INFLUENCE OF RECENT MAJOR ATMOSPHERIC RIVER EVENTS ON SNOWPACK IN WESTERN WASHINGTON

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ABSTRACT

Mid-latitude, east Pacific cyclones, with attached atmospheric rivers (ARs), are important in producing extreme, basin-wide precipitation events along the west coast of the U.S. and Canada. ARs are narrow corridors, <~1,000 km wide, of concentrated low-level water vapor, extending >~2,000 km long (Bao et al., 2006). After making landfall, ARs often produce abundant orographic rainfall when intersecting mountainous terrain. They are a major component in linking weather with climate, as they can produce a relatively high amount of the annual winter precipitation in a few days. ARs play an important role in water management, flood control, and water supply, as well as public safety. Studies indicate ARs generally increase snowpack through California, but in western Washington their influence generally causes minor decreases in snow water equivalent due to generally lower terrain and relatively higher AR snow levels. This paper explains the nature of recent major AR weather events (WY 2004 - 2009) and examines their effect on the snowpack in western Washington. (KEYWORDS: atmospheric rivers, orographic rainfall, precipitation, flood control, water management)

INTRODUCTION

The climate of western Washington is mild and wet, with most of the annual rainfall in the fall and winter months. The basins favor winter snow at the medium and higher elevations, with rain in the lower elevations. The upper basin topography is steep and drainages are considered flashy. Rapid and high runoff occurs from intense rainfall produced by mid-latitude cyclones with attached atmospheric rivers (ARs) (Ralph, et al., 2006) (Figure 1).

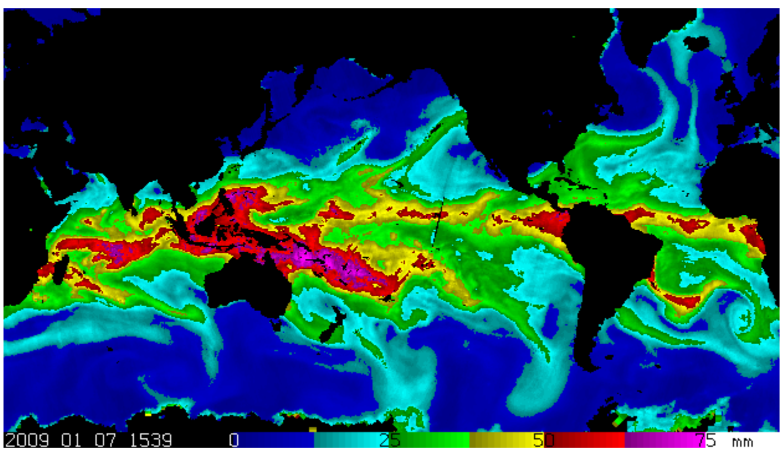

Figure 1. AR low level moisture aimed at western Washington on January 7, 2009. Incoming ARs are best assessed utilizing satellite microwave imagery, like this image from the SSM/I satellite.

Four intense ARs struck western Washington between WY 2003-2009. The region was inundated with record rainfall, historic flooding, avalanches and thousands of landslides. Tens of thousands of people have been impacted, with tens of millions in damages and flood flight costs. Despite the impressive impacts, effective flood risk management operations by the U.S. Army Corps of Engineers (USACE) and others have resulted in prevention of potentially billions of dollars in flood damages. All these AR events share common themes, yet they were uniquely different.

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The impact of ARs on snowpack will differ depending on elevation and proximity to the AR heavy precipitation core. Location and duration of the warm air advection sector in a storm can also affect snowpack. Precipitation at higher elevations, above 7,000-8,000 ft, might occur as snow due to colder air temperatures, resulting in snow accumulation. There are no Snow Telemetry (SNOTEL) sites above 6,000 ft in the Cascade Range, but higher elevation ski area observations occasionally confirm this. Intermittently there is shallow, cold continental air flowing from the east into the western Cascade Range, which will temporarily push local snow levels downward under overall AR conditions. For the most part, the warm sector of a storm, containing the AR, will see snowpack lessen with rain-on-snow melting. The impact is most pronounced at elevations below 6,000-8,000 ft, which is most of the Cascade Range, except for the higher peaks. The warm sector also contains the highest water vapor and precipitation rates. There can be a variety of effects on snowpack, including retention of rain in the snowpack, which could reduce immediate flood risk.

CRITERIA FOR RECENT MAJOR AR EVENTS IN WESTERN WASHINGTON

The selection of these four recent, major AR events met several different criteria. They all display common themes, yet differ in the location, magnitude and duration. Their severity was memorable to the public and emergency management professionals, whereas each AR event resulted in a major public safety concern due to flooding.

These four selected weather events can be generalized into two different groups depending on weather patterns and basins of impact. The October 20-t21, 2003 and December 3-4 , 2007 events showed a more southerly flow and concentrated mainly on the coast, Olympic Mountains and northern Cascade Range. The November 6-7, 2006 and Jan 7-8, 2009 events exhibited south and westerly flow, favoring westerly oriented basins and the central and southern Cascade Range. All events spread precipitation throughput the region, but their major influence was usually centered near the AR core producing the heaviest precipitation rates in specific areas.

All four events met the minimum criteria for AR classification based on the Special Sensor Microwave Imager (SSM/I) satellite imagery displaying an integrated water vapor of greater than 2,cm. (Neiman et al., 2008a).

These specific AR events produced major and historic flooding in western Washington. Each storm generated one or more "floods of record" (U. S. Geological Survey record peak instantaneous flow- highest peak on record) at different western Washington stream gages. Also, each event produced more than a 15.00 inch multi-day storm total at one or more rain gages and one or more rain gages had > 6 inches in 24 hours. In addition, each event broke one or more daily rainfall records.

Often, daily maximum high or maximum low temperature records were also broken, due to strong warm air advection. In addition, hourly rainfall rates often exceeded .30 inches per hour at one or more rain gages for many hours.

All of these events resulted in major flood control dam regulation to be undertaken by the USACE, Seattle District at one or more dam projects. The USACE Water Management Reservoir Control Center and Emergency Management was activated and staffed 24/7 during these events. Each event caused a major public flood threat and caused tens of millions of dollars in damages and related flood flight, avalanche control and landslide cleanup costs. Despite damages, billions of dollars in flood damages were prevented by active flood risk management and storm intensity forecasting (Figure 2).

WEDNESDAY, JANUARY 7, 2009

HEAVY RAIN, BREEZY
High, 52. Low, 45.
> LOCAL B14

The Seattle Times

75¢

Independent and locally owned since 1896 | seattletimes.com
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DOWNPOUR

Deluge will hit Cascade snowpack

Flooding may close I-5 again at Centralia

Avalanche shuts down Stevens Pass

BY SANDI DOUGHTON
Seattle Times science reporter

Cities across Western Washington are bracing for another slap from a season that has already dealt the region a series of nasty blows.

This time, the pain will come in the form of drenching rain followed by floods and the threat of landslides and avalanches, forecasters warned Tuesday. Some rivers, particularly in Lewis County, could reach record levels, and it's possible Interstate 5 near Centralia could be submerged again — as it was for several days in December 2007.

Major flooding also was forecast on the Skagit River near Concrete, the Snohomish River near Monroe, the Tolt River near Carnation, and the Snoqualmie River near Carnation and Snoqualmie Falls.

Please see > FLOODING, A6

WEB EXTRA
The latest forecast, *traffic alerts and a list of flooding-related resources are at* seattletimes.com

COURTNEY BLETHEN / THE SEATTLE TIMES
High winds and rain on Tuesday caused cars to inch along the 520 bridge.

City never responded to Metro's plea to plow

CALLS WEREN'T RETURNED, BUS-SYSTEM CHIEF SAYS

Poor communication crippled transit snow plan

BY EMILY HEFFTER
Seattle Times staff reporter

A chaotic command center and poor communication with Seattle road crews kept so many buses out of service that Metro's emergency snow plan was all but useless during the Christmas snowstorm that stranded thousands of riders, a Metro official said Tuesday.

King County Metro General Manager Kevin Desmond told the City Council that

Please see > METRO, A6

Figure 2. Seattle Times headline for the January 7, 2009 AR event

October 2003 AR Event

The October 2003 AR event was unique in many ways. It first impacted British Columbia to the north, and then settled over the northwest section of western Washington. The AR was active for six days. This AR event was very early in fall/winter flood season and the earliest a major and historic flood had ever been recorded. The AR hammered western Washington with flooding, devoid of the classic antecedent flood criteria. In this case there was a lack of mountain snow, dry soil conditions and a record dry period before the storm hit. Seattle was pummeled with an all-time 24 hour record rainfall of 5.02 inches of rain, shattering the previous record. Rainfall was substantial and intense as seen in the Thunder Basin SNOTEL site (Figure 3). Note, the river flooding came with the second and final intense surge of precipitation. Storm totals in the mountains were greater than 20 inches of rain. There was virtually no snowpack in the Cascade Range

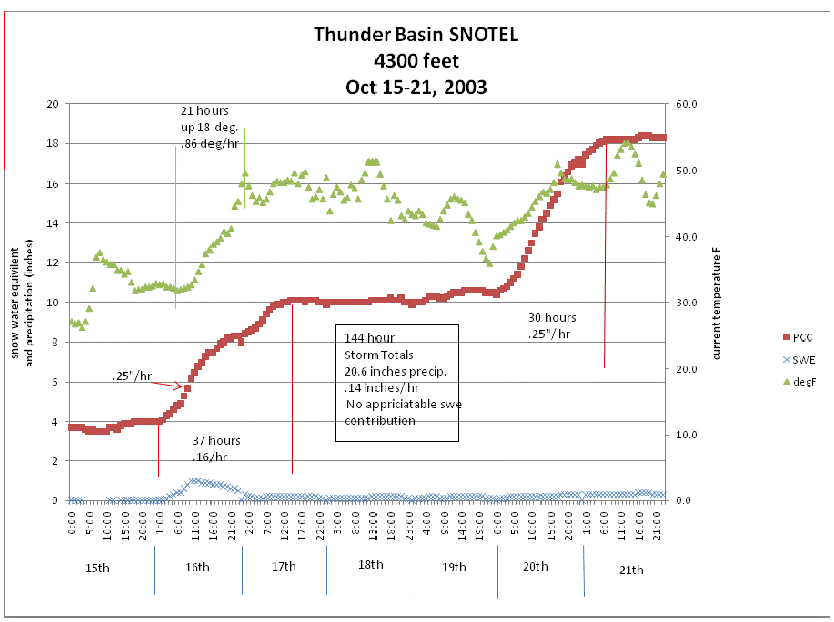

Figure 3. Thunder Basin SNOTEL had a total of 20.6 inches precipitation (PCC) in 144 hours. Note the rapid rise in temperature and sustained high temperatures during both storm surges.

<u>November 2006 AR Event</u>

The November 2006 event also occurred with little or no snowpack in the Cascade Range. This event initially targeted the northern Cascade Range, but suddenly shifted slightly southward and settled over the central and southern Cascade Range as seen in (Figure 4) (Neiman et al., 2008b). Historic flooding occurred from the central to the southern Cascade Range but the Skagit Valley was spared from forecasted catastrophic flooding, resulting from the minor move southward.

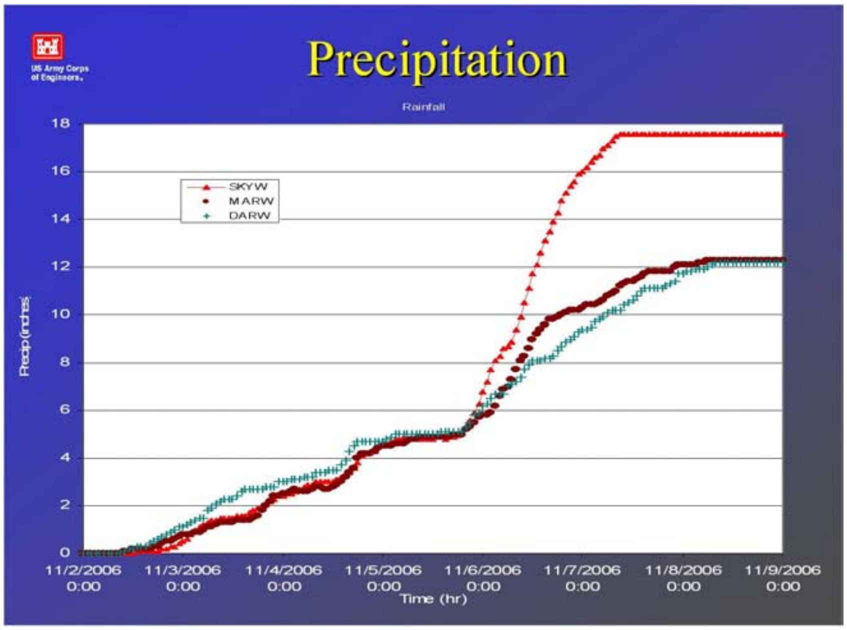

Figure 4. Precipitation concentration shifts south (SKWY), sparing catastrophic flooding in the Skagit River Valley (MARW & DARW).

Rainfall was heavy with high rainfall rates. Storm totals were impressive with amounts ranging from 10 – 38.5 inches, causing record peak runoff in 12 western Washington, rivers including the Skykomish River (Figure 5). The June Lake SNOTEL site near Mt. St. Helens received large amounts of rainfall; a new "unofficial" state record with 14.6 inches in 24 hours was recorded on November 6, 2006 (Figure 6)

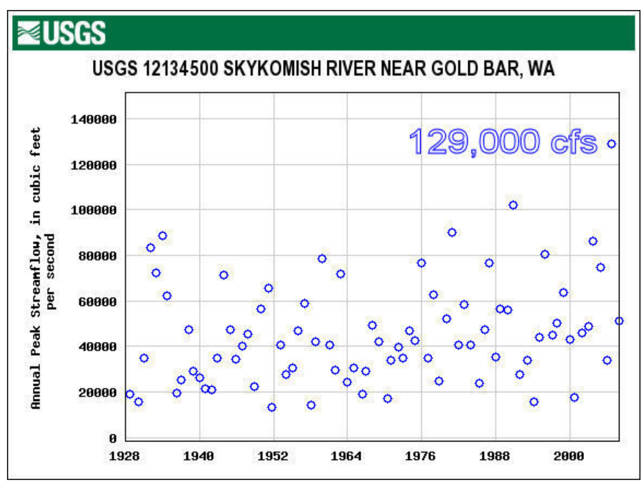

Figure 5. November 2006 - Record 129,000 cubic feet per second

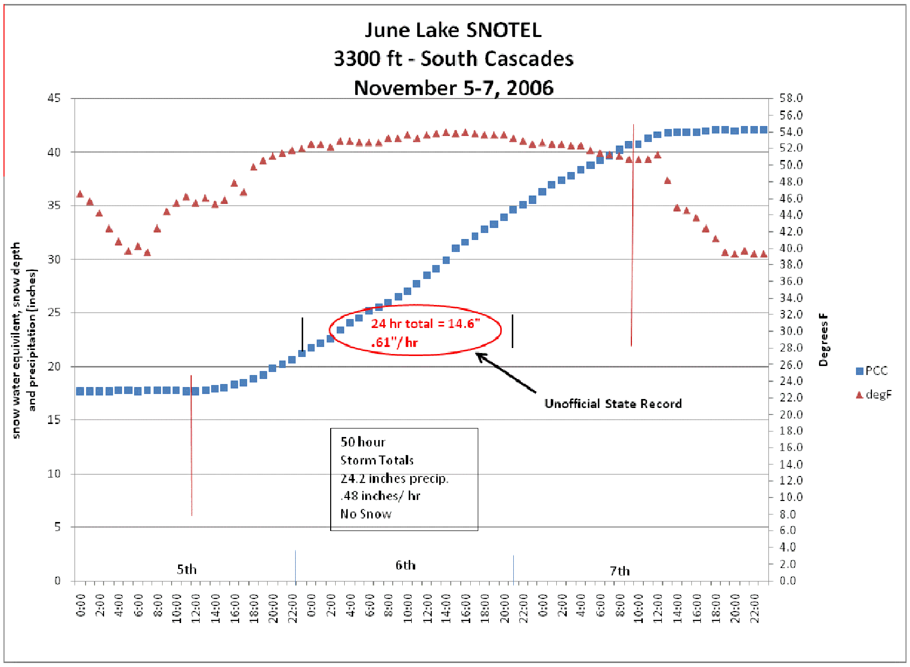

Figure 6. June Lake SNOTEL, November 5-7, 2006

December 2007 AR Event

The December 2007 AR event occurred with 50-70% of average snowpack at higher elevation but well above average at elevations below 3,500 feet. Snowpack contained very low density snow from a previous sustained, very cold weather pattern with a moderate-to-heavy precipitation cycle, previous to the AR event (Figure 7). Low density snow allowed for the apparent absorption of the rain event with very little loss of snow water equivalent at the higher sites. However, some low elevation sites were stripped of all snow by the end of the storm (Figure 8).

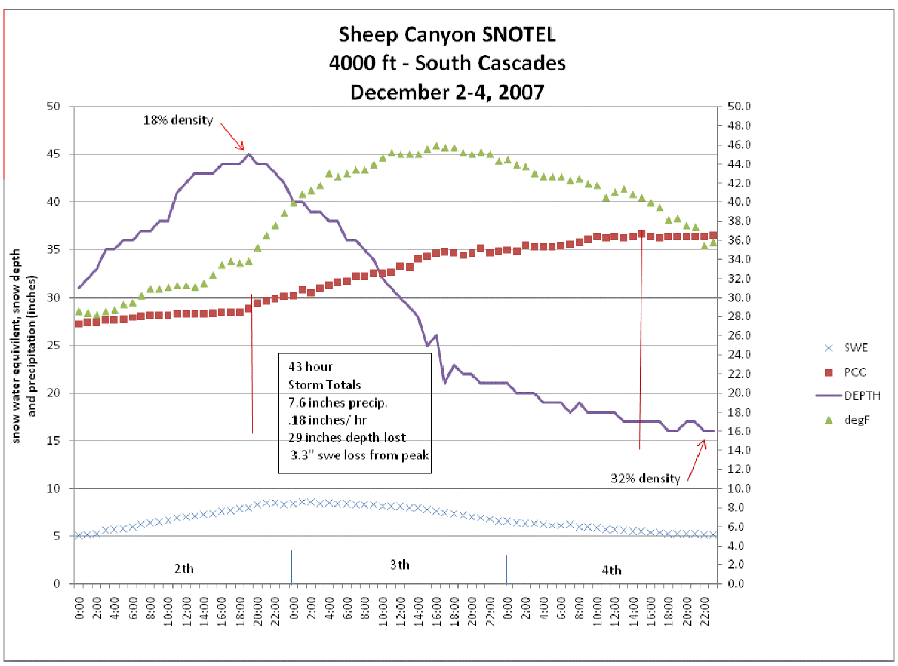

Figure 7. Sheep Canyon SNOTEL showed very low density snow prior to the AR event.

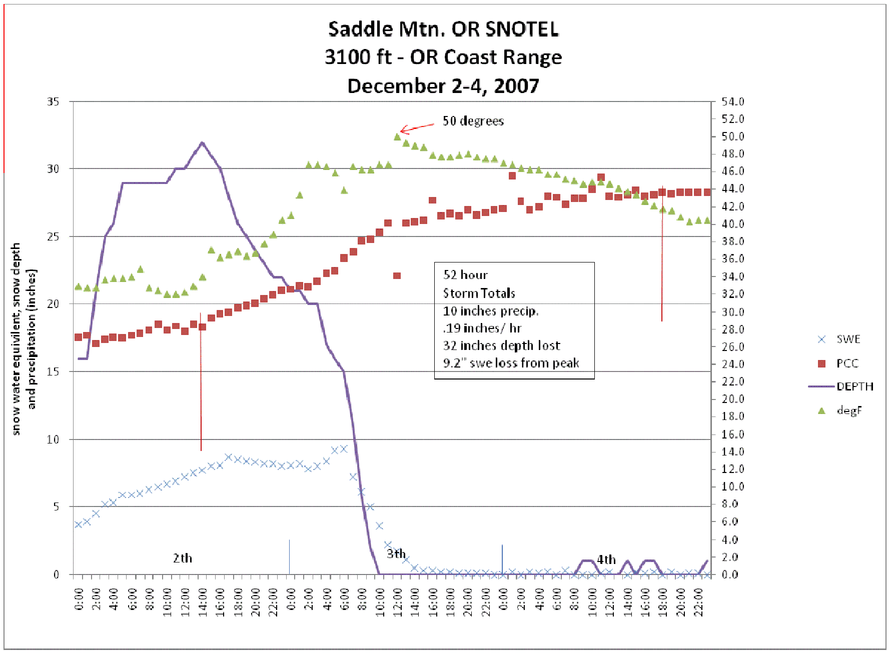

Figure 8. Saddle Mountain SNOTEL, Oregon Coast Range

Heavy rain and extraordinary storm totals and rainfall rates occurred in the southwest part of western Washington in the Chehalis River basin (Figure 9). The Chehalis River at Doty recorded a 500 year flood event at over 60,000 cubic feet per second (Figure 10).

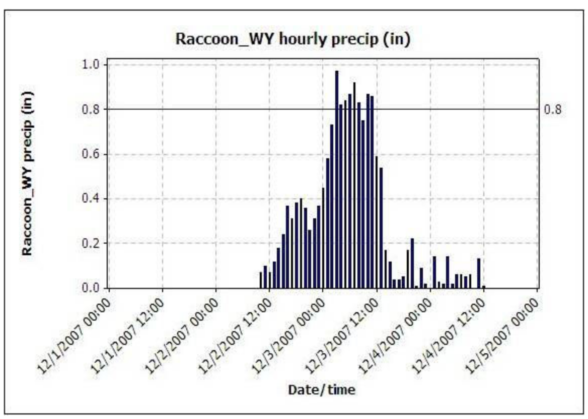

Figure 9. Raccoon Creek hourly precipitation (Courtesy Weyerhaeuser)

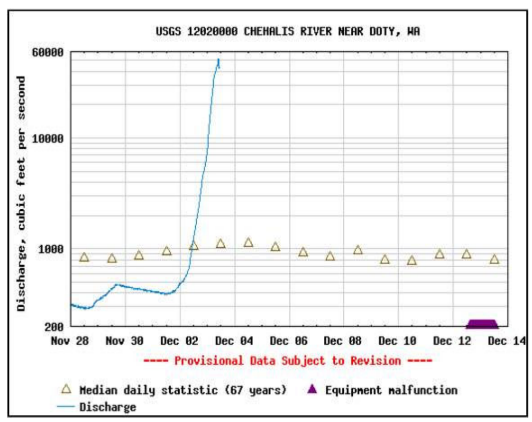

Figure 10. Chehalis River at Doty (500 yr flood): the gage failed on this graph, but USGS later estimated greater than 62,000 cfs, more than twice the former record.

This storm also produced very strong and damaging winds, with gusts exceeding 120 miles per hour (Tillamook, OR.) Wind duration was also a factor, with winds in the 40-60 mile per hour range for about 72 hours. 18 lives were lost in relation to this AR event.

January 2009 AR Event

The January 2009 AR event was aimed mainly at the central Cascade Range of Washington. There was a low elevation snowpack below 1,500 ft with between a trace to 18 inches. On average snowpack was near normal in the central Cascade Range (Figure 11). Roughly there was 10-20 inches of rain. Snow density was low. The snow level was 7,000 ft during the storm but varied from the colder northern Cascade Range to milder southern Cascade Range. Some snow accumulation occurred later in the northern Cascade Range, whereas the central and southern Cascade Range saw limited snowmelt and apparently some precipitation storage in the snowpack.

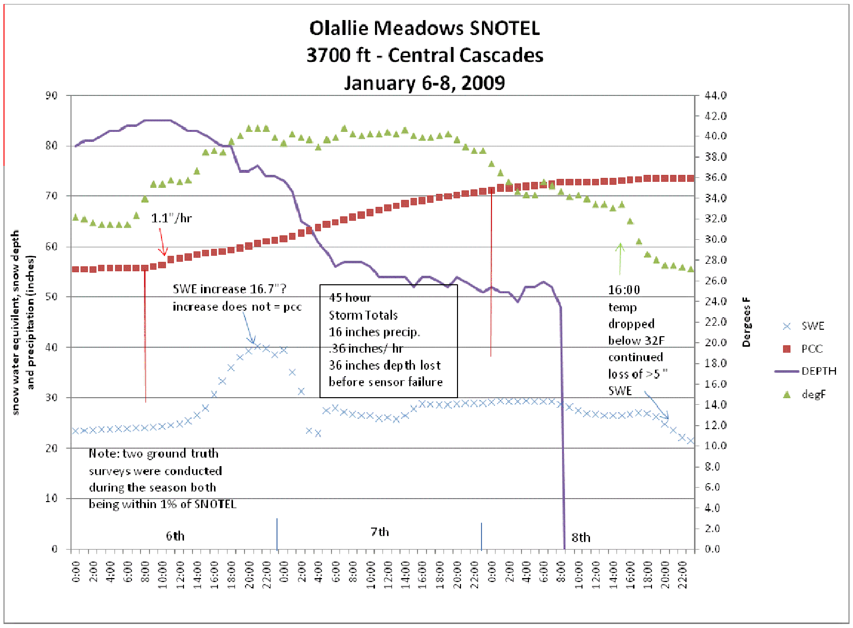

Figure 11. Olallie Meadows SNOTEL, Central Cascade Range

This event produced near record high flows for several rivers in the central Cascade Range. The following graphs indicate the record high flows for the Snoqualmie River at Carnation and the Tolt River near Carnation, WA (Figures 12 & 13).

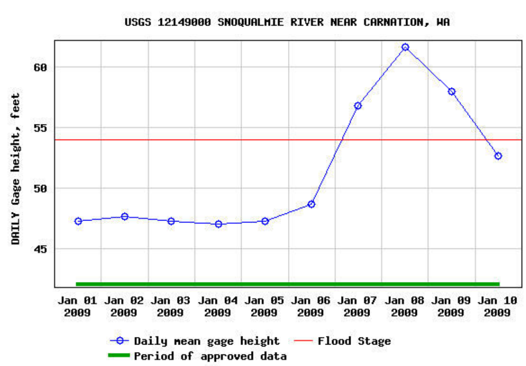

Figure 12. Snoqualmie 8 ft above flood stage

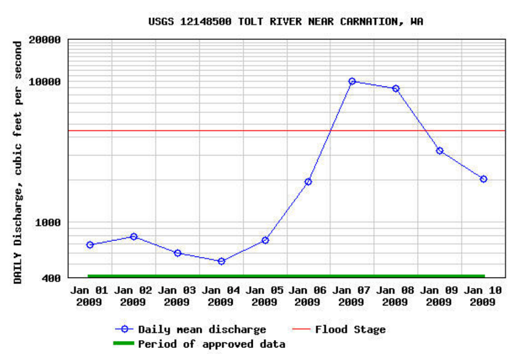

Figure 13. Tolt River record flood 2009

Not uncommon to AR events are landslide activity. This storm proved to not only follow suit but to produce a large number of landslides. Washington State agencies reported that at least 1,500 landslides of all sizes and magnitudes occurred all over the state due to this event. One in particular was the Hyak Ski Area slide which destroyed the ski lift and caused damage to more than one local residence (Figure 14)

Figure 14. Landslide at Hyak ski area, January 7, 2009

SUMMARY

The influence of atmospheric rivers on snowpack in western Washington favors rain-on-snow precipitation events. This is due to high snow levels caused by strong warm air advection associated with incoming AR storms. ARs rarely add new snowpack due to these high snow levels. Snowpack may sometimes reduce flood risk by storing or slowing rainfall runoff, especially falling on low density snowpack. Snowmelt does occur, but is considered minor, compared with copious rainfall, which remains the primary driver for flooding. Note in two of these four major AR events there was little or no snowpack, yet all events produced historic flooding. It should also be noted ARs are narrow and sometimes their effects are limited to a few basins. Occasionally major SWE loss does occur (Saddle Mountain & Olallie Meadows). The culprit appears to be strong winds coupled with high humidity producing greater melt efficiency, but this should be further investigated.

REFERENCES

Bao, J.W., S.A. Michelson, P.J. Neiman, F.M. Ralph, and J.M. Wilczak. 2006. Interpretation of enhanced integrated water-vapor bands associated with extratropical cyclones: Their formation and connection to tropical moisture. *Mon. Wea. Rev.*, **134**, 1063-1080

Neiman, P.J., F.M. Ralph, G.A. Wick, J. Lundquist, and M.D. Dettinger. 2008a. Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite observations. *J. Hydrometeor*., **9**, 22-45.

Neiman, P.J., F.M. Ralph, G.A. Wick, Y.-H. Kuo, T.-K. Wee, Z. Ma, G.H. Taylor, and M.D. Dettinger. 2008b. Diagnosis of an intense atmospheric river impacting the Pacific Northwest: Storm summary and offshore vertical structure observed with COSMIC satellite retrievals. *Mon. Wea. Rev.*, **136**, 4398-4420.

Ralph, F.M., P.J. Neiman, G.A. Wick, S.I. Gutman, M.D. Dettinger, D.R. Cayan, and A.B. White. 2006. Flooding on California's Russian River: The role of atmospheric rivers. *Geophys. Res. Lett.*, **33**, L13801, doi:10.1029/2006GL026689