THE SPATIAL AND TEMPORAL VARIABILITY OF RAIN-ON-SNOW

Sue A. Ferguson*
USDA-FS, Pacific Northwest Research Station

ABSTRACT: Snow melt during rainfall causes large-scale flooding and avalanching. These rain-on-snow events are most well-documented in the coastal mountain ranges of western North America. To determine what role they play in interior mountains, we analyzed flood frequencies in the Columbia River basin and modeled rain-on-snow potential from daily temperature and precipitation data. Applying the model with geographically distributed weather data allowed maps of rain-on-snow potential at 2km spatial resolution to be generated for characteristic climate years of 1982 (cold and wet), 1988 (warm and dry), and 1989 (average). It was found that rain-on-snow events are more likely during cool, wet years (such as 1982). A greater number of events and more widespread distribution of events occur during this type of climate. The cool temperatures allow low-elevation snow to accumulate and frequent storms bring the possibility of mid-winter rain. Warm, dry years (1988) are less likely to experience rain-on-snow events. There is little low-elevation snow at these times and only occasional precipitation. During all years, areas most susceptible to rain-on-snow are those where topography allows incursion of relatively warm, moist marine air that flows from the Pacific Ocean into the Columbia Plateau and up the Snake River Valley. These areas include the Cascade mountains; northern Idaho, northeastern Washington, and northwestern Montana where valleys open into the Columbia plateau; the Blue Mountains of northeastern Oregon; and western Wyoming and central Idaho adjacent to the Snake River.

KEYWORDS: snow, avalanches, rain-on-snow, floods

1. INTRODUCTION

Rain falling on snow is a major cause of mid-winter avalanches (Wilson 1986; Conway and others, 1988; Heywood, 1988; Osterhuber and Kattelman, 1998). Also, rain-on-snow (ROS) can produce severe runoff and erosion with intense and damaging floods (Harr 1981; Beaudry and Golding 1985;Hall and Hannaford 1983; Harr and Cundy 1990). Most ROS effects have been documented in coastal areas of western North America. Further away from the coast a pervasive winter snow cover is typical but mid-winter rain is less common. Unlike other continental interiors, however, the Columbia River basin has a unique topographic configuration that allows incursion of warm, moist air from the Pacific Ocean. This causes occasional rain to fall onto the existing snow cover. Resulting floods are less frequent but equally destructive (Cooley and Robertson 1983; MacDonald and others 1995; Zuzel and Greenwalt 1985; Zuzel and others 1983; Speers and others 1990). Anecdotal evidence suggests that related rain-on-snow (ROS) avalanches in interior Columbia basin are equally significant.

Because documentation of ROS events is limited, it is difficult to anticipate and mitigate potential hazards. To help overcome the lack of useful information, this work investigates the spatial and temporal distribution of ROS events in the basin as a special project for the scientific integration team of the Interior Columbia Basin Ecosystem Management (ICBEM) project (Jensen and others 1997) .

As time was limited for ICBEM results, we began our investigation by analyzing the spatial extent of rain-induced floods, which are more easily distinguished from pure snow-melt floods than rain-induced avalanches are from other avalanche types in the historical record.

* Dr. Sue A. Ferguson, USDA-FS, Pacific Northwest Research Station, 4043 Roosevelt Way NE, Seattle, WA 98105-6497; tel. 206-732-7828; fax. 206-732-7801; email. Sferguson@fs.fed.us

Next we reviewed the literature to define a simple algorithm that could be used to identify ROS patterns from daily climate data. Finally, we mapped ROS potential across the Columbia basin and identified problem areas.

2. EXTENT OF ROS PROBLEMS IN THE COLUMBIA RIVER BASIN

Unregulated stream gages in the Wallis-Lettenmaier-Wood data set (1991) in the Columbia Basin above the Dalles were used to assess the extent of ROS problems in the interior Columbia basin. The maximum daily flow for each station was found in the 40-year period of record, 1948-1987. Floods were classified as ROS events if they occurred during the months of October to February. Those that occurred in other months were classified as pure snow melt (i.e., dominantly radiation melt) events. Note that rain falling on spring snow also can cause flooding. The character of spring events are different than those in winter (McDonald and Hoffman 1995) with larger floods more common during winter (Johnson and McArthur 1973).

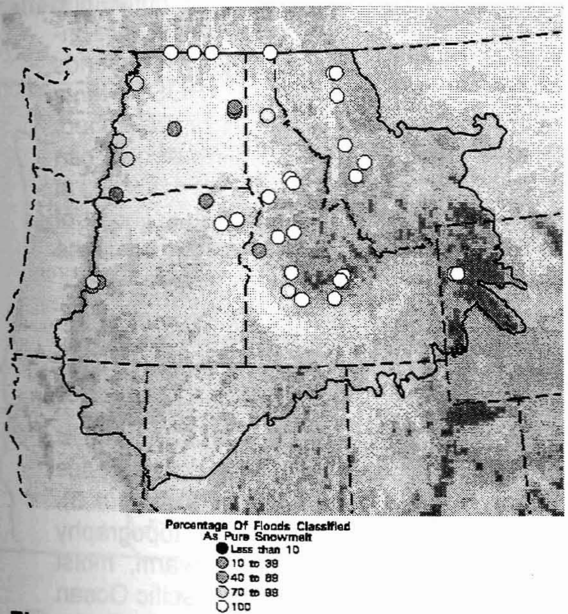

Figure 1. Percent of floods that are classified as pure snow melt on unregulated river gage sites in the interior Columbia river basin.

Figure 1 shows the gage sites and the percentage of floods that were classified as rain-on-snow or pure snow melt at each site. Twenty three of the stations had no floods that were classified as rain-on-snow. These stations generally either represent streams that head in the Rockies or represent relatively high elevation catchments. Those stations in the interior basin that were classified with a high percentage of ROS floods represent relatively low elevation catchments. This agrees with Harr and Cundy (1992) findings that ROS events occurring at low elevations can significantly enhance resulting floods.

Even with a low percentage of ROS floods, it is interesting to note that several stations experience their heaviest floods during the infrequent ROS events. For example, Figure 2 shows that only one ROS event occurred on the Boise River near Twin Springs, Idaho; yet is was the largest flood event ever recorded. A similar tendency for ROS to be associated with large flooding is seen in most basin streams. In a different study, MacDonald and Hoffman (1995) found several streams in northwestern Montana and northeastern Idaho where mid-winter rain falling on snow was responsible for the largest peak flows recorded.

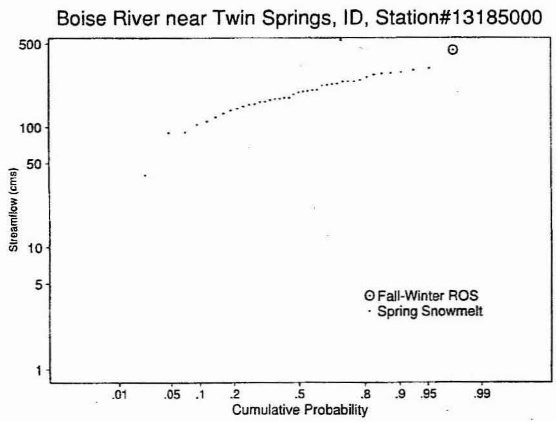

Figure 2. Cumulative probability of flood events on the Boise river near Twin Springs, ID.

The results of this simple analysis are useful in showing the possible extent of ROS events in the basin. It only can show potential problems in relatively large catchments, however, below which stream gages are located. Significant flooding on smaller streams or portions of catchment basins can be critical when considering avalanching, fish and riparian habitats, slope stability, and road maintenance. Also, the seasonal analysis of stream gage data does not distinguish whether a snow cover preceded flooding or not. Significant mid-winter floods in the basin can be caused by rain falling on frozen soil, without snowmelt (Zuzel and others 1983; Molnau and Bissel 1983).

3. MODELING THE DISTRIBUTION OF ROS EVENTS

Wet-snow avalanching often coincides with flood events, occurring at high elevations where percolating rain water helps to strip away layers of snow. Resulting avalanches occur within a few minutes to a few hours after the onset of rain (Conway and Raymond 1993). In most cases, a layer of new snow is required. This is true both for avalanching (e.g., Conway and Raymond 1993; Osterhuber and Kattelman 1998) and floods (e.g., Zuzel and Greenwalt 1985; Hall and Hannaford 1983; Kattleman and others 1991; Zuzel and others 1983; Beaudry and Golding 1983). The depth of new snow required prior to a slide or flood has been observed at less than 2.5 cm (1") to well over 40 cm (16"). The relationship between the amount of new snow and the magnitude of warming or subsequent rain appears to make little difference in determining the onset of an event as long as the snow is relatively fresh, within a few days (Osterhuber and Kattelman 1998). So-called active snow is assumed to have low enough density to allow rapid response to an influx of rainwater.

Following Zuzel and Greenwalt (1985) we define a ROS event as 1) existing snow, 2) maximum daily temperature exceeding 0 °C, and 3) rain. No amount of snow or rain, or magnitude of temperature increase is specified. Because spatially distributed snow cover information were not available for this study, we approximated snow accumulation as precipitation occurring with maximum daily temperature less than 0 °C in the two weeks before the onset of warming and rain. The two week period was chosen to ensure that the snow was relatively new and "active."

Spatial temperature and precipitation records were specifically generated for the ICBEM project (Thorton and Running 1996). The Thornton and Running daily weather data were generated by a topographically sensitive, spatial regression program, MTCLIM-3D, for three characteristic years; 1982 (cool and wet), 1988 (warm and dry), and 1989 (normal) as defined by the Columbia River Basin Ecological Assessment Project (see Ferguson 1998). Because the data were for calendar years, not water years, ROS events that may occur in the first 2 weeks of January were not captured.

The occurrence of a ROS event at any given point or pixel on a map does not determine whether avalanching or flooding ensues. Rather, the magnitude of rain-on-snow that causes sliding or runoff depends on the spatial extent of ROS events throughout a particular slope or watershed. A spatial view of ROS events not only can show the probability of an event occurring at a particular place, but also the likelihood of the aggregation of events needed to cause flooding or wide-spread avalanching.

4. MAPPED ROS POTENTIAL

Mapping ROS event potential showed that during a typical winter in the northwest (1989) certain areas of the basin experience ROS events on a regular basis (Figure 3). These include places where the topography allows incursion of relatively warm, moist marine air that flows from the Pacific Ocean into the Columbia Plateau and up the Snake River Valley. For example, on the eastern slopes of the Cascade mountains moisture spills over from the coast. In northern Idaho, northeastern Washington, and northwestern Montana, valleys open into the Columbia Plateau. The Blue Mountains of northeastern Oregon is in direct line with moisture flowing through the Columbia gorge. Western Wyoming and central Idaho are adjacent to the Snake River, which also opens into the Columbia.

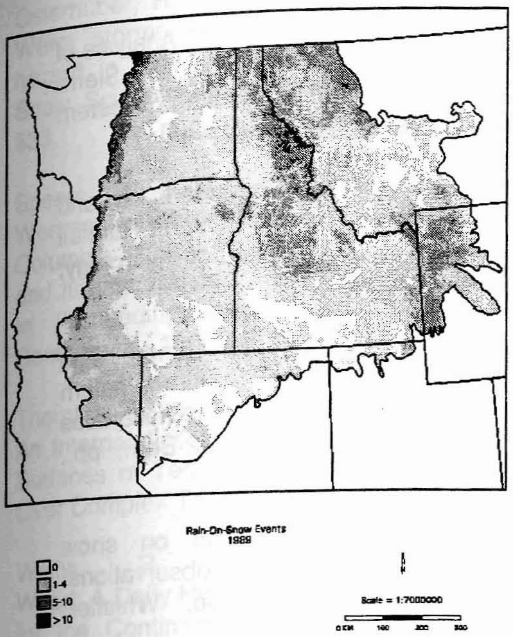

Figure 3. Potential rain-on-snow event pattern during the normal winter of 1989.

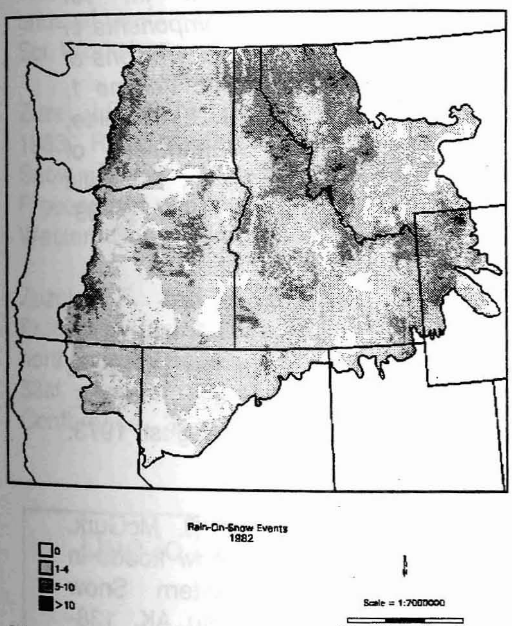

Figure 4. Potential rain-on-snow event pattern during the cool, wet winter of 1982.

Zuzel and Greenwalt (1985) found that the number ROS events in the transient snow zone of northeastern Oregon average about 5 per year. Cooley and Robertson (1983) note that snow accumulation can occur 3 to 4 times each year in the transient snow zone of Idaho and if these are followed by rain, flooding often ensues. These observations match mapped occurrences during the typical year of 1989.

During years that are colder and wetter than normal (e.g., 1982) it appears that a higher frequency of ROS events occur in already susceptible areas (Figure 4). Also, ROS events appear to occur in less susceptible areas, like eastern Idaho and southwestern Montana. In colder than normal years, snow has a greater chance of accumulating at low elevations. The wetter

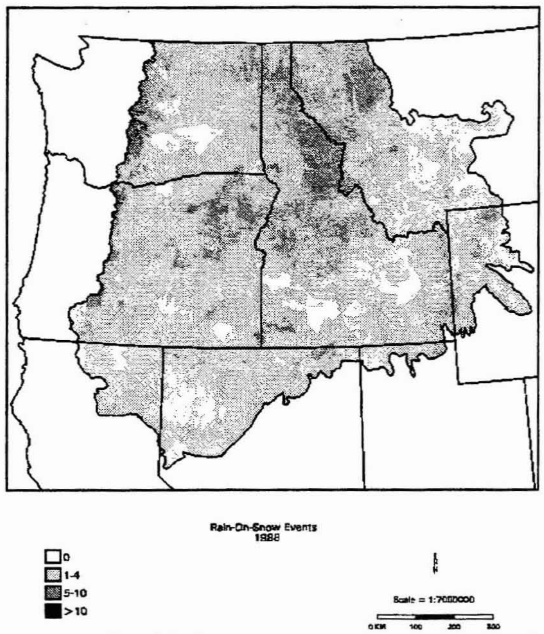

Figure 5. Potential rain-on-snow event pattern during the warm, dry winter of 1988.

than normal conditions, however, indicate that a number of precipitating storms pass over the area. Many are snow storms, but because of the proximity to moderating maritime weather, a few rain storms also are possible during the wet northwest winter.

When the climate is warmer and drier than normal (e.g., 1988) the area that ROS events occur is reduced (Figure 5). There is little low elevation snow at these times and only occasional precipitation.

5. CONCLUSION

Maps showing ROS potential during characteristic climate years were helpful in assessing the potential spatial and temporal distribution of related flooding and avalanching. Lack of a more complete climate record and consistent observations of actual events, however, prevented more rigorous analysis. Nevertheless, the simple rule for identifying ROS conditions is consistent with case studies found in the literature. Also, because our simple rule uses daily climate data it easily can be applied anywhere there is an interest in estimating the frequency of potential ROS events.

6. ACKNOWLEDGEMENTS

This work was partly funded by the interagency Interior Columbia River Basin Ecological Assessment Project and the USDA-FS, Pacific Northwest Research Station. Many thanks to Dennis Lettenmaier, Kristina Colburn, Don Jewett, and Miriam Rorig for their contributions to this project.

7. REFERENCES

Beaudry, P. and D. L. Golding; Snowmelt During Rain-on-Snow in Coastal British Columbia; 51st Annual Meeting Western Snow Conference, pp. 55-66; 1983.

Conway, H., and C.F. Raymond, 1993. Snow stability during rain. J. Glaciol., 39 (133), 635-642.

Conway, H., S. Breyfogle and C. Wilbour, 1988. Observations relating to wet snow stability. Proc. Int. Snow Sci. Workshop, Whistler, BC. 211-222.

Cooley, K. R. and D. C. Roberson; Monitoring a Rain on Snow Event, 51st Annual Meeting Western Snow Conference; pp. 19-26; 1983.

Ferguson. S. A. 1998. Climatology of the interior Columbia River basin. Anonymous. Anonymous. Portland, Oregon:U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. PNW-GTR. 53p.

Hall, R. L. and J. F. Hannaford; Analysis of Three Rain on snow Floods in the Sierra Nevada; 51st Annual Meeting Western Snow Conference; pp. 46-54; 1983.

Harr, R. D. ; Some Characteristics and Consequences of Snowmelt During Rainfall in Western Oregon; Journal of Hydrology; 53; pp. 277-304; 1981.

Harr, R. D. and T. W. Cundy; The November 1990 Floods in Western Washington, U.S.A.; Internationales Symposium Interpraevent 1992-Bern; pp., 229-239, 1992.

Heywood, L. 1988. Rain on snow avalanche events – some observations. Proc. Int. Snow Sci. Workshop. Whistler, BC. 125-136.

M. Jensen, I. Goodman, K. Brewer, T. Frost, G. Ford, and J. Nesser. Biophysical Environments of the Basin. In: *An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins: Volume 1*, edited by T. M. Quigley and S. J. Arbelbide, Portland, Oregon:USDA Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1997, p. 99-307.

Johnson, C.W.; McArthur, R.P. 1973. Winter storm and flood analyses, northwest interior. In Proceedings of the Hydraulic Division Specialty Conference. ASCE. Boseman, Montana. 15-17 August 1973. 359-369.

Kattelman, R., N. Berg, and B. McGurk. 1991. A history of rain-on-snow floods in the Sierra Nevada. Western Snow Conference, April 13-15. Juneau, AK. 138-141.

MacDonald, L. H. and J. A. Hoffman; Causes of Peak Flows in Northwestern Montana and Northeastern Idaho; Water Resources Bulletin; 31, no. 1, pp 79-95, 1995.

Osterhuber, R. and R. Kattelmann. 1998. Warm storms associated with avalanche hazard in the Sierra Nevada. Proc. Int. Snow Sci. Workshop, Sunriver, OR. 526-533.

Speers, D.D.; D.J. Barcellos; and R.T. Wortman. 1990. The 1948 flood on the Columbia River: An analysis of its cause and its importance in operational planning. In Proceedings of the Western Snow Conference. 160-163.

Thornton, P. and S. Running; MT-CLIM-3D; An Interpolation Logic for Generating Daily Surfaces of Temperature and Precipitation Over Complex Topography; 1994.

Wallis, J. R. , D. P. Lettenmaier, E. F. Wood; A Daily Hydroclimatological Data Set for the Continental United States; Water Resources Research; v. 27, pp. 1657-1663, 1991.

Wilson, N. 1986. A widespread cycle of unusual avalanche events. Proc. Int. Snow Sci. Workshop. Snowbird, UT 153-154.

Zuzel, J.F., R. N. Greenwalt, R. R. Allmaras. 1983. Rain on Snow: Shallow, Transient Snow Packs with Frozen Soils. In Proceedings of the 51st Annual Meeting Western Snow Conference. 67-73.

Zuzel, J.F. and R. N. Greenwalt. 1985. Probability distributions of rain on snow for northcentral Oregon. In Proceedings of the 53st Annual Meeting Western Snow Conference. 37-43.

Due to technical difficulties, this paper was not presented at the workshop. A copy of the presentation can be found at:

http://www.fs.fed.us/pnw/fera/sue/snow.html
select ISSW2000