Snowmelt and Peak Streamflow Relationships for the Big Wood River in Southeast Idaho

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1. INTRODUCTION

Peak streamflow within southeast Idaho generally occurs as a result of spring snowmelt (see unpublished Natural Resource Conservation Service (NRCS) document). Although rain-on-snow events have been known to produce some of the largest peak flows on record, their frequency of occurrence is considerably lower. Numerous researchers have exploited similar knowledge in developing statistical snowmelt and peak streamflow relationships for river basins across the West (Farnes, 1984; Sarantitis and Palmer, 1988; Ferguson *et al.*, 2015). In an effort to provide stakeholders with predictive tools to estimate peak streamflow and timing as a result of snowmelt, the NRCS routinely generates Snow-Stream Comparison charts for a number of select basins within Idaho (https://www.nrcs.usda.gov). Unfortunately, relationships for many of the basins within southeast Idaho have not been developed. The primary objective of this study was to develop the programs and methodologies needed to establish snowmelt and peak streamflow relationships for the Big Wood River basin. These tools would then be used at a later date to produce similar relationships in the remaining headwater basins within southeast Idaho as well as provide stakeholders with additional decision support information well in advance of potential flood events.

2. METHODOLOGY and RESULTS

Historical daily snow water equivalent (SWE) values along with supplemental meteorological data were obtained for six automated snow telemetry (SNOTEL) sites within the Big Wood River basin (Chocolate Gulch, Dollarhide Summit, Galena, Galena Summit, Hyndman, and Lost Wood Divide) (Fig. 1). The data were accessed through the NRCS web portal (https://wcc.sc.egov.usda.gov/nwcc/tabget?state=ID) resulting in a period of record for SWE data extending back to 1982 for all but one site (Chocolate Gulch), while supplemental meteorological data were added to the data suite in the fall of 1988. Corresponding historical daily peak streamflow data were also obtained for six automated U.S. Geological Survey (USGS) sites within the Big Wood River basin (Big Wood River at Hailey, Big Wood River near Ketchum, East Fork Big Wood River at Gimlet, North Fork Big Wood River near Ketchum, Trail Creek at Ketchum, and Warm Springs Creek near Ketchum) (Fig. 1). Limited data were available through the USGS website (https://waterdata.usgs.gov/id/nwis/current/?type=flow&group_key=basin_cd) with only one dataset, the Big Wood River at Hailey, extending back to 1979 while the remaining five sites had a prohibitively short period of record extending back to the spring of 2011. Both the NRCS and USGS datasets were subsequently subdivided into individual water years (October-September) for use in statistical processing and graphical display routines.

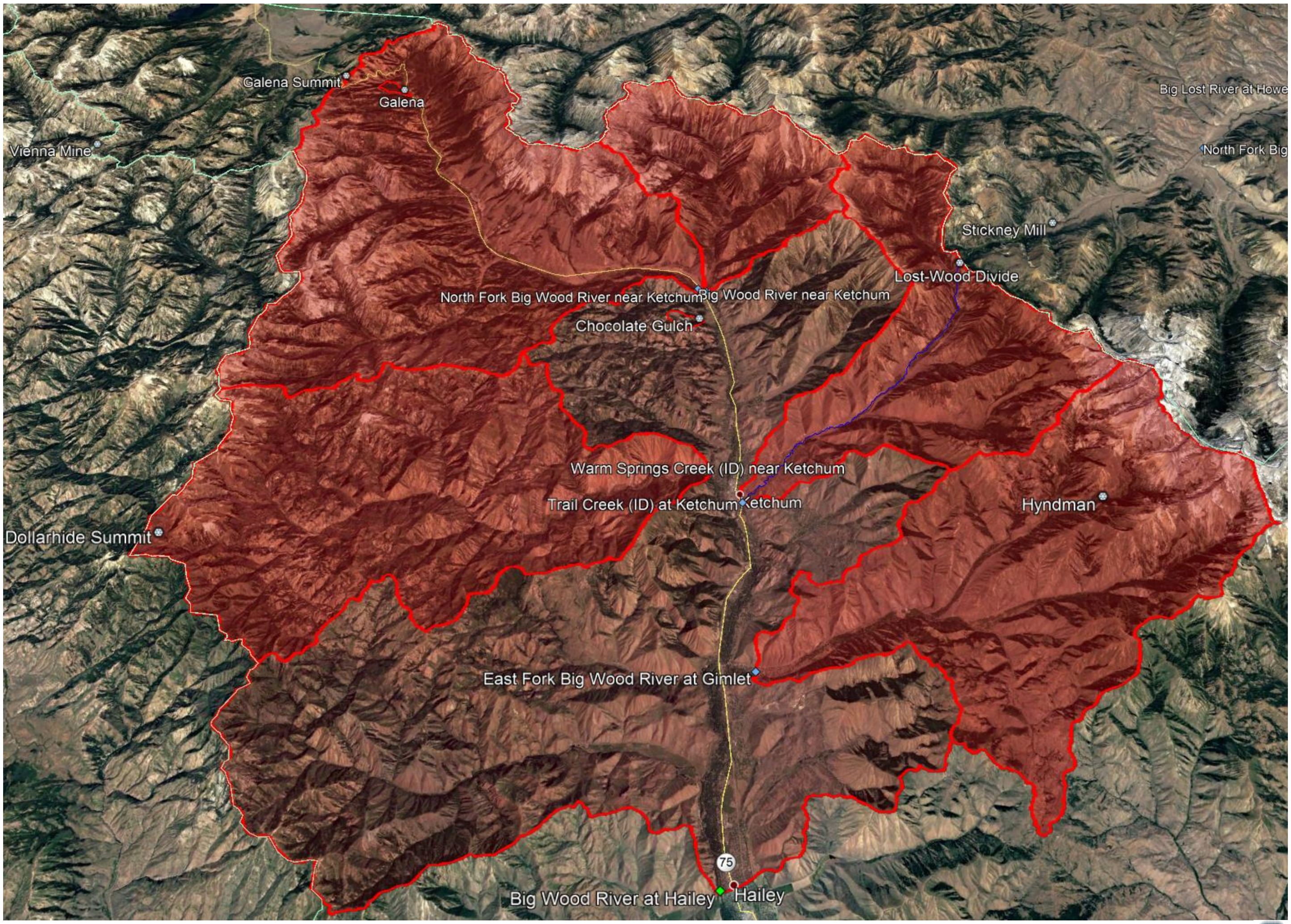

Figure 1. Big Wood River basin from Hailey in the south to Galena Summit in the north.  represents SNOTEL locations.  represents stream gauge locations. Darker red shaded areas delineate smaller portions of the overall basin that are monitored by USGS stream gauges.

Daily SWE and associated meteorological data for each SNOTEL site were plotted alongside the corresponding daily USGS peak flow data for the Big Wood River at Hailey as a function of Days from Peak SWE for each water year (e.g. Fig. 2). Each graph was then visually inspected and the cause of peak flow was subjectively determined by use of the associated meteorological data available for each SNOTEL site (MacDonald and Hoffman,1995). Typically, this exercise would be completed for each smaller SNOTEL - USGS basin couplet (e.g. Dollarhide Summit and Warm Springs Creek near Ketchum) but can also be done for larger basin comparisons as shown in Table 1.

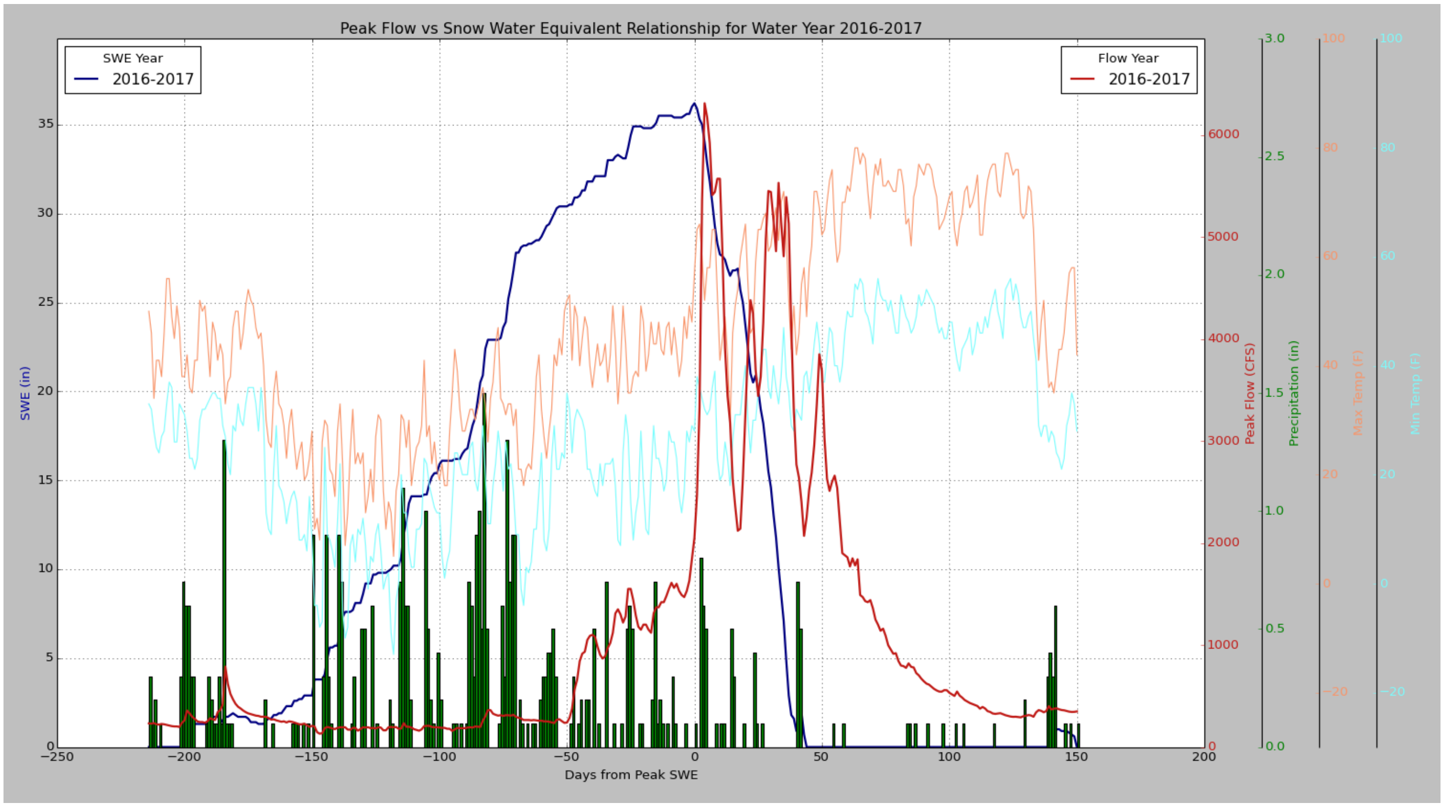

Figure 2. Daily SWE (dark blue line) and peak flow (dark red line) versus Days from Peak SWE for the water year 2016-2017 for Galena Summit SNOTEL and the Big Wood River at Hailey, respectively. Daily supplemental max and min temperature (^{o}F, light red and blue lines, respectively) and water equivalent precipitation (nearest 0.1 inch, green bars) for Galena Summit SNOTEL.

SNOTEL	*n*	Rain	Snowmelt	Rain-on-Snow
Chocolate Gulch	24	5	17	2
Dollarhide Summit	36	1	22	13
Galena	35	4	22	9
Galena Summit	36	4	25	7
Hyndman	37	9	25	3
Lost Wood Divide	36	6	22	8

Table 1. Cause of peak daily flow for the Big Wood River at Hailey for each SNOTEL site listed. *n* represents the total number of water years evaluated. Remaining columns represent the stratified rain, natural snowmelt, and rain-on-snow cases.

The stratification of peak flow based upon cause was performed in order to focus strictly on the natural snowmelt - peak flow process. After removing years which exhibited rain and rain-on-snow peak flow events, the remaining water years were processed to determine the period of observed flooding and the average peak flow date with respect to Days from Peak SWE for each individual SNOTEL site (not shown). In addition to analyzing the SWE values for each individual SNOTEL site, the daily peak SWE from Dollarhide Summit, Galena, Galena Summit, Hyndman, and Lost Wood Divide SNOTELs were summed to produce a SWE Index value which was plotted alongside the peak flow from the Big Wood River at Hailey with respect to Days from the Peak SWE Index (Fig. 3). It was reasoned that the SWE Index would provide a more comprehensive picture of basin-wide SWE conditions rather than one individual SNOTEL site.

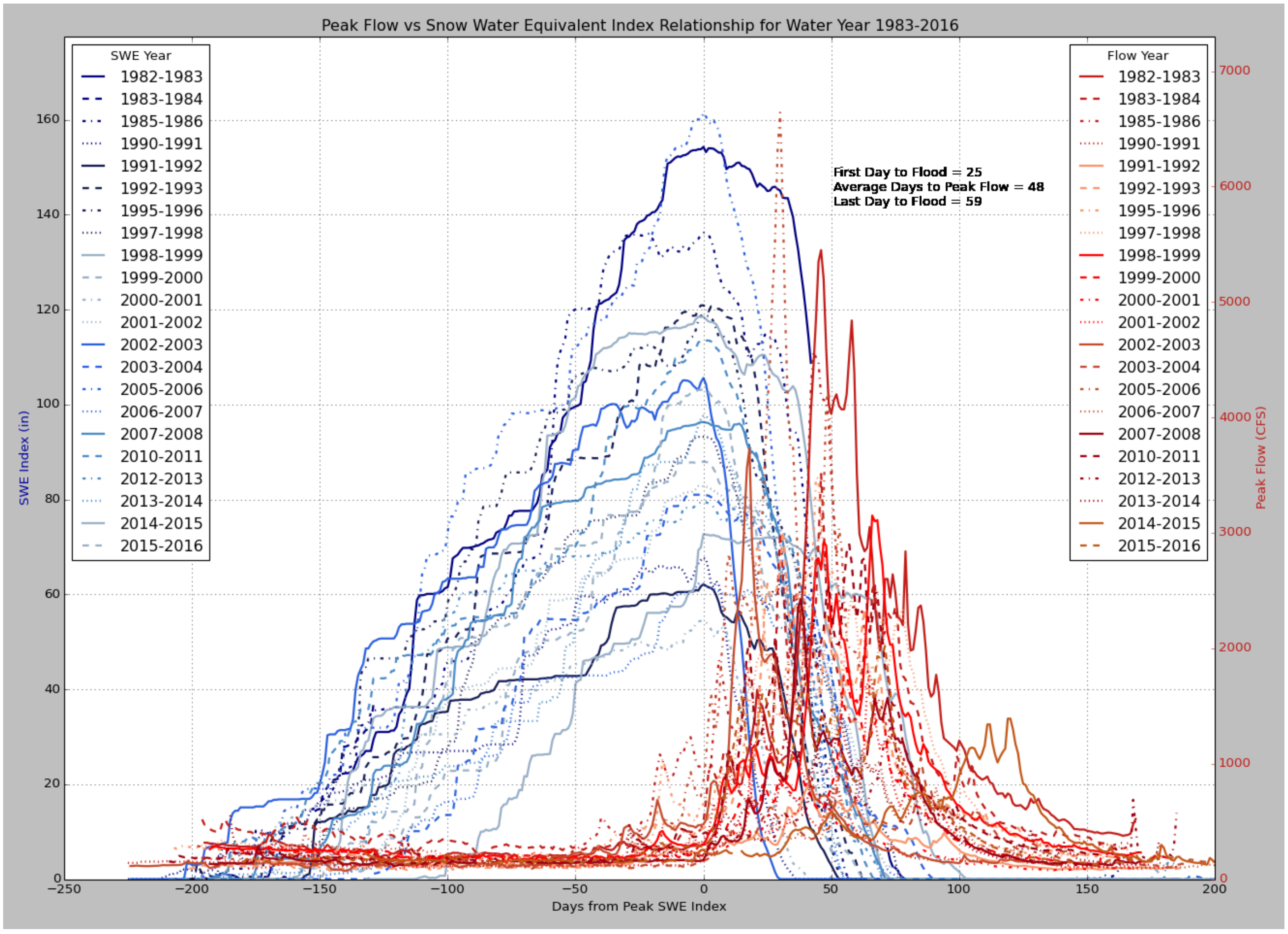

Figure 3. Peak flow (red lines) for the Big Wood River at Hailey and SWE Index (blue lines) for Dollarhide Summit, Galena, Galena Summit, Hyndman, and Lost Wood Divide SNOTELs versus Days from Peak SWE Index for natural snowmelt events. Climatological flood information provided within inset.

In this case, the stratified data indicated that the first day to flood for the Big Wood River at Hailey was historically 25 days after the peak SWE Index and the last day to flood was 59 days after the peak. On average, the peak flow occurred 48 days after the peak SWE Index. The expectation here is that the flood timing information could help to frame the period of concern for stakeholders well in advance (up to 30 days or more) of potential flood events, while numerical modeling would be much better suited to address the short-lead time (7-10 days or less) vagaries of mountain weather associated with rain and rain-on-snow events as well as refine the expected period of flooding.

It stands to reason that larger yearly SWE values would likely produce larger yearly peak flows. In order to test this assumption, the maximum yearly flow was plotted against the corresponding maximum yearly SWE for each individual SNOTEL site within the basin (not shown). Stronger relationships would be expected in the smaller SNOTEL - USGS basin couplets but as mentioned previously, the short period of record (less than 7 years) for all but the Big Wood River at Hailey prevented such analysis. Additionally, pairing one SNOTEL site representing a small portion of the basin against a river gauge which measures the entire outflow of the basin might also prove to be a tenuous exercise. To address this latter issue, the yearly peak SWE Indices were plotted against the maximum yearly flow for the Big Wood River at Hailey (Fig. 4). The strength of this relationship was then tested using Pearson's correlation coefficient (r) which measures the strength of a linear relationship between paired data. Values of r approaching ± 1 indicate very strong correlations whereas values near zero denote no linear correlation. The level of significance, or p-value, was also calculated which indicates the risk of concluding that a correlation exists when in reality there may not be one. Usually, a significance level of 0.05 (5%) or less is acceptable. Also, a linear regression equation was established allowing the independent maximum SWE Index value to be used as a predictor of the expected yearly peak flow. And finally, the standard error was calculated which represents the average distance that the observed values deviated from the regression line. The smaller the value, the closer the observed values are to the regression line. Surprisingly, all of the individual SNOTEL and basin summed indices scored very strongly ($r > 0.84$) with significance levels less than 0.001 (e.g. Fig. 4 inset).

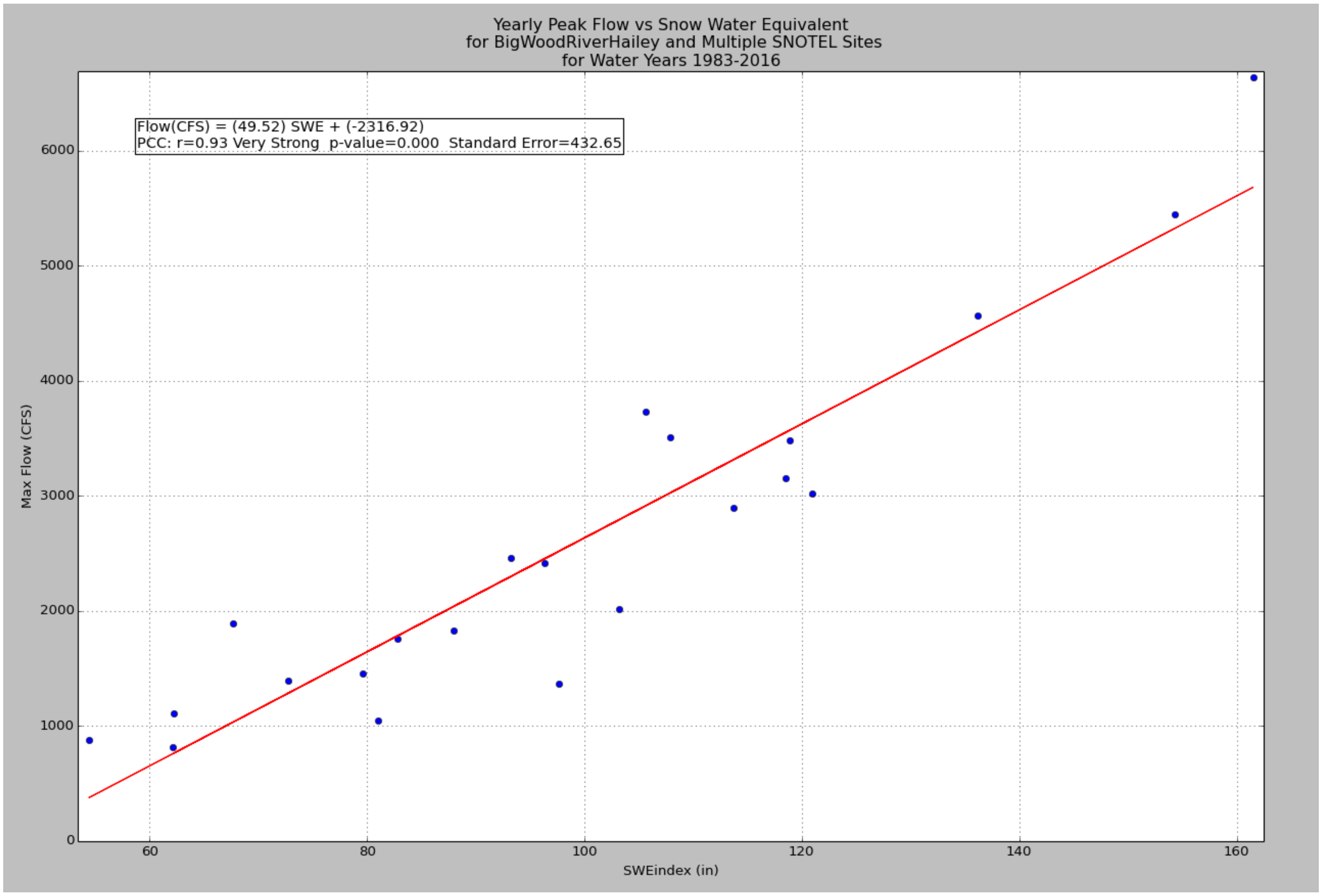

Figure 4. Yearly peak flow for the Big Wood River at Hailey versus the SWE Index for Dollarhide Summit, Galena, Galena Summit, Hyndman, and Lost Wood Divide SNOTELs for the stratified snowmelt years only. The regression equation, Pearson correlation coefficient (r), p-value, and standard error are provided within the inset.

As an initial means of independently testing the relationships shown in Figures 3 and 4, the observed peak SWE Index and associated date were culled from the rain and rain-on-snow years and used as input, with the resulting predicted peak flow values and dates listed in Table 2. The peak flow for all but two of the years fell within the expected time frame for flooding while 6 of the 13 years were within seven days of the average peak flow. As anticipated, the regression equations underperformed with 9 of the 13 years producing higher observed flows than predicted, which was primarily due to the injection of additional moisture into the basin in the form of rain which also served to hasten the snowmelt process.

Water Year	Pk SWE Index (in)	Pred Pk Flow (CFS)	Obs Pk Flow (CFS)	Date Obs Pk SWE Index	Date Pred Pk Flow	Date Obs Pk Flow
1984-1985	85.5	1917	1320	4/1	5/19	5/26
1986-1987	57.2	516	1380	3/31	5/18	5/17
1987-1988	68.8	1090	1350	4/10	5/28	6/5
1988-1989	111.5	3205	1710	4/5	5/23	5/11
1989-1990	61.7	739	1300	3/30	5/17	6/11
1993-1994	50.7	194	991	4/10	5/28	6/1
1994-1995	144.7	4849	3970	5/9	6/26	6/5
1996-1997	165.1	5859	4440	4/14	6/1	6/5
2004-2005	72.5	1273	3640	4/22	6/9	5/20
2008-2009	87.7	2026	2480	4/11	5/29	6/5
2009-2010	69.3	1115	2780	4/14	6/1	6/7
2011-2012	100.4	2655	3600	4/1	5/19	4/27
2016-2017	168.6	6032	6310	4/21	6/8	5/7

Table 2. Rain and rain-on-snow water year peak SWE Index values used as the independent variable in the regression equation presented in Fig. 4 to produce predicted peak flow values. Observed peak flow values exceeding predictions are shaded tan. Observed peak SWE Index dates were used in conjunction with the flood onset timing information presented in Fig. 3 to produce predicted peak flow dates. Observed peak flow dates falling within seven days of the predicted peak flow date are shaded green. Dates falling outside the predicted flood range are shaded red. Flood years are shaded light blue.

Finally, yearly peak SWE and SWE Index were plotted against the Days to Peak Flow for the stratified snowmelt years (e.g. Fig. 5) to see if there were any visually identifiable relationships that might be culled from the presentation. The focus here was threefold. First, to examine if there might be any type of linear relationship associated with the amount of SWE and the Days to Peak Flow (e.g. higher peak SWE Indices produce earlier peak flows). Second, whether a normalized clustering of cases might be seen around the average peak flow day with fewer cases in the tails. And finally, whether a minimum SWE threshold could be established for flooding. The linear correlation here was weak at best and no strong visual clustering was observed near the average peak flow day (in this case 48), likely owing to the obvious fact that temperature plays a much more significant role in the *timing* of snowmelt. Although outside the scope of the current work, further investigation into this latter detail would likely yield a method in which cumulative cooling degree days (based on 32^{o}F) could be used to refine the predicted peak flow day. Although not shown here, it was of interest to note that when plotting the entire period of record, a SWE Index demarcation ($SWE_{index} \simeq 120$ in.) for flood years (red dots) versus non-flood years (blue dots) began to emerge. Granted this observation is a bit tenuous given that there were only seven flood years noted during the period examined (1983-2017).

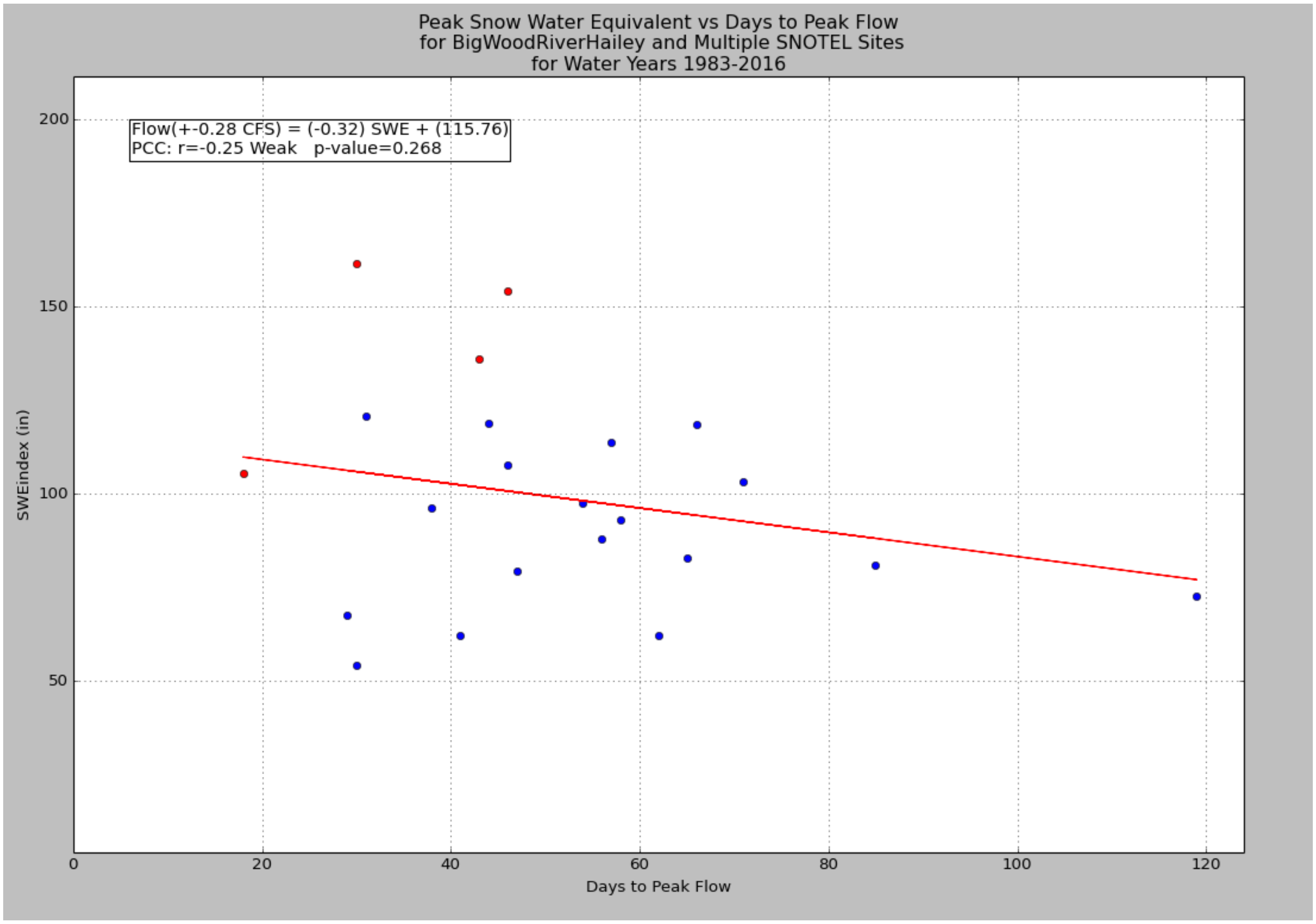

Figure 5. Yearly SWE Index for Dollarhide Summit, Galena, Galena Summit, Hyndman, and Lost Wood Divide SNOTELs versus Days to Peak Flow at the Big Wood River at Hailey for the stratified snowmelt years from 1983-2016. Red dots delineate flood years.

3. CONCLUSION

Developing snowmelt and peak streamflow relationships within river basins primarily dominated by spring snowmelt can prove helpful in establishing benchmarks for the timing and strength of seasonal runoff. As was shown here, the timing of peak flow can be framed as early as 30 to 60 days in advance by utilizing the date of peak SWE in combination with historical flow data. This knowledge coupled with the ability to estimate the magnitude of the peak flow using the established regression equations could provide stakeholders with ample time to prepare for and mitigate the impacts of the anticipated flood wave due to natural snowmelt processes. These types of relationships however, do not address the short-term vagaries of mountain weather such as rain or rain-on-snow peak flow events which are best handled through modeling.

4. ACKNOWLEDGMENTS

Thanks go out to Kurt Buffalo (SOO - WFO Pocatello) for reviewing this document and providing helpful suggestions.

5. REFERENCES

An Introduction to Snowmelt and Peak Streamflow Comparisons. NRCS Unpublished Document. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_045600.pdf

Farnes, P.E., 1984: Predicting Time of Peak Snowmelt Runoff from Snow Pillow Data. 52nd Annual Western Snow Conference, 1984, Sun Valley, Idaho. https://westernsnowconference.org/sites/westernsnowconference.org/PDFs/1984FarnesA.pdf

Ferguson, K.J., J. McNamara, R. Abromovich, and J. Johnston, 2015: From Snow to Flow: Estimating the Timing of Peak Streamflow from SNOTEL Ablation Curves. 83rd Annual Western Snow Conference, 2015, Grass Valley, California. https://westernsnowconference.org/files/PDFs/2015Ferguson.pdf

MacDonald, L.H. and Hoffman, J.A., 1995: Causes of Peak Flows in Northwestern Montana and Northeastern Idaho. JAWRA Journal of the American Water Resources Association, 31: 79-95. http://www.nrel.colostate.edu/assets/nrel_files/labs/macdonald-lab/pubs/CausesofPeakFlowinNorthwesternMontanaandNortheasternIdaho.pdf

Sarantitis, B.C. and Palmer, P.L., 1988: A Peakflow Forecast for Payette Lake Using SNOTEL Data. 56th Annual Western Snow Conference, 1988, Kalispell, Montana. https://westernsnowconference.org/sites/westernsnowconference.org/PDFs/1988Sarantitis.pdf