PAPER 5

Modelling Flood Risk Assessment, an Evaluation of Different Methods

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Modelling Flood Risk - an Evaluation of Different Methods

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ABSTRACT

As part of the Pitt Review into the 2007 flooding, MWH were commissioned to evaluate the capability of modelling methods for assessing flood risk. The study carried out in May and June 2008 assessed five different methods of varying complexity. This investigated how well the methods replicated known flooding for location and spatial extent, as well as the time and level of information required. The work demonstrated that results were both catchment and return period dependent. The simpler or high level methods were capable of identifying broad areas with significant flood risk. However they often identified the wrong flooding locations or extent of flooding at a detailed level. More integrated approaches, whilst often more complex, were better able to replicate both location and extent. Since the publication of the report a number of the methods have been developed further to extend capability and reduce limitations.

KEYWORDS

Flood Risk, 1D Modelling, 2D Modelling, Above & Below Ground Methods.

INTRODUCTION

The summer 2007 floods demonstrated the need to understand the uncertainty around the capability of current approaches to flood risk modelling and mapping. There has been doubt expressed by many that it is not possible to reliably model flood risk from pluvial flooding in urban areas. Others suggest it is possible but requires a significant amount of time and data. Others claim that significant detail is not necessary and flood risk can be reasonably assessed using quick high level approaches.

MWH, supported by JBA, were appointed by the Cabinet Office (in support of the Pitt Review) to investigate modelling capability for assessing flood risk. The report was published on the Pitt Review web site in June 2008 (Pitt 2008).

This paper summarises the study and highlights some of the advances since its publication in assessing flood risk modelling and mapping in urban areas. It is intended to demonstrate current capability for practitioners working in flood risk management to make informed decisions on the most suitable application.

There are a large number of different modelling methods that can be used for replicating and predicting flooding in urban areas. These methods are being constantly improved and developed. A representative cross-section of the methods available in 2008 were used in the assessment but this does not claim to have been an exhaustive study.

OBJECTIVES AND MEASURES

The aim of the study was to assess how different methods accurately predict flooding and hence flood risk. Although specific software was used, the project was not about recommending software types but what each method could achieve and be used for. The specific objectives were:

- Review the capability of a number of current modelling tools
- Review a number of appropriate methods suitable for different circumstances and requirements
- Acknowledge known limitations of different methods to model urban flooding
- Identify the comparative performance of different methods

A number of parameters were considered important to assess what each method was sensitive to. The key parameters are listed below:

- Rainfall storm duration
- Rainfall return period
- Capacity of the sewer and pipe drainage systems.
- The general topography of the area
- The detail and resolution to which topographic data is available

The authors expectation's in general were that for rainfall events with a low return period, the sewerage network can be expected to be the key parameter controlling flood risk. However, as the event becomes more extreme, it was expected that the overland component of flooding became progressively more important.

FIVE APPROACHES TO ASSESS FLOOD RISK

The project analysed five principal approaches to modelling flood risk. The methods are described briefly below in increasing order of complexity.

A - Topographic index analysis. This approach utilises information derived from a digital elevation model (DEM) to identify areas at risk from flooding. The topographic index comes from a score that combines; (i) areas identified as flat, (ii) areas identified as local depressions, and (iii) areas close to drainage pathways from an analysis of slope and contributing area.

B - 2D Overland routing of a spatially-uniform rainfall event. A rainfall hyetograph is applied to each 2D model grid cell during simulation. It is used to route the resulting flood water overland, and determine the locations at which flood water accumulates and the areal extent of flooding (Hunter *et al*., 2008).

C - Decoupled hydraulic sewer model and 1D overland routing. This approach has two distinct modelling components. Firstly, the sub-surface sewer and pipe network system is modelled using an appropriate hydraulic model. Secondly, the flow/volume expelled from manholes is routed overland using simple one dimensional flow routing paths. The tool includes a routine that automatically connects properties to sewers to replicate below ground flooding mechanisms (flooding due to backing up from overloaded sewers).

D - Decoupled hydraulic sewer model and 2D overland routing. This approach is similar to C above, but a 2D approach to surface flood routing is used. The water leaving the below ground system was fed into the overland flow model. The overland flow remains above ground and this method does not enable water to re-enter the below ground system.

E - Coupled hydraulic sewer model and 2D overland routing. This approach is similar to that in method D, but the surface and subsurface hydraulic models interact dynamically and feedback within a single software program.

TEST CATCHMENTS

Three real catchments from the UK with distinct and different catchment characteristics were used. These had varied geography, topography and drainage system types.
*Catchment 1****. This catchment has a mix of steep and flat topography, and is heavily urbanized. The catchment is predominantly served by a gravity based foul and surface water system, with combined sewer overflows (CSOs) and suffers from interaction with a local watercourse.***

Catchment 2. The catchment is less densely populated than catchment 1 with predominantly flat topography. The catchment is a pumped system, mostly combined with a number of CSOs.

Catchment 3. This catchment is the smallest of the three and relatively steep. It is predominantly served by a combined system with minor areas of separate sewerage. There are a number of CSOs that provide flood relief to the sewer system.

DATA REQUIREMENTS

Each method required different levels of information to carry out the assessment which is summarised in Table 1. This only lists critical information and additional data sets can be required that are important, eg: detailed topographic information including fences and walls are not listed. Data requirements are an important factor in selecting the method being used as both availability and cost can limit the accuracy and quality of any method. In addition, it is always recommended that actual flood data is collated to validate predicted results.

Table 1 – Summary information required for each assessment method

	Topographic index	2D overland routing	Sewer model and 1D routing	Decoupled sewer model and 2D routing	Coupled sewer model and 2D routing
Rainfall	✗	✓	✓	✓	✓
Mapping	✗	✓	✓	✓	✓
Sewer Model	✗	✗	✓	✓	✓
DTM	✗	✓	✓	✓	✓
DEM	✓	✓	✓	✓	✗
Address data	✗	✗	✓	✗	✗

RESULTS

For each area and modelling method, the flood consequence has been calculated on the basis of flood depth and extent. This has allowed the different modelling methods to be readily compared with each other and with actual recorded flooding.

Each method was analysed for 10, 30 and 100 year return period storms of short, medium and long rainfall durations. These different return periods and durations have been chosen to determine if some methods are more suited to certain types of storm event.

Topographic Index Analysis

This method was found to be limited for the catchments assessed, and provides a very high level of assessment of flood risk due to topography. It was able to indicate where flooding may arise from watercourses and the subsequent flow paths relatively quickly (Figure 1). Without the use of rainfall and true understanding of susceptible areas this method does not truly indicate flood risk and is of limited use for this application. This analysis also has the problem of being almost impossible to validate against real data. The method simply shows paths of least resistance and low spots, no account for below ground systems or vulnerability to a given rainfall event can be determined.

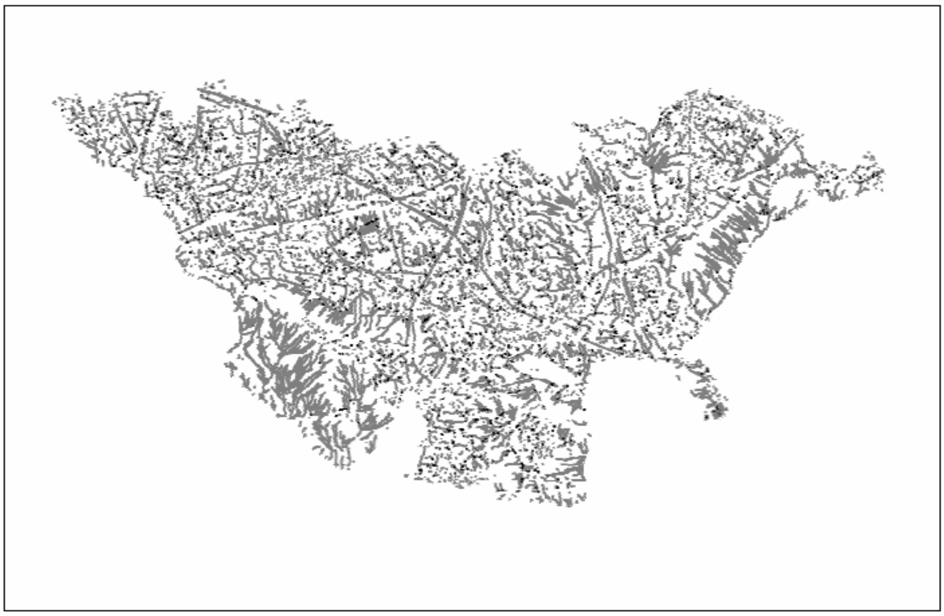

Figure 1 Catchment 3. Topographic index analysis results with the flow paths indicated in the dark gray colour.

2D Overland Routing

This approach produced a number of flood risk maps identifying areas where water is likely to pond. The method is quick to set-up, obtain results and is fairly robust (Bradbrook *et al*., 2004), but does not account for the below ground systems, and therefore the rainfall will continue to accumulate and cannot drain down. Where a sewerage or drainage system conveys significant storm flow, this can transfer flow from one part of a drainage area to another leading to a different distribution of flooding. This effect is not allowed for in this method. The results using this method differed between catchments, this can be attributed to the different topography and the impact of the below ground systems. In addition the runoff characteristics of different surface types will change the results.

In Catchment 1, most of the known flooding locations were identified, however it had a tendency to over predict both flood depth and the areal extent of flooding (Figure 2). In catchment 2, flood areas were significantly over predicted due to its flat topography. With no well defined flood pathways flood water simply accumulated on the surface rather than run off to low spots, where in practice substantial volumes of run-off are pumped away. In catchment 3, this method tended to predict flooding in the wrong locations, missing many flooding locations altogether whilst predicting flooding in areas where none occurs. This was more pronounced for the more frequent, less intense storms.

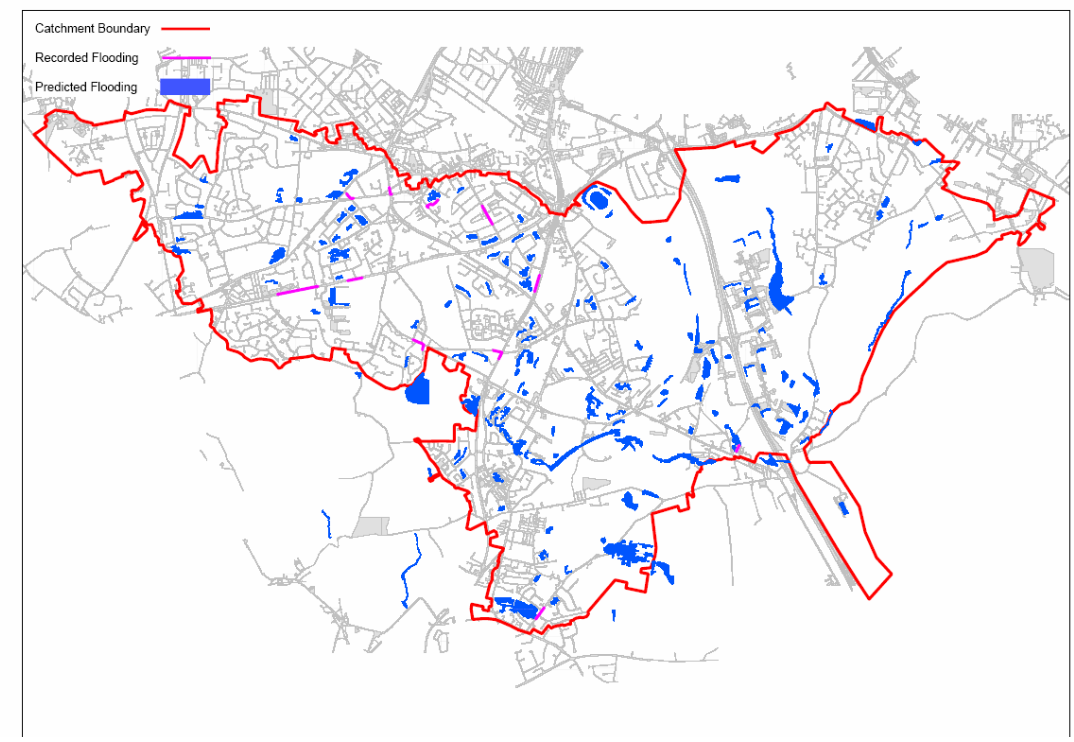

Figure 2 Catchment 3, 2D overland routing approach.

Decoupled Sewer and 1D Overland Flow Routing

This approach produced a good replication of the flooding locations, compared with recorded flooding but the technique was unable to accurately replicate the areal extent of flooding A limitation of this technique is that the output identifies flooding on a property basis therefore post processing is required to define the areal extent of flooding and produce consistent maps. This process can lead to uncertainty in understanding flood volume at a particular location. A particular feature of this tool was that it automated the connection of individual properties to the sewer network so was able to indicate flood risk through surcharge. This proved to be very important in the flat catchment (2), and this method proved best at replicating known flooding here (Figure 3).

The method requires a large amount of data due to the below and above ground modelling but as it is largely automated it is not resource intensive and can be applied to large areas.

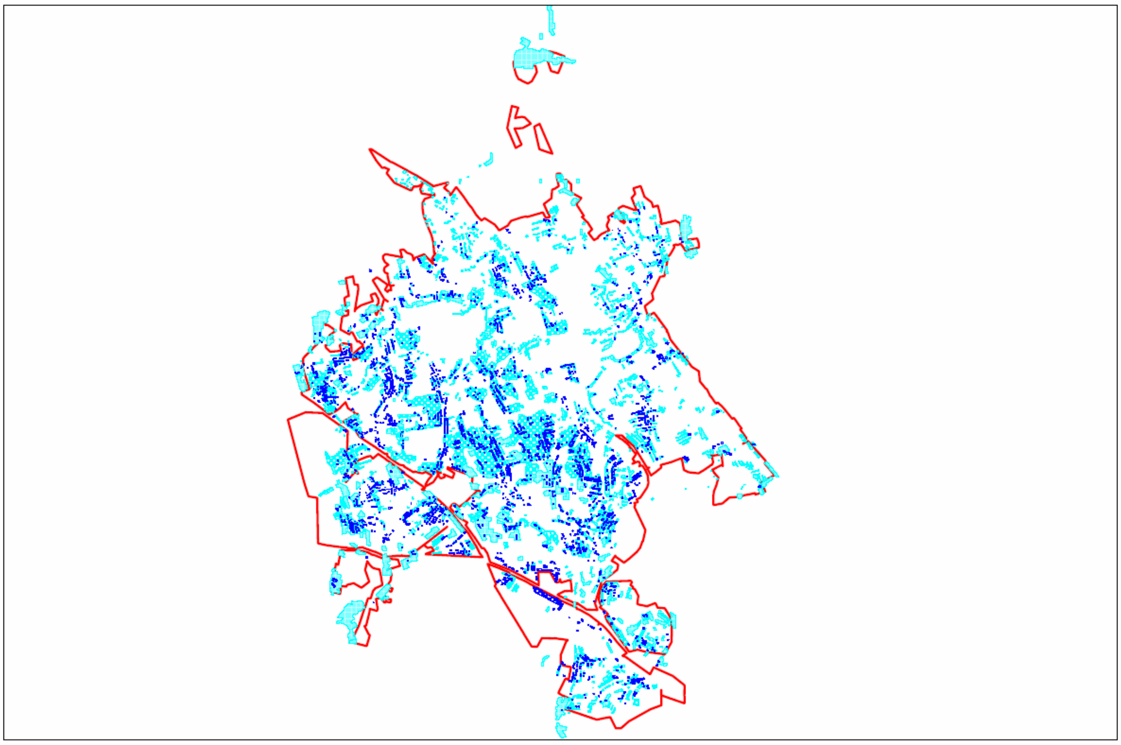

Figure 3 Catchment 1, Decoupled sewer and 1D overland flow routing. Dark areas indicate predicted surface flooding and light gray areas indicate possible flooding due to surcharge.

Decoupled Sewer and 2D Overland Flow Routing

This approach provided a good representation of the location and areal extent of flooding on the surface for all three catchments (Figure 4). In this approach, two different pieces of software were used, however other alternatives may be available. In this test the process was found to be slower than the coupled 2D approach due to the current output files not supplying the data in the correct format. This could be easily rectified and in some catchments could run more quickly than the 2D coupled approach at present. Although a valid method, this approach may be considered superseded by coupled 2D approaches as the data requirements are similar.

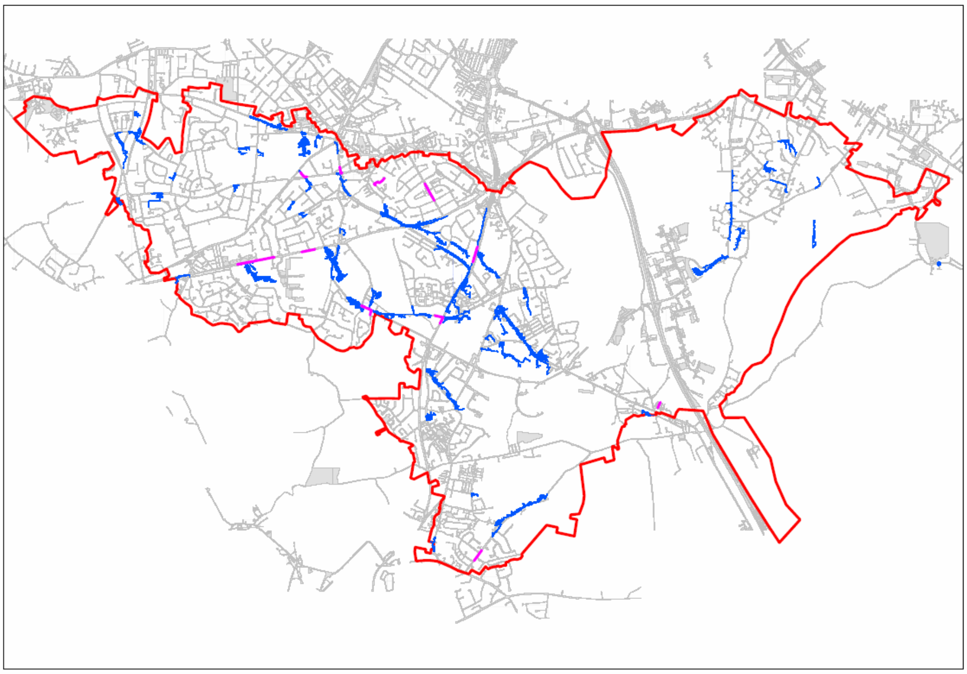

Figure 4 Catchment 3, Decoupled sewer and 2D overland flow routing with a 1 in 30 year return period storm. Surface flooding is shown as dark shaded areas.

Coupled Sewer and 2D Overland Flow Routing

This approach produced similar results to the decoupled method of sewer and overland flow routing, as would be expected. A particular advantage though was that the rate of flooding (escaping from a modeled point such as a manhole) was replicated and that flows could return to the sewer system as well.

The extent of the flooding for a 1 in 30 year return period storm event in catchment 3 is shown in Figure 5. This shows the slightly improved accuracy of predicted flooding locations. The combination of the below ground flooding mechanism in the decoupled sewer and 1D approach with this approach would be expected to produce excellent results.

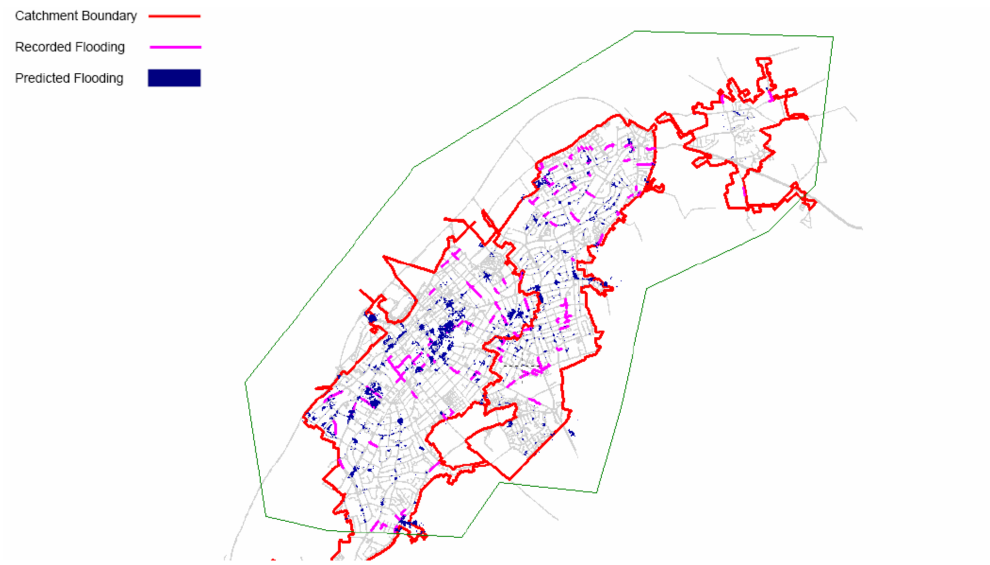

Figure 5 Catchment 2, Coupled sewer and 2D overland flow routing with a 1 in 30 year return period storm.

DISCUSSION

The project investigated five different methods for assessing flood risk modelling. These differed in complexity, cost and data requirements. It is not as simple as one method is best, but particular methods are more suitable for specific levels of investigation e.g. in a hierarchal approach.

Of the five methods tested in the report the topographic method was the weakest for understanding flood risk. The method is quick and works for large areas but the results do not provide the user with any meaningful understanding of flood risk or how it might be quantified or mitigated.

The 2D surface routing method, which applies blanket rainfall across the catchment, does not model below ground drainage (sewerage) systems. The method is quick and can be scaled up to assess many areas quickly. It works better for more extreme events and less well for more frequent events, and where the sewerage infrastructure plays an important part in draining the catchment. Where this is the case results can be misleading. It is most suited as a first pass high level assessment for identifying areas at significant risk of flooding, but not for determining specific flood locations in urban areas.

Combining a hydraulic sewer model and 1D overland flood routing proved to be a good compromise for identifying properties at risk of surface water flooding. The results were close to observed flooding although areal extent of flooding is not a standard output of this method. An added advantage of the method used was that it included an automated system for modelling of below ground flooding mechanisms (where sewers back up causing flooding of property). This method gave the best match with Sewerage Undertaker's flooding databases.

The decoupled sewer model and 2D overland model gave improved representation of surface flooding (volume and areal extent). However as this method did not link the above and below ground models nor assess property risk to surcharge it failed to identify some of the more frequent property flooding. As this method requires two pieces of software to run sequentially, this method may be considered outdated with the advancement of coupled 2D approaches.

The coupled sewer flow and 2D overland routing method represents an excellent flood modelling approach. During this study it was found that the quantity of data and computer time means that generation of a mesh on a catchment scale required the use of large mesh elements. This reduces the accuracy of flood predictions. The method was found to work better when applied to smaller areas, though this computational limit may well cease to be as important as computing power improves. This method gave the best representation of the areal extent of flooding observed for the July 2007 floods (figure 6).

The assessment demonstrated that even in extreme events, the sewerage system makes an important contribution to draining urban areas. During smaller intensities the accounting for the below ground system was even more important when understanding risk and how it can be mitigated. Models that replicate surface flooding without accounting for the sewerage system cannot therefore be expected to accurately assess or map detailed flood risk. However, due to their ease of use and lower data requirements, they are valuable for showing areas that are naturally vulnerable to flooding due to their topography. This makes them useful as a first pass in flood risk assessment.

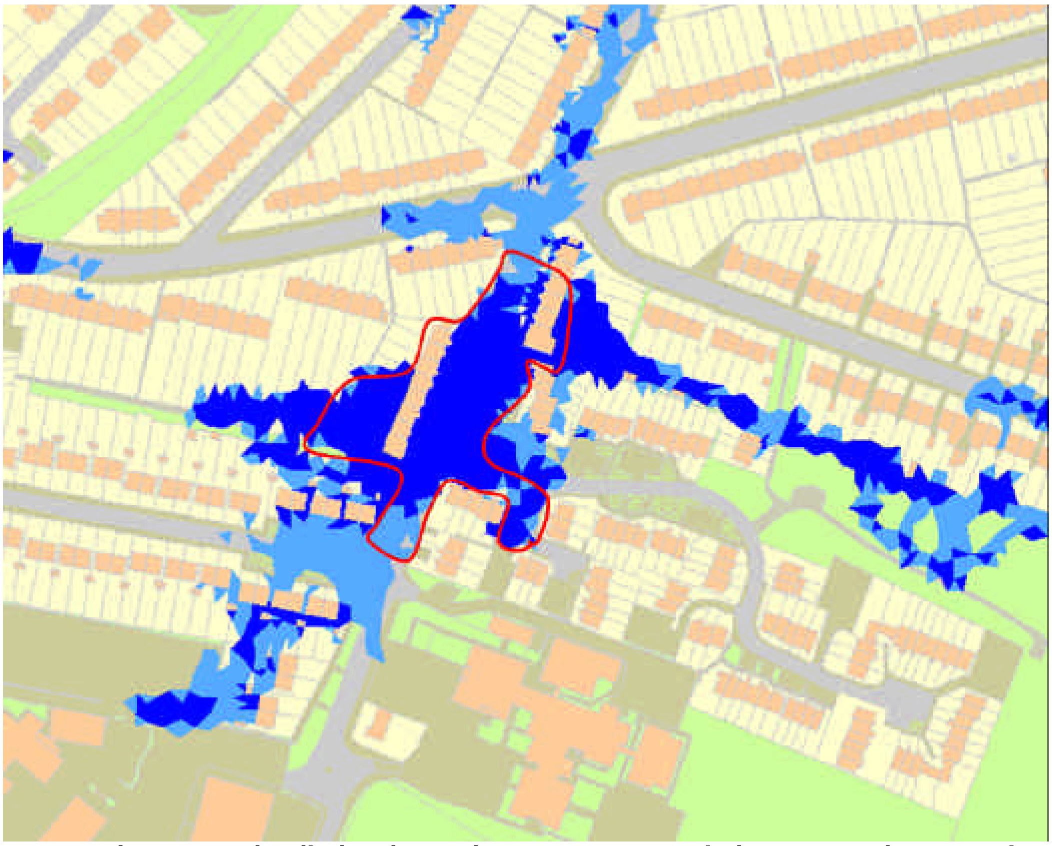

Figure 6 Catchment 1, detailed sub catchment area, coupled sewer and 2D overland flow routing for event of July 2007. The figure indicates the known flooding from video evidence as a thin line. The simulation is shown in a dark shading to represent predicted depths above 50mm and lighter colour is above 10mm.

MODELLING ADVANCES POST STUDY

The modelling of flood risk is constantly developing and improving. Since the study was carried out in June 2008 a number of the software packages have been developed further and have a number of significant improvements over the versions used for the Pitt Review study

It was noted that the 2D above ground model applied a blanket rainfall that requires a blanket allowance for rainfall "loss". Work is continuing to improve guidance on calculating the loss to improve the reliability of flood prediction. Part of this work has resulted in reducing the volume of water applied during the simulation. These improvements were used to model the Environment Agency's "Areas Susceptible to Surface Water Flooding" dataset which maps surface water flood susceptibility across England and Wales.

The sewer model with 1D overland modelling approach improves as the modelling software advances and when the models are designed with detailed flood analysis in mind.

The coupled 2D approach is now sufficiently advanced for general application. The following improvements are now available:

- Increased speed of mesh generation: This has helped both speed up the assessment and increase the scale to which the assessment can be carried out.
- Better understanding of GIS data and how it impacts upon mesh generation
- Improved data clean-up tools to aid mesh generation

- Enhanced results processing and outputs

Coupling this approach with the below ground model available with the 1D surface modelling method will provide additional capability in the future.

CONCLUSIONS

The results from the study indicated that all but the topographic method produced results that could add value to the understanding of flood risk. The topographic method while having its uses is difficult to put into a context of flood risk.

The less detailed (above ground only) method produced a good match to known 'at risk' areas in broad terms and could be used for analysing large areas quickly. However as the method does not account for the effects of the sewerage system, the method can be misleading at the detailed level and should not be relied on to give detailed flooding locations in urban areas.

Methods accounting for both above and below ground systems have been shown to produce the most accurate match of flooding against known flooding. They are therefore considered the most useful for gaining detailed understanding of flood risk. They do however tend to have a greater demand for data and tend to be more expensive and slower techniques. With current computer power and the availability of LiDAR data at a reasonable cost, these methods are however suitable for use in developing strategies for managing urban flood risk in view of the high cost of urban flooding and the large investment required to effectively manage it.

Using a coupled 2D approach and linking the results to properties can be achieved and the methods now available do allow for a comprehensive flood risk assessment within a reasonable timescale and cost. It should be noted that no single method is 'better' than another. Each have there uses and it is the project circumstances that should drive the selection of the method.

The field of flood risk modelling is constantly advancing with increased computer power and advanced software regularly improving the level of detail and speed at which evaluations can be carried out. The report indicated that hydraulic modelling can be used as a good prediction tool for flood risk analysis, It also recognised that improvements are being made as practitioners learn how to use and further adapt the new software.

DISCLAIMER

The views expressed in this paper are those of the authors and do not necessarily represent the views of MWH, JBA, WaPUG, Cabinet Office or those who provided data for the project to be undertaken.

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REFERENCES

Balmforth, D.,Digman, C., Bamford, T., Waller, S., Hunter, N., (2008) Evaluation of Modelling Approaches for Flood Risk Assessment. http://www.cabinetoffice.gov.uk/thepittreview/evidence.aspx 26th October 2008

Bradbrook K.F., Lane, S.N., Waller, S.G. and Bates, P.D. (2004) Two dimensional diffusion wave modelling of flood inundation using a simplified channel representation. *International Journal of River Basin Management* **2** (3), 211-224.

Hunter, N.M., Bates, P.D., Neelz, S., Pender, G., Villanueva, I., Wright, N.G., Liang, D., Falconer, R.A., Lin, B. and Waller, S.G. (2008) Benchmarking 2D hydraulic models for urban flooding. *Proceedings of the Institution of Civil Engineers – Water Management* **161** (1), 13-30.P

Pitt, M. (2008) Pitt Review. Learning Lessons from the 2007 Floods, June 2008, Cabinet Office, London, http://www.cabinetoffice.gov.uk/thepittreview/final_report.aspx 26th October 2008