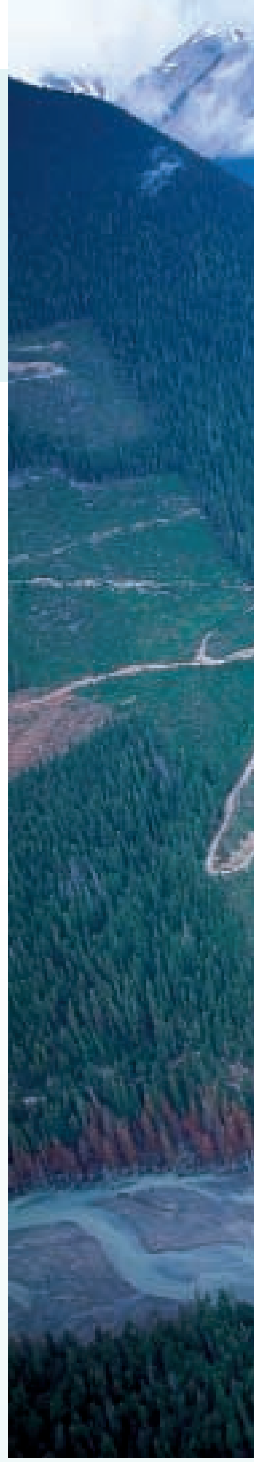
Debris Flows



BC's Worst Mountain Hazard

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It begins high in a mountain watershed where a landslide impacts a creek, is diluted, and surges down the waterway. The resulting slurry increases in volume, picking up more and more sediment and organic debris as it rages along the channel. Now a torrent of mud, rocks and water, it spills out at the valley bottom, spreading its load onto a fan where it can cause great damage to buildings and infrastructure.

Debris flows destroy millions of dollars in assets, interrupt major lifelines and kill thousands of people every year. During the December 1998 debris flow at Caracas, Venezuela, approximately 25,000 people perished within a few hours. BC's mountains are also host to this common hazard. For example, Highway 99 between Horseshoe Bay and Britannia has a history of destructive debris flows, including a series of events that occurred in the early 1980s with the loss of 11 lives.

Most recently, in January 2002, debris flows in Hope and Chilliwack caused significant property damage and spilled over the Trans Canada Highway. Previous studies by geotechnical engineers and geomorphologists had identified those areas as prone to debris flows. These events demonstrate the need for more proactive attention by legislators to debris flow hazards in developed areas and along major transportation routes, building upon the substantial advances in understanding these hazards gained by BC engineers and geoscientists over the past 20 years.

Process Definition

Globally, debris flows are probably the most damaging landslide type. Their destructive potential is well understood in the scientific community.

Steep mountain creeks are typically subject to a wide variety of events ranging from clearwater floods to debris flows. Of those creek processes, debris flows are the most hazardous due to their high volume, discharge and impact forces. The ability to distinguish a potential debris flow hazard from floods is therefore of paramount importance.

Debris flows are channelized landslides involving a very rapid, surging flow of water heavily charged with mineral and organic debris in a steep channel. They are sometimes called *debris torrents* if coarse-grained in texture and carrying large amounts of organic debris, or *mudflows* if rich in silts and clays. *Lahars* are debris flows originating from volcanic sources. The media frequently uses the incorrect and misleading term *mudslide* to describe debris flows.

Debris flows are usually triggered by small landslides (hundreds or thousands of cubic metres) that occur in the steep sections of small watersheds. During their descent down the channel they may increase in volume to several tens of thousands of cubic metres or more by entraining loose material stored in the channel. They occur in most mountainous regions and may travel several kilometres at velocities of 5-10 m/s. Some large lahars may travel up to 100 km and reach velocities exceeding 30 m/s.

Process Recognition

Field evidence of past debris flows may include boulder lobes and lateral levees, inverse grading in debris flow deposits, a lack of sorting of deposits, scour marks high up the channel side slopes, trees scarred by boulder impacts, and pronounced superelevation of flow in channel bends. Further signs on air photographs include steep channel gradients, abundant debris sources, landslide activity in the upper basin areas, and a relatively steep (10-15°) fan deposit at the creek mouth.

Despite these fairly clear "silent witnesses," debris flow hazards are not always recognized. In particular, creeks with long recurrence intervals of debris flows (several decades or more), where physical evidence is scarce, might be judged as "normal" mountain streams.

If a debris flow hazard is not recognized, development along the creek is usually preceded by a hydrologic study to determine the design flood for a 200-year return period using traditional hydrologic methods. Debris flows, however, can reach peak discharges up to 50 times higher than the design flood, overwhelming control structures such as culverts, bridges, dykes and berms.

Frequency and Magnitude

Defining the level of hazard posed by debris flows requires knowing the frequency with which events occur as well as typical event magnitudes.

The frequency of debris flows in a particular creek is a function of precipitation characteristics, type and amount of debris supply sources and watershed geometry. Frequency may also be altered by human impacts such as logging or forest road construction, drainage alterations and mining activities, to name a few of the usual suspects.

Two types of debris flow prone watersheds can be distinguished. One basin type produces an almost infinite amount of material for

Debris flows are a major hazard in BC's mountainous terrain and may occur annually in unstable volcanic source areas such as the Mt Meager area. Photo at left shows a debris flow on Capricorn Creek in the Mt Meager volcanic complex, July 1998. *Above:* Debris flow at Turbid Creek, Mt Cayley, upper Squamish River valley, August 1993 (photos: M Jakob).

transport, and debris flows will occur if a climatic threshold, such as an extreme rainfall event, is exceeded. In the second type, the channel is almost completely scoured after each debris flow and requires recharge of debris over time to become "ripe" for the next event, irrespective of whether climatic thresholds are exceeded. Accordingly, debris flow frequencies can vary by orders of magnitude.

In unstable volcanic source areas, such as the Mount Meager area of the upper Lillooet River valley, debris flows may occur annually. Other creeks located in massive granitic rocks of the Coast Mountains with low recharge rates produce debris flows only on a decadal or even century time scale.

Although the high frequency debris flow creeks appear particularly dangerous, the low frequency creeks can be more hazardous because they may occur at much higher magnitudes and may therefore be much more destructive. In addition, low frequency debris flow creeks do not necessarily display the obvious signs of past events.

Debris flow magnitude depends on the amount of available debris in the channel as well as the size of the triggering landslide event. Volumes typically reach tens of thousands of cubic metres. The associated peak discharge may reach several hundred cubic metres per second; lahars can be orders of magnitude larger.

In rare cases, debris flow scour continues unabated through the debris flow fan, which substantially increases the flow volume. A good example is the November 1995 event at Hope Creek near Hope, where tremendous amounts of colluvium and glacial materials eroded from the debris fan produced a debris flow volume of approximately 50,000 m^3.

There is reason to believe that if the present trend of increasingly wetter conditions in coastal areas continues, debris flow occurrence will increase in frequency and possibly magnitude. Preparing for possible changes requires an understanding of the type of climatic events that trigger debris flows.

Climatic Triggers

Debris flows are typically triggered during wet weather, especially in the fall and winter months in coastal BC. November and December are most notorious for debris flow occurrence.

During October rains, the shallow soils typical of most of coastal BC begin to saturate. Precipitation often peaks in November, when daily rainfall amounts may exceed 100 mm. Shallow landslides are initiated, which often trigger debris flows. A recent study by Kerr Wood Leidal Associates for the Greater Vancouver Regional District showed that the four-week and two-day cumulative rain amounts, as well as the one-hour rainfall intensity, best explain the occurrence of debris flows on the North Shore mountains.

By late January, snow in most watersheds has reached a thickness at which rain is effectively absorbed without conveying it to the forest soils below the snowpack. Even so, very intense storms can

Large scale debris flow mitigation structures in southern BC include this debris basin at Mackay Creek in North Vancouver (photo: M Jakob).

sometimes trigger debris flows. Snowmelt during rainstorms plays an important role, particularly when the storm has a warm, southerly air flow and causes an abrupt rise in freezing level. During a storm in December 2001 that triggered at least four debris flows along Indian Arm, the temperature in Vancouver rose to an unseasonable 12°C within a few hours, adding water to the soil column by rapid snow melt.

A climatic threshold can be used to issue landslide awareness warnings or evacuation orders for the most hazardous areas. Although this may help to prevent injury or loss of life, existing development in debris flow hazard areas typically requires active mitigation measures to reduce the risk to acceptable levels.

Local Research Efforts

BC engineers and geocientists have substantially advanced our knowledge of debris flows over the past 20 years. A bibliography of scientific papers and consultant reports on subaerial debris flows is accessible at http://sts.gsc.nrcan.gcca/egd/DF2000cit.html.

In UBC's Department of Geography, Dr Mike Bovis PGeo has conducted extensive research on the impacts of logging on debris flows, channel recharge rates, frequency-magnitude relations and the impacts of glacial retreat on debris flow activity. Dr Oldrich Hungr PEng/PGeo of UBC's Department of Earth and Ocean Sciences, and Director of the Geological Engineering Program, has investigated the mechanics of debris flows, debris flow runout prediction and the design of mitigation structures. He recently developed computer software to simulate debris flow motion and runout.

Additional research has been conducted by Dr Jonathan Fannin PEng (Department of Civil Engineering) on shallow landslides that trigger debris flows, and Dr Dave McClung PGeo (Department of Geography) on probabilistic estimates of debris flow runout.

Consultants Mike Currie PEng, Nigel Skermer PEng, Doug VanDine PEng/PGeo and Bob Gerath PGeo have advanced the design of debris flow mitigation measures and carried out numerous detailed debris flow hazard and risk assessments.

Research scientists at the Ministry of Forests have furthered our understanding of the impacts of logging and forest road construction on debris flow activity as well as the importance of debris flow fans in forestry applications.

Hazards Mitigation

Once the process has been recognized and its hazard quantified, debris flow mitigation measures may be recommended if human life or assets are at risk. A wide spectrum of passive and active mitigation measures is available in the conceptual planning stage. Passive measures focus on land use zoning, while active measures include debris basins, debris barriers, channelization and check dams.

The most recent examples of large scale debris flow mitigation structures in southern BC are a debris basin on Mackay Creek in North Vancouver, a double debris barrier at Whistler Creek and a debris flow deflection berm at Peq Creek near Pemberton, all designed by Kerr Wood Leidal Associates.

The most appropriate strategy for debris flow mitigation depends on the morphology of the creek fan, the level of debris flow hazard and the potential consequences. Full debris flow mitigation can cost several million dollars per site and may not be cost effective in every situation. Nonetheless, where significant risks exist, taking no action may be difficult to justify.

Legislative Framework

The need for debris flow research, mitigation works and a strong legislative framework has long been recognized in densely populated mountainous areas such as Japan and the European Alps. Entire ministries are responsible for recognizing and preventing debris flow hazards, and research institutions collaborate with field practitioners.

In Canada, jurisdiction over natural hazards is currently divided among many agencies within federal, provincial and municipal governments. Effective management requires centralization of responsibilities. Mitigative efforts should focus not only on new development but also existing development in hazardous areas. It appears that a new legislative framework is needed.

Conclusion

Debris flows are the most hazardous landslide process in many mountainous regions of the world, including BC. Since the late 1970s our understanding of debris flow processes has greatly improved, although it is far from complete. However, this knowledge is as yet only partially reflected in existing legislation. With an expanding population in this mountainous province, scientific understanding of debris flows must go hand in hand with an appropriate regulatory framework to ensure that lives and property are protected.

Dr Matthias Jakob PGeo is a senior geoscientist for Kerr Wood Leidal Associates of North Vancouver whose principal focus involves analyzing debris flow hazards. Dr Jakob is currently undertaking a comprehensive study of debris flow hazards and risk assessments for the District of North Vancouver as well as a number of other debris flow studies throughout BC.