

## **Fluvial geomorphological response along the upland sediment cascade during the record-breaking December 2015 floods, Cumbria, UK**

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Between 0900 GMT on 4th December and 0900 GMT on 6th December 2015, Atlantic Storm Desmond produced over 260 mm of rainfall in Cumbria, northwest England, representing a new UK 48 hour rainfall maximum, and breaking previous records set in 2005 and 2009. The December 2015 event resulted in a number of rivers significantly exceeding their 2009 levels, over-topping recently-commissioned flood defences, destroying bridges and flooding thousands of homes. Our research aim is to identify factors controlling significant geomorphological and sedimentary response during Storm Desmond along the upland sediment cascade including: Rattling Beck (Glenridding), a high gradient upland stream draining the flanks of Helvellyn (950 m.a.o.d.), and a 25km extended reach of the lower gradient piedmont Derwent River corridor downstream of Bassenthwaite Lake.

Rattling Beck descends steeply from the eastern slopes of the Helvellyn massif draining across an alluvial fan into Lake Ullswater. On 5th December 2015 the village of Glenridding was severely impacted by flooding which deposited boulder-sized sediment within the centre of the village, completely blocking the pre-existing stream course and causing avulsion of waning stage flows through riverside properties. A major new sediment lobe was deposited on the existing alluvial fan downstream of the village, grading to the temporarily raised lake water level. Although a number of hillslope failures occurred in the higher catchment, the majority of the sediment transported by Rattling Beck and impacting the village was acquired within a 2km reach upstream of Glenridding through erosion of older glacial and alluvial sediments. Lateral channel erosion was enhanced by inability of flood flows to rework highly resistant boulder bar lag deposits related to a previous mine tailings dam failure in 1927.

The River Derwent corridor extends for 30km downstream of Bassenthwaite Lake to the Irish Sea at Workington and has a sinuous course ranging in maximum width from 500m to <150m in reaches narrowed by human modification. Despite the Derwent's relatively low gradient, significant erosional and depositional impacts occurred as a result of Storm Desmond, often reactivating discrete areas along the river corridor that saw major sediment shift and channel alteration in the 2009 floods. 2015 channel avulsions are associated with floodplain erosion principally initiated by the ploughing of, and scour around, large woody debris. Large gravel sheets (< 0.5 km<sup>2</sup>) characterised by distal slip faces up to 1m high were deposited at river corridor expansions downstream of actively eroding hillslopes and artificially narrowed reaches.

Overall, major geomorphological response to Storm Desmond floods in Rattling Beck and the River Derwent is seen to be amplified by centennial-scale human modifications to river corridors and alluvial fans. River corridor engineering on the River Derwent and village construction on Rattling Beck's depositional fan at Glenridding moved both systems out of their natural equilibrium exacerbating the effects of storm-generated flooding on the Derwent (2009, 2015) and Rattling Beck (2015).