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# Implications of Water and Sediment Connectivity for Road Infrastructure in the deeply incised Alpine Arly Canyon, France

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This study deals with the chronically vulnerable D1212 national road situated in the Arly canyon between Megève and Ugine in the French Alps of Savoie. It was unwisely constructed in the 1880s within a hotpot of hyper-concentrated flood flow, landslide and rockfall risks giving rise to major economical and safety issues. Since the last glacial retreat (17,000 years ago) the deeply-incised Arly Canyon is an intrinsic example of ongoing water and sediment connectivity. In total, the Arly canyon has eroded to depths varying between 30 to 250 m creating a narrow and rather uniform river bed with an inclination of about 4°. Locally, where some river widening occurs due to less resistant rocks, slopes decrease to 3° creating pockets of temporary deposition. However, there is no permanent, pluri-annual deposition on the remaining river bed which is restricted to transferring sediment that has been eroded from the neighbouring slopes and torrents draining small sub-catchments. A detailed hydrological, geoinformatical, geological and geomorphological analysis with 12 cross-sections was carried out to determine Holocene and present-day fluvial and slope dynamics. Present erosion rates of landslides, rockfalls and fluvial sediments are obtained from own and existing monitoring studies. According to the Rosgen classification this is a typical class A 3 River that is perpetually unstable. Water and sediment interactions dominate the entire surface of the canyon river bed. Therefore, the 13 km road inserted along the canyon floor will always remain incompatible with the environment. Furthermore, since the road location is restricted to the river bed and along one valley side only, the natural river course was narrowed and relocated to the opposite side. This asymmetry becomes particularly hazardous during flood events. Fluvial erosion then concentrates on the banks opposite to the road causing severe slope undercutting and triggering large-scale landslides. The road can either be cutoff by a combination of landslides, extreme local fluvial dynamics (exceeding 4 m variations in depth) or rockfalls. For more than 130 years the road has had to be maintained in a never-ending sequence of repair works making it one of the most expensive and dangerous roads in Europe. Under the pressure of climate change, this situation could be aggravated. Between 1999 and 2003 the road was closed for 84 days on average per year, with a record closure of 182 days in 2015 and 146 days in 2016 and road cutoffs of up to 300m in length. In future, it is suggested that a new road should be built on the safer mid-valley flanks, where roads were located prior to the 19th century, instead of trying to maintain the D1212 at all costs.