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Geomorphological characteristics of increased landslide activity in the Gudbrandsdalen valley, Norway

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The Gudbrandsdalen valley in Eastern Norway lies in a region where annual precipitation is generally low (down to 300 mm/year). The landslide activity has consequently historically been low, although the lower part of the valley sides generally is draped with thick layers of Quaternary deposits, primarily of glacial or glaciofluvial origin. The perception of natural hazards in the valley was previously primarily connected to flooding in the main river in the valley bottom during early summer, due to large discharges resulting from snowmelt in the mountainous regions west and east of the valley. However, several high-intensity events have changed the image of the region. Starting with a localized, but intense, landslide event in the Northern part of the valley in year 2008, two larger events covering almost the entire valley occurred in the years 2011 and 2013. A high number of landslides was triggered in all these events, including many flash floods and debris flows/debris slides in small and steep tributary rivers along the valley slopes.
Landslide triggering covers different release mechanisms:
In 2008, landslides were triggered without precipitation in not-frozen soil deposits without snow cover in the lower part of the valley. Groundwater flow through the permeable bedrock ("Otta schist") resulting from snow-melt in the elevated mountainous areas caused landslide triggering due to positive pore-water pressures forming at the bedrock surface below soil deposits, or at depressions in the terrain. Subsequent rainfall resulted in even more landslides being released.
In later events (years 2011 and 2013) many landslides were caused by surface water taking new paths downslope, often due to man-made changes in existing waterways (typically poorly planned drainage solutions or new roads). Relatively small discharges in slopes with unconsolidated and easily erodible glacial deposits (typically lateral moraine) in many cases lead to small initial slides that down-slope developed into large erosional debris slides/floods of considerable size. Also along existing tributary rivers, the intense rainfall events resulted in flash-floods with heavy erosion and entrainment of deposits from the riverbed, including massive transport of trees.
Also on open slopes a number of landslides were observed, assumedly triggered primarily by direct infiltration of rainfall, and possibly assisted by groundwater flow in underlying bedrock.
Considerable damage to infrastructure and also dwellings has resulted from the events. A new approach has proved necessary to capture the risk elements connect to landslide and flood for this valley region when it comes to planning purposes. Among others, there is a need to consider the potential damage resulting from under-dimensioned culverts leading to complete failure of railroad or road embankments). Work is underway in order to improve the understanding of release mechanisms for typical landslides in the valley, which also will be highly relevant for other areas in Norway were similar natural hazards are encountered, and where climatic change may change the regional landslide activity.