COMPARING LOCAL STREAM FLOW PEAKS TO THE ONSET OF WET AVALANCHE CYCLES

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ABSTRACT: When the snow has melted from the valley floors, peak flow levels in our local streams may help predict the onset of annual wet avalanche events. Park City Mountain Resort (PCMR), located on the Wasatch Back of Utah, is unique geographically when compared to neighboring resorts in the Cottonwood Canyons. With several east-facing low-elevation starting zones, PCMR tends to see the first wet avalanche activity of each spring. Additionally, the streams in the surrounding basin begin to flow early allowing for discharge monitoring and forecasting while upper elevation drainages are still covered in ice and snow.

Forecasting the onset of wet slab activity each spring can be a challenge. Preliminary observations have been made at PCMR that show a relationship between the first stream flow peaks and wet avalanche activity. For this study, data from a network of automated local stream gauges were used to compare both archived and forecasted flows in local streams with the onset of these avalanches. This project is presented as a work in progress. Data sets are limited at this time and only preliminary results are presented. With future work, the author hopes to build upon this initial analysis and perhaps develop a reliable forecasting tool for use at PCMR and similar areas.

KEYWORDS: Wet slab avalanches, avalanche forecasting, stream discharge

1. INTRODUCTION

Springtime wet avalanche cycles can be a part of any given year in Utah's Wasatch Range. For ski area operations, forecasting the timing of these cycles can be challenging. Further adding to the challenge is evidence that accidents involving wet slabs are more likely to be naturally triggered than those involving dry slab avalanches (Peitzch 2008). The primary tools for managing wet avalanche hazard at Park City Mountain Resort (PCMR) are snowpack observations, area closures when conditions become suspect, and active mitigation when necessary. Often closures can interrupt area operations and negatively impact the skiing experience for resort guests. Further, in some cases complete closures are not practical. Alternatively, anyone involved in ski area or highway forecasting is aware that leaving areas open too long can have tragic consequences. As with other resorts, the PCMR Snow Safety Department is always working to add to its forecasting toolbox.

Comparing stream flow with wet avalanche events is not new in the avalanche science community. In his *Conceptual Model for Wet Slab Forecasting*, Blase Reardon looks for "evidence that meltwater is flowing through the snowpack, such as water running across the road and rising streams" (Reardon 2008, p. 19). Observations by this author and others in the Wasatch (Murakami 2012) and documented in Glacier National Park, MT (Reardon 2004) and Arapahoe Basin, CO (Hartman, Borgeson 2008) have noted an increase in stream flows a couple days before both natural (MT) and human-triggered (CO) events. Alternatively, others have observed stream flow increases *after* wet slab and glide avalanche events. Ron Simenhois, working in southeast Alaska "hoped to associate trends in stream flow with glide avalanche activity," but observed stream changes after the onset of avalanching and concluded that these changes were "not useful for forecasting" (Simenhois, Birkeland 2010, p. 848, 849). Forecasters on New Zealand's Milford Road observed that an increase in direct water outflow from the snowpack can be an indicator of the return to stability during rain and melt events (Carran, Conway 2006, Conway, *et al*. 2008).

In mid-March 2011 we were facing a lower-elevation snowpack primed for wet activity as well as a forecast for unseasonably warm temperatures and rain. Influenced specifically by the work of Hartman and Borgeson, I began to explore an indirect or *canary in a coal mine* relationship between increases in stream discharge and the onset of wet activity at PCMR. In other words, climatic conditions that lead to an initial spike in stream flow such as increases

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in temperatures and/or rain may also be indicative of decreasing stability in the snowpack above. For this study, past wet slab cycles at PCMR and archived stream data from local streams were compared. Indeed a relationship has been found wherein the first peak flows of the year occurred a few days before the onset of wet avalanche events. Furthermore, this study investigates the possibility that stream flow forecasts from the Colorado Basin River Forecast Center (CBRFC) could be used as an additional tool for forecasting the onset of wet avalanche cycles. If the CBRFC is forecasting sudden increases in local stream discharge, should we be prepared for wet avalanche conditions a couple days later?

2. STUDY AREA BACKGROUND

Park City Mountain Resort (PCMR) lies in north central Utah along the east side of the central Wasatch Range, 30 km east of the Salt Lake Valley. The resort area covers 1335 ha and ranges in elevation from 2100 m at the base to 3050 m along the summit ridgeline. Among the six neighboring resorts of the Wasatch, PCMR is unique in that there are several relatively low elevation (below 2750 m) avalanche starting zones. In seasons with weather and snowpack conditions conducive to wet avalanche activity, often these paths are among the earliest to avalanche and have in the past proven to be accurate predictors of activity on upper-elevation slopes.

This study focuses on the east-facing (80^{O}-100^{O}) starting zones along Crescent Ridge; known internally at PCMR as Ski Team Ridge. This north-south running ridge is central to the lower half of the resort and has starting zone elevations ranging 2652 m to 2350 m (Figure 1). In regards to operational wet avalanche hazard reduction at PCMR, the snow safety department can take a passive, hands-off approach to the upper mountain paths by simply closing them. This approach is not practical with Crescent Ridge as it presents several avalanche forecasting and mitigation challenges. First, due to difficult skier egress, most starting zones are either permanent closures or not open frequently enough to benefit from skier compaction. Second, open terrain is immediately adjacent to several of these starting zones with access controlled by signage and rope lines. And finally, these paths potentially threaten open runs, structures, and primary resort skier access/egress runs. In particular, two paths along Crescent Ridge have a history of dangerous and relatively destructive avalanches; Gobbler's Knob and Rocky Point.

Gobbler's Knob is located approximately half-way down the ridge with a starting zone elevation of 2515 m. This area is immediately adjacent to a terrain park and park-specific chairlift and is open via two access gates when conditions permit. Moreover, the Gobbler's Knob runout threatens Gotcha Cut-off; an intermediate run which feeds skiers to the resort center. The starting zone is convex, steep (38^{O}) and transected by a thin cliff band.

Figure 1, Crescent Ridge with Gobblers Knob (left) and Rocky Point (right). Photo courtesy of Eric Hoffman, PCMR Marketing

In the spring of 1985, a World Cup race event was being held on runs adjacent to Gobbler's. March 19^{th} was the opening day of events and many skiers were using Gotcha Cut-Off to access viewing points along the course. At this time, the Gobbler's area was a permanent closure. Around mid-day, two brothers violated the closures at the top of Gobbler's to avoid the crowds and cut over to the race course. Upon crossing the upper rock bands, they triggered a point-release wet slide and were partially buried and injured. The slide continued to fan out as it descended towards Gotcha Cut-off. Most skiers heard the sound of breaking trees and had time to move away from the advancing snow. Unfortunately one, Marilyn Harrell, sought

shelter against a cut bank and was buried and killed under 2.7 m of debris.

On the northern most end of Crescent Ridge lies Rocky Point. As is typical of these starting zones, it is east-facing, convex, and mostly bare of vegetation except for shrubs. A thin cliff band runs mid-slope. The starting zone elevation is 2378m with a slope angle of 36^{O}. Competition-dedicated runs and a chairlift are threatened below and open terrain is adjacent to the starting zone. While no fatalities have occurred here in resort history, skiing public have violated closures to enter this area and a few have triggered small slides. Active avalanche hazard mitigation has produced several class 2-3 slides which have removed mature trees and piled debris near the structures and ski runs below.

3. RIVER BASINS AND STREAM DATA

PCMR is located on the headwaters of East Canyon Creek and Silver Creek; tributaries of the Upper Weber River Basin. The Weber River drains 6400 km^2 of the east slope of the central Wasatch Range and south slope of the Uinta Mountains in northeast Utah (Utah DNR 2010).

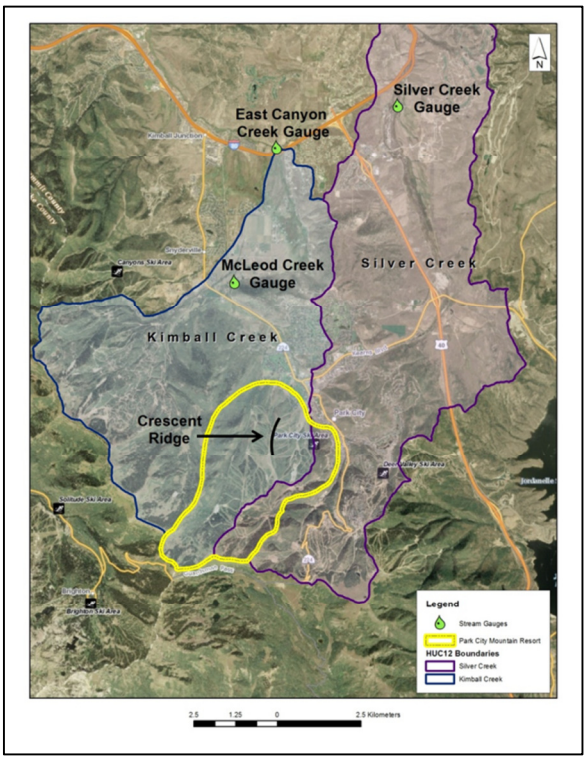

Figure 2, PCMR boundaries with stream basins and gauge locations. GIS courtesy of Karen Lannom

Gauge Name	ID #	Location	Elevation
McLeod Creek	10133600	Lat 40 41'15", Long 111 31'58", 5.1 km NW of Park City, UT	2009 m
East Canyon Creek	10133650	Lat 40 43'26", Long 111 31'08", 8 km NNW of Park City, UT	1939 m
Silver Creek	10129900	Lat 40 44'07", Long 111 28'31", 11.3 km NE of Pak City, UT	1972 m

Table 1, USGS Waterdata stream gauge locations

Crescent Ridge lies in the south east corner of Kimball Creek's basin which is a tributary of East Canyon Creek. Of East Canyon Creek's 106 km^2 drainage area, approximately 10 km^2 are within PCMR's boundaries. Silver Creek drains 45 km^2, 3.3 km^2 of which is within PCMR.

The automated stream gauges used for this study are operated by the United States Geological Survey (USGS) in cooperation with the Snyderville Basin (Utah) Water Reclamation District. They are managed by the USGS Salt Lake City field office. Specific gauge locations used for this study are shown in Figure 2 and listed in Table 1. These gauges can be accessed and read remotely via interactive maps on the Colorado Basin River Forecast Center (CBRFC) or USGS Waterdata websites.

4. STREAM DISCHARGE FORECASTS

The US National Weather Service (NWS) operates 13 River Forecast Centers (RFC) throughout the US. The RFC mission is "*to produce the Nation's river, flood and water supply forecasts in support of saving lives and property and to enhance the economy and environment of the country*" (NWS 2006). The CBRFC operates from the NWS office in Salt Lake City.

Stream forecasts are generated using a combination of historical data, current conditions including stream discharge, temperature, precipitation, snow cover and soil moisture, and climatic forecasts for temperature and precipitation. Models are run twice a day at 0600 and 1300 local time. Additional model runs are made if local conditions and/or forecasts change significantly from previous runs. Accuracy of

these forecasts is directly related to availability of current data. Fortunately for this study, the stream basins surrounding PCMR have several sensors high in the watersheds and stream forecasts have a higher rate of accuracy when compared to other more remote areas (McInerney 2012). As with real-time stream discharge data, these stream forecasts can be accessed via interactive maps on the CBFRC site.

5. FINDINGS AND DISCUSISON

Researching PCMR records, I investigated three seasons with notable wet avalanche activity and coinciding archived stream data; 1985, 2002, and 2007.

For March 1985, the year of the Gobbler's Knob fatality, only archived data for East Canyon Creek was found. There were a couple moderate increases in discharge including one starting the on 16th, three days prior the accident. There is then a steep increase in stream discharge starting on March 22nd (Figure 3). PCMR weather archives show a rapid warm up on that date preceding a warm wet storm which produced 7.6 cm of SWE at the Summit weather station (2820 m). PCMR route sheets record a significant avalanche cycle with mitigation work from March 26th to 30th. Unfortunately these records contain incomplete information regarding the size or type of these slides. Again note that the increase in stream flow begins three days prior to this cycle.

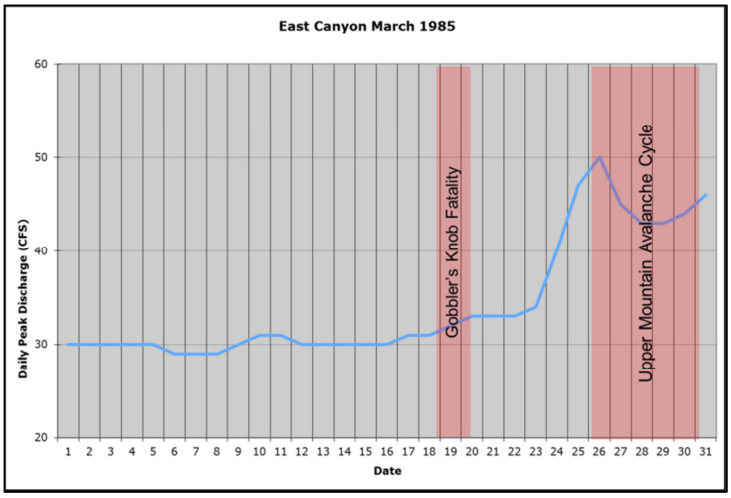

Figure 3, East Canyon Creek daily peak discharge March 1885

Spring 2002 was another with a relatively thin snowpack structure conducive to wet avalanche activity. The first significant warm up of the season started on March 20th with wet avalanche activity starting on the 24th. On that day an explosive-triggered wet slab on Rocky Point ran nearly full-track. The debris toe came to rest about 40 meters from the medals stand and JumboTron display used for the recently completed 2002 Olympics (Figure 4). Figure 5 shows stream discharge for East Canyon Creek and Silver Creek. Unfortunately there was no archived data for McLeod Creek. East Canyon Creek's first notable increase in flow starts March 22nd with a peak on the 24th, the day of the Rocky Point avalanche. Silver Creek in this case has no significant increase until after the onset of activity; however the discharges of both creeks climb significantly towards the end of the month. It is worth noting that upper-elevation wet avalanche activity started around the first of April that year.

In mid-March 2007 the Wasatch Range experienced a significant wet avalanche cycle. A substantial warm up started on March 12th. Average 24 hour high/low temps for a week starting on the 12th of 10.5 c and 1.7 c respectively were recorded at PCMR's Summit weather station (2820 m). In a period from March 13th to 21st, 26 large wet slabs and wet loose avalanches, both natural and artificially released, were reported to the Utah Avalanche Center. As can be typical of these cycles, initial activity started around PCMR. Full- depth class 2-3 wet slabs were released with explosives on Gobbler's and Rocky Point. As the warm temperatures continued, larger slides were released from PCMR's

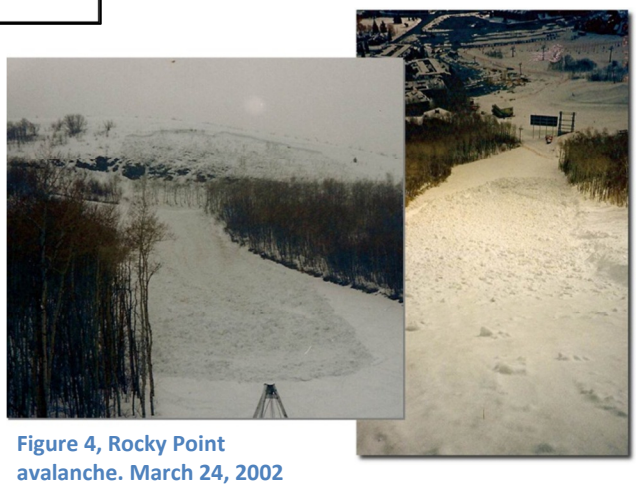

Figure 4, Rocky Point avalanche. March 24, 2002

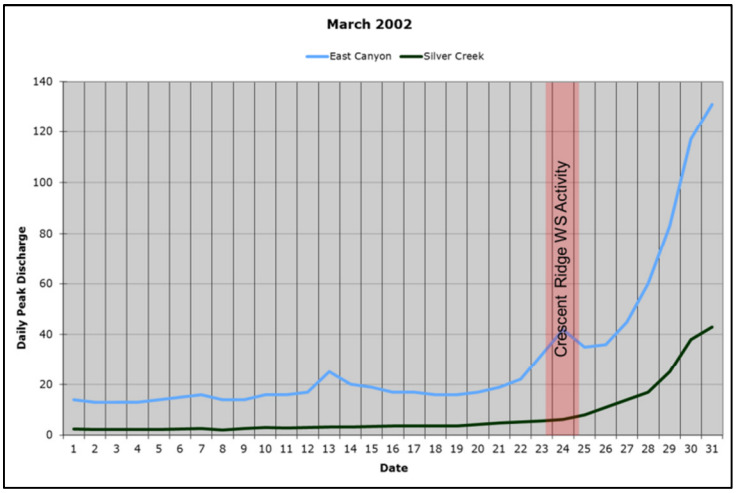

Figure 5, daily peak discharge March 2002

upper slopes (elev >2800 m) culminating with one 300 meter-wide avalanche in Scott's Bowl on March 18th classified as WS-AB-R4D3-G.

Figure 6 shows daily peak discharge data from March 2007 for East Canyon Creek, Silver Creek, and McLeod Creek. All three gauges show the first significant increase in flow for the season starting after the 7th. Silver Creek was the first to peak on the 9th, three days prior to the onset of avalanche activity on Crescent Ridge. East Canyon Creek's flow tapers on the 10th then spikes again to a peak on the 14th, three days prior to the upper elevation activity. McLeod Creek's increase is less noticeable when compared to the other higher-volume creeks, but there are increases in flow which peak on the 8th and again on the 14th.

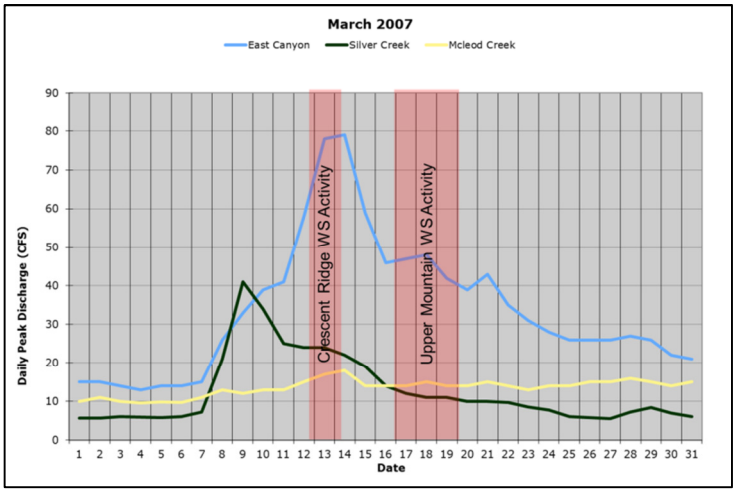

Figure 6, daily peak discharge March 2007

Of all the avalanches reported elsewhere in the Wasatch during this cycle, there is another worth noting. On March 13th a class 4 natural wet slab released off the west face of Gobbler's Knob (no relation to PCMR) in Big Cottonwood Canyon 15 km west of PCMR. Stream gauges for both Big Cottonwood and Little Cottonwood creeks show a steep increase in discharge starting on the 11th (Kobernik 2008).

Recall that the main focus of this study was is determine the usability of CBRFC stream forecasts in forecasting the onset of wet avalanche cycles. Returning to March 16th, 2011, we were preparing for a warm, wet spring storm. Curious what the stream forecasts may show, I looked at real time and forecast flow data for both East Canyon and Silver creeks. McLeod Creek, due to its higher elevation was frozen over at this time and data from this gauge was not used. Figure 7 shows the steam forecasts as they were generated that day. Indeed, a note was recorded in the PCMR weather logs that "*East Canyon gauge shows peak flow.*" For both streams the first steep increase in discharge for the season was forecast to start early on the 17th. The anticipated storm moved into the PCMR area the evening of the 16th. By morning 1.5 cm of water accumulated over the resort, most of which was rain below 2400 meters elevation. Morning hazard mitigation on rocky point released two wet slabs categorized as WS-AE-R3D3-O/G.

Spring 2012 looked to be another season of wet avalanches with a thin snowpack and rapidly warming temperatures. Unfortunately for this study, the snowpack along Crescent Ridge was pretty much melted out by mid-March. There was one event at PCMR worth noting though. The weekend of March 4th was forecast to be mild after a week-long storm cycle that produced 50 cm of snow with 3.9 cm of water at the PCMR Summit weather station (2820 m). Indeed the 4th and 5th saw clear skies with daytime high temps near 5 c and lows just below 0 c. CBRFC forecasts for the 4th show an observed spike on the 1st and forecast spike in flow for both Silver Creek and East Canyon

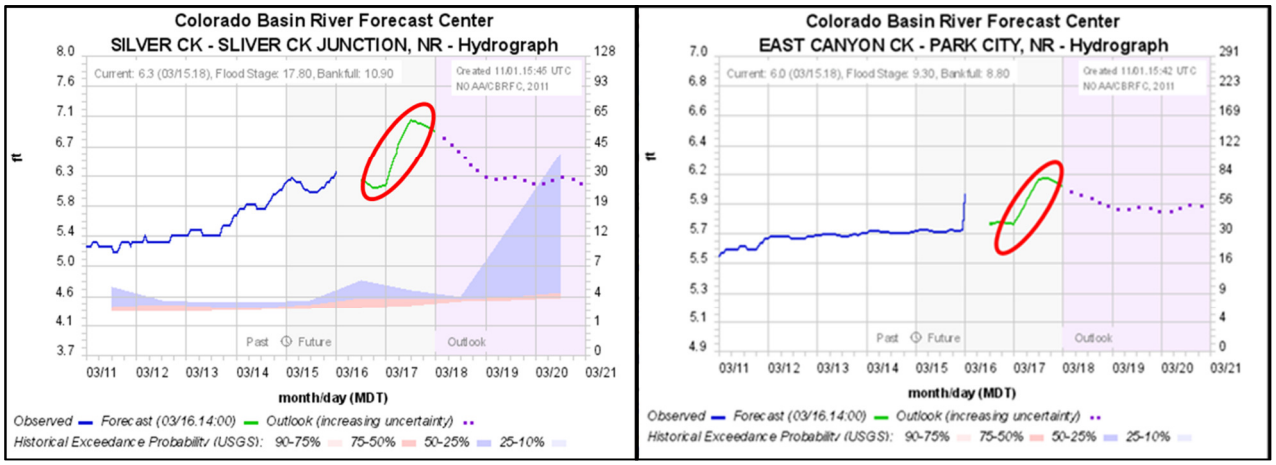

Figure 7, CBRFC forecasts for March 16 2011

Creek starting just after the 5th (Figure 8). A natural avalanche cycle was reported throughout the central Wasatch March 4th and 5th. Included among these was an avalanche from an east-facing slope above PCMR at 2860 m elevation classified as SS-N-R3D2-O. The slide released around mid-day under maximum sun. While this was a dry, storm snow event (as were the others in the Wasatch), it appeared to have been initiated by a point release WL from rock bands just above the crown.

Late April 2012 did see a wet slab cycle in the central Wasatch after PCMR had closed for the season. From April 22nd to 27th, over a dozen large wet slabs on northeast aspects around 3,000 m elevation were reported to the Utah Avalanche Center (UAC 2012). A look at the April 20 stream forecast for Big Cottonwood Creek near Salt Lake City shows a steep increase in flow starting 48 hours prior to the onset of this activity (Figure 9).

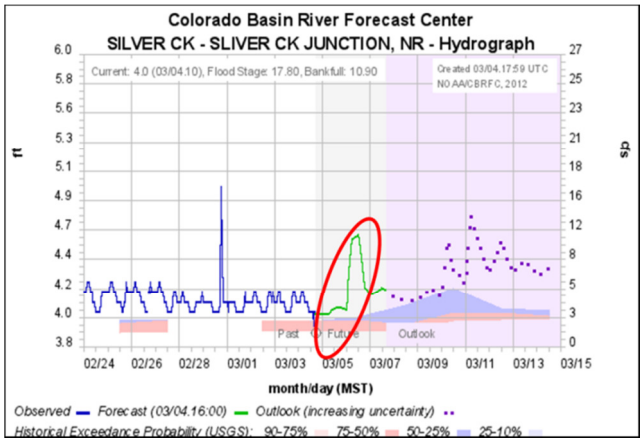

Figure 8, CBRFC forecast for March 5 2012

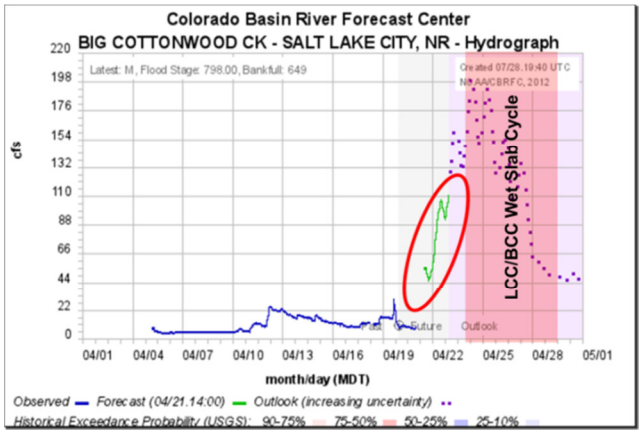

Figure 9, CBRFC forecast for April 20, 2012

7. SUMMARY

As stated in the introduction, this project is a work in progress and data sets are too limited at this time to draw any hard conclusions. Table 2 shows a summary of the findings. From the information presented, a few important points can be highlighted:

- Archived stream discharge data show the first significant flow spikes for a given season tend to occur around three days prior to the onset of wet avalanche activity in the cases presented. While this study focuses on such events at PCMR, there is

Year	Stream, Date of Discharge Increase	Avalanche Activity and Date
1985	East Canyon, March 16	Gobbler's Knob fatality, March 19
	East Canyon, March 23	PCMR upper mountain cycle, March 26-30
2002	East Canyon, March 22	Crescent Ridge, March 24
	East Canyon and Silver Creek, March 26	PCMR upper mountain cycle, April 1-5
2007	McLeod Creek, March 7 and 12	Crescent Ridge, March 13, PCMR upper mountain cycle, March 17-19
	East Canyon, March 8 and 11	
	Silver Creek, March 8	
	Big and Little Cottonwood Creeks, March 11	Gobbler's Peak BCC, March 13
2011	Silver Creek, March 14	Rocky Point, March 17
	East Canyon Creek, March 16	
2012	East Canyon and Silver Creek, March 5	PCMR and central Wasatch cycle, March 4-5
	Big Cottonwood Creek, April 20	Central Wasatch cycle April 23-27

Table 2, summary of discharge peaks and avalanche activity

evidence of a similar relationship with events elsewhere in the central Wasatch.

- Determining the timing and volume of discharge increases that may relate to wet slab activity is subject to observer interpretation. More precise statistical analysis could help determine threshold periods and levels.

- Of the gauges and corresponding discharge forecasts used, no single one stands out as superior within the context of this study. In developing this potential forecasting tool, all available local gauges should be compared before making any forecast decisions.

- CBRFC stream discharge forecasts have shown to be fairly accurate for the creeks draining PCMR especially with regards to the timing of increases in flow.

- Though this study has only compared two seasons worth of *forecast* data, I feel there is enough of a relationship between the first seasonal discharge peaks and the onset of wet avalanche activity to continue this work. Over the next few seasons, I will continue to build my dataset with the hope that these stream forecasts can become part of our toolbox for seasonal wet slab forecasting.

8. ACKNOWLEDGEMENTS

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I must also acknowledge the memory and career of Leif Eric Borgeson (1961-2011). This study was truly inspired by and benefited from his work in wet slab forecasting at Arapaho Basin.

9. REFERENCES

Carran, Wayne and Conway, Howard. 2006. Water outflow from snow during rain and melt events; Milford Highway, New Zealand. *Proceedings of the 2006 International Snow Science Workshop*. Telluride CO. P 796.

Conway, Howard *et al*. 2008. Guidelines for forecasting snow avalanches on the Milford Road, New Zealand. *Proceedings of the 2008 International Snow Science Workshop*. Whistler BC. P 257-261.

Hartman, Hal and Borgeson, Leif Eric. 2008. Wet slab instability at the Arapaho Basin Ski Area. *Proceedings of the 2008 International Snow Science Workshop*. Whistler BC. P 163-169.

Kobernik, Brett. 2008. Gobbler's Knob avalanche: Utah 3/13/07. *The Avalanche Review*, v. 26. No. 4, p 23.

McInerney, Brian. July 2012. Personal Communication.

Murakami, Eric. April 2012. Personal communication.

Peitzsch, Eric. 2008. Wet Slabs: What do we really know about them*?* *The Avalanche Review*, v. 26. No. 4, p 20-21.

Reardon, Blase and Lundy, Chris. 2004. Forecasting for natural avalanches during spring opening of the Going to the Sun Road, Glacier National Park, USA. *Proceedings of the 2004 International Snow Science Workshop*. Jackson WY. P 565-581.

Reardon, Blase. 2008. A conceptual model for wet-slab forecasting. *The Avalanche Review*, v. 26. No. 4, p 18-19.

Simenhois, Ron and Birkeland, Karl. 2010. Meteorological and environmental observations from three glide avalanche cycles and the resulting hazard management technique. *Proceedings of the 2010 International Snow Science Workshop*. Squaw Valley CA. P 846-853.

US National Weather Service. 2006. *Colorado Basin River Forecast Center*. http://www.cbrfc.noaa.gov/us/inform.php

US Forest Service Utah Avalanche Center. 2012. *Current conditions spring 2012.* http://old.utahavalanchecenter.org/services

Utah Division of Natural Resources. 2010. *Great Salt Lake Information System.* http://www.greatsaltlakeinfo.org/Background/WeberRiver.