Module 4: Natural Hazards

The height, steep slopes, frequent geological instability, and extreme climates of mountainous terrain give rise to a variety of natural hazards, which may impose risks on human well-being and property.

- Floods
- Wildfires
- Mass-Movement
- Avalanches

Floods

Where weather-systems encounter mountains, they are deflected upward to higher elevations, where atmospheric pressures and temperatures are lower. Any water-vapour in these systems is then more likely to condense into liquid (or solid) form, and in due course to fall as precipitation – as rain or snow. In some situations, the air-mass may become lodged or 'stuck' against the mountains, potentially delivering large volumes of rain or snow over several days.

Steep mountain slopes with thin soils and sparse vegetation quickly channel liquid water into small upland valleys. Runoff of water from heavy rainfall is likely to travel more easily over the surface where the natural vegetation has been substantially disrupted, for example by logging or wildfires. Trees and the underlying 'duff' of decaying organic matter help to diffuse and soak-up rain, so that it is less likely to move over the. Where the vegetation has been removed, it is more likely that surface runoff will travel easily and rapidly. Wildfires, and periods of hot, dry weather, may result in a hard 'crust' being formed on the surface, again facilitating rapid runoff.

It follows that retaining land-cover with rich vegetative cover helps to reduce the risk of flooding, by slowing the rate of initial runoff. It has also been shown that the dams, ponds and channels built by beavers can help mitigate these risks (although these are less likely to be found in the high elevation 'headwaters.')

Some other natural flood-mitigation approaches: https://thenarwhal.ca/topics/bc-floods-solutions/

Once the runoff generated from rainfall and/or snowmelt has flowed into rills, gullies and stream valleys, it flows rapidly to lower elevations, joining with other streams and increasing in volume and energy as it travels. As it does so, it will transport loose regolith downstream: this is likely to erode the valley further.

Wherever the rate of volume flow exceeds the capacity of the containing channel, overbank flow, a.k.a. flooding, will occur. This is most likely in broader valleys (often glacially-excavated) at lower elevations. In particular, where flows encounter shallower gradients along these larger valleys, or spill into the floodplain, the associated sudden reduction in energy results in much of their sediment-load being deposited (beginning with coarser particles through to finer material, as the energy drops).

Floods arising from glacial lake outbursts are of increasing concern as glaciers retreat. The Tsho Rolpa Glacial Lake below, for example, is one the largest glacial lakes in Nepal. There is high risk of moraine dam breaches due to rapid glacial melt and the Tarkading Glacier calving into the lake. It is subject to hazard mitigation systems that include remote monitoring and warning sirens to protect villages downstream.

Tsho Rolpa Glacial Lake, Nepal.
Photo by Robert Plummer.

Lake Palcacocha in Peru's Cordillera Blanca is at similar risk, with threat 50,000 people below should it breach its banks and cause a flood and landslide.

Some recent Canadian examples of flooding in mountainous terrain:

Southern Alberta (Canmore, High River, Calgary,) June 2013:

A low-pressure system channelling moisture from the south-east (as far as the Gulf of Mexico) became 'lodged' against the Rocky Mountains, delivering large volumes of rainfall, in turn accelerating melt of high-elevation snowpack, leading to extreme high-volume / high-energy flows and flooding in several settlements.

Upper Peace District, British Columbia, June 2016:

Similarly, a low-pressure system (again channelling moisture from the Gulf of Mexico) delivered large volumes of rainfall on the eastern flanks of the mountains. Logging (for oil and gas exploration / extraction and salvage of timber affected by mountain pine-beetle) and clearances by wildfires, together with relatively dry conditions earlier in the spring, may have exacerbated the flooding, by exposing more open ground and preventing or slowing soil recharge ('soaking-in.')

Berg Lake, 30 June 2021:

A major storm system – possibly driven originally by pyrocumulonimbus events above intense fires in the central Interior – delivered ~215 mm rain in five hours in this area close to Mount Robson: the resultant flows drove major coarse debris transport and deposition (~3m in height in some areas), substantially damaging a trail important to the local economy. https://www.therockymountaingoat.com/2021/07/dozens-evacuated-by-air-after-berg-lake-flash-flood/

South-west British Columbia, November 2021:

Atmospheric rivers (intense bands of atmospheric moisture sourced from as far away as the Philippines) delivered large volumes of rain to the western flanks of the Coast Mountains (277.5 mm from 14 to 15 November in Hope, British Columbia.) Soils and drainage systems in the area were already saturated, so runoff was rapid and energetic, exacerbated in areas already logged or cleared by wildfire. This resulted in major disruption to transportation infrastructure – seven bridges destroyed on Hwy 5; Hwy 8 severely damaged in ~30 locations; debris / mud flows crossed Hwy 1, Hwy 7, Hwy 99, Hwy 3; flooding in Abbotsford, Princeton, and Merritt.

Wildfires

Mountain slopes are often forested and are therefore likely to accumulate high fuel-loads. South-facing unshaded slopes receive higher amounts of solar radiation, resulting in higher temperatures, and lower soil-moisture. Lightning is more likely to strike mountain peaks than lowlands, so sparking wildfires. The probability of such events is much higher during periods of hot, dry weather. Mountain landscapes may amplify these conditions: they usually occur under high atmospheric pressure, where the air is sinking – mountains may constrain its ability to spread-out near the surface, so it compresses and therefore heats further. Also, differential heating between sun-exposed and shaded areas may drive thermal winds which become stronger along narrow valleys and may fan the flames of wildfires.

Where conditions are hot and dry, fuel-loads high, and winds strong, wildfires may generate pyrocumulonimbus 'firestorms', which generate (usually dry) lightning. From 3 pm on 30 June 2021 to 8 am on 1 July 2021, several events of this type drove storms which yielded over 700,000 lightning pulses across a large swath of British Columbia and Alberta, over 110,000 of which hit the ground.

https://twitter.com/kyletwn/status/1410089092797243394

https://www.nesdis.noaa.gov/news/raging-wildfires-spark-lightning-over-british-columbia

https://www.vaisala.com/en/blog/2021-07/pyrocumulonimbus-event-british-columbia-canada

Mountainous regions present a range of challenges for fire-fighting. Fires generally burn up-slope but this also depends on the direction and strength of winds. Rugged terrain presents challenging conditions for ground and air operations. Dense smoke in high-pressure conditions is slow to clear from valleys – many parts of British Columbia frequently experience extremely poor air-quality for extended periods during the wildfire season.

Climate change has demanded improved management of wildfire risk globally. New initiatives to maintain mountain forests and biodiversity from wildfire have been introduced in the South Caucusus, for example. Solutions include strengthened forecasting and communication, and new weather stations such as those in the Khosrov Forest State Reserve in Azizkend, Armenia. Drawing on available human resources, more women are now trained to fight forest fires, and there is better equipment for access to difficult mountain locations.

Mass Movements

In some situations, large volumes of rock (either previously solid, or unconsolidated regolith) may lose its 'structural coherence' in relation to its location, somehow shifting from stable and static to unstable, so that it is able to move under the force of gravity from higher to lower elevations. These 'mass-movements' may be sudden, rapid and difficult to predict, or relatively slow and steady. Where these events are large and energetic, they may be highly hazardous to people or property in their path.

One way of exploring the differences between types of mass-movement is to look at the nature of the geological material which moves:

(Initially) Solid Rock

One form of mass-movement occurs when the connections between a large volume of solid rock and the rest of that geological unit weaken: most often, this occurs along one or more structural 'joints' (planar discontinuities or cracks), or a layer of slightly different composition. If this surface of weakness slopes downwards towards the edge of an existing outer slope or cliff, then when it gives way (probably under the cumulative effects of weathering, and often with the help of lubrication through the introduction of water), the upper unit will detach and **slide**, falling down or off the outer slope to lower elevations.

Elliot Creek (central coast), November 2020: ~50 million tonnes of rock

This landslide was likely released following removal of supporting glacial ice ('debuttressing,') and a year of above-average precipitation. It was equivalent to the mass of all the 25 million cars in Canada – or 150 Empire State Buildings – travelling down a valley together at between 140 and 170 km/h.

- https://hakai.org/the-big-slide/?utm_campaign=reprint&utm_source=piquenewsmagazine
- https://www.frontiersin.org/articles/10.3389/feart.2022.916069/full
- https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021GL096716
- https://bc.ctvnews.ca/mobile/b-c-landslide-caused-100-metre-high-tsunami-set-off-earthquake-scale-study-1.5842552?cache=/7.386407?clipId=104070

Big Bar slide (Fraser River, southern Cariboo), Early 2019: ~85,000 m^3

This was a relatively small combination of rockslide and rockfall on a canyon section of the Fraser River. The rock fell directly into the river, instantly forming a new waterfall around 5.5 m in height.

This presented a major obstacle to salmon of several species migrating up the river, so considerable effort was expended in finding ways to remove as much as possible of the rock as possible, while building routes along which it would be easier for the salmon to pass.

Frank Slide (Alberta, southern Rocky Mountains,) April 1903: 44 million m^3 / 110 million tonnes: 70-90 fatalities

This slide was partly anthropogenic - coal-mining - but also followed a wet winter and cold snap with high groundwater saturation and sudden freezing. Oral traditions of local Indigenous peoples (Blackfoot, Ktunaxa) had referred to the peak as "the mountain that moves."

Loose or fragmented rock – including large boulders

If the volume of geological material is already fragmented to some degree, rather than being mainly solid, it is easier for it to begin to move: often this will be provoked by increased flows of water (during a storm or rapid snowmelt), the addition of new material above the deposit, or shaking from seismic activity. On near-vertical slopes, the movement may be a simple **rockfall**. On longer, somewhat less steep slopes, the looser structure allows a more chaotic, turbulent type of movement: if the rock fragments are mainly dry, they may become suspended on an air-cushion within a **rock-avalanche**: alternatively, larger proportional volumes of water may result in the development of a coarse **debris-flow**.

Meager Creek (Coast Mountains, near Pemberton British Columbia), August 2010: ~48,500,000 m^3

Several accumulations of loose rock (originally disaggregated in an alpine glacial setting, and perched high in the valley) released and fell onto another area of weak rock saturated with groundwater. These volumes of rock moved rapidly as a debris flow along the 7 km length of the Capricorn Creek valley, damming Meager Creek for 19 hours, forming a lake 1.5 km in length.

Unconsolidated regolith – smaller particle-size

Scree or talus accumulations are generally relatively stable, under 'normal' conditions: the smaller fragments, which are often angular, tend to fit and lodge against one another in a way which resists movement. However, this coherence may be overcome, particularly by substantial injections of water during periods of high runoff from rainstorms or rapid snowmelt, or from groundwater springs. In such cases, the volume, energy and duration of the flows are likely to dictate the violence of the flow and the distance it travels.

The widespread debris flows and mudflows experienced throughout much of south-west British Columbia in November 2022 were examples of this kind of event, when heavy rain fell over several days onto already saturated surfaces. The runoff rapidly swept large volumes of rock and smaller particles (as well as vegetation, including trees) which had accumulated in the upper reaches of uplands and mountain valleys to lower elevations, amplifying as more material and water was gathered into the flows. These flows destroyed or damaged property and transport infrastructure in their path, severely disrupting human activities in these areas for weeks to months.

In mountainous areas of British Columbia, particularly in steep-sided glacially-eroded valleys, only small amounts of relatively flat land are available. Many of these are alluvial fans – areas in which material transported by water from higher elevations has been deposited, often where the river or creek enters a lake. These settings are often thought of as being attractive locations on which to build – the idea of 'waterfront property' is appealing to many. However, the valleys above the fans were carved by rapid and destructive flows of this type, and they are likely to happen again – these are often dangerous settings in which to site property developments.

Soil

As the geological particles become smaller, and organic matter from decaying vegetation is added, they contribute to the formation of soil. Once again, the addition of large volumes of water within a soil layer on a slope may encourage it to slip – generally slowly (as **soil-creep**), but potentially suddenly and rapidly. The risk of this increases considerably where the binding effect of vegetation (particularly tree-roots) is removed, for example by logging. Sudden mudflows are also more likely to be generated in areas affected by wildfires.

In March 2014, following some six weeks of heavy rainfall, a relatively shallow slope on the flank of the Stillaguamish River near Oso Washington State flowed suddenly downhill and over the river, destroying 49 properties and resulting in 43 fatalities.

It may be difficult to know where and/or when any of these types of events may be likely to happen: the most useful clues are found in the surrounding landscape – understanding the geology, topography, climate, and building a picture of past events by examining the shape and structure of the terrain provides a great deal of information. The problem often seems to be that events which occur quite frequently in geological timescales – at intervals of hundreds to thousands of years – may seem unlikely from a human perspective. In the context of more extreme weather events driven by climate-change, assumptions of this nature may prove to be particularly costly.

Avalanches

A comparable form of mass-movement may occur on mountain slopes where large volumes of snow have accumulated, and at some point lose their structural coherence, resulting in rapid down-slope transport. Snow is a complex material: it may fall as flakes to granules, to form a snowpack. Depending on temperature, humidity and other factors, these tiny grains are likely to change shape (**snow metamorphosis**), in turn potentially altering the snowpack's internal cohesive strength and stability. Many avalanches are caused where a weak layer is covered by fresh snow, so that it is buried within the snowpack. All it takes for snow overlying the weak layer to start moving is a **trigger**: this may be natural (e.g. new snowfall, wind-deposited snow, or a rapid temperature-change, driving shifts in moisture-distribution, density and the effect of gravitational forces) or human (e.g. weight added by someone on skis / snowboard / snowmobile.)

Avalanche, Mount Dhaulagiri, Nepal.
Photo by Robert Plummer.

There are two main types of avalanche, involving movement of loose snow (**sluffs**) or **slabs**:

Sluff avalanches – the snow equivalent of mass-movement by loose regolith – occur in loosely-bonded snow at and near the snowpack surface. Movement begins at a single release-point: as the snow moves, it gathers more loose snow, so that the avalanche grows wider as it travels (thus typically having an inverted V-shape planform). Sluffs may be dry (in powder-snow) or wet (where the snowpack has a relatively high liquid-water content). Dry sluffs are not generally highly destructive or dangerous, although – as with any avalanche risk – it is always best to avoid them! Wet sluffs are denser and more fluid, so may move faster. They are most common in the warmer and wetter maritime climates (e.g. British Columbia Coast Mountains), and in spring, as a result either of melt driven by strong solar radiation, or rainfall. The extra speed and weight may make them more dangerous to any humans or property (as well as trees etc.) in their path.

Slab avalanches are comparable to large rockslides. They occur where a layer which was previously at the snowpack surface has physical characteristics which prevent coherence with new snow subsequently accumulated above it.

For example, where feathery **hoar crystals** have formed on a surface and persist under new accumulations of snow, they may at some point collapse. Alternatively, 'slippery' ice-crust layers may be formed by strong winds, or by some degree of thaw-freeze. Typically, a slab avalanche is triggered when the upper layers of snowpack begin to move over the weak layer, often because of loading by yet more snow, or human activity. These tend to be the most destructive and dangerous types of avalanches.

The overlying layers forming the slab may be **hard** or **soft**, depending on the density of – and degree of granular bonding within – the snowpack. Soft slabs are less dense and more loosely bonded than hard slabs, but denser and more tightly bonded than newly fallen snow. The lines of failure along which a soft slab releases are likely to propagate over shorter distances than those in the more cohesive hard slabs and tend to break-up as they move.

A third variety is a **wet-slab** avalanche: these typically occur in spring, when meltwater or rainfall percolate through the snowpack and into a deeper weak layer – the relatively warm water breaks the bonds maintaining cohesion between the upper and lower parts of the snowpack and may also lubricate movement of the former over the latter. Wet sluffs may occur as precursors, indicating potential for imminent release of a wet-slab avalanche