

# Hydraulic modelling of the Carlisle 2005 floods

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## Introduction and aim

The Cumbrian city of Carlisle suffered from serious flooding in 2005 when intense rainfall caused the Rivers Eden, Petteril and Caldew to overflow. The damage that ensued caused disruption across the region and affected 2,700 households.

This project aimed to reproduce the flood event using computational modelling, to develop a better understanding of the nature and causes of the event.

The aim of this project was fulfilled by the following specific objectives:

- 1) conduct a comprehensive literature review of recent developments in flood modelling;
- 2) evaluate the model for application to real-world urban flood events;
- 3) investigate the effects of spatial resolution; and
- 4) suggest potential improvements to the model.

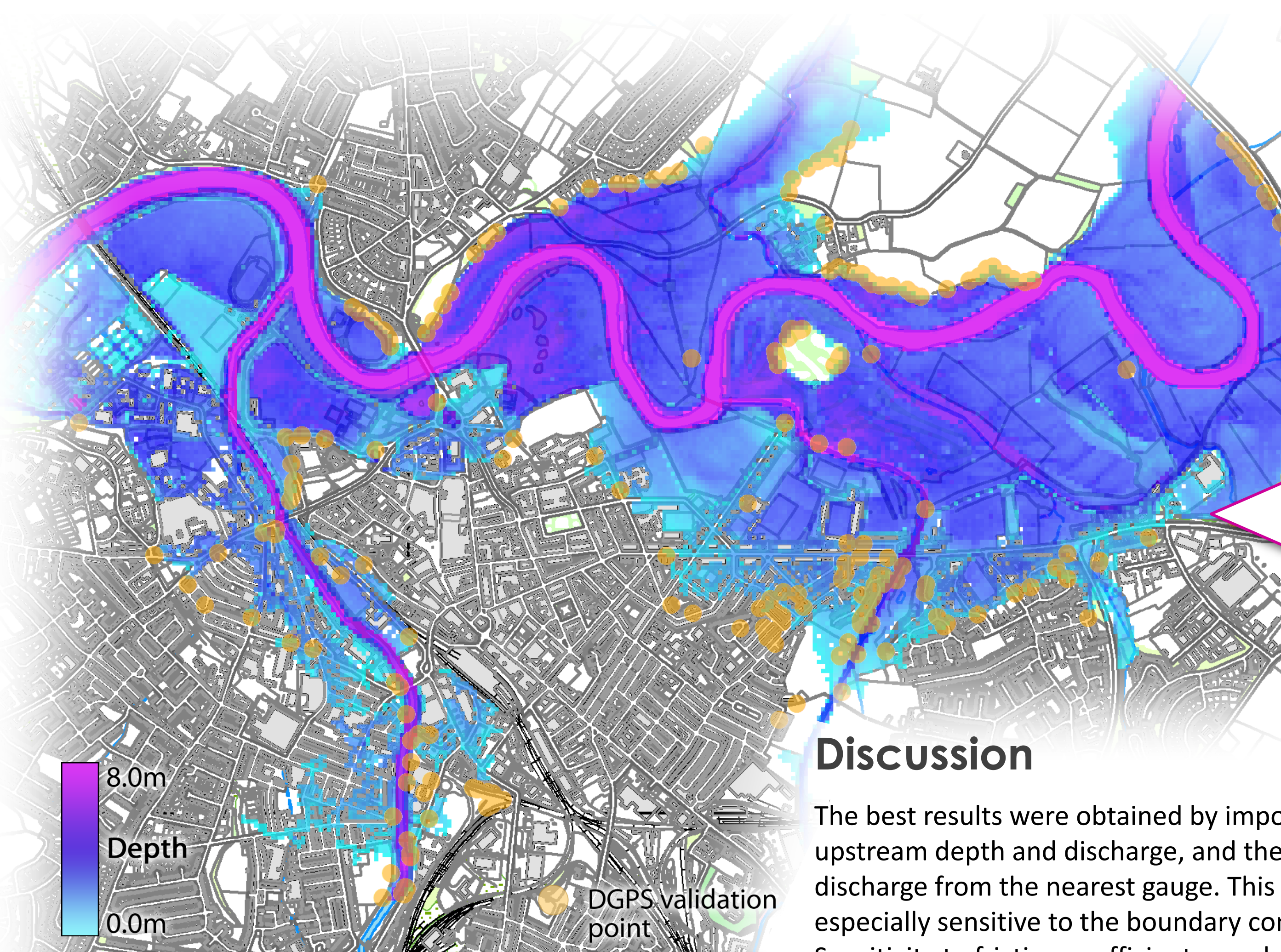
The combination of small tributaries, closely spaced buildings and the long duration of the event make this urban flood event a particularly challenging case to accurately reproduce.

## Approach

A finite volume Godunov-type scheme implemented in the NewChan model was used. This approach is able to conserve mass and momentum, even when shocks are observed, thereby delivering an accurate result regardless of the nature of flow. Two distinct versions of the model were used, incorporating either uniform or dynamically adaptive Cartesian grids. Basic parallelism for solving the Riemann problem was implemented with OpenMP.

Simulations were attempted with upstream discharge imposed for each of the three channels, and again with the depth also imposed. The effects of different configurations were also assessed for the downstream boundary of the Eden.

Two successive rounds of calibration were used to determine the optimal friction coefficients. 90 combinations of coefficients for the floodplain and Eden channel were simulated, and the pair with the lowest root mean square error was then used with a range of coefficients for the Caldew channel.

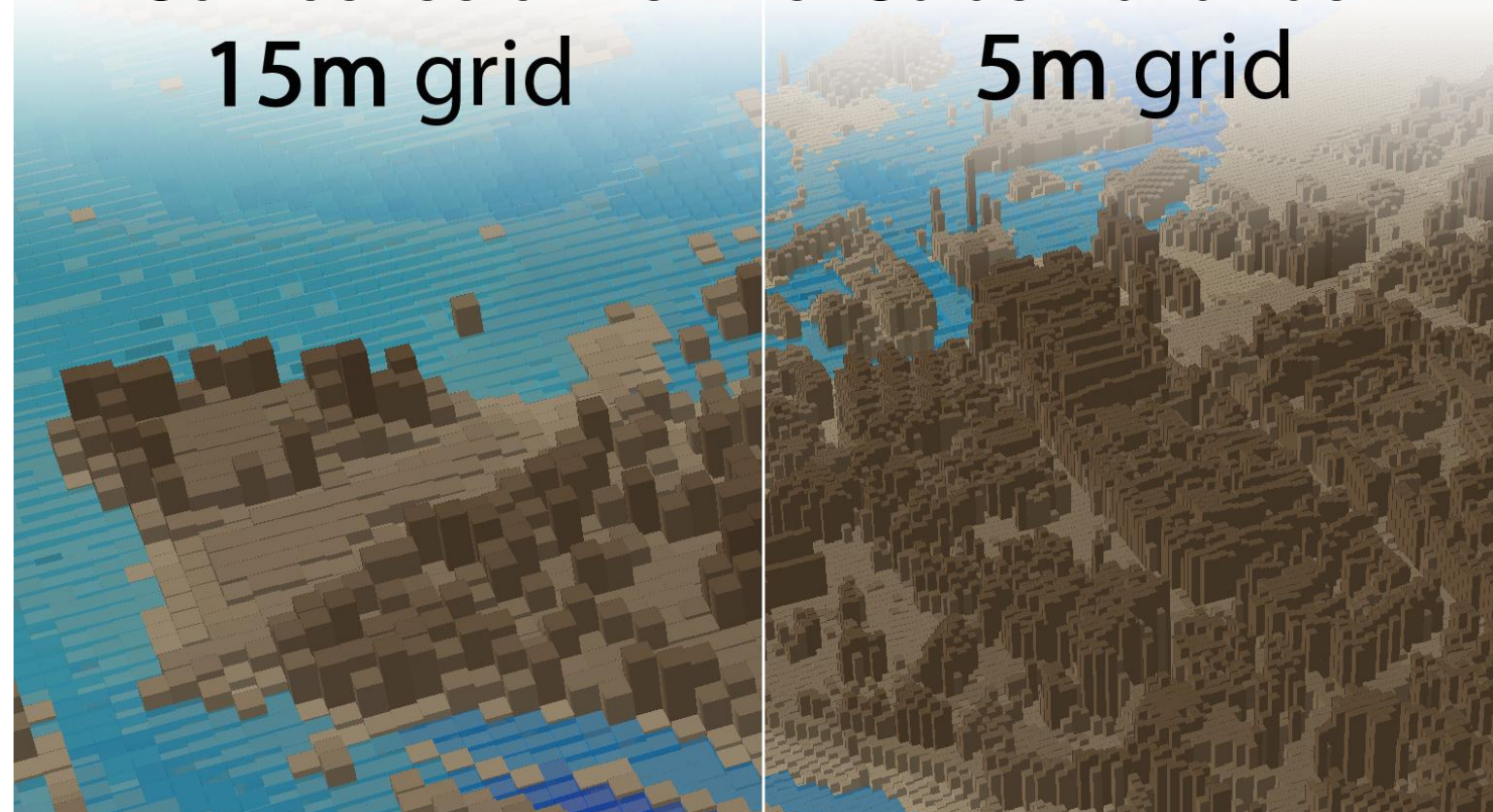


### Spatial resolution

The effects of different grid resolutions were assessed at 25m, 15m, 10m, and 5m. Using a uniform grid, simulation run-times varied from 50 minutes to 5 days, as a result of the higher number of cells and smaller time-step required for mass and momentum conservation. An adaptive grid, in which the cells are resized according to its flow characteristics, can reduce this time by around a third without a significantly detrimental effect on the accuracy of the results.

#### Confluence of the River Caldew and Eden

##### 15m grid      5m grid



## Discussion

The best results were obtained by imposing both the upstream depth and discharge, and the downstream discharge from the nearest gauge. This case is especially sensitive to the boundary configuration. Sensitivity to friction coefficients was less pronounced, with textbook values likely to provide an appropriate degree of accuracy.

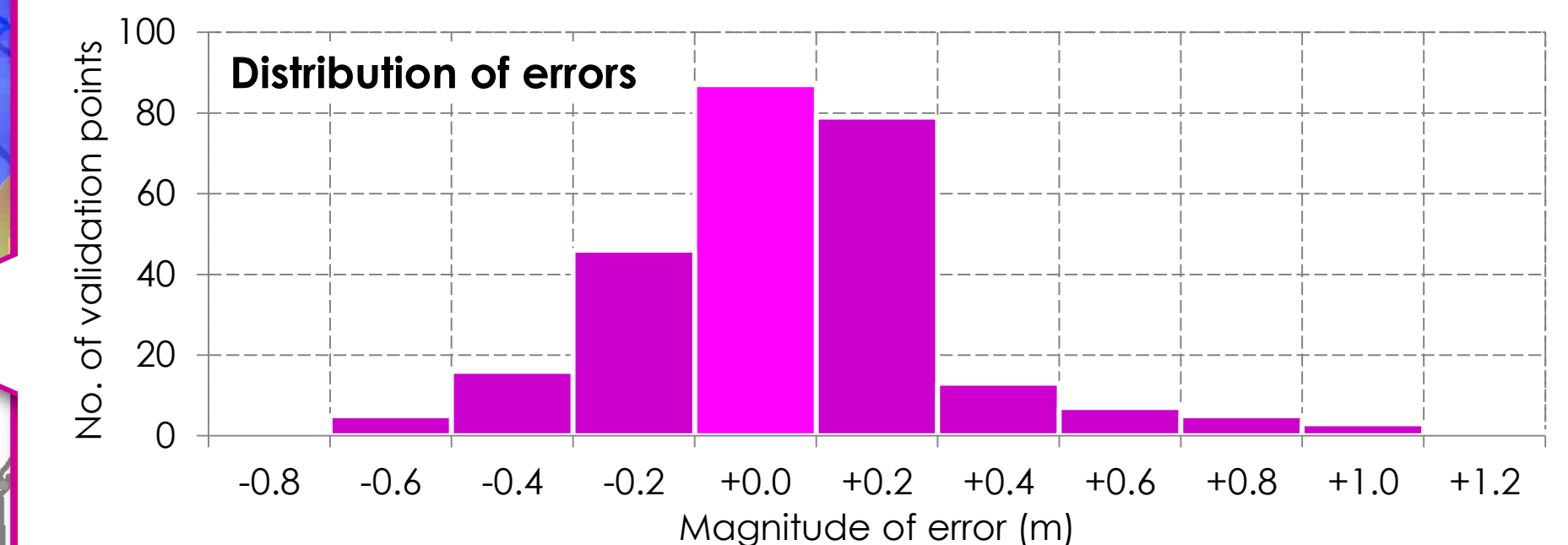
While good results were obtained using a 15m resolution, it is difficult to meaningfully improve on these results given the inherent errors in the validation data. Similar post-event surveys for future events should prove highly beneficial to model development.

Problems transpired with the implementation of transmissive boundary conditions in NewChan. A combination of factors, commonly occurring in the falling limb of a storm event can cause an untrue excess of water. Further work will be required to ascertain the best approach for rectifying this.

The run-time for simulations on 5m and 10m grids is prohibitively lengthy for common use, and yet such a complex urban environment features many small gaps that require these resolutions. If considering the effects of flood defences (e.g. levees), these high resolutions will be essential; adaptive grids are useful but not a panacea, for expediting such simulations.

## Accuracy of results

Comparison of 263 validation points obtained in two post-event surveys shows that the model reproduces the event with a root mean square error of 28cm using a 15m grid resolution. This is considerably lower than the estimated error in the DGPS field measurements, and comparable to the results of other published studies. Fit statistics and the distribution of errors also suggest a good reproduction, albeit with a tendency to over-estimate inundation depths around the Caldew.



## Conclusions

- The nature of the numerical scheme implemented in NewChan makes it ideal for urban flood modelling.
- Accurate results were readily achieved even at low resolutions.
- High resolution modelling will be essential for design applications.
- The importance of boundary conditions should not be underestimated.
- A more considered approach to parallelism has the greatest potential benefits.

## Further work

The outcomes of this project are now being used for further research in urban flood modelling. The effects of different implementations for boundary conditions, such as using Riemann invariants and restricting backflow, are currently being investigated. Acceleration techniques using parallelism on Graphics Processing Units (GPUs) are being used to develop a new model.

## Acknowledgements

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