Snowmelt-Induced Debris Flow Literature Search

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The literature shows that snowpack conditions commonly cause or contribute to debris flows in alpine areas throughout the world. The most current and comprehensive research on the subject is centered in the Swiss Alps. In the Central European Alps, the alpine areas are relatively population dense when compared with other alpine regions of the world. The large potential for the loss of life and property, combined with recent warming trends in the Alps, have led to increased interest in studying, predicting, and mitigating debris flows there. Snow-triggered debris flows have been studied to a lesser extent in the Pacific Northwest, the Himalayas, and other regions.

Numerous debris flows occurred in Switzerland during the summer of 1987. The initiation of several debris flows on the talus slopes of the upper part of alpine catchment basins was attributed to a blockage of water underneath a perennial snow patch at the toe of the rock wall (Rickenmann and Zimmerman, 1993). Snowmelt was considered a triggering factor for the initiation of the first pulse of these debris flows. The melting of old snow patches during the spring and summer months enhanced local water saturation of the underlying unconsolidated sediments. This was followed by a large second pulse of rain precipitation. The combination of the two pulses led to over 600 recorded debris flows in the Swiss Alps during the summer of 1987. There were two major rain storm events in July and August in the region. Air temperatures were high and the snow line was 3000m a.s.l. during most of the debris-flow events. Precipitation fell as rain-on-snow in the higher periglacial regions, resulting in pronounced debris-flow activity in the higher elevations. In July, there was still significant snow cover, which resulted in the long-term saturation of loose debris by melting snow. This saturation led to rain-triggered debris-flow events in both July and August.

Another widely-examined debris-flow hazard in the Swiss Alps involves the breaching of periglacial lakes. Snow plays an important role in the formation of these lakes. Four potentially hazardous periglacial lakes were studied near Valais in the Swiss Alps (Haeberli, et. Al 2001). Three of the lakes were naturally dammed by ice and snowdrifts. The lakes were formed in topographic depressions at their associated glacier margins. During the 1960s and 1970s, the glaciers grew and the related depressions were filled year-round by accumulating snow and ice. From the late 1980s to present, during a general warming trend, the lakes have been enlarged by successive snow and ice melt toward the glaciers. The authors warn that the formation of slush avalanches in snow covering the outflow of these lakes can cause a sudden increased discharge towards two of the lakes during spring and early summer. The recommendation the authors made for debris-flow hazard mitigation was to establish a comprehensive observation system, combined with additional installation of protective barriers such as flood-release overflow structures.

Single-flow and multiple-flow GIS-models were created for the assessment of hazards from glacier lake outbursts (Huggel, et. al. 2003). The models are topography based and use primarily ASTER satellite-derived digital elevation models. The model was applied to the Tasch Lake area of Switzerland, which experienced a devastating debris flow on June 25, 2001, during a period without any significant precipitation. Considerable parts of the village of Tasch were destroyed or damaged by the event. Elevated air temperatures during the period prior to the event led to high snowmelt input to the lake. Tasch Lake had previously been dammed by pieces of lake ice and snow deposits. The elevated water level caused larger hydraulic gradients and piping in the core of the moraine dam. The snow and ice blockage ruptured and the resulting water initiated the debris flow that devastated the village. The single-flow GIS model was able to more accurately recreate the event than the multiple-flow version and was suggested as a possible predictive tool for the regional assessment of debris-flow hazards.

The winter of 1999 brought unprecedented amounts of snow to the European Alps. Switzerland was confronted with floods partly due to snowmelt (Bardou and Niggli, 2003). During the following two summers, large amounts of snow were still found in gullies down to 1000m a.s.l. On average, more than three meters of snow could be found in these gullies. The snow was found under a few centimeters of rock fragments, which insulated the underlying snow. During the summers of 1999 and 2000, small debris flows occurred in many of the upper watersheds throughout the European Alps. Some of these debris flows occurred during clear weather and were not triggered by rain precipitation. The debris flows were observed to contain large amounts of snow. The authors performed statistical analyses over selected watersheds to correlate winter snowfall with the number of floods occurring during the following summers. They concluded that snow precipitation is often the underlying cause of debris flows in mountainous torrents during the first thunderstorms of the summer and that temperature and antecedent climatic history of the watershed must be examined in addition to rainfall to give a complete picture of debris-flow triggers.

Snow avalanche deposits were examined as possible contributors to debris flows (Bardou and Delaloye, 2004). Snow avalanche deposits in gullies were shown to be both potential amplifying factors and potential reducing factors of debris flows in the Valais Alps of southwest Switzerland. Snow deposits increased the base flow under the snowpack and created a sliding plane for sediments, primarily during summer rain storms. Conversely, snow avalanche deposits were shown to reduce the impact energy of raindrops, mainly during the time of winter storms. The authors also contend that it is not currently possible to establish rainfall threshold values for debris-flow triggering. The authors also state that it is difficult to attribute debris-flow triggering in alpine environments to rainfall alone due to hydrogeological variability in these regions. In another study in the Himalayas (Wei and Gao, 1992), debris flows were triggered without simultaneous rainfall. An intense snowmelt in the early summer enhanced both superficial and subsurface runoff to provide the trigger for debris-flow initiation. The Swiss study discusses two contributions of snow avalanche deposits to debris-flow triggering. The first is the increase in base flow of melt at the base of the snowpack. The second contribution occurs when the snow deposits are covered by sediments. Increased temperatures during the summer cause the upper zone of the snowpack to soften, forming a very efficient sliding plane for the sediments covering it. Subsequent small slips in these sediments fill gullies with loose, highly mobile material. Consequent debris flows can result simply from the alternation of snowmelt events with these sediment slips. The authors concluded through debris-flow and snow-avalanche-event distributions that the number of debris flows is typically more significant during the two summers following a winter of large snow accumulation and subsequent avalanche activity. The severity of debris flows is generally the greatest during the second summer following significant snow avalanche activity. During the first summer, the extra deposits of very dense avalanche snow insulate the gully bed to reduce base flow.

Limited work has been done on the effects of snowpack on debris flows in the Pacific Northwest. The eruption of Mt. St. Helens in March of 1982 caused hot eruption products to interact with a thick snowpack (Waitt, et. al. 1983). The authors state that the eruption of Mt. St. Helens would have been confined to the crater and upper flanks of the volcano had it not been for the thick snow that mantled the steep crater wall. A lateral blast during the eruption generated a large snow avalanche that flowed 8 kilometers down the volcano. The heat from the eruption also caused rapid snowmelt, creating a transient lake whose rapid discharge triggered a lahar (volcanic debris flow). There were two outlets to the transient lake. The snow melted faster than water could escape from the outlets, so the water discharged rapidly from the lake, creating a flood that swept down the crater breach. The flood picked up enough debris to emerge at the bottom as a lahar with a peak discharge of 13,800 m^3/sec. The lahar flowed into Spirit Lake and the Toutle River, severely eroding a debris retention dam 35 kilometers downstream from the crater.

Debris flows resulting from the breach of neoglacial-age moraine dams in the Three Sisters and Mount Jefferson Wilderness Areas of Oregon have also been documented (O’Connor, Hardison, and Costa, 2001). This area has the highest concentration in the U.S. of lakes dammed by glacial moraines. There have been 11 moraine breach debris flows described in this area since 1930. The authors state that many breaches were probably the result of erosion of steep lake outlet channels, triggered by unusually large discharges caused by avalanche waves in the lakes or by precipitation and melting snow and ice. The potential currently exists for at least five more neoglacial lake moraine dam breaches in this area.

A debris flow created by a 1996 rain-on-snow event in the Blue Mountains of Washington was described at a Geological Society of America meeting (Carson, 2002). In February of 1996 there was a warm-rain event on deep snow covering frozen ground in this area. Thousands of small slumps of loess and colluvium liquefied to become long, thin debris flows. Many of these flows were initiated at breaks-in-slope like road fills and farm berms. One particular flow originated from a logging road fill and formed a debris dam below the road. Continued runoff from this rain-on-snow event caused the dam to breach. The discharge, estimated at 62 m^3/s, inundated a home with four residents.

Another debris flow in Washington was reported at the H.J. Andrews Experimental Forest in the central Cascades during a 1996 rain-on-snow event (Harris, et. al. 1997). Runoff from snowmelt and rain generated 24 debris flows in the Lookout Creek basin.

Debris flows of non-eruptive origin have also been studied on Mt. Shasta in Northern California (Blodgett, et. al., 1996). The primary snow-related cause of debris flows in this area has been the release of melt water into and over the ground. The area of historic debris-flow deposition below Mt. Shasta, the second largest volcano on the West Coast, is now being developed and populated. New non-eruptive debris flows comparable to those that have occurred in the past could be devastating to this community. Debris flows on Mt. Shasta generally originate near the termini of glaciers above 2,740 m a.s.l. Some debris flows also are caused by snowmelt streams originating in snow fields that are regions of permanent snow cover, such as the upper areas of Diller Canyon. Debris flows on Mt. Shasta have only been observed during the summer. Warm air temperatures and ablation of glaciers and snowpack are the primary triggers of debris flows on the mountain. The specific cause of these debris flows is generally a combination of water released from natural impoundments, snow and glacial melt, and precipitation on the stream basins during the summer snow and glacial melt season. Groundwater recharged by snowmelt or rain precipitation may also cause slump failure and debris flows into stream channels. One debris flow resulting from the release of water from channels blocked by snow and ice was observed in 1934. Warm summer weather caused rapid snowmelt on top of Konwakiton Glacier. This melt caused waterfalls that flowed into fissures in the glacier and reached the base. Large blocks of snow and ice were carried away from the glacier in the resulting torrent. Temporary dams were formed and then breached, resulting in a large debris flow.

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