WHAT MAKES RAIN-ON-SNOW EVENTS HAZARDOUS: FIELD STUDY AT WARD VALLEY, LAKE TAHOE BASIN

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ABSTRACT

Rain-on-snow events tend to be more hazardous than snow-free-rainfall-runoff or snowmelt events in Western States. The field observations in Ward Creek watershed, Tahoe Basin, showed that the snowmelt induced by energy flux from raindrops scarcely contributes to the hillslope runoff during the major rain-on-snow event of May 7, 2000, due to the cold weather. Spring high flows in the Sierra Nevada may be mainly due to the high soil-water content in the top soil kept by continuous snowmelt water supply. It was also found that the overland flow or longitudinal flow within the snowpack may still happen even over unfrozen and unsaturated topsoil on a relatively mild hillslope (16 %). The overland/in-snow flow may be due to the difference in hydraulic conductivities of the snow and the top-soil. This overland flow within the snowpack may form up to 10 percent of the peak flood discharge at the field hillslope scale. It may be hypothesized that the overland/in-snow flow on the unsaturated top soil may be a common phenomenon. The high flood peak of the rain-on-snow events may be magnified by this in-snow fast runoff mechanism as well as the snowmelt by raindrop energy transfer. To test this observation-based hypothesis, further studies on the runoff process within the snowpack are desirable. (KEYWORDS: field measurement, rain-on-snow event, snowmelt, overland flow, spring flood)

INTRODUCTION AND METHOD

Field study is an essential component of hydrologic science since all hydrological models should be verified by such observation-based knowledge of real watersheds. Hillslope runoff processes including the flow process at the boundary between the snowpack and ground surface were investigated at the northwest sector of the Ward Creek watershed, Lake Tahoe Basin.

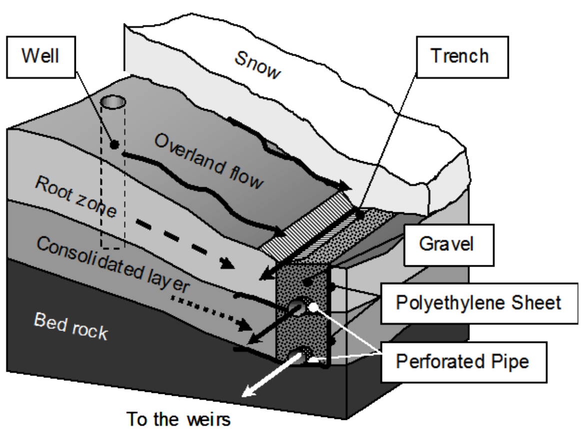

Figure 1. Schematic of subsurface and overland flow monitoring in the hillslope. The surface and sub-surface trenches collecting three types of hillslope runoffs: overland flow, root zone discharge, and consolidated layer discharge.

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Three types of hillslope runoff, overland flow, subsurface flow through the root zone, and subsurface flow through the consolidated soil layer, were continuously measured in this study, as described in Figure 1 (Ohara et al. 2011). In October 1997, a trench for subsurface flow measurements was constructed and was connected to a manhole that accommodated the instruments for continuous flow measurements of the subsurface runoff at two soil layers. Polyethylene sheets and drainage pipes were installed to separate, capture and measure the subsurface flow within the root zone and consolidated zone. For overland flow measurements, a gutter was installed along the uphill side of the trench to capture the overland flow. This overland flow trench was strong enough to resist snow weight, and was covered by a net to prevent debris from entering it. In addition to the hillslope measurements, stream channel flow was also measured at High Yellow Creek which runs nearby. These manholes had sturdy covers so that all discharge from the hillslope could be continuously measured under deep snow cover during winter.

RESULTS

Fortunately, a relatively large rain-on-snow event was observed during May 6-10, 2000 that caused a significant flood in this area. The observed hydrographs and the ground water table during this event are shown in Figure 2. It may be seen from this figure that the overland flow hydrograph reflects the pattern of rainfall and snowmelt rate well while the runoff from the root zone and the consolidated layer forms a single flood peak in their respective discharge hydrographs. Rain started around noon time of May 6th and continued until the morning of May 7th. Snowmelt peaked during the day-time of May 7th while the snow kept melting throughout the event. However, from Figure 2 it is seen that the contribution of snowmelt is much smaller than that of rainfall during May 6-May 7 as total rainfall and snowmelt during this two-day period were 98.0 mm and 33.7 mm, respectively. Our analysis reveals that snowmelt during a rain-on-snow event may be a minor contributor to the floodwater production in the Lake Tahoe Basin, Sierra Nevada.

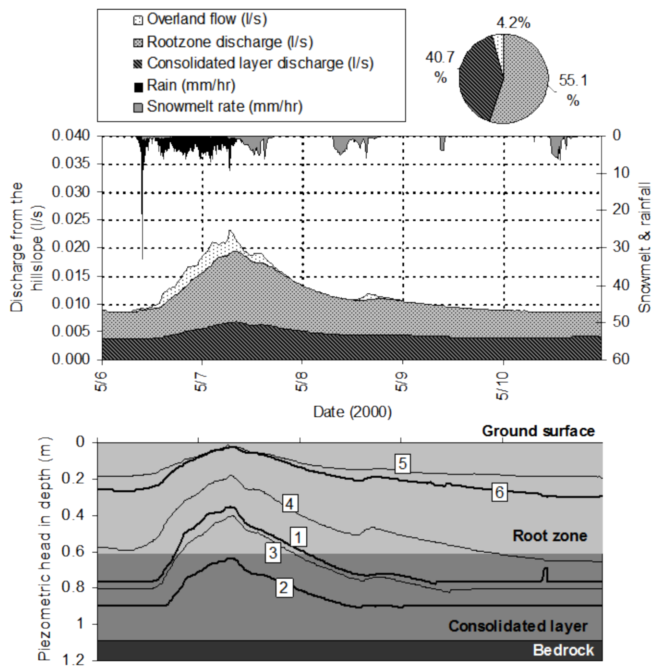

Figure 2. Observed hillslope runoff hydrographs through various pathways, rainfall intensity, and estimated snowmelt rate during a rain-on-snow event (top graph), and corresponding groundwater table at the 6 wells in terms of distance from ground surface (bottom graph)

Meanwhile, only one significant runoff event that had a medium size rainfall of 27 mm depth was recorded during the effective observation period. Although some response to the rainfall was observed in the observed sub-surface runoffs, no effective overland flow was detected during this snow-free event.

Figure 3 shows the observed hillslope runoff discharge hydrographs through various pathways, and estimated snowmelt rate during the representative spring snowmelt runoff event, and the corresponding groundwater table at 6 wells in terms of distance from the ground surface. It may be inferred from the observation that overland flow under a snowpack may not be negligible even over unfrozen and unsaturated highly-permeable topsoil. In contrast to the case of snow-free event, the observed overland flow was very large during the snowmelt events with daily average snowmelt rate of 33.3 mm. This result implies that the snowpack enhances overland flow.

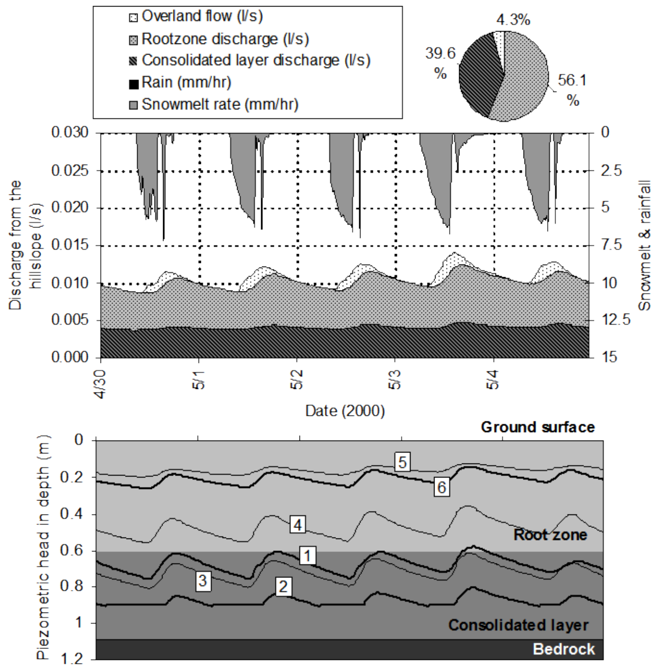

Figure 3. Observed hillslope runoff hydrographs through various pathways, and model-estimated snowmelt rate during a spring snowmelt-only runoff event (top graph), and the corresponding groundwater table at 6 wells in terms of distance from the ground surface (bottom graph)

The unexpected result of this field study was the observation of significant overland flow over the unsaturated and unfrozen topsoil during all snowmelt events, including early snowmelt events. Dunne and Black (1971) observed hydrographs that were produced largely by overland flow from a snow-covered hillslope in the Sleepers River Experimental Watershed, Vermont. They concluded that this is due to a thin layer of concrete frost in the porous topsoil. Because the permeable topsoil became impermeable by the freezing of the early snowmelt water, major amount of snowmelt water stayed in the snowpack, and flowed laterally. However, the case of the Ward Creek experimental site may be different from that of the Sleepers River Experimental Watershed. The observed soil surface temperature stayed at zero (^{o}C). This indicates the presence of unfrozen wet snow, a mixture of ice and water, at the bottom of the snowpack.

Since the observed groundwater table elevations were significantly below the ground surface during snowmelt events at the field site, a more plausible hypothesis of the observed overland flow mechanism may be the presence of a runoff pathway within the snowpack toward a receiving stream downstream of the pack, as explained schematically in Figure 4. The authors believe that this capillary suction of the porous snow may cause the difference between snowmelt and snow-free events in the amount of overland runoff.

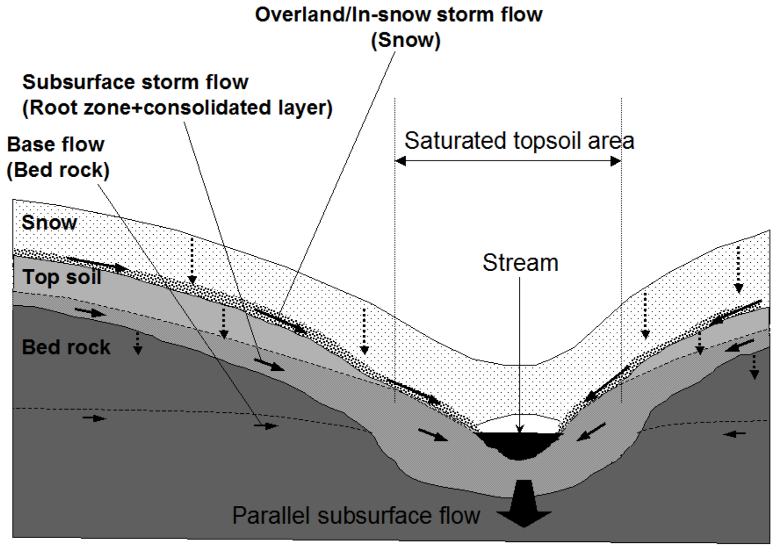

Figure 4. Schematic of hillslope runoff pathways at a riparian cross-section in a snow covered watershed. Note that the root zone and consolidated layer are shown as single top soil layer in the figure.

CONCLUSIONS

In order to quantify runoff through various flow paths at a snow-covered hillslope, a field monitoring site was established in the Ward Creek watershed of the Lake Tahoe Basin, Sierra Nevada. The detailed description of this study can be found in Ohara et al. (2011).

The subsurface stormflow was the major contributor to the hillslope runoff process, and occupied more than 90-95 percent of total runoff at the headwater hillslope of the field site. This result is in agreement with other, earlier field studies (Dunne and Black, 1971; Bayard et al., 2005). Even with unfrozen unsaturated topsoil at a snow-covered hillslope, significant overland/in-snow flow (5-10 % of peak discharge) was observed compared to the case of a snow-free event. This indicates that lateral water flow may exist within a snowpack over a hillslope surface. Since the ground surface temperature stayed at zero degrees Celsius during the whole snowmelt season, the bottom portion of the snowpack seemed to be saturated with snowmelt and/or rain water.

This study shows that on a snow-covered hillslope, the overland/in-snow flow that amplifies the peak flow discharge may be a more common phenomenon than has been considered previously. Therefore, modeling of a rain-on-snow event may require careful handling of the initial groundwater table levels, subsurface stormflow, and overland/in-snow flow processes. The speed of water movement within the saturated snow was estimated to be around 6 meters per hour (Singh et al., 1997), which is much faster than subsurface storm flow. This fast runoff component may be one of the important contributors to floods due to rain-on-snow events.

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