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Significance of flow clustering and sequencing on sediment transport: 1D sediment transport modelling

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This paper considers 1D hydraulic model data on the effect of high flow clusters and sequencing on sediment transport.

Using observed flow gauge data from the River Caldew, England, a novel stochastic modelling approach was developed in order to create alternative 50 year flow sequences. Whilst the observed probability density of gauge data was preserved in all sequences, the order in which those flows occurred was varied using the output from a Hidden Markov Model (HMM) with generalised Pareto distribution (GP). In total, one hundred 50 year synthetic flow series were generated and used as the inflow boundary conditions for individual flow series model runs using the 1D sediment transport model HEC-RAS. The model routed graded sediment through the case study river reach to define the long-term morphological changes. Comparison of individual simulations provided a detailed understanding of the sensitivity of channel capacity to flow sequence.

Specifically, each 50 year synthetic flow sequence was analysed using a 3-month, 6-month or 12-month rolling window approach and classified for clusters in peak discharge. As a cluster is described as a temporal grouping of flow events above a specified threshold, the threshold condition used herein is considered as a morphologically active channel forming discharge event. Thus, clusters were identified for peak discharges in excess of 10%, 20%, 50%, 100% and 150% of the 1 year Return Period (RP) event. The window of above-peak flows also required cluster definition and was tested for timeframes 1, 2, 10 and 30 days. Subsequently, clusters could be described in terms of the number of events, maximum peak flow discharge, cumulative flow discharge and skewness (i.e. a description of the flow sequence).

The model output for each cluster was analysed for the cumulative flow volume and cumulative sediment transport (mass). This was then compared to the total sediment transport of a single flow event of equivalent flow volume. Results illustrate that clustered flood events generated sediment loads up to an order of magnitude greater than that of individual events of the same flood volume. Correlations were significant for sediment volume compared to both maximum flow discharge ($R2<0.8$) and number of events ($R2$ -0.5 to -0.7) within the cluster. The strongest correlations occurred for clusters with a greater number of flow events only slightly above-threshold. This illustrates that the numerical model can capture a degree of the non-linear morphological response to flow magnitude. Analysis of the relationship between morphological change and the skewness of flow events within each cluster was also determined, illustrating only minor sensitivity to cluster peak distribution skewness. This is surprising and discussion is presented on model limitations, including the capability of sediment transport formulae to effectively account for temporal processes of antecedent flow, hysteresis, local supply etc.