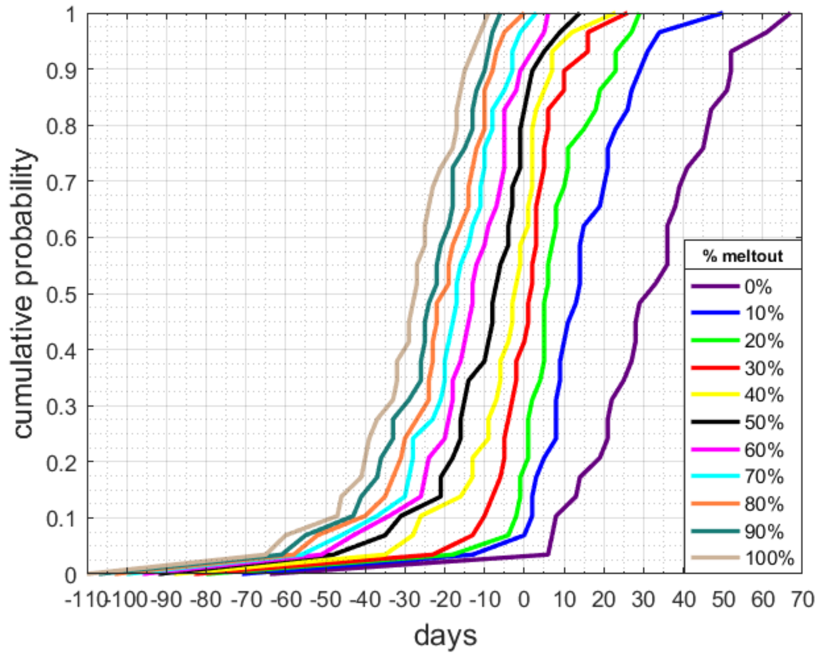

Figure A.22 CDF probability model estimating the number of days from each meltout percentage at Crater Meadow SNOTEL to peak streamflow at Lochsa River near Lowell, Idaho.

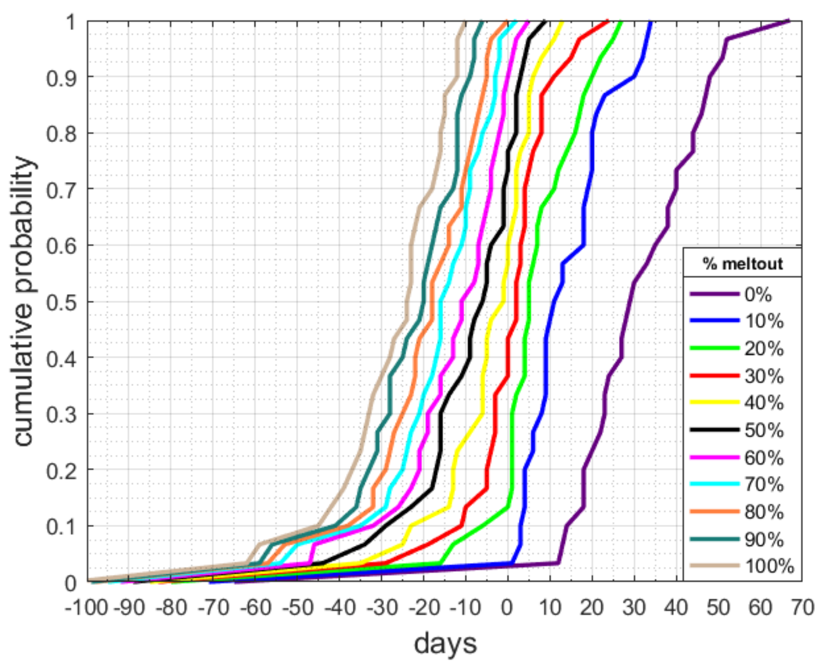

Figure A.23 CDF probability model estimating the number of days from each meltout percentage at Hemlock Butte SNOTEL to peak streamflow at Lochsa River near Lowell, Idaho.

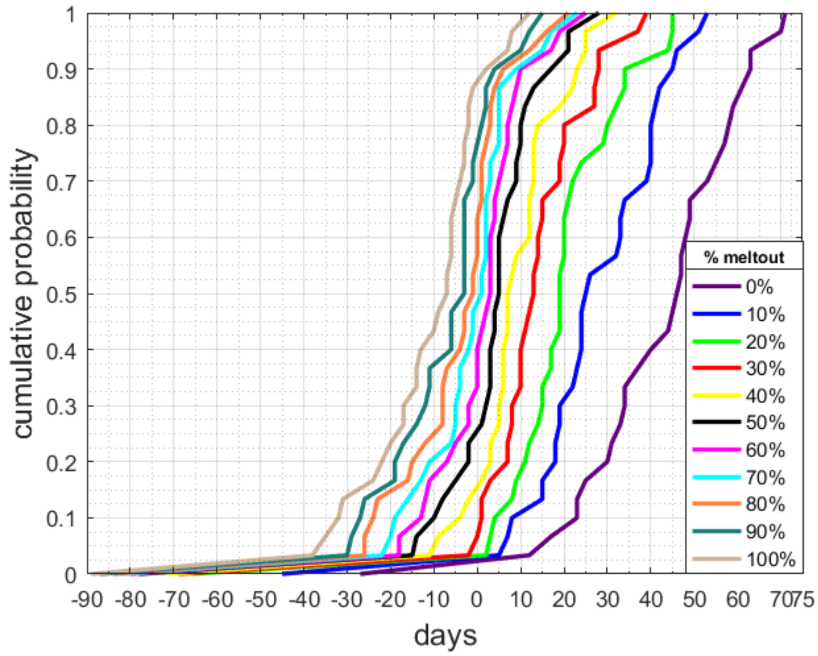

Figure A.24 CDF probability model estimating the number of days from each meltout percentage at Lolo Pass SNOTEL to peak streamflow at Lochsa River near Lowell, Idaho.

Moyie River at Eastport, Idaho CDF Probability Models

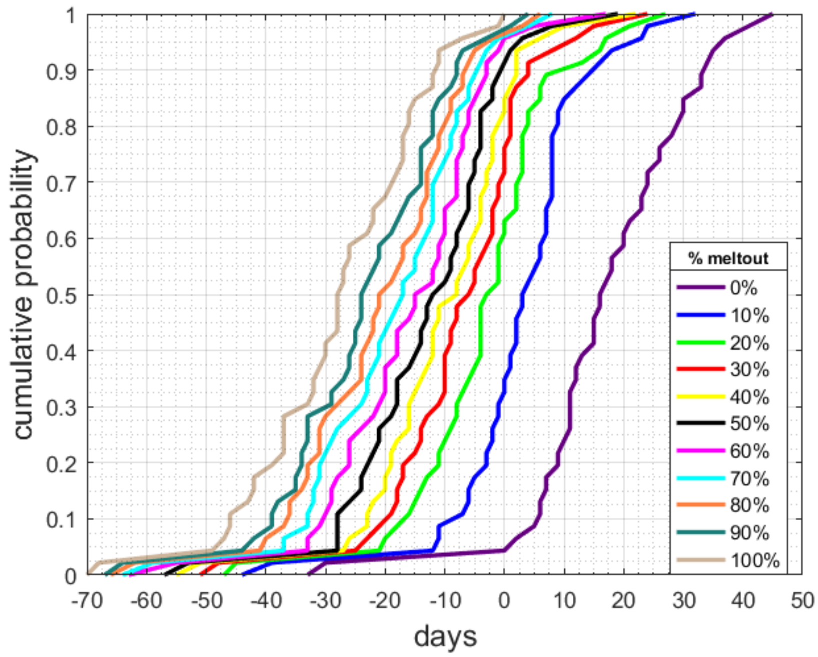

Figure A.25 CDF probability model estimating the number of days from each meltout percentage at Hawkins Lake SNOTEL to peak streamflow at Moyie River at Eastport, Idaho.

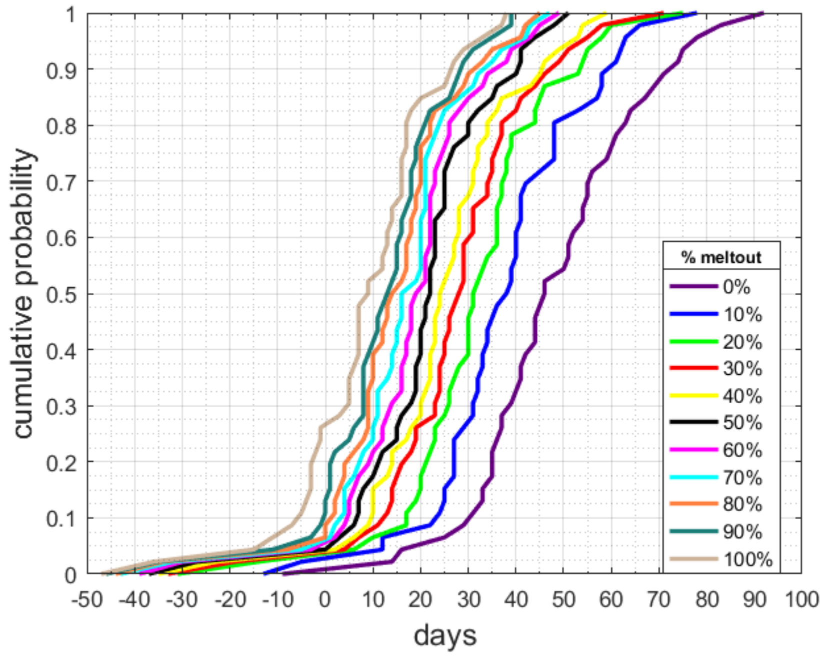

Figure A.26 CDF probability model estimating the number of days from each meltout percentage at Graver Creek SNOTEL to peak streamflow at Moyie River at Eastport, Idaho.

Owyhee River near Rome, Idaho CDF Probability Models

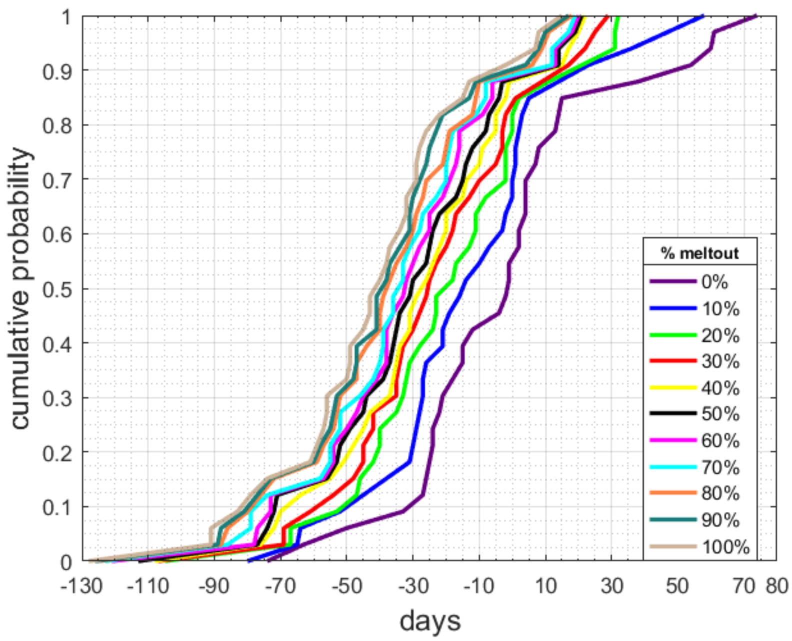

Figure A.27 CDF probability model estimating the number of days from each meltout percentage at South Mtn. SNOTEL to peak streamflow at Owyhee River near Rome, Idaho.

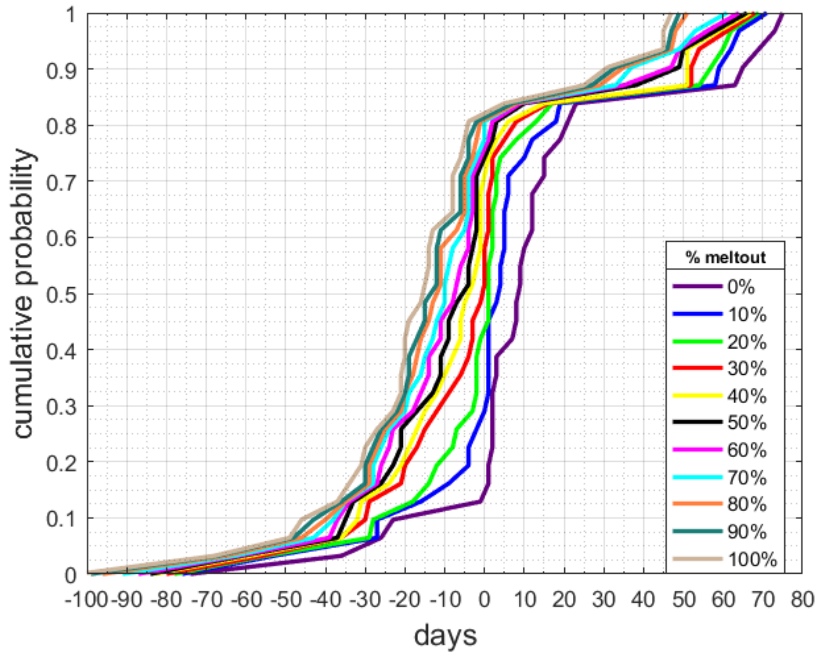

Figure A.28 CDF probability model estimating the number of days from each meltout percentage at Mud Flat SNOTEL to peak streamflow at Owyhee River near Rome, Idaho.

Salmon Falls Creek near San Jacinto, Nevada CDF Probability Models

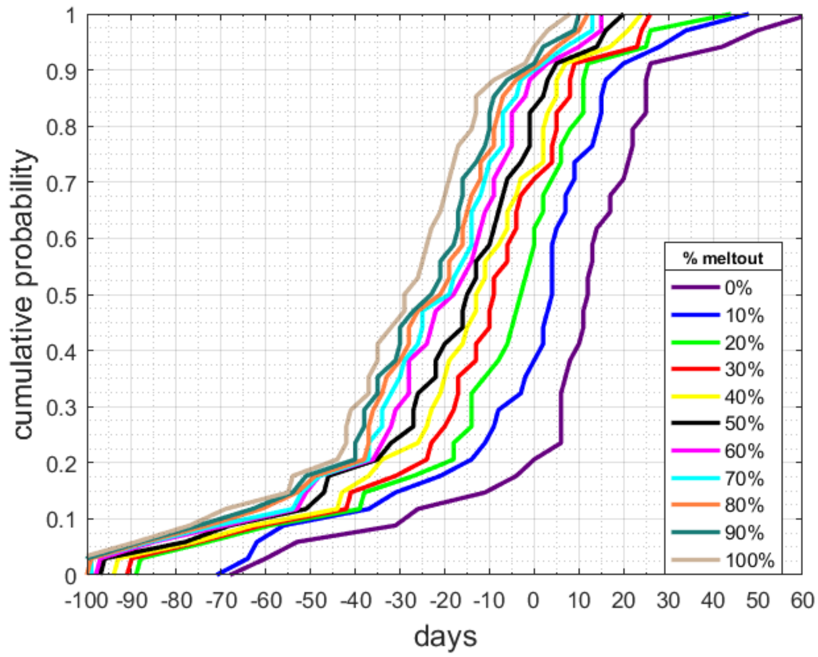

Figure A.29 CDF probability model estimating the number of days from each meltout percentage at Pole Creek R.S. SNOTEL to peak streamflow at Salmon Falls Creek near San Jacinto, Nevada.

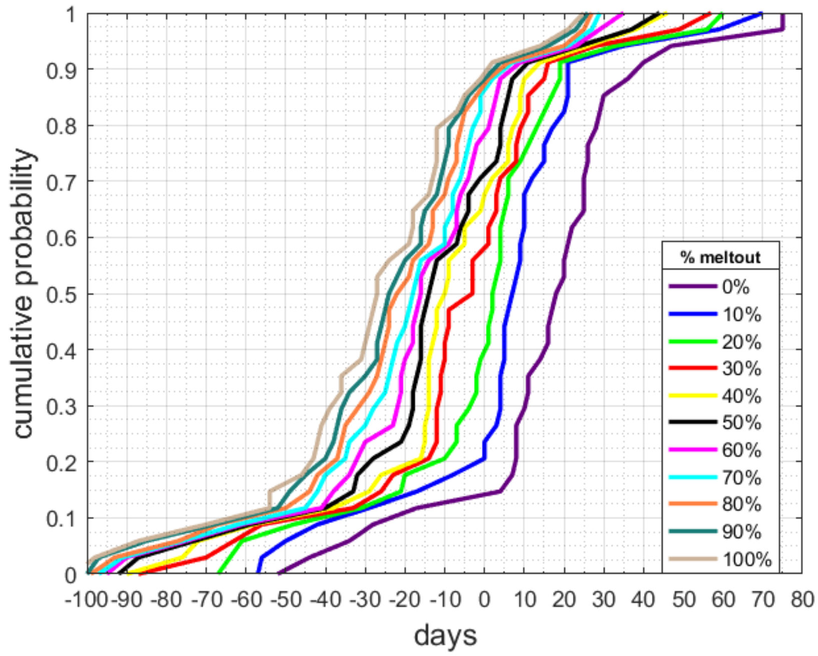

Figure A.30 CDF probability model estimating the number of days from each meltout percentage at Bear Creek SNOTEL to peak streamflow at Salmon Falls Creek near San Jacinto, Nevada.

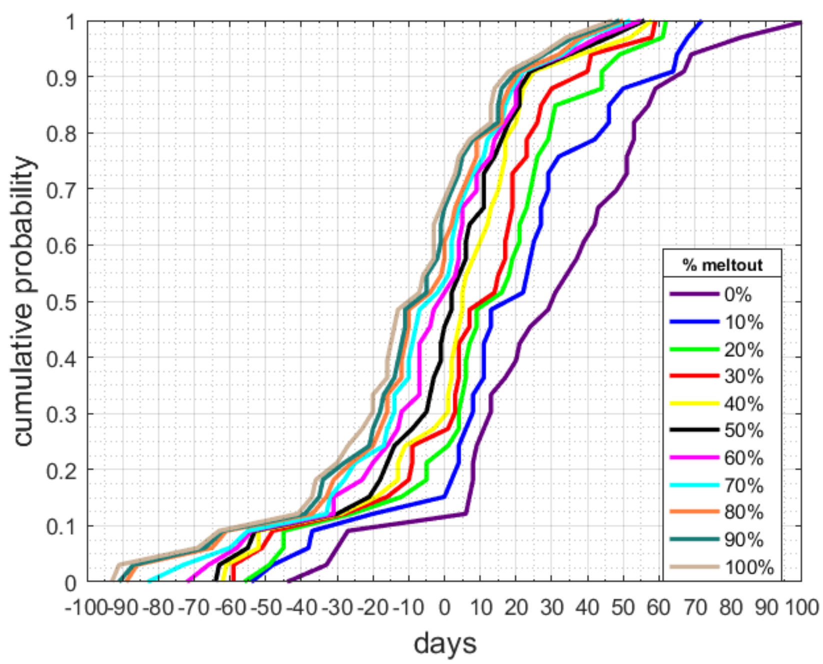

Figure A.31 CDF probability model estimating the number of days from each meltout percentage at Bostetter R.S. SNOTEL to peak streamflow at Salmon Falls Creek near San Jacinto, Nevada.

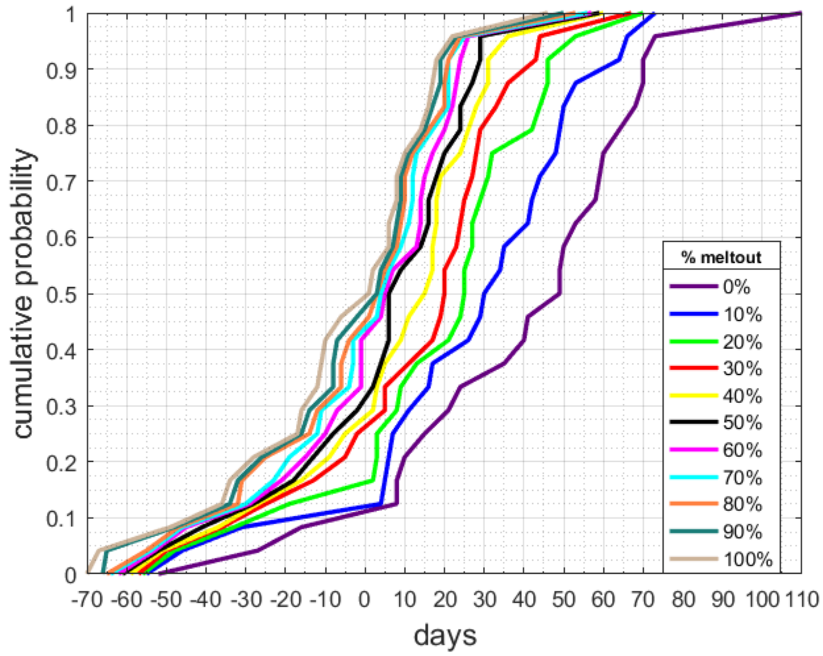

Figure A.32 CDF probability model estimating the number of days from each meltout percentage at Wilson Creek SNOTEL to peak streamflow at Salmon Falls Creek near San Jacinto, Nevada.

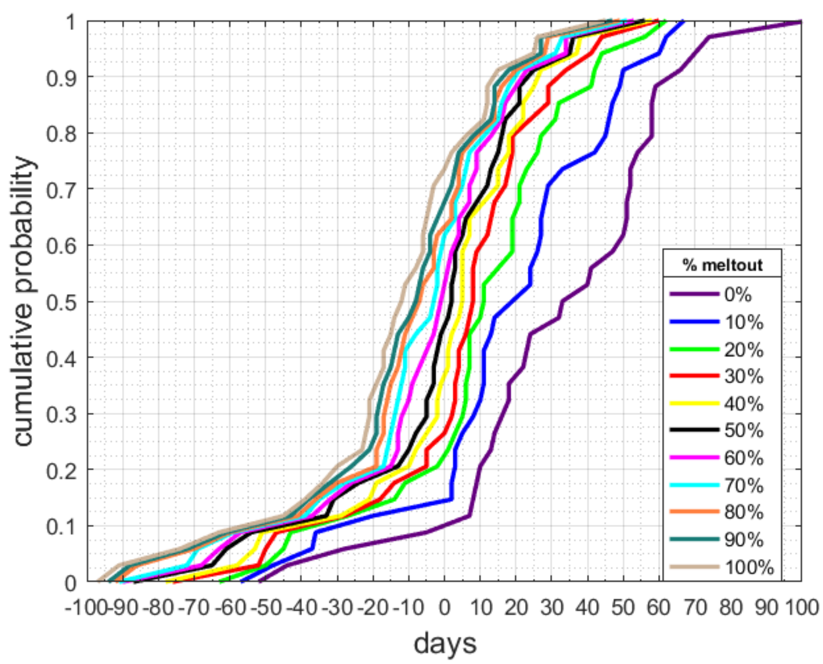

Figure A.33 CDF probability model estimating the number of days from each meltout percentage at Magic Mtn. SNOTEL to peak streamflow at Salmon Falls Creek near San Jacinto, Nevada.

Middle Fork Salmon River at MF Lodge near Yellow Pine, Idaho CDF Probability Models

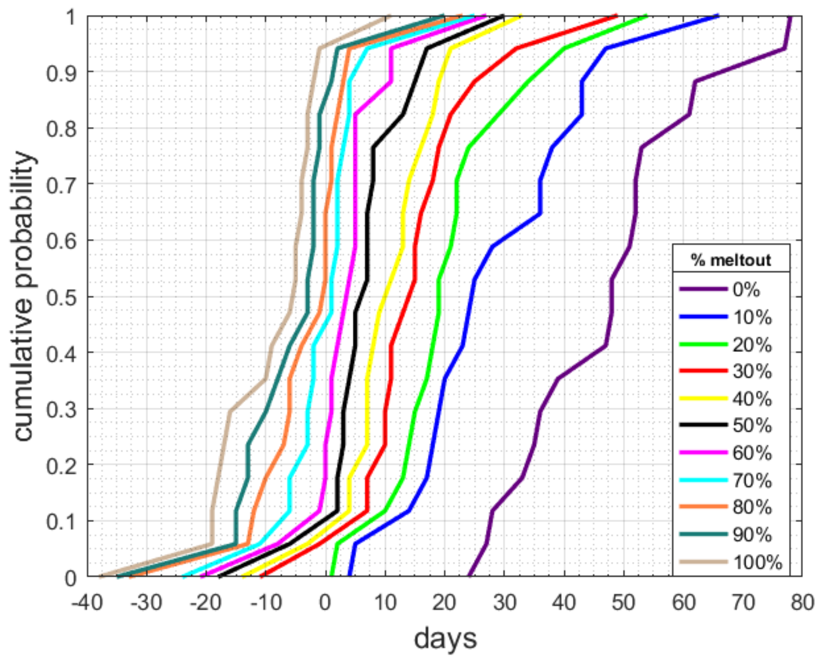

Figure A.34 CDF probability model estimating the number of days from each meltout percentage at Banner Summit SNOTEL to peak streamflow at MF Salmon River at MF Lodge near Yellow Pine, Idaho.

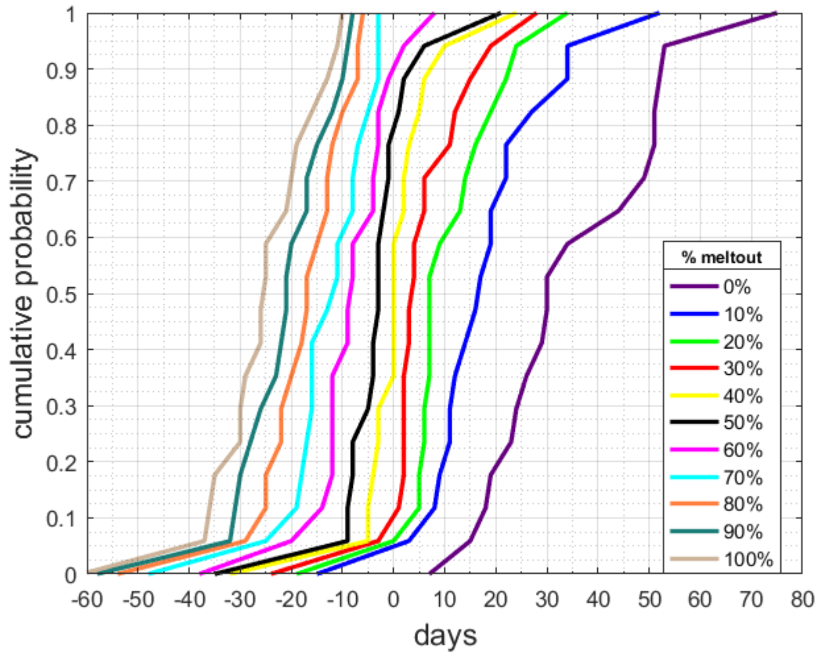

Figure A.35 CDF probability model estimating the number of days from each meltout percentage at Deadwood Summit SNOTEL to peak streamflow at MF Salmon River at MF Lodge near Yellow Pine, Idaho.

South Fork Salmon River near Krassel Ranger Station, Idaho CDF Probability Models

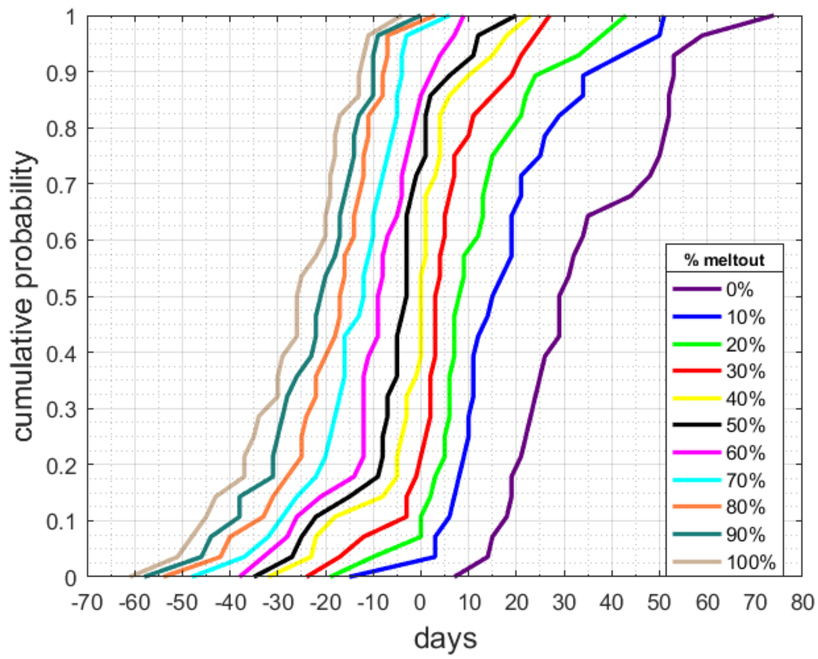

Figure A.36 CDF probability model estimating the number of days from each meltout percentage at Deadwood Summit SNOTEL to peak streamflow at SF Salmon River near Krassel Ranger Station, Idaho.

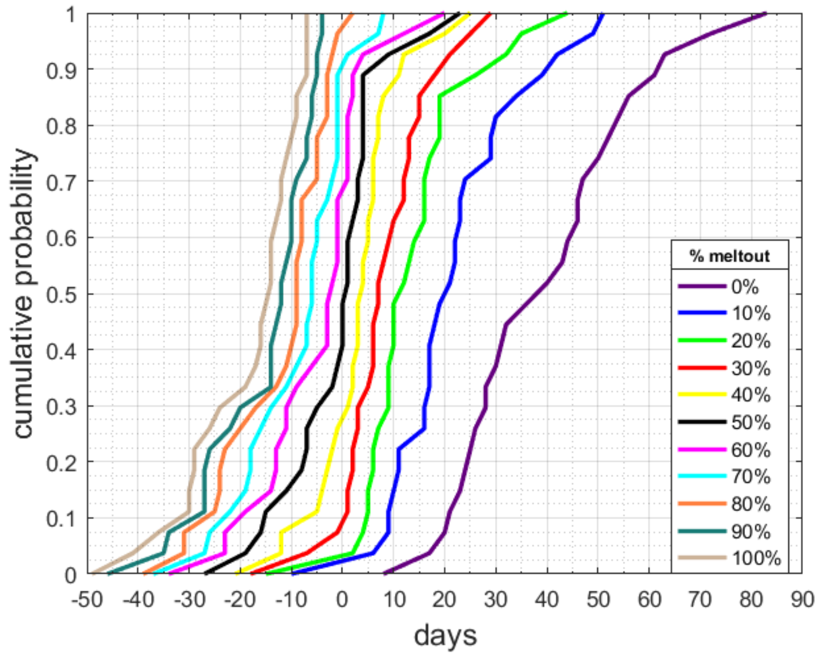

Figure A.37 CDF probability model estimating the number of days from each meltout percentage at Big Creek Summit SNOTEL to peak streamflow at SF Salmon River near Krassel Ranger Station, Idaho.

Selway River near Lowell, Idaho CDF Probability Models

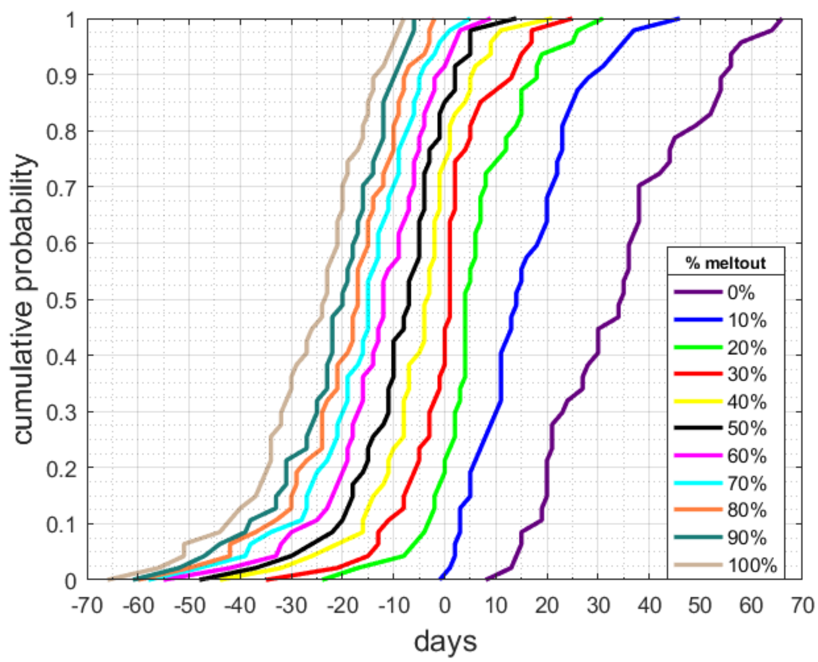

Figure A.38 CDF probability model estimating the number of days from each meltout percentage at Twin Lakes SNOTEL to peak streamflow at Selway River near Lowell, Idaho.

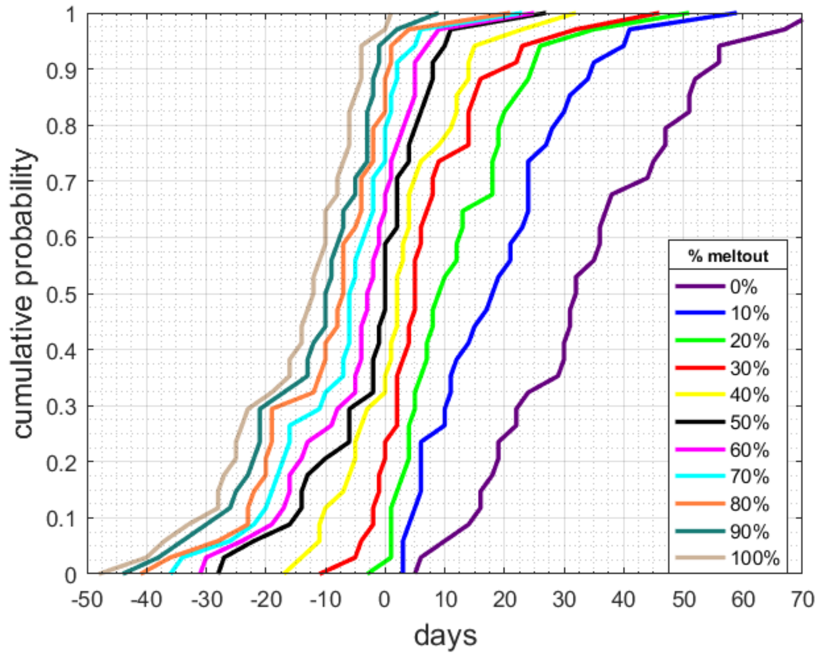

Figure A.39 CDF probability model estimating the number of days from each meltout percentage at Mountain Meadows SNOTEL to peak streamflow at Selway River near Lowell, Idaho.

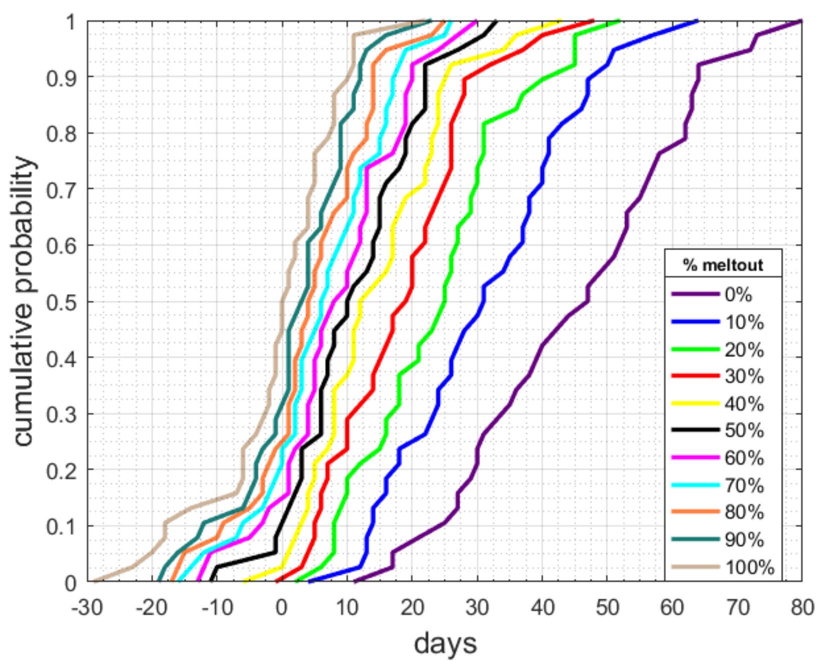

Figure A.40 CDF probability model estimating the number of days from each meltout percentage at Nez Perce Camp SNOTEL to peak streamflow at Selway River near Lowell, Idaho.

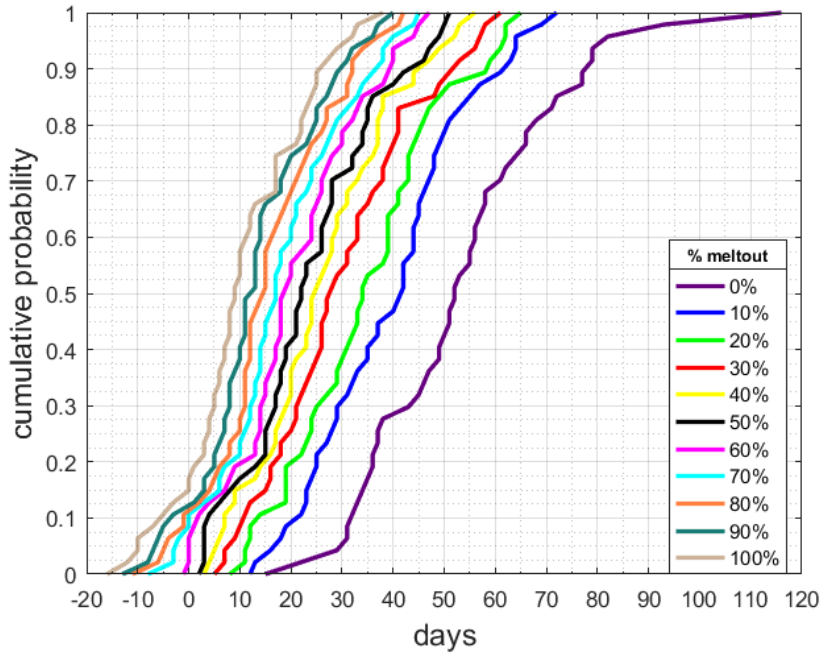

Figure A.41 CDF probability model estimating the number of days from each meltout percentage at Twelvemile Creek SNOTEL to peak streamflow at Selway River near Lowell, Idaho.

Snake River above Jackson Hole at Flagg Ranch, Wyoming CDF Probability Models

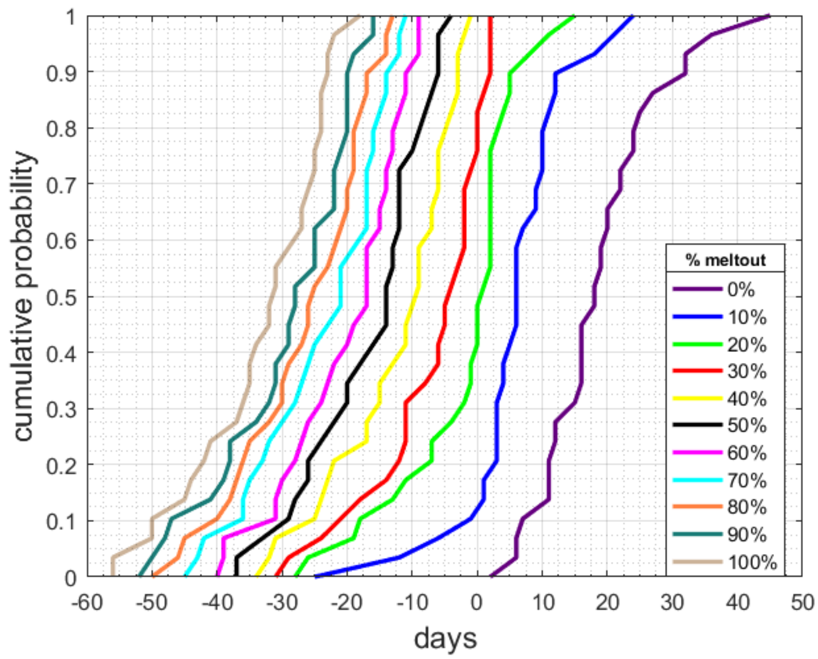

Figure A.42 CDF probability model estimating the number of days from each meltout percentage at Two Oceans Plateau SNOTEL to peak streamflow at Snake River above Jackson Hole at Flagg Ranch, Wyoming.

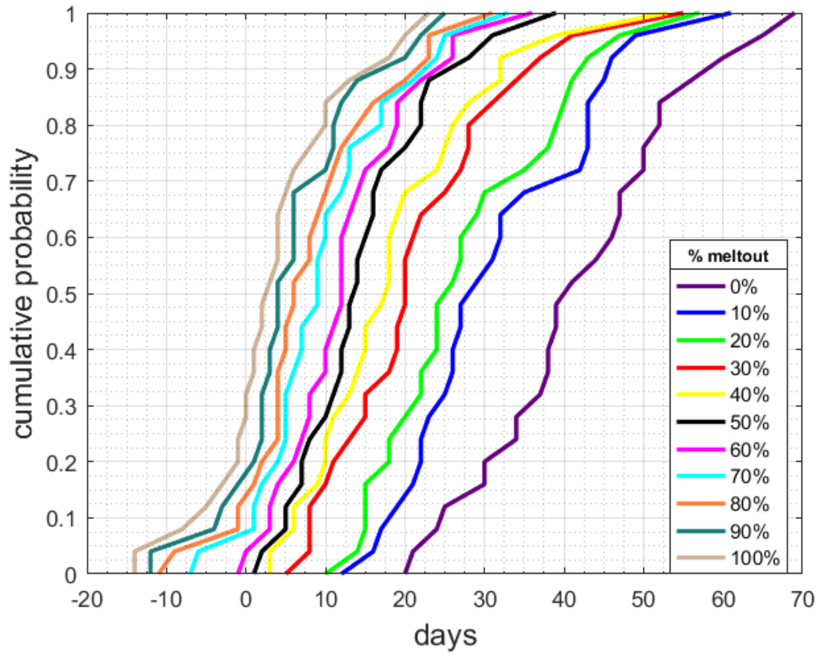

Figure A.43 CDF probability model estimating the number of days from each meltout percentage at Thumb Divide SNOTEL to peak streamflow at Snake River above Jackson Hole at Flagg Ranch, Wyoming.

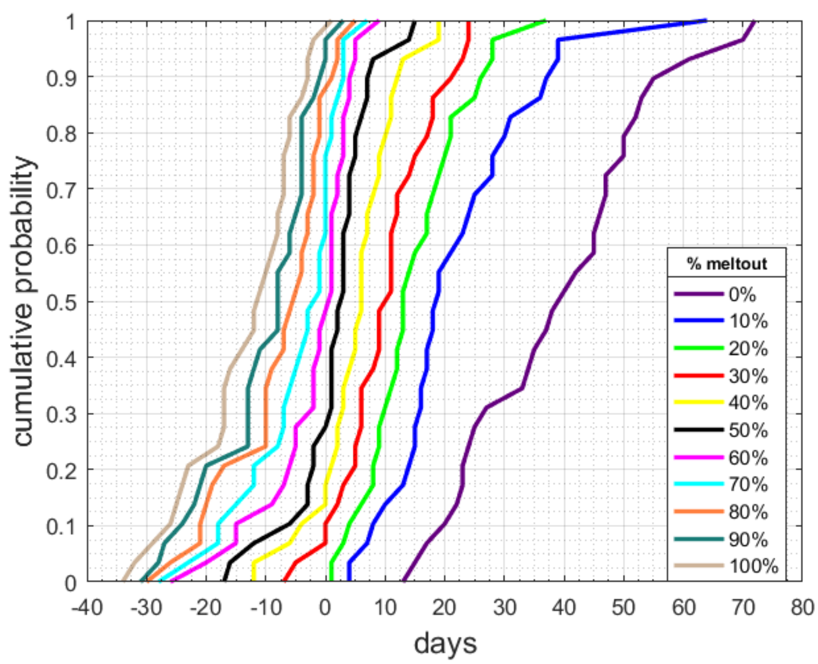

Figure A.44 CDF probability model estimating the number of days from each meltout percentage at Lewis Lake Divide SNOTEL to peak streamflow at Snake River above Jackson Hole at Flagg Ranch, Wyoming.

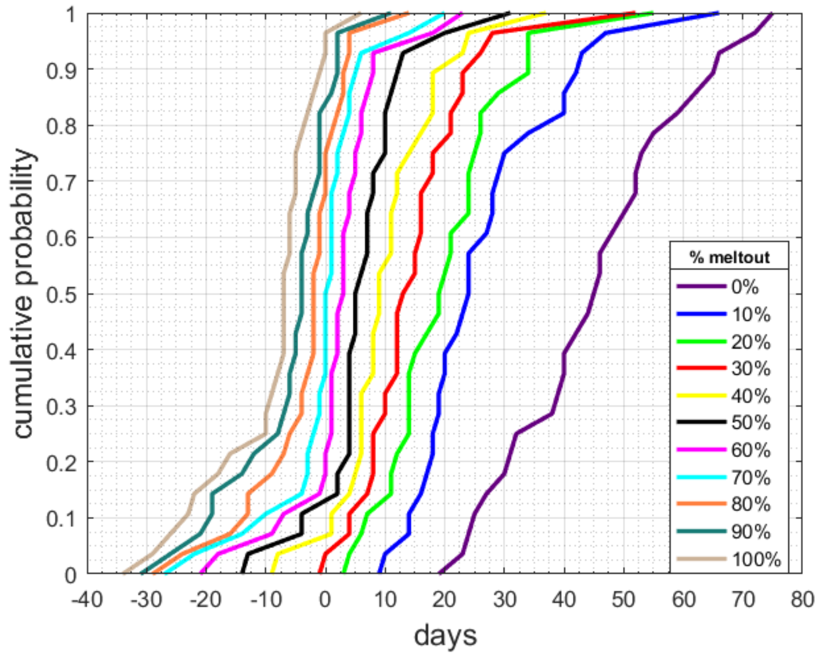

Figure A.45 CDF probability model estimating the number of days from each meltout percentage at Grassy Lake SNOTEL to peak streamflow at Snake River above Jackson Hole at Flagg Ranch, Wyoming.

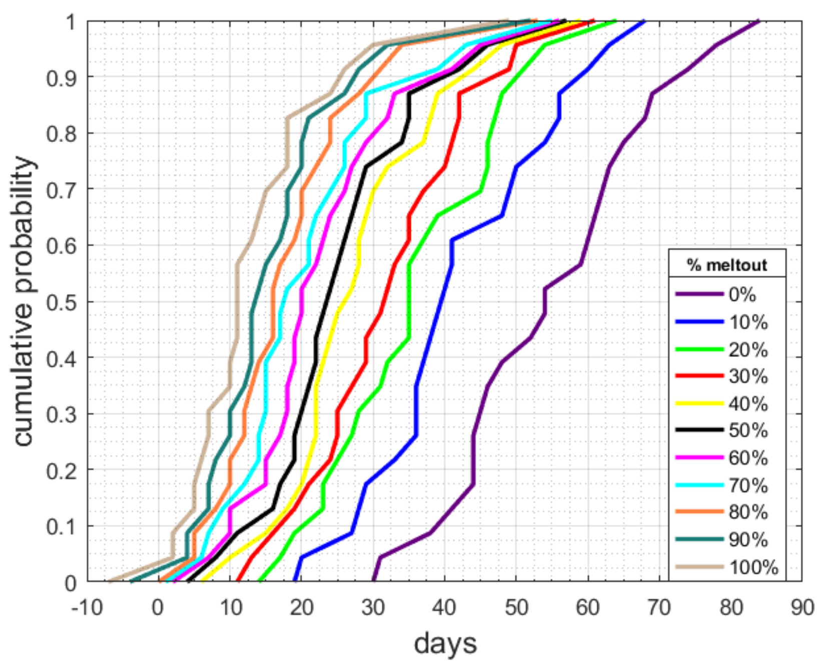

Figure A.46 CDF probability model estimating the number of days from each meltout percentage at Snake River Station SNOTEL to peak streamflow at Snake River above Jackson Hole at Flagg Ranch, Wyoming.

Teton River above South Leigh Creek near Driggs, Idaho CDF Probability Models

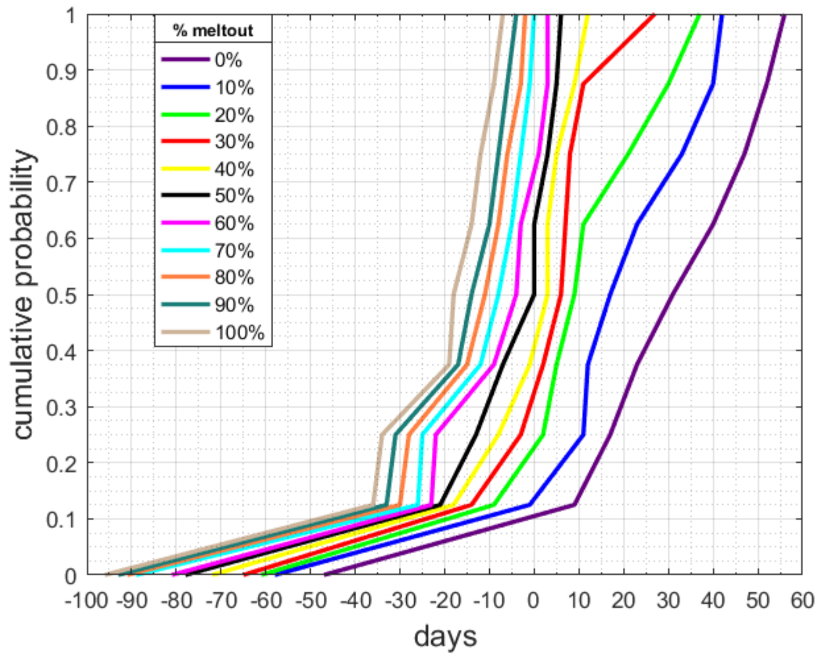

Figure A.47 CDF probability model estimating the number of days from each meltout percentage at Grand Targhee SNOTEL to peak streamflow at Teton River above South Leigh Creek near Driggs, Idaho.

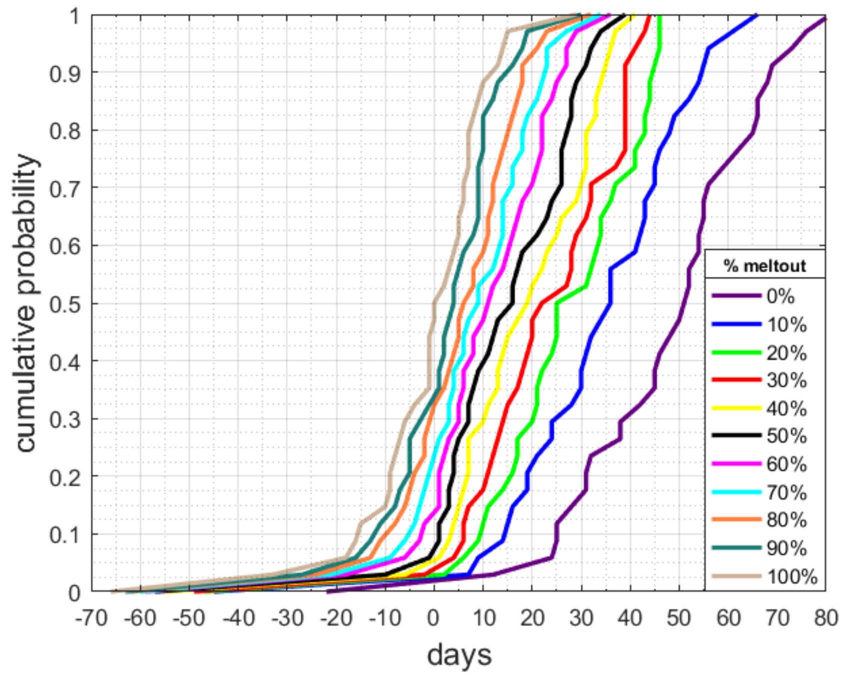

Figure A.48 CDF probability model estimating the number of days from each meltout percentage at Phillips Bench SNOTEL to peak streamflow at Teton River above South Leigh Creek near Driggs, Idaho.

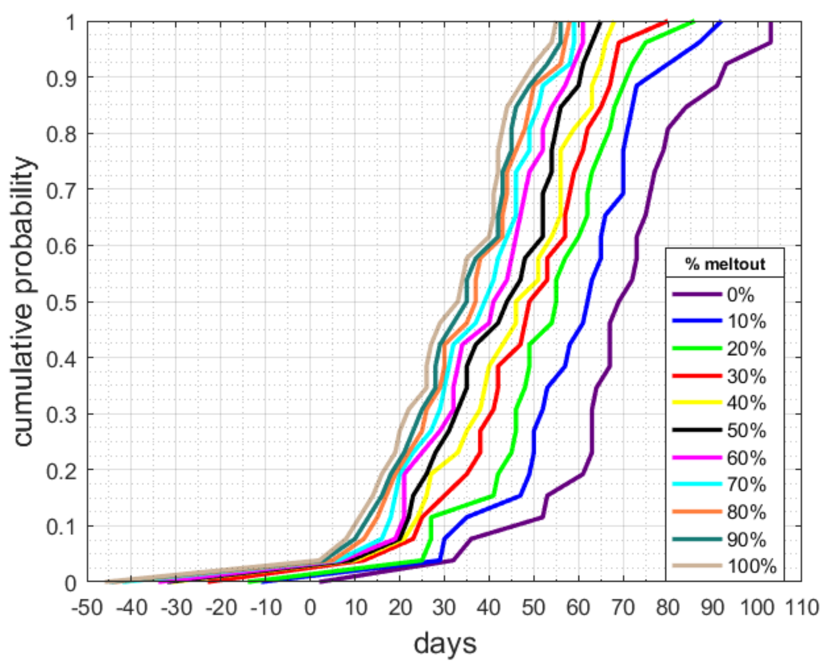

Figure A.49 CDF probability model estimating the number of days from each meltout percentage at Pine Creek Pass SNOTEL to peak streamflow at Teton River above South Leigh Creek near Driggs, Idaho.

APPENDIX B

Correlation Tables

Table B.1 Spearman's Rho correlation coefficients for correlations between date of each incremental percent meltout (0% [max SWE] to 100%); max SWE, and date of peak streamflow. Bold values indicate statistical significance ($p < 0.05$).

SNOTEL-Streamflow Pair	Date Max SWE / Date Peak Q	Date 10% Meltout / Date Peak Q	Date 20% Meltout / Date Peak Q	Date 30% Meltout / Date Peak Q	Date 40% Meltout / Date Peak Q	Date 50% Meltout / Date Peak Q	Date 60% Meltout /Date Peak Q	Date 70% Meltout / Date Peak Q	Date 80% Meltout / Date Peak Q	Date 90% Meltout / Date Peak Q	Date 100% Meltout / Date	Max SWE (in) / Date Peak Q
Boise River nr Twin Springs ID												
Trinity Mtn	0.28	**0.46**	**0.48**	**0.51**	**0.43**	**0.45**	**0.39**	**0.36**	**0.35**	**0.35**	0.32	0.17
Atlanta Summit	0.21	**0.41**	**0.45**	**0.49**	**0.49**	**0.45**	**0.42**	**0.38**	0.33	0.30	0.30	0.15
Jackson Peak	**0.37**	0.32	**0.55**	**0.48**	**0.52**	**0.54**	**0.51**	**0.54**	**0.50**	**0.49**	**0.47**	0.34
Mores Creek Summit	0.27	0.30	**0.49**	**0.52**	**0.49**	**0.45**	**0.45**	**0.44**	**0.45**	**0.42**	**0.42**	0.29
Graham Guard Sta.	0.10	0.15	0.32	0.27	0.31	**0.36**	0.31	0.30	0.25	0.27	0.27	0.13
SF Boise River nr Featherville ID												
Vienna Mine	**0.46**	**0.59**	**0.56**	**0.51**	**0.45**	**0.40**	0.33	**0.37**	**0.36**	**0.38**	**0.37**	0.27
Trinity Mtn.	0.33	**0.52**	**0.40**	**0.43**	0.32	0.32	0.25	0.25	0.26	0.25	0.25	0.21
Atlanta Summit	0.28	**0.37**	**0.41**	**0.40**	**0.44**	**0.44**	**0.41**	**0.39**	0.33	0.34	0.34	0.05
Camas Creek Divide	0.05	0.19	0.10	0.06	0.06	0.16	0.18	0.17	0.18	0.18	0.19	0.20
Prairie	-0.26	-0.20	-0.14	-0.12	-0.14	0.03	0.02	0.04	0.04	0.05	0.06	0.07
Big Lost River at Howell Ranch nr Chilly ID												
Smiley Mountain	0.02	0.23	0.08	0.05	0.16	0.17	0.24	0.25	0.13	0.14	0.14	-0.16
Bear Canyon	0.05	0.12	0.13	0.22	0.28	**0.34**	**0.41**	**0.43**	**0.44**	**0.48**	**0.48**	**0.42**
Lost-Wood Divide	0.14	0.23	0.25	**0.35**	**0.40**	**0.46**	**0.49**	**0.50**	**0.52**	**0.54**	**0.55**	**0.43**
Stickney Mill	0.22	0.33	**0.35**	0.31	0.33	0.33	**0.35**	0.33	0.32	0.33	0.33	**0.41**
Big Wood River at Hailey ID												
Vienna Mine	0.28	**0.45**	**0.65**	**0.68**	**0.61**	**0.61**	**0.57**	**0.59**	**0.58**	**0.58**	**0.57**	0.28
Galena Summit	0.23	0.32	**0.40**	**0.51**	**0.51**	**0.54**	**0.55**	**0.54**	**0.55**	**0.52**	**0.57**	0.20
Lost-Wood Divide	0.18	0.28	0.33	**0.40**	**0.48**	**0.52**	**0.54**	**0.52**	**0.52**	**0.53**	**0.54**	0.26
Hyndman	**0.34**	**0.41**	**0.35**	**0.36**	**0.39**	**0.41**	**0.40**	**0.39**	**0.44**	**0.45**	**0.46**	0.22
Galena	0.34	0.27	0.32	**0.36**	**0.36**	**0.45**	**0.47**	**0.48**	**0.48**	**0.48**	**0.46**	0.11
Chocolate Gulch	0.09	0.31	0.40	0.41	0.40	**0.43**	**0.45**	**0.48**	**0.50**	**0.51**	**0.49**	**0.46**
Bruneau River nr Hot Springs ID												
Pole Creek R.S.	0.32	0.30	0.33	**0.37**	**0.40**	**0.34**	**0.34**	0.32	0.27	0.25	0.22	-0.22
Bear Creek	0.24	0.22	0.28	0.25	0.25	0.26	0.26	0.21	0.21	0.16	0.11	-0.29
Seventysix Creek	0.23	0.13	0.12	0.01	0.06	0.08	0.11	0.09	0.15	0.13	0.12	-0.29
Wilson Creek	**0.45**	0.13	0.11	0.23	0.32	0.31	0.34	0.34	0.30	0.32	0.32	-0.17
Big Bend	0.13	0.11	0.05	0.02	-0.06	-0.07	0.00	-0.01	-0.02	-0.04	-0.03	-0.24
Lochsa River nr Lowell ID												
Savage Pass	0.04	0.31	**0.54**	**0.55**	**0.50**	**0.49**	**0.47**	**0.45**	**0.44**	**0.43**	**0.43**	0.29
Crater Meadows	-0.12	**0.42**	**0.50**	**0.53**	**0.45**	**0.39**	**0.38**	**0.39**	**0.39**	**0.42**	**0.39**	0.34
Hemlock Butte	0.14	**0.57**	**0.54**	**0.56**	**0.57**	**0.45**	**0.44**	**0.41**	**0.42**	**0.46**	**0.45**	**0.43**
Lolo Pass	0.30	0.26	**0.36**	**0.50**	**0.54**	**0.57**	**0.58**	**0.56**	**0.53**	**0.52**	**0.45**	0.28

Table B.1 Continued

SNOTEL-Streamflow Pair	Date Max SWE / Date Peak Q	Date 10% Meltout / Date Peak Q	Date 20% Meltout / Date Peak Q	Date 30% Meltout / Date Peak Q	Date 40% Meltout / Date Peak Q	Date 50% Meltout / Date Peak Q	Date 60% Meltout /Date Peak Q	Date 70% Meltout / Date Peak Q	Date 80% Meltout / Date Peak Q	Date 90% Meltout / Date Peak Q	Date 100% Meltout / Date Peak Q	Max SWE (in) / Date Peak Q
Moyie River at Eastport ID												
Hawkins Lake	**0.57**	**0.66**	**0.58**	**0.60**	**0.61**	**0.58**	**0.55**	**0.54**	**0.52**	**0.51**	**0.50**	**0.29**
Garver Creek	0.15	0.20	0.22	0.24	0.23	**0.35**	**0.39**	**0.41**	**0.39**	**0.43**	**0.36**	0.26
Owhyee River nr Rome ID												
South Mtn.	0.21	**0.44**	**0.42**	**0.45**	**0.51**	**0.46**	**0.44**	**0.42**	**0.38**	**0.42**	**0.42**	0.15
Mud Flat	**0.47**	**0.39**	**0.39**	**0.37**	0.33	**0.36**	**0.36**	**0.39**	**0.42**	**0.39**	**0.38**	0.20
Salmon Falls Creek nr San Jacinto NV												
Pole Creek R.S.	**0.56**	**0.53**	**0.43**	**0.45**	**0.46**	**0.39**	**0.43**	**0.44**	**0.45**	**0.47**	**0.54**	0.23
Bear Creek	**0.58**	**0.59**	**0.56**	**0.51**	**0.49**	**0.46**	**0.47**	**0.46**	**0.42**	**0.42**	**0.40**	0.18
Bostetter R.S.	0.24	0.23	**0.41**	**0.42**	**0.52**	**0.53**	**0.51**	**0.47**	**0.40**	**0.40**	**0.37**	-0.13
Wilson Creek	0.18	0.22	**0.45**	**0.50**	**0.63**	**0.64**	**0.65**	**0.66**	**0.66**	**0.62**	**0.63**	-0.01
Magic Mountain	0.14	0.32	**0.45**	**0.50**	**0.49**	**0.46**	**0.45**	**0.46**	**0.42**	**0.42**	**0.40**	-0.13
SF Salmon River nr Krassel R.S. ID												
Deadwood	0.06	0.33	**0.41**	**0.52**	**0.45**	**0.41**	**0.43**	**0.40**	**0.40**	0.34	0.34	0.21
Big Creek	0.16	**0.44**	**0.57**	**0.59**	**0.64**	**0.60**	**0.55**	**0.57**	**0.58**	**0.54**	**0.55**	0.35
MF Salmon River at MF Lodge nr Yellow Pine ID												
Banner Summit	0.44	0.35	**0.59**	**0.58**	**0.62**	**0.67**	**0.72**	**0.72**	**0.64**	**0.62**	**0.66**	0.09
Deadwood Summit	0.21	**0.49**	**0.52**	**0.57**	**0.60**	**0.59**	**0.65**	**0.61**	**0.61**	**0.54**	**0.55**	-0.01
Selway River nr Lowell ID												
Twin Lakes	**0.35**	**0.69**	**0.74**	**0.71**	**0.65**	**0.62**	**0.58**	**0.54**	**0.56**	**0.58**	**0.55**	**0.43**
Mountain Meadows	0.28	**0.54**	**0.67**	**0.71**	**0.70**	**0.69**	**0.65**	**0.61**	**0.59**	**0.58**	**0.58**	**0.36**
Nez Perce Camp	0.13	**0.40**	**0.51**	**0.60**	**0.62**	**0.65**	**0.65**	**0.68**	**0.69**	**0.73**	**0.67**	**0.43**
Twelvemile Creek	**0.31**	**0.31**	**0.35**	**0.33**	**0.41**	**0.44**	**0.49**	**0.45**	**0.49**	**0.51**	**0.52**	**0.31**
Snake River ab Jackson Lake at Flagg Ranch WY												
Two Ocean Plateau	**0.67**	**0.75**	**0.67**	**0.73**	**0.69**	**0.68**	**0.70**	**0.66**	**0.64**	**0.63**	**0.64**	**0.60**
Thumb Divide	0.34	**0.50**	**0.49**	**0.53**	**0.54**	**0.65**	**0.68**	**0.66**	**0.64**	**0.67**	**0.67**	**0.39**
Lewis Lake Divide	**0.37**	**0.56**	**0.72**	**0.75**	**0.78**	**0.81**	**0.82**	**0.78**	**0.73**	**0.72**	**0.69**	**0.47**
Grassy Lake	0.06	**0.54**	**0.61**	**0.63**	**0.67**	**0.70**	**0.71**	**0.71**	**0.75**	**0.70**	**0.68**	**0.39**
Snake River Station	0.24	0.34	0.32	**0.41**	**0.46**	**0.46**	**0.43**	**0.42**	**0.53**	**0.53**	**0.53**	0.35
Teton River ab South Leigh Creek nr Driggs ID												
Grand Targhee	0.64	0.43	0.46	0.57	**0.73**	**0.69**	0.68	0.68	0.68	0.68	0.68	0.55
Phillips Bench	0.29	0.29	**0.48**	**0.49**	**0.55**	**0.58**	**0.62**	**0.63**	**0.64**	**0.68**	**0.68**	**0.49**
Pine Creek Pass	0.29	**0.40**	**0.46**	0.36	0.36	0.38	**0.40**	0.38	**0.41**	**0.41**	**0.44**	0.38

Table B.2 Spearman's Rho correlation coefficients for correlations between magnitude max SWE and the number of lag days between each incremental percent meltout (0% [max SWE] to 100%) and peak streamflow. Bold values indicate statistical significance ($p < 0.05$).

SNOTEL-Streamflow Pair	Max SWE (in) / Max SWE to Peak Q Lag (days)	Max SWE (in) / 10% MO to Peak Q Lag (days)	Max SWE (in) / 20% MO to Peak Q Lag (days)	Max SWE (in) / 30% MO to Peak Q Lag (days)	Max SWE (in) / 40% MO to Peak Q Lag (days)	Max SWE (in) / 50% MO to Peak Q Lag (days)	Max SWE (in) / 60% MO to Peak Q Lag (days)	Max SWE (in) / 70% MO to Peak Q Lag (days)	Max SWE (in) / 80% MO to Peak Q Lag (days)	Max SWE (in) / 90% MO to Peak Q Lag (days)	Max SWE (in) / 100% MO to Peak Q Lag (days)
Boise River nr Twin Springs ID											
Trinity Mtn	-0.29	**-0.52**	**-0.53**	**-0.57**	**-0.59**	**-0.61**	**-0.61**	**-0.60**	**-0.61**	**-0.62**	**-0.65**
Atlanta Summit	-0.31	**-0.48**	**-0.48**	**-0.49**	**-0.51**	**-0.53**	**-0.52**	**-0.49**	**-0.53**	**-0.51**	**-0.53**
Jackson Peak	-0.10	-0.25	**-0.35**	-0.33	**-0.37**	**-0.36**	**-0.42**	**-0.45**	**-0.46**	**-0.46**	**-0.48**
Mores Creek Summit	-0.06	-0.17	**-0.36**	**-0.39**	**-0.35**	**-0.36**	**-0.39**	**-0.43**	**-0.41**	**-0.43**	**-0.43**
Graham Guard Sta.	-0.24	-0.26	**-0.36**	**-0.36**	**-0.43**	**-0.45**	**-0.48**	**-0.49**	**-0.47**	**-0.47**	**-0.47**
SF Boise River nr Featherville ID											
Vienna Mine	-0.32	**-0.65**	**-0.61**	**-0.59**	**-0.61**	**-0.60**	**-0.58**	**-0.61**	**-0.64**	**-0.66**	**-0.70**
Trinity Mtn.	-0.33	**-0.66**	**-0.59**	**-0.65**	**-0.67**	**-0.68**	**-0.67**	**-0.69**	**-0.72**	**-0.73**	**-0.75**
Atlanta Summit	**-0.41**	**-0.59**	**-0.66**	**-0.66**	**-0.66**	**-0.68**	**-0.67**	**-0.65**	**-0.69**	**-0.69**	**-0.70**
Camas Creek Divide	-0.31	**-0.47**	**-0.42**	**-0.47**	**-0.51**	**-0.54**	**-0.53**	**-0.53**	**-0.55**	**-0.59**	**-0.61**
Prairie	-0.16	-0.34	**-0.41**	**-0.49**	**-0.52**	**-0.61**	**-0.66**	**-0.70**	**-0.72**	**-0.71**	**-0.72**
Big Lost River at Howell Ranch nr Chilly ID											
Smiley Mountain	-0.53	**-0.53**	-0.47	-0.52	-0.51	-0.51	**-0.54**	**-0.56**	**-0.59**	**-0.58**	**-0.58**
Bear Canyon	0.07	-0.03	-0.04	-0.08	-0.03	-0.04	-0.08	-0.10	-0.14	-0.19	-0.29
Lost-Wood Divide	0.08	0.03	-0.07	-0.12	-0.10	-0.14	-0.21	-0.32	**-0.35**	**-0.38**	**-0.41**
Stickney Mill	-0.03	-0.10	-0.07	-0.07	-0.09	-0.10	-0.13	-0.15	-0.20	-0.21	-0.21
Big Wood River at Hailey ID total flow											
Vienna Mine	-0.16	**-0.39**	**-0.40**	**-0.49**	**-0.53**	**-0.56**	**-0.55**	**-0.58**	**-0.63**	**-0.65**	**-0.70**
Galena Summit	-0.18	-0.27	-0.34	**-0.38**	**-0.43**	**-0.44**	**-0.48**	**-0.54**	**-0.54**	**-0.54**	**-0.57**
Lost-Wood Divide	-0.13	-0.23	**-0.35**	**-0.38**	**-0.38**	**-0.42**	**-0.51**	**-0.58**	**-0.63**	**-0.65**	**-0.67**
Hyndman	-0.16	-0.22	-0.29	**-0.36**	**-0.41**	**-0.41**	**-0.46**	**-0.45**	**-0.43**	**-0.48**	**-0.50**
Galena	-0.26	**-0.41**	**-0.51**	**-0.52**	**-0.50**	**-0.54**	**-0.63**	**-0.61**	**-0.64**	**-0.67**	**-0.70**
Chocolate Gulch	0.20	0.02	-0.08	-0.13	-0.22	-0.23	-0.26	-0.26	-0.26	-0.27	-0.25
Bruneau River nr Hot Springs ID											
Pole Creek R.S.	**-0.54**	**-0.45**	**-0.46**	**-0.49**	**-0.56**	**-0.56**	**-0.60**	**-0.60**	**-0.60**	**-0.61**	**-0.61**
Bear Creek	**-0.67**	**-0.72**	**-0.68**	**-0.65**	**-0.66**	**-0.70**	**-0.72**	**-0.76**	**-0.76**	**-0.76**	**-0.76**
Seventysix Creek	**-0.62**	**-0.64**	**-0.61**	**-0.60**	**-0.60**	**-0.63**	**-0.66**	**-0.67**	**-0.71**	**-0.71**	**-0.73**
Wilson Creek	**-0.61**	**-0.51**	-0.37	**-0.39**	**-0.48**	**-0.54**	**-0.54**	**-0.52**	**-0.56**	**-0.56**	**-0.60**
Big Bend	**-0.65**	**-0.71**	**-0.72**	**-0.70**	**-0.69**	**-0.70**	**-0.71**	**-0.71**	**-0.71**	**-0.72**	**-0.74**
Lochsa River nr Lowell ID											
Savage Pass	0.19	0.15	-0.05	-0.11	-0.20	-0.28	-0.33	-0.34	**-0.40**	**-0.46**	**-0.50**
Crater Meadows	0.07	0.05	-0.17	-0.21	-0.26	-0.31	-0.34	**-0.42**	**-0.45**	**-0.45**	**-0.46**
Hemlock Butte	0.25	0.05	-0.09	-0.17	-0.23	-0.26	-0.29	-0.34	-0.34	**-0.36**	**-0.39**
Lolo Pass	-0.03	-0.05	-0.05	-0.11	-0.21	-0.33	**-0.36**	**-0.40**	**-0.43**	**-0.43**	**-0.45**

Table B.2 Continued

SNOTEL-Streamflow Pair	Max SWE (in) / Max SWE to Peak Q Lag (days)	Max SWE (in) / 10% MO to Peak Q Lag (days)	Max SWE (in) / 20% MO to Peak Q Lag (days)	Max SWE (in) / 30% MO to Peak Q Lag (days)	Max SWE (in) / 40% MO to Peak Q Lag (days)	Max SWE (in) / 50% MO to Peak Q Lag (days)	Max SWE (in) / 60% MO to Peak Q Lag (days)	Max SWE (in) / 70% MO to Peak Q Lag (days)	Max SWE (in) / 80% MO to Peak Q Lag (days)	Max SWE (in) / 90% MO to Peak Q Lag (days)	Max SWE (in) / 100% MO to Peak Q Lag (days)
Moyie River at Eastport ID											
Hawkins Lake	0.08	0.02	0.03	-0.01	-0.07	-0.15	-0.18	-0.20	-0.21	-0.19	-0.15
Garver Creek	-0.04	-0.15	-0.21	-0.23	-0.28	**-0.30**	-0.27	**-0.29**	**-0.31**	**-0.30**	**-0.34**
Owhyee River nr Rome ID											
South Mtn.	-0.12	-0.22	-0.23	-0.18	-0.18	-0.20	-0.22	-0.24	-0.26	-0.27	-0.27
Mud Flat	0.05	-0.07	-0.07	-0.11	-0.09	-0.09	-0.12	-0.12	-0.12	-0.12	-0.12
Salmon Falls Creek nr San Jacinto NV											
Pole Creek R.S.	-0.03	0.12	0.17	0.11	0.09	0.08	0.05	0.03	0.02	0.02	-0.01
Bear Creek	-0.11	-0.23	-0.13	-0.07	-0.09	-0.07	-0.10	-0.15	-0.16	-0.17	-0.21
Bostetter R.S.	-0.31	**-0.34**	**-0.38**	**-0.42**	**-0.44**	**-0.42**	**-0.42**	**-0.44**	**-0.44**	**-0.43**	**-0.44**
Wilson Creek	-0.25	-0.27	-0.17	-0.12	-0.24	-0.26	-0.27	-0.28	-0.30	-0.30	-0.31
Magic Mountain	-0.28	-0.33	**-0.43**	**-0.40**	**-0.40**	**-0.43**	**-0.44**	**-0.44**	**-0.45**	**-0.45**	**-0.46**
MF Salmon River at MF Lodge nr Yellow Pine ID											
Banner Summit	-0.07	-0.16	-0.12	-0.29	-0.45	-0.47	**-0.49**	**-0.49**	**-0.51**	**-0.54**	**-0.58**
Deadwood Summit	-0.18	-0.25	-0.28	-0.31	-0.29	-0.25	-0.44	-0.45	**-0.58**	**-0.61**	**-0.68**
SF Salmon River nr Krassel R.S. ID											
Deadwood	-0.21	**-0.39**	**-0.46**	**-0.46**	**-0.47**	**-0.44**	**-0.55**	**-0.53**	**-0.61**	**-0.65**	**-0.68**
Big Creek	-0.14	-0.27	**-0.40**	**-0.45**	**-0.46**	**-0.51**	**-0.60**	**-0.62**	**-0.64**	**-0.62**	**-0.68**
Selway River nr Lowell ID											
Twin Lakes	**0.30**	0.06	-0.11	-0.18	-0.18	-0.23	-0.25	-0.27	**-0.31**	**-0.32**	**-0.35**
Mountain Meadows	0.02	-0.13	-0.33	**-0.34**	**-0.36**	**-0.40**	**-0.42**	**-0.44**	**-0.46**	**-0.48**	**-0.54**
Nez Perce Camp	0.04	0.10	0.11	0.09	0.07	0.01	-0.03	-0.07	-0.10	-0.13	-0.14
Twelvemile Creek	-0.16	-0.13	-0.21	-0.19	-0.24	-0.26	**-0.30**	**-0.32**	**-0.36**	**-0.37**	**-0.42**
Snake River ab Jackson Lake at Flagg Ranch WY											
Two Ocean Plateau	-0.04	0.05	0.05	0.00	-0.02	-0.02	-0.06	-0.02	-0.06	-0.10	-0.12
Thumb Divide	0.18	-0.25	-0.17	-0.17	-0.28	-0.32	**-0.39**	**-0.44**	**-0.48**	**-0.53**	**-0.56**
Lewis Lake Divide	0.02	-0.15	-0.18	-0.19	-0.28	**-0.48**	**-0.54**	**-0.54**	**-0.57**	**-0.58**	**-0.60**
Grassy Lake	0.18	-0.11	-0.18	-0.19	-0.21	-0.25	-0.32	**-0.48**	**-0.52**	**-0.54**	**-0.52**
Snake River Station	0.07	0.01	-0.02	-0.03	-0.12	-0.16	-0.20	-0.32	-0.31	-0.31	-0.31
Teton River ab South Leigh Creek nr Driggs ID											
Grand Targhee	-0.40	-0.20	0.05	0.02	0.01	0.01	-0.05	-0.12	-0.12	-0.12	-0.12
Phillips Bench	0.11	0.19	0.10	0.08	0.09	0.04	0.02	0.00	-0.02	-0.04	-0.06
Pine Creek Pass	0.10	0.01	0.04	0.05	0.04	0.04	0.01	-0.03	-0.05	-0.03	-0.05

APPENDIX C

Water Year Date Tables

Table C.1 Water Year Day Calendar – Common Years

Day	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Day
1	1	32	62	93	124	152	183	213	244	274	305	336	**1**
2	2	33	63	94	125	153	184	214	245	275	306	337	**2**
3	3	34	64	95	126	154	185	215	246	276	307	338	**3**
4	4	35	65	96	127	155	186	216	247	277	308	339	**4**
5	5	36	66	97	128	156	187	217	248	278	309	340	**5**
6	6	37	67	98	129	157	188	218	249	279	310	341	**6**
7	7	38	68	99	130	158	189	219	250	280	311	342	**7**
8	8	39	69	100	131	159	190	220	251	281	312	343	**8**
9	9	40	70	101	132	160	191	221	252	282	313	344	**9**
10	10	41	71	102	133	161	192	222	253	283	314	345	**10**
11	11	42	72	103	134	162	193	223	254	284	315	346	**11**
12	12	43	73	104	135	163	194	224	255	285	316	347	**12**
13	13	44	74	105	136	164	195	225	256	286	317	348	**13**
14	14	45	75	106	137	165	196	226	257	287	318	349	**14**
15	15	46	76	107	138	166	197	227	258	288	319	350	**15**
16	16	47	77	108	139	167	198	228	259	289	320	351	**16**
17	17	48	78	109	140	168	199	229	260	290	321	352	**17**
18	18	49	79	110	141	169	200	230	261	291	322	353	**18**
19	19	50	80	111	142	170	201	231	262	292	323	354	**19**
20	20	51	81	112	143	171	202	232	263	293	324	355	**20**
21	21	52	82	113	144	172	203	233	264	294	325	356	**21**
22	22	53	83	114	145	173	204	234	265	295	326	357	**22**
23	23	54	84	115	146	174	205	235	266	296	327	358	**23**
24	24	55	85	116	147	175	206	236	267	297	328	359	**24**
25	25	56	86	117	148	176	207	237	268	298	329	360	**25**
26	26	57	87	118	149	177	208	238	269	299	330	361	**26**
27	27	58	88	119	150	178	209	239	270	300	331	362	**27**
28	28	59	89	120	151	179	210	240	271	301	332	363	**28**
29	29	60	90	121		180	211	241	272	302	333	364	**29**
30	30	61	91	122		181	212	242	273	303	334	365	**30**
31	31		92	123		182		243		304	335		**31**

Table C.2 Water Year Day Calendar – Leap Years (1972, 1976, 1980, 1984, 1988, 1992, 1996, 2000, 2004, 2008, 2012)

Day	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Day
1	1	32	62	93	124	153	184	214	245	275	306	337	**1**
2	2	33	63	94	125	154	185	215	246	276	307	338	**2**
3	3	34	64	95	126	155	186	216	247	277	308	339	**3**
4	4	35	65	96	127	156	187	217	248	278	309	340	**4**
5	5	36	66	97	128	157	188	218	249	279	310	341	**5**
6	6	37	67	98	129	158	189	219	250	280	311	342	**6**
7	7	38	68	99	130	159	190	220	251	281	312	343	**7**
8	8	39	69	100	131	160	191	221	252	282	313	344	**8**
9	9	40	70	101	132	161	192	222	253	283	314	345	**9**
10	10	41	71	102	133	162	193	223	254	284	315	346	**10**
11	11	42	72	103	134	163	194	224	255	285	316	347	**11**
12	12	43	73	104	135	164	195	225	256	286	317	348	**12**
13	13	44	74	105	136	165	196	226	257	287	318	349	**13**
14	14	45	75	106	137	166	197	227	258	288	319	350	**14**
15	15	46	76	107	138	167	198	228	259	289	320	351	**15**
16	16	47	77	108	139	168	199	229	260	290	321	352	**16**
17	17	48	78	109	140	169	200	230	261	291	322	353	**17**
18	18	49	79	110	141	170	201	231	262	292	323	354	**18**
19	19	50	80	111	142	171	202	232	263	293	324	355	**19**
20	20	51	81	112	143	172	203	233	264	294	325	356	**20**
21	21	52	82	113	144	173	204	234	265	295	326	357	**21**
22	22	53	83	114	145	174	205	235	266	296	327	358	**22**
23	23	54	84	115	146	175	206	236	267	297	328	359	**23**
24	24	55	85	116	147	176	207	237	268	298	329	360	**24**
25	25	56	86	117	148	177	208	238	269	299	330	361	**25**
26	26	57	87	118	149	178	209	239	270	300	331	362	**26**
27	27	58	88	119	150	179	210	240	271	301	332	363	**27**
28	28	59	89	120	151	180	211	241	272	302	333	364	**28**
29	29	60	90	121	152	181	212	242	273	303	334	365	**29**
30	30	61	91	122		182	213	243	274	304	335	366	**30**
31	31		92	123		183		244		305	336		**31**

APPENDIX D

Trend Analysis

Table D.1 Mann-Kendall trend test tau values for number of lag days between each incremental meltout and peak streamflow. Bold values indicate statistical significance ($p < 0.05$).

SNOTEL-Streamflow Pair	Period	Max SWE to Peak Q Lag (days)	10% Meltout to Peak Q Lag (days)	20% Meltout to Peak Q Lag (days)	30% Meltout to Peak Q Lag (days)	40% Meltout to Peak Q Lag (days)	50% Meltout to Peak Q Lag (days)	60% Meltout to Peak Q Lag (days)	70% Meltout to Peak Q Lag (days)	80% Meltout to Peak Q Lag (days)	90% Meltout to Peak Q Lag (days)	100% Meltout to Peak Q Lag (days)
Boise River nr Twin Springs ID												
Trinity Mtn	1981-1989, 1991-2015	-0.13	-0.06	-0.06	-0.03	-0.04	-0.03	-0.02	-0.01	-0.02	-0.03	-0.02
Atlanta Summit	1981, 1984-2015	-0.02	-0.05	0.02	0.01	0.04	0.03	0.02	0.05	0.04	0.06	0.08
Jackson Peak	1982-1983, 1985-1988, 1990-2015	-0.01	-0.02	-0.01	0.00	-0.03	-0.03	-0.02	-0.05	-0.05	0.01	0.01
Mores Creek Summit	1982-2015	0.06	0.09	0.08	0.08	0.10	0.11	0.10	0.08	0.08	0.07	0.08
Graham Guard Sta.	1981-2015	-0.02	0.00	-0.01	-0.01	0.00	0.01	0.03	0.03	0.05	0.05	0.06
SF Boise River nr Featherville ID												
Vienna Mine	1982-1983, 1985-2015	-0.15	0.04	0.03	0.05	0.06	0.04	0.06	0.04	0.03	0.03	0.02
Trinity Mtn.	1981-1989, 1991-2015	-0.07	0.05	0.01	0.03	0.02	0.04	0.05	0.06	0.04	0.04	0.06
Atlanta Summit	1981, 1984-2015	-0.04	-0.03	0.03	0.06	0.10	0.09	0.09	0.09	0.10	0.12	0.16
Camas Creek Divide	1993-2015	-0.12	0.02	0.01	0.07	0.10	0.10	0.09	0.16	0.13	0.16	0.17
Prairie	1987-2015	-0.05	-0.07	-0.05	-0.09	-0.06	-0.13	-0.14	-0.15	-0.15	-0.13	-0.11
Big Lost River at Howell Ranch nr Chilly ID												
Smiley Mountain	2002-2015	0.13	0.12	0.06	0.04	0.00	0.07	0.15	0.14	0.12	0.13	0.13
Bear Canyon	1981-2015	-0.05	-0.06	-0.06	-0.07	-0.07	-0.09	-0.08	-0.07	-0.07	-0.07	-0.05
Lost-Wood Divide	1982, 1984-2015	-0.07	-0.04	-0.03	-0.02	-0.02	-0.04	-0.02	-0.01	-0.04	-0.01	0.00
Stickney Mill	1981-2015	-0.04	-0.02	0.00	0.00	-0.02	-0.01	-0.03	-0.03	-0.03	-0.02	-0.02
Big Wood River at Hailey ID total flow												
Vienna Mine	1982-1983, 1985-2015	-0.16	-0.08	-0.07	-0.01	-0.02	-0.03	0.02	0.01	0.02	0.01	-0.02
Galena Summit	1982-1983, 1986-2015	-0.08	-0.08	-0.12	-0.13	-0.08	-0.07	-0.03	-0.05	-0.05	-0.05	-0.06
Lost-Wood Divide	1982, 1984-2015	0.00	0.00	0.03	0.02	0.02	0.03	0.04	0.04	0.04	0.06	0.08
Hyndman	1983-2015	-0.07	0.00	-0.02	-0.03	-0.01	-0.05	-0.04	-0.03	-0.07	-0.06	-0.06
Galena	1981-2015	0.03	0.07	0.08	0.07	0.07	0.04	0.04	0.01	-0.01	0.00	0.01
Chocolate Gulch	1994-2015	-0.23	-0.15	-0.03	-0.01	0.04	0.02	0.02	0.03	0.02	0.00	-0.01
Bruneau River nr Hot Springs ID												
Pole Creek R.S.	1981-2015	0.13	0.10	0.08	0.13	0.14	0.12	0.13	0.13	0.12	0.12	0.11
Bear Creek	1979-1980, 1982-2015	0.10	0.12	0.15	0.11	0.13	0.14	0.16	0.18	0.16	0.18	0.18
Seventysix Creek	1991-2015	0.09	0.11	0.14	0.17	0.18	0.18	0.16	0.15	0.14	0.13	0.13
Wilson Creek	1979-2015	-0.09	-0.02	0.10	0.14	0.11	0.06	0.04	0.04	0.02	0.07	0.06
Big Bend	1979-2015	0.15	0.14	0.13	0.14	0.17	0.18	0.17	0.15	0.14	0.14	0.13
Lochsa River nr Lowell ID												
Savage Pass	1984-2015	0.02	0.01	-0.01	0.05	0.00	0.00	0.00	-0.02	-0.05	-0.05	-0.08
Crater Meadows	1985-2015	-0.06	-0.10	-0.16	-0.09	-0.11	-0.10	-0.14	-0.20	-0.20	-0.18	-0.18
Hemlock Butte	1984-2015	-0.13	-0.05	-0.02	0.01	0.01	0.02	-0.02	-0.01	-0.02	-0.04	-0.06
Lolo Pass	1984-2015	-0.07	-0.16	-0.08	-0.09	-0.10	-0.10	-0.10	-0.12	-0.10	-0.08	-0.10

Table D.1 Continued

SNOTEL-Streamflow Pair	Period	Max SWE to Peak Q Lag (days)	10% Meltout to Peak Q Lag (days)	20% Meltout to Peak Q Lag (days)	30% Meltout to Peak Q Lag (days)	40% Meltout to Peak Q Lag (days)	50% Meltout to Peak Q Lag (days)	60% Meltout to Peak Q Lag (days)	70% Meltout to Peak Q Lag (days)	80% Meltout to Peak Q Lag (days)	90% Meltout to Peak Q Lag (days)	100% Meltout to Peak Q Lag (days)
Moyie River at Eastport ID												
Hawkins Lake	1969-2015	0.16	0.15	0.18	0.19	**0.21**	**0.21**	0.18	0.19	0.16	0.16	0.17
Garver Creek	1969-2015	-0.08	-0.10	-0.13	-0.09	-0.06	-0.04	-0.04	-0.06	-0.06	-0.06	0.00
Owhyee River nr Rome ID												
South Mtn.	1982-2015	0.15	0.16	0.12	0.13	0.11	0.13	0.14	0.14	0.13	0.13	0.14
Mud Flat	1982, 1985-2015	0.17	0.14	0.16	0.14	0.16	0.13	0.15	0.15	0.15	0.15	0.16
Salmon Falls Creek nr San Jacinto NV												
Pole Creek R.S.	1981-2015	-0.10	-0.09	-0.11	-0.07	-0.05	-0.04	-0.02	-0.01	-0.01	-0.01	0.01
Bear Creek	1979, 1982-2015	-0.06	-0.06	-0.05	-0.06	-0.05	-0.01	0.02	0.05	0.03	0.03	0.03
Bostetter R.S.	1982-2015	0.03	0.02	0.02	0.05	0.03	-0.03	-0.01	-0.02	-0.02	-0.03	-0.01
Wilson Creek	1991-2015	-0.10	-0.12	-0.07	-0.07	-0.07	-0.10	-0.10	-0.12	-0.13	-0.12	-0.13
Magic Mountain	1981-2015	-0.02	-0.04	0.02	0.01	0.00	-0.05	-0.03	-0.04	-0.04	-0.04	-0.04
MF Salmon River at MF Lodge nr Yellow Pine ID												
Banner Summit	1999-2016	-0.03	-0.13	-0.18	-0.11	-0.13	-0.13	-0.14	-0.13	-0.12	-0.09	-0.13
Deadwood Summit	1999-2016	-0.23	-0.23	-0.25	-0.30	-0.31	-0.33	-0.30	-0.28	-0.24	-0.22	-0.20
SF Salmon River nr Krassel R.S. ID												
Deadwood	1981,1982, 1986, 1990-2015	-0.18	-0.13	-0.10	-0.08	-0.14	-0.10	-0.14	-0.05	-0.05	-0.06	-0.07
Big Creek	1982, 1986, 1990-2015	0.10	0.08	0.06	0.15	0.14	0.11	0.12	0.14	0.16	0.18	0.19
Selway River nr Lowell ID												
Twin Lakes	1968-2015	0.08	0.06	0.13	0.11	0.12	0.11	0.12	0.13	0.12	0.13	0.14
Mountain Meadows	1981-2015	0.06	0.08	0.16	0.12	0.10	0.10	0.10	0.06	0.04	0.04	0.05
Nez Perce Camp	1977-2015	0.13	0.05	-0.05	-0.09	-0.07	-0.08	-0.06	-0.06	-0.03	-0.05	0.01
Twelvemile Creek	1968-2015	**0.21**	0.07	0.10	0.06	0.08	0.08	0.07	0.04	0.03	0.06	0.07
Snake River ab Jackson Lake at Flagg Ranch WY												
Two Ocean Plateau	1984-2015	-0.01	0.03	0.08	0.19	0.17	0.11	0.07	0.10	0.10	0.14	0.12
Thumb Divide	1988-2015	0.20	0.16	0.14	0.17	0.15	0.18	0.20	0.21	0.22	0.21	0.22
Lewis Lake Divide	1984-2015	0.04	0.02	0.04	0.12	0.09	0.12	0.12	0.08	0.10	0.11	0.13
Grassy Lake	1984-2015	-0.13	0.09	0.14	0.11	0.09	0.06	0.00	-0.03	-0.05	-0.06	-0.07
Snake River Station	1990-2015	-0.01	0.14	0.15	0.20	0.09	0.11	0.05	0.07	0.05	0.10	0.12
Teton River ab South Leigh Creek nr Driggs ID												
Grand Targhee	2007-2015	0.50	0.39	0.22	0.28	0.25	0.25	0.25	0.22	0.22	0.22	0.22
Phillips Bench	1981-2015	0.10	0.06	0.05	0.04	0.04	0.06	0.06	0.07	0.08	0.05	0.06
Pine Creek Pass	1989-2015	0.02	0.07	0.08	0.07	0.06	0.02	0.00	0.00	0.03	0.02	0.02

Table D.2 Mann-Kendall trend test tau values for magnitude max SWE, date of each incremental percent meltout, and date of peak streamflow. Bold values indicate statistical significance ($p < 0.05$).

SNOTEL-Streamflow Pair	Period	Max SWE (in)	Date max SWE (day WY)	Date 10% Meltout (day WY)	Date 20% Meltout (day WY)	Date 30% Meltout (day WY)	Date 40% Meltout (day WY)	Date 50% Meltout (day WY)	Date 60% Meltout (day WY)	Date 70% Meltout (day WY)	Date 80% Meltout (day WY)	Date 90% Meltout (day WY)	Date 100% Meltout (day WY)	Date peak Q (day WY)
Boise River nr Twin Springs ID														
Trinity Mtn	1981-1989, 1991-2015	-0.13	-0.05	-0.06	-0.07	-0.13	-0.12	-0.13	-0.14	-0.13	-0.13	-0.13	-0.13	-0.11
Atlanta Summit	1981, 1984-2015	0.04	-0.02	0.01	-0.05	-0.10	-0.13	-0.13	-0.13	-0.14	-0.14	-0.15	-0.17	-0.03
Jackson Peak	1982-1983, 1985-1988, 1990-2015	-0.14	-0.14	-0.08	-0.11	-0.09	-0.07	-0.09	-0.09	-0.08	-0.09	-0.10	-0.12	-0.07
Mores Creek Summit	1982-2015	-0.20	-0.13	-0.21	-0.16	-0.18	-0.19	-0.19	-0.19	-0.20	-0.20	-0.19	-0.18	-0.03
Graham Guard Sta.	1981-2015	-0.23	-0.17	-0.14	-0.12	-0.12	-0.14	-0.14	-0.19	-0.19	-0.20	-0.20	-0.21	-0.08
SF Boise River nr Featherville ID														
Vienna Mine	1982-1983, 1985-2015	-0.09	0.09	-0.06	-0.06	-0.11	-0.07	-0.09	-0.10	-0.09	-0.09	-0.08	-0.07	-0.05
Trinity Mtn.	1981-1989, 1991-2015	-0.13	-0.05	-0.06	-0.07	-0.13	-0.12	-0.13	-0.14	-0.13	-0.13	-0.13	-0.13	-0.08
Atlanta Summit	1981, 1984-2015	0.04	-0.02	0.01	-0.05	-0.10	-0.13	-0.13	-0.13	-0.14	-0.14	-0.15	-0.17	-0.04
Camas Creek Divide	1993-2015	-0.25	0.04	-0.10	-0.05	-0.11	-0.14	-0.17	-0.13	-0.21	-0.24	-0.25	-0.26	0.01
Prairie	1987-2015	0.05	0.07	0.10	0.18	0.20	0.17	0.13	0.13	0.11	0.13	0.12	0.11	0.05
Big Lost River at Howell Ranch nr Chilly ID														
Smiley Mountain	2002-2015	-0.12	-0.18	-0.13	-0.07	-0.08	0.12	0.06	0.00	0.03	-0.07	-0.12	-0.12	0.14
Bear Canyon	1981-2015	-0.17	-0.09	-0.16	-0.18	-0.20	-0.23	-0.23	-0.22	**-0.24**	**-0.25**	**-0.24**	-0.22	-0.15
Lost-Wood Divide	1982, 1984-2015	-0.16	-0.05	-0.11	-0.15	-0.16	-0.15	-0.19	-0.17	-0.16	-0.15	-0.17	-0.17	-0.10
Stickney Mill	1981-2015	-0.08	-0.17	-0.13	-0.17	-0.18	-0.16	-0.16	-0.14	-0.13	-0.13	-0.14	-0.14	-0.15
Big Wood River at Hailey ID total flow														
Vienna Mine	1982-1983, 1985-2015	-0.09	0.09	-0.06	-0.06	-0.11	-0.07	-0.09	-0.10	-0.09	-0.09	-0.08	-0.07	-0.08
Galena Summit	1982-1983, 1986-2015	-0.01	-0.03	0.01	-0.05	-0.04	-0.08	-0.09	-0.12	-0.06	-0.04	-0.04	-0.07	-0.09
Lost-Wood Divide	1982, 1984-2015	-0.16	-0.05	-0.11	-0.15	-0.16	-0.15	-0.19	-0.17	-0.16	-0.15	-0.17	-0.17	-0.09
Hyndman	1983-2015	-0.15	-0.07	-0.11	-0.13	-0.14	-0.12	-0.09	-0.10	-0.10	-0.10	-0.13	-0.12	-0.11
Galena	1981-2015	-0.07	-0.11	-0.14	-0.15	-0.12	-0.10	-0.11	-0.12	-0.08	-0.08	-0.07	-0.07	-0.03
Chocolate Gulch	1994-2015	-0.30	-0.01	-0.12	-0.30	**-0.36**	**-0.35**	**-0.33**	-0.29	-0.26	-0.26	-0.25	-0.24	-0.20
Bruneau River nr Hot Springs ID														
Pole Creek R.S.	1981-2015	-0.11	-0.02	0.08	0.09	0.03	0.01	-0.04	-0.04	-0.05	-0.05	-0.04	-0.09	0.10
Bear Creek	1979-1980, 1982-2015	**-0.24**	-0.02	-0.04	-0.07	-0.08	-0.06	-0.06	-0.08	-0.15	-0.15	-0.18	-0.18	0.08
Seventysix Creek	1991-2015	-0.21	-0.06	-0.10	-0.14	-0.12	-0.13	-0.12	-0.13	-0.09	-0.07	-0.05	-0.08	0.09
Wilson Creek	1979-2015	0.12	0.07	0.08	-0.06	-0.16	-0.15	-0.14	-0.13	-0.15	-0.15	-0.17	-0.18	0.03
Big Bend	1979-2015	-0.18	-0.17	-0.16	-0.13	-0.12	-0.18	-0.17	-0.15	-0.10	-0.10	-0.09	-0.08	0.09
Lochsa River nr Lowell ID														
Savage Pass	1984-2015	0.09	0.00	-0.01	0.06	0.02	-0.01	-0.05	-0.03	0.01	0.03	0.03	0.05	0.07
Crater Meadows	1985-2015	0.24	0.24	0.21	0.25	0.16	0.20	0.18	0.25	**0.29**	**0.27**	0.25	0.23	0.13
Hemlock Butte	1984-2015	0.05	0.22	0.12	0.13	0.03	0.02	0.04	0.07	0.06	0.07	0.07	0.06	0.07
Lolo Pass	1984-2015	0.08	0.06	**0.26**	0.15	0.18	0.14	0.11	0.08	0.06	0.05	0.06	0.07	0.07

Table D.2 Continued

SNOTEL-Streamflow Pair	Period	Max SWE (in)	Date max SWE (day WY)	Date 10% Meltout (day WY)	Date 20% Meltout (day WY)	Date 30% Meltout (day WY)	Date 40% Meltout (day WY)	Date 50% Meltout (day WY)	Date 60% Meltout (day WY)	Date 70% Meltout (day WY)	Date 80% Meltout (day WY)	Date 90% Meltout (day WY)	Date 100% Meltout (day WY)	Date peak Q (day WY)
Moyie River at Eastport ID														
Hawkins Lake	1969-2015	-0.11	-0.16	-0.18	**-0.21**	-0.20	-0.19	**-0.21**	**-0.20**	**-0.20**	-0.18	-0.19	-0.20	0.03
Garver Creek	1969-2015	-0.12	0.09	0.13	0.19	0.14	0.10	0.05	0.06	0.09	0.08	0.06	0.01	0.03
Owhyee River nr Rome ID														
South Mtn.	1982-2015	**-0.34**	-0.14	-0.14	-0.13	-0.16	-0.17	-0.18	-0.17	-0.18	-0.16	-0.18	-0.20	0.09
Mud Flat	1982, 1985-2015	-0.17	0.10	0.03	-0.02	-0.07	-0.11	-0.09	-0.09	-0.07	-0.08	-0.07	-0.08	0.13
Salmon Falls Creek nr San Jacinto NV														
Pole Creek R.S.	1981-2015	-0.11	-0.02	0.08	0.09	0.03	0.01	-0.04	-0.04	-0.05	-0.05	-0.04	-0.09	0.00
Bear Creek	1979, 1982-2015	-0.21	-0.01	-0.05	-0.09	-0.11	-0.09	-0.10	-0.12	-0.15	-0.15	-0.16	-0.16	-0.02
Bostetter R.S.	1982-2015	-0.19	-0.12	0.02	-0.07	-0.09	-0.06	-0.02	-0.05	-0.07	-0.04	-0.03	-0.06	-0.02
Wilson Creek	1991-2015	0.12	0.07	0.08	-0.06	-0.16	-0.15	-0.14	-0.13	-0.15	-0.15	-0.17	-0.18	-0.04
Magic Mountain	1981-2015	-0.05	-0.06	0.05	-0.07	0.01	0.02	0.07	0.05	0.03	-0.01	0.01	-0.01	0.00
MF Salmon River at MF Lodge nr Yellow Pine ID														
Banner Summit	1999-2016	-0.01	0.00	0.11	0.10	0.13	0.10	0.07	0.10	0.12	0.14	0.12	0.11	-0.11
Deadwood Summit	1999-2016	0.02	0.24	0.18	0.21	0.22	0.15	0.17	0.23	0.27	0.17	0.18	0.20	-0.11
SF Salmon River nr Krassel R.S. ID														
Deadwood	1981,1982, 1986, 1990-2015	-0.09	0.10	0.09	0.03	-0.03	-0.04	-0.07	-0.04	-0.05	-0.08	-0.06	-0.07	-0.18
Big Creek	1982, 1986, 1990-2015	-0.16	-0.08	-0.08	-0.09	-0.13	-0.11	-0.11	-0.11	-0.14	-0.15	-0.15	-0.17	-0.12
Selway River nr Lowell ID														
Twin Lakes	1968-2015	-0.07	**-0.20**	-0.16	-0.19	**-0.20**	**-0.23**	-0.20	**-0.21**	**-0.22**	**-0.22**	**-0.21**	**-0.24**	-0.12
Mountain Meadows	1981-2015	-0.01	-0.08	-0.06	-0.13	-0.05	-0.07	-0.11	-0.10	-0.11	-0.10	-0.07	-0.07	-0.01
Nez Perce Camp	1977-2015	0.00	-0.15	0.01	0.08	0.11	0.16	0.18	0.17	0.15	0.12	0.10	0.01	0.02
Twelvemile Creek	1968-2015	-0.17	**-0.30**	**-0.21**	**-0.25**	-0.17	-0.18	-0.18	-0.18	-0.15	-0.16	-0.18	-0.19	-0.12
Snake River ab Jackson Lake at Flagg Ranch WY														
Two Ocean Plateau	1984-2015	0.20	0.04	0.01	-0.02	-0.05	-0.04	0.01	0.00	-0.02	-0.03	-0.06	-0.05	0.01
Thumb Divide	1988-2015	0.08	0.02	0.03	0.02	-0.02	-0.03	-0.03	-0.03	-0.08	-0.09	-0.09	-0.09	0.02
Lewis Lake Divide	1984-2015	0.00	0.12	0.07	0.01	-0.03	0.00	0.00	0.00	0.00	-0.03	0.00	-0.03	0.01
Grassy Lake	1984-2015	0.06	**0.28**	0.01	0.03	0.07	0.08	0.06	0.04	0.05	0.09	0.10	0.09	0.04
Snake River Station	1990-2015	0.02	0.05	-0.04	-0.04	-0.09	-0.03	-0.02	-0.01	-0.03	0.01	0.01	0.00	-0.06
Teton River ab South Leigh Creek nr Driggs ID														
Grand Targhee	2007-2015	-0.33	-0.44	-0.33	-0.14	-0.14	-0.31	-0.28	-0.22	-0.22	-0.22	-0.22	-0.22	-0.08
Phillips Bench	1981-2015	-0.06	-0.16	-0.09	-0.11	-0.11	-0.12	-0.11	-0.08	-0.08	-0.09	-0.05	-0.06	0.02
Pine Creek Pass	1989-2015	0.04	0.08	-0.03	-0.04	-0.08	-0.04	0.01	0.05	0.03	-0.01	0.00	0.00	0.05

APPENDIX E

Historical Dataset Metrics and Descriptions

Table E.1 Description of metrics (column headers) for historical datasets provided in "Additional Files" as .csv files

Metric	Units	Description
Year	year	Water year (October 1 - September 30)
Date Peak Q	day of WY	Date of maximum mean daily discharge recorded at the streamgage station
Date Max SWE	day of WY	Date of maximum SWE accumulation at the SNOTEL site (if max SWE was sustained for more than one day or occurred on more than one date, the date of the last occurrence was selected)
Date Meltout	day of WY	Date of complete meltout - first date of reported zero SWE value at the SNOTEL site
Peak Q	cfs (ft^3/s)	Maximum mean daily discharge recorded at the streamgage station
Max SWE	inches	Magnitude maximum SWE at the SNOTEL site
SWE Day Peak Q	inches	SWE value reported on the day of peak streamflow
Percent Melted Day Peak Q	%	Percent of maximum SWE melted at the time of peak streamflow - value of SWE remaining on the day of peak Q divided by max SWE, multiplied by 100
Number of Melt Days	#	Number of days melt occurred (loss of SWE) from the date of max SWE to the date of meltout at the SNOTEL site
Average Melt Rate	in/day	Average daily melt rate at the SNOTEL site - max SWE divided by total number of days of melt
Max Melt Rate	in/day	The greatest amount of melt (loss of SWE) that occurred on any one day at the SNOTEL site
Date Max Melt Rate	day of WY	Date of maximum melt rate
3-day Cum. Melt	inches	Summed total of: melt (loss of SWE) recorded at the SNOTEL site on day of peak flow, one day prior to peak flow, and two days prior to peak flow
3-day Cum. Precip	inches	Summed total of: precipitation recorded at the SNOTEL site on the day of peak flow, one day prior to peak flow, and two days prior to peak flow
Cum. Oct-Nov Precip	inches	Summed total of daily precipitation recorded at the SNOTEL site from October 1 to November 30