Spatial targeting of natural flood risk management within large river catchments: A nested approach of SCIMAP-Flood and CRUM3

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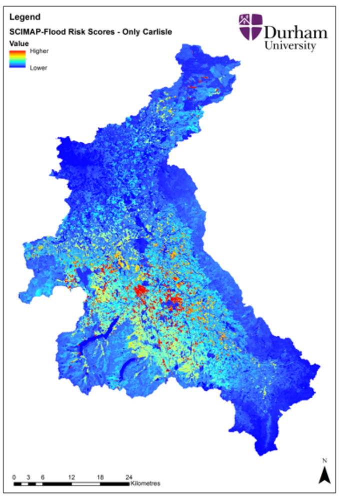
To manage flood risk within a large river catchment, such as the River Eden (2300 km^2), there is a need to consider the spatial targeting at two scales: 1, the whole of the large scale catchment and 2, the local sub-basin. With large catchments, there are multiple points of impact and hence an action to reduce flood risk in one location may increase the risk in another due to changes in the timing sub-catchment flood peaks and associated synchronisation. The range of rainfall patterns and storm tracks will give different flood timing dynamics in each event. Therefore, there is a need to consider how these variables interact to give integrated spatial targeting maps for NFM which has the greatest chance of reducing flood risk over a range of possible future events. Once the key locations have been identified, the details of the effectiveness of processed mitigation actions on flood magnitudes can be calculated through the application of detailed hydrological and hydraulic models. This report therefore proposes a two stage approach to managing flood risk within the River Eden catchment:

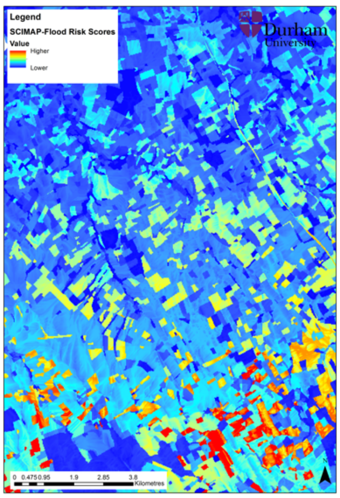
1. The use of spatially detailed, catchment wide, risk based mapping, accounting for rainfall patterns, sub-catchment synchronisation and multiple points of impact, to identify key sub-catchments
2. The application of detailed physically based models, within an uncertainty framework, within these identified locations to design and test the proposed NFM scheme.

Landscape Scale Spatial Targeting for NFM: SCIMAP-Flood

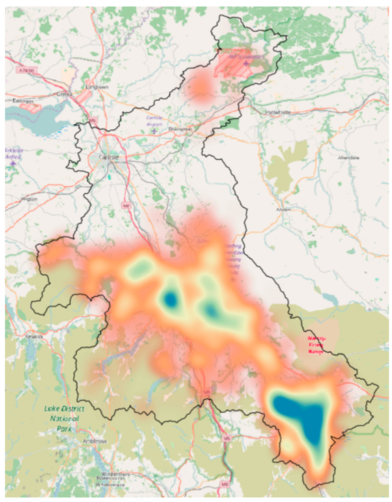
The suitability of a site for the implementation of natural flood risk mitigation measures is determined by 1, the travel time of the flood waters to the point of impact, 2, the spatial pattern of the rainfall depth pattern, 3, the effectiveness of the land cover in generating rapid flood flows (overland, drains and near surface flows) and 4, the strength the of the hydrological connectivity from the landscape to the river channels. This report presents the initial version of the new SCIMAP-Flood tool for spatial targeting of NFM measures at the landscape scale. This approach is based on the SCIMAP fine sediment risk mapping tool (Reaney et al. 2011) but expanded to capture flood issues. The SCIMAP-Flood tool assigns risk weights to each of the flood hazard driving factors and then combines these to give a point scale assessment of the potential value of slowing flows at that location for decreasing flood peaks at the point of impact. This assessment is based on the critical source area concept whereby there needs to be both a generation of flood risk and an active hydrological connection to the river channel (Heathwaite et al. 2005). The source risk is determined as a function of travel times, rapid runoff generation potential and the rainfall pattern and the hydrological connectivity is determined by the Network Index (Lane et al. 2004). Example results of SCIMAP-Flood are shown in the figure below.



SCIMAP-Flood for the River Eden catchment for the single point of impact in Carlisle



Detail of the field scale nature of SCIMAP-Flood for the River Roe catchment



Action clusters identifies areas where there are multiple flood sources. Shown for all points of impact

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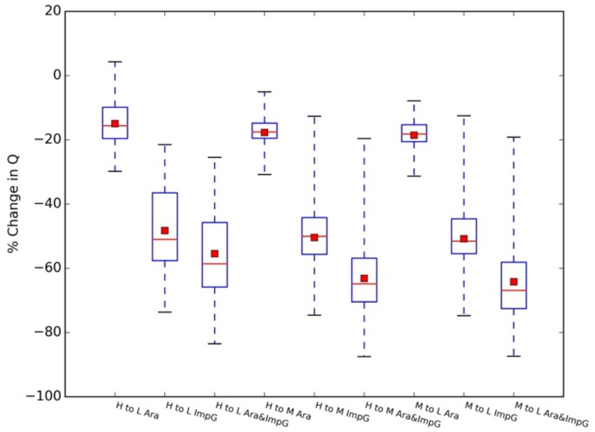
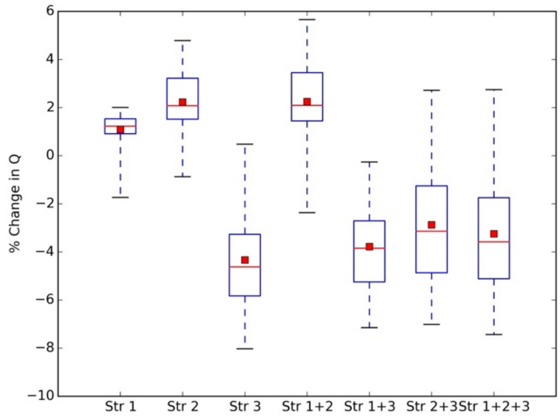
Sub-Catchment Scale Spatial Targeting for NFM: CRUM3

Having determined the key sub-catchments from SCIMAP-Flood, the next part of the analysis uses the CRUM3 hydrological model to investigate the performance of mitigation actions. CRUM3 is a fully spatially distributed, process based hydrological model running at the landscape scale (Lane et al., 2009). CRUM3 consists of four key elements: weather, 1D vertical hydrological processes, 2D landscape processes and routing and the river channel network. The model was used within the GLUE predictive uncertainty estimation framework (Beven & Binley 1992). The results for soil compaction management through aeration and the implementation of woody debris dams are presented for the River Roe catchment, although others scenarios were considered. The assessment of mitigation action performance was assessed by the change in the peak discharge for each of the behavioural model parameter sets, hence capturing some of the predictive uncertainty. The results for the land cover targeted soil aeration scenarios and for the implementation of large woody debris dams on different stream orders are shown below.



The peak discharge percentage change using the land cover targeted soil aeration scenarios. ‘H’ refers to heavy compaction levels, ‘M’ is medium and ‘L’ is light. ‘Ara’ is arable land cover and ‘ImpG’ is improved grassland.



Large Woody Debris (LWD) dam scenarios for peak flow reduction for the Strahler (Str) numbered stream combinations using the -40% maximum discharge reduction from Wenzel et al. (2014).

The greater the amount of catchment area assigned to soil aeration application the greater the reduction in peak discharge. Though unrealistic as the sole mitigation action due to the required area to be aerated and the unlikeliness that the entire catchment will be compacted, the use of soil aeration has a significant impact on the peak discharge in the River Roe catchment. The results for simulating large woody debris dams are shown for the maximum reported reduction in peak discharge of 40%, although other lower levels were also modelled. The implementation of large woody debris dams in both Strahler one and Strahler two channel reaches results in an increase in mean and median peak discharge. This increase is potentially due to the flow restriction prolonging the maximum discharge moving downstream and the cumulative effect at the point of impact is a prolonged, but restricted, maximum discharge. All three scenario sets with large woody debris dams on Strahler three channels had a reduction in peak discharge with a mean reduction of -4.33% and a median of -4.61%.

Summary and Conclusions

- The combination of the rapid risk and opportunity mapping with SCIMAP-Flood and the detailed hydrological modelling with CRUM3 provides a powerful toolkit to spatially target and assess the performance of natural flood risk management schemes.
- SCIMAP-Flood enables the rapid and cost effective identification of sub-catchments and the areas within those catchments that are most likely to be contributing to the flood peak at the defined point of interest, such as Carlisle or Appleby-in-Westmoreland.
- CRUM3 can then be implemented to test NFM schemes and provide quantitative predictions of the change in flood peak magnitude, as required for project funding.

Beven, K. and Binley, A., 1992. The future of distributed models: Model calibration and predictive uncertainty. *Hydrological Processes*, 6, pp.279–298. **Heathwaite**, A.L., Quinn, P.F. & Hewett, C.J.M., 2005. Modelling and managing critical source areas of diffuse pollution from agricultural land using flow connectivity simulation. *Journal of Hydrology*, 304(1), pp.446–461. **Lane** S N, Reaney S M and Heathwaite A L 2009: Representation of landscape hydrological connectivity using a topographically-driven surface flow index; Water Resources Research, **45**, W08423 **Reaney** S. M., Lane S. N., Heathwaite A. L. and Dugdale L. J.2011: Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance; Ecological Modelling Volume 222, Issue 4, 24 February 2011, Pages 1016-1029 **Wenzel**, R., Reinhardt-Imjela, C., Schulte, A. & Bölscher, J., 2014. The potential of in-channel large woody debris in transforming discharge hydrographs in headwater areas (Ore Mountains, South-eastern Germany). *Ecological Engineering*, 71, pp.1–9.