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Natural hazards in the Alps triggered by ski slope engineering and artificial snow production

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In the Alps there is increasing concern of man-made triggering of natural hazards in association with ski slope engineering and pressures from climate change. However literature on the topic is rare. Ski run development has been intensified in the past decade to accommodate a higher density of skiers. In order to absorb the increased flux of skiers promoted by continually increasing lift capacity, ski runs are subject to more and more enlargement, straightening and leveling. This has required large-scale re-leveling of slopes with the removal of soil and protective vegetation using heavy machinery during the summer season. Slope-ward incision on steep slopes, creation of artificial embankments by leeward deposition and development of straight ski runs perpendicular to steep slopes have resulted in both shallow and deep erosion, gullying, triggering of small landslides and even bedload transport in marginal channels.

Other natural hazards have been triggered directly or indirectly due to intensification of artificial snow production. This has increased exponentially in the last decade in order to secure the skiing season under increasingly warm temperatures and erratic snowfall and decreasing snow depth and snow duration in association with climate change. The consequences are multiple. Firstly, in order to economize both costs and quantity of artificial snow production, ski runs are leveled as far as possible in order to avoid topographical irregularities, protruding vegetation or rocks. The combination of topsoil removal and prolonged duration of artificial snow cover results in a decreased vegetation cover and period as well as species alteration. Together with greatly decreased permeability of the underground, snowmelt and intensive summer precipitation trigger surface runoff, erosion and even small landslides. After more than a decade of intensive cover by artificial snow, most such steep ski runs at altitudes above 1400 m are reduced into highly erosive, vegetation-poor scree slopes in summertime. Secondly, the production of artificial snow requires increasingly large quantities of water during low flow periods and causes an exponential increase in the construction of water reservoirs and pipelines. Such reservoirs are often constructed in depressions occupied by wetlands but also on slopes, hilltops and in proglacial locations at high altitudes up to 3000m. Reservoir construction removes vegetation, soil and regolith over surface areas of up to 150 000 m2 and depths of more than 20 m. During their construction, the temporary or permanent storage of large quantities of sediment on steep slopes has lead in several cases to the production of debris flows. Each reservoir requires road construction and vehicle parking areas for heavy weight vehicle access. These are frequently subject to erosion, gullying, and small landslides. Some reservoirs are vulnerable to catastrophic drainage triggered by earthquakes, avalanches and other natural hazards typical for mountain environments since they are only sealed with plastic membranes. Thirdly, the melt of artificial snow introduced by water transfers from other catchments can cause a relatively large local surplus of water which in turn increases spring and summer flood peaks as well as sediment transport.

Most steep ski runs have introduced artificial drainage canals across the ski runs to avoid concentration of surface flow and to prevent erosion. Slopes are also covered with organic soils and re-vegetated where possible. However, given the present trends of intensification of use and precipitation extremes, it is unlikely that erosion and mass movements can be prevented in the next few decades for the duration of the amortization of investments.