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2D FLOODING ANALYSIS IN SCOTLAND

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Key Words

2D hydrodynamic model, flow paths, InfoWorks, urban drainage.

Abstract

This paper discusses two methods of modelling above ground flood extents and overland flow paths using InfoWorks CS. The first of these methods uses 1D overland flow paths and the 1D flood mapping tool available in InfoWorks CS. The second method uses the new 2D surface flow model recently developed by Wallingford Software and available in version 8.5 of InfoWorks CS.

The Brechin catchment in Scotland provides a real-life case study where the two methods have been compared in order to determine the most robust and accurate modelling approach to assess a flooding problem in the catchment and potential solutions

INTRODUCTION

Following severe flooding on the River South Esk in Brechin in November 2002, a flood defence scheme was proposed by Angus Council. The proposed scheme involved constructing flood defences along the north bank of the river in Brechin (see Figure 1).

One of the main concerns about the proposed scheme was an expected increase in flooding of properties in the lower areas of Brechin due to sewer flooding caused by either flood water being trapped behind the flood defences and not being able to reach the river or insufficient head to allow discharge through the outfalls as the river level itself will increase. Therefore, as part of the Brechin Flood Alleviation Scheme, a pumping system was proposed to deal with excess stormwater and sewer flows that could not be discharged during periods of high river levels. HR Wallingford was commissioned by Angus Council to carry out a drainage modelling study to estimate pumping station requirements to prevent flooding behind the flood walls and bunds.

There are two parts to the drainage system in Brechin. There is a combined sewerage system that serves most of the urban catchment and there is also a network of culverted burns that drain the rural catchments to the north and pass through the town to the river. There are also overflows from the combined system to the culverted burns. Short, intense storm events cause flooding from the combined system, whilst longer, lower intensity storms are more critical for the culverted burns. This means that each system can act as a relief to the other either via the overflows or via overland flow paths.

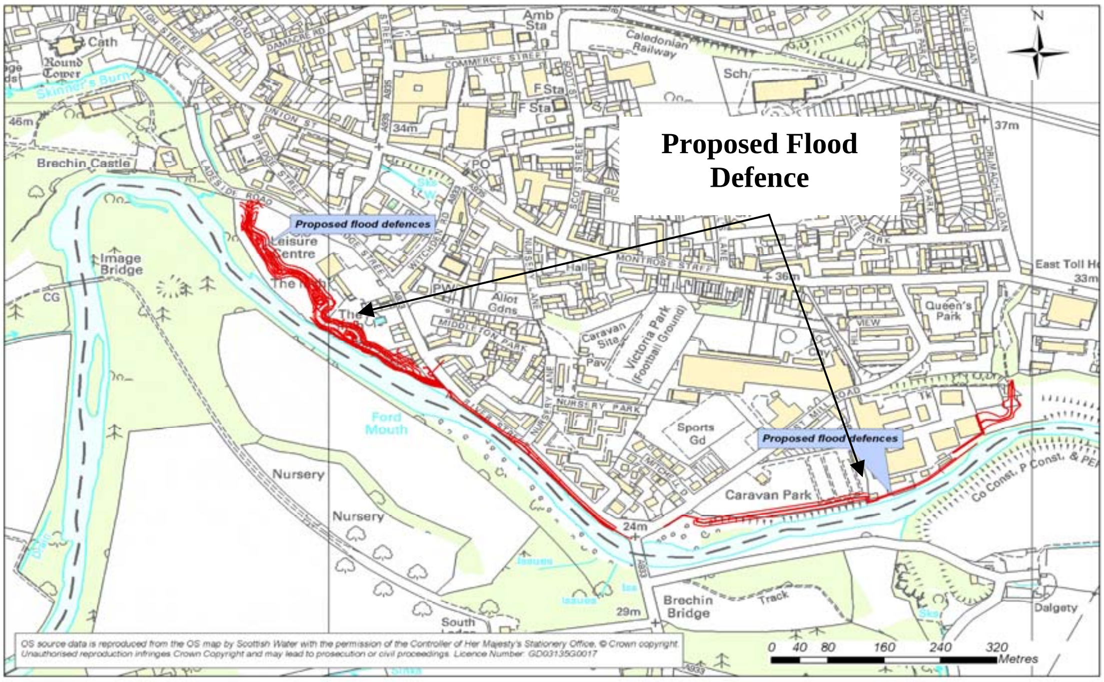

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Figure 1. Layout of proposed flood defences

An existing model of the Brechin combined sewerage system provided by Scottish Water was used as the basis of the modelling study. 1D overland flow paths were added to the model and 1D flood mapping was used initially to present the areas that would be affected by the flooding.

Shortly after the submission of the first phase of the study, a 2D surface flow model was developed by Wallingford Software. The Brechin model was used by Wallingford Software and HR Wallingford as a case study to assist with the beta-testing of the 2D surface flow model and train staff in the use of InfoWorks CS 2D. It would also increase knowledge of the catchment and subsequently provide a better service to the client in the next project phase. This paper describes both modelling methods and compares the results.

1D Model

Approach

At the time of the first phase of the study, the modelling options available for representing flooding were the following (either separately or in combination):

- "Lost" flooding, where flood water from manholes leaves the system and cannot re-enter the network. However, this flood water can be subsequently used as inputs for a 2D spreading model such as TUFLOW or TELEMAC.
- "Stored" flooding, where a level-storage area relationship (i.e. flood cones) is defined and flows are allowed to return to the system, via the same node, once the network has spare capacity.
- 1D Overland flow paths, where an above ground network of channels is defined, connected to the underground system via manholes, representing the most likely overland flow paths for flooding from the manholes.

Brechin is a fairly steep catchment. Therefore, the use of "stored" flooding was inappropriate as this would result in unrealistic flooding in the upstream sections of the combined sewerage system. As the interaction between the culverted burns and the combined system would play such an important roll in the overall system performance, the use of "lost" flooding in combination with other 2D modelling packages did not look like a feasible option. Therefore, it was decided that a 1D overland flow network was the best option to ensure a conservative representation of the likely flows arriving at the critical areas of flooding behind the flood defences.

The roads considered likely to act as overland flow paths were identified after an initial set of simulations had been run and flooding locations identified. The above ground links were defined by duplicating the underground links, with invert levels set at the sewer cover levels and the channel cross sections defined by an average width of a road. Manholes were given a flood type of "stored" (with the standard geometry of a double cone). This storage would only be activated if the flood water was not conveyed away from the manhole via the overland flow paths.

The 1D flood mapping tool in InfoWorks CS was used to determine the areas that were likely to be affected by the flooding. At all flooding manholes a flood depth is calculated by subtracting the flood level from the ground model elevation, as shown in Figure 2. This flood depth is then calculated throughout a flood compartment for multiple flood points using either a TIN or Inverse Distance Weighting (IDW) method. The flood compartments defined the extent of the floodable area behind the proposed flood defences.

1D flood mapping can only provide an indication of where flooding will occur rather than any quantitative assessment. This is because, as shown in Figure 2, if the volume of the flood cone does not match the volume identified by the ground model, then inaccuracies will occur. Flood cones also have limitations on their degree of "flatness". Very flat cones would create instabilities, as small variations on flood depth would mean large volume variations of stored water. Therefore, it is extremely difficult to accurately describe the storage available above ground using a combination of flood cones and overland flow links.

Results

One of the main conclusions from this first stage of the study was that very high pump rates were required for the proposed pumping station, based on the model results and alternative options needed to be identified. Reducing the pump rate by creating additional storage capacity was clearly an alternative, but the volumes were very large and a more radical solution was proposed and investigated.

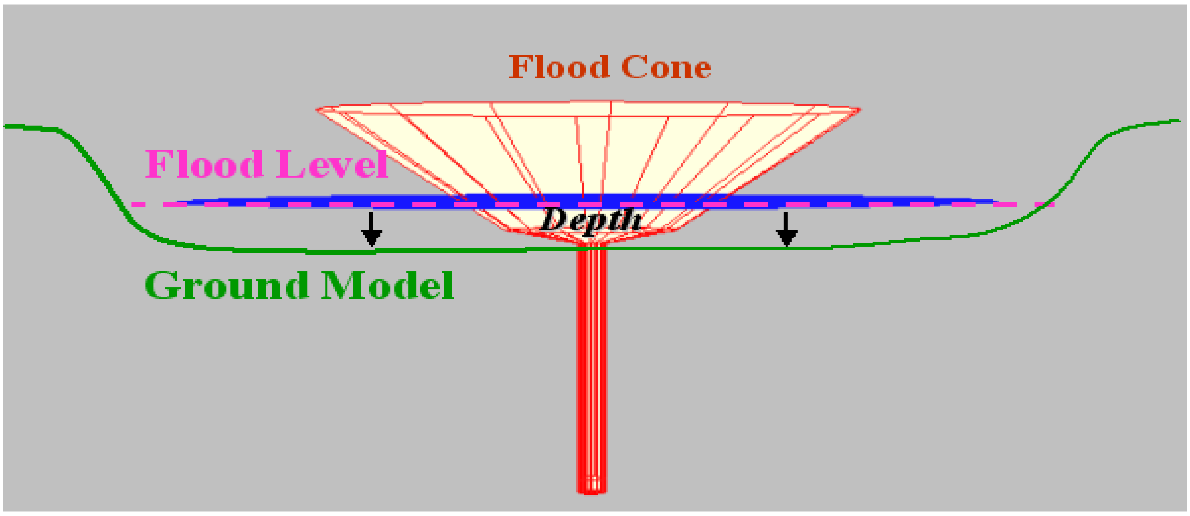

Figure 2. Diagram to illustrate 1D flood mapping

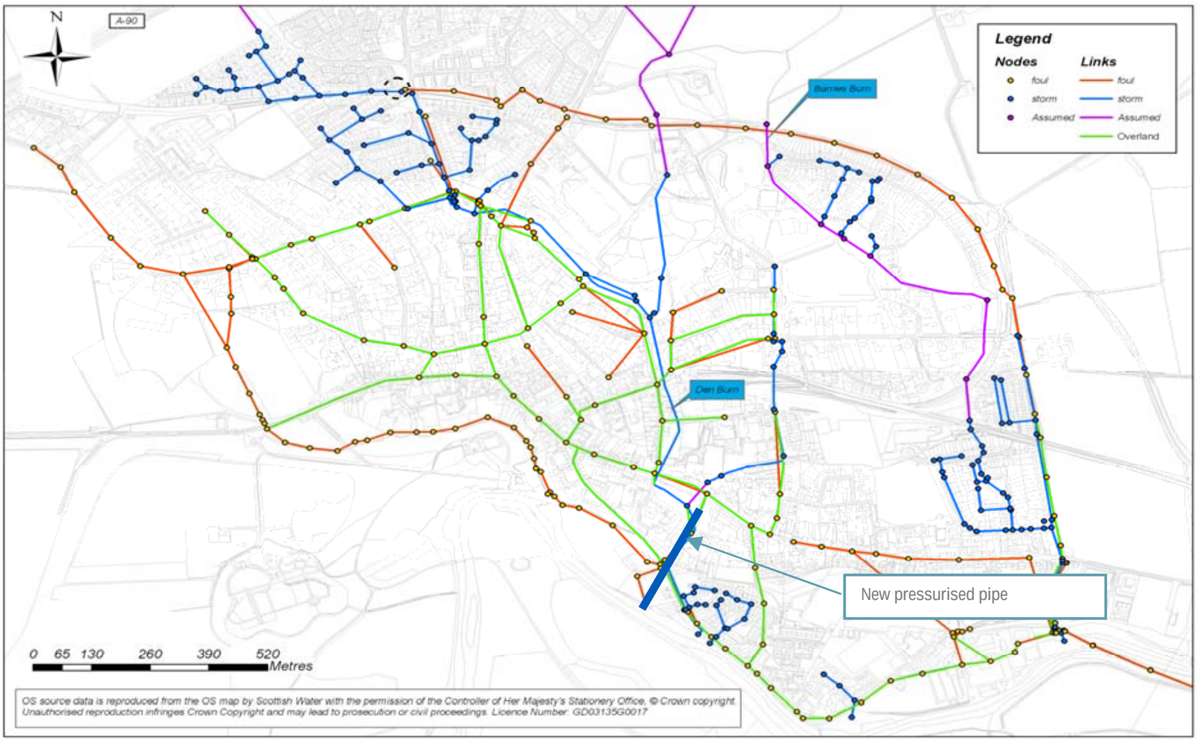

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Figure 3. Alternative solution for Brechin Study

This option proposed the replacement of the downstream end of the main culverted stream with a pressurised pipe, which would both serve the main drainage and intercept overland flows for the upper section of the city (Figure 3). This solution reduced pumping rates significantly as there is sufficient head to discharge into the Esk South River regardless of the river water level. However, the solution is extremely sensitive to the assumption of flood pathways and connections to the culvert. Therefore, it was recommended that additional data, through further survey work, would provide greater confidence in the model results. This would be essential prior to proceeding to a detailed option assessment and design.

2D Surface Flow model

Approach

All 1D overland flow links were removed and the flood type of the manholes was changed to 2D. This connects the 2D overland and 1D underground systems by means of a weir, as shown in Figure 4. The length of the weir is taken as the circumference of the manhole shaft and a coefficient of 0.5 was applied.

A 2D mesh was constructed using a digital terrain model (DTM), generated with the data available at that time: cover levels from the InfoWorks CS model, Land Form Profile data (every 5m) and a detailed survey of the river flood plain carried out during a previous study. This hybrid ground model was accurate in the areas of ponding behind the flood defences and very coarse across the rest of the catchment, including those upper areas of the catchment were overland flows were expected to occur. However, an improvement in accuracy was achieved for the main roads in these upper parts of the catchment, as the 5 m contour lines were refined by the model cover levels. Accepting the limitations of data available, it was decided that the ground model was adequate for an academic comparison exercise (see Figure 5).

The proposed flood defences were modelled explicitly as walls, which prevent flood water being conveyed to the river.

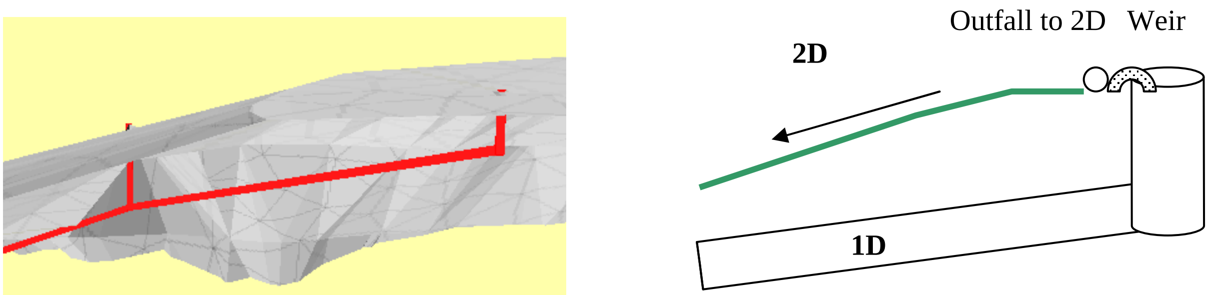

Figure 4. Schematic to show the connection between the underground 1D and 2D networks

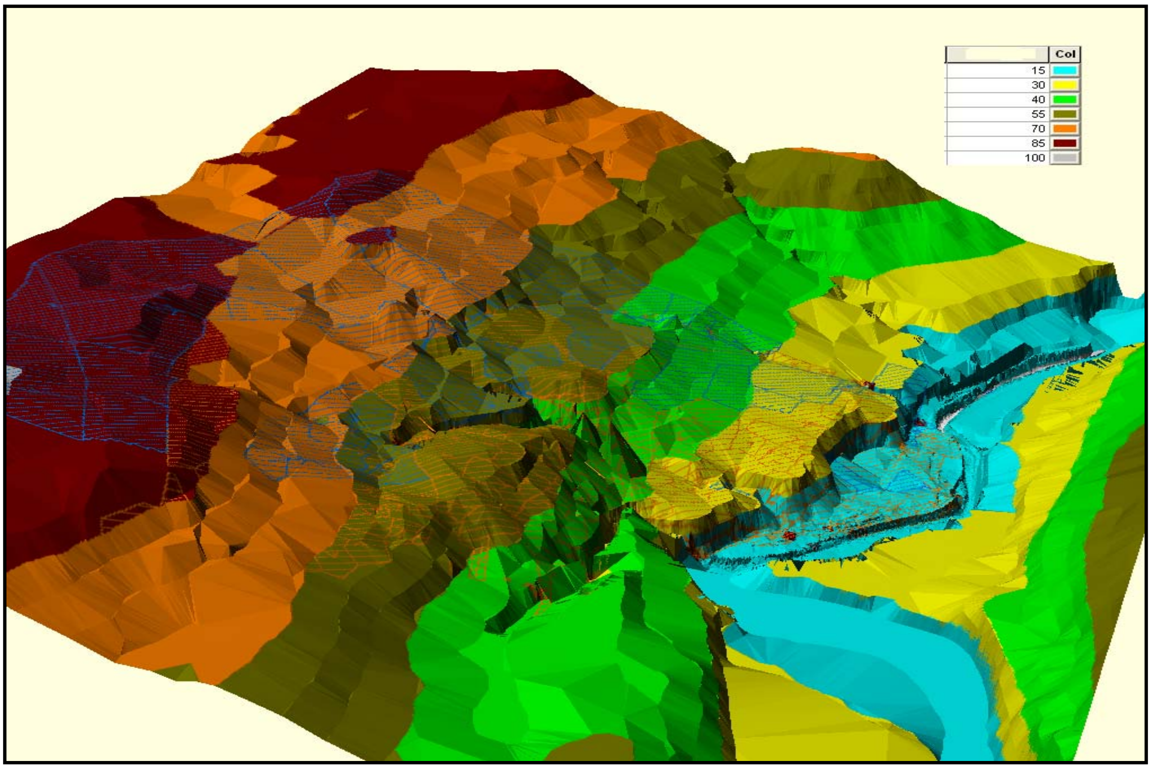

Figure 5. Brechin digital ground model (3D view)

Buildings were imported as polygons and modelled as voids so that flow could not penetrate them (see Figure 6). Bearing in mind that it was not possible to consider the effect of building with the 1D modelling method, these were removed from the model at a later date in order to provide a closer comparison with the 1D results. Of course, in reality the buildings should be considered.

A 100 year rainfall event was run through both models (old-1D and new-2D) under the following conditions:

- 1080 minutes of duration
- 17 year return period river levels
- No pumping rate by the flood defences

Results

Figure 7 shows a comparison between the 1D and 2D results. The flood extent is wider for the 2D model, mainly due to the fact that overland flow paths are shown (for example the area identified with an orange arrow on the right-hand side of the figure). In the 1D model, as overland flow paths are represented as links, they do not contributed to the flood mapping.

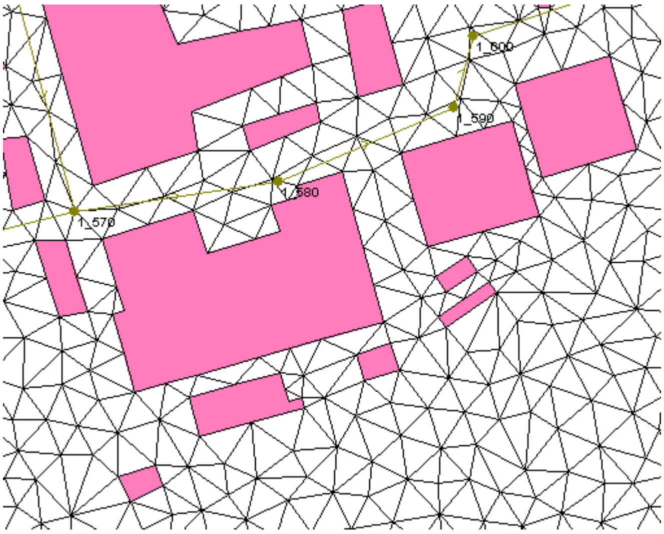

Figure 6. Meshing around buildings

The results show a similar range of depths (up to more than 1m) for both models, although the average depth is higher in the 2D model than the 1D model. This is mainly due to four factors:

1) The 2D model automatically defines additional and more complex flow paths that did not exist in the 1D model. Figure 7 shows an additional flood route (blue arrow in the centre of the figure) which was not represented in the 1D model. The identification of flow paths with the 1D approach is extremely difficult, especially in ponding areas. The 1D overland flow links do not take into account the variable nature of the geometry of the channel. It is difficult to define a channel shape that will represent the extent of the overland flow path.

2) The 1D flood mapping technique is based on interpolation between modelled nodes, which becomes inaccurate when the density of modelled nodes is relatively low, as is the case here.

3) There is 5% more water stored on the surface with the 2D model compared to the 1D model. It is to be expected that the 2D model would predict a larger flood volume. 2D nodes work as a “lost” flood type, until they become surcharged, at which point they start working as a “stored” flood type (without the restriction regarding the dimensions of the flood cone required with the 1D model). Networks with nodes set as “lost” flood type predict a greater maximum flood volume than those set as “stored”, due to former not having the option of returning water to the system.

4) Overland flow links can act as storage areas. Figure 8 shows how much care needs to be taken in defining overland flow paths by assuming they follow the same path as a road. It can be seen that there is an increase in elevation which has resulted in an overland link with a negative gradient. This can result in a large storage volume in the overland links upstream. Since the flood level is calculated at the nodes, the storage in these 1D links can result in the flood level not being correctly represented. This is because the floodable area would have been defined without taking into account storage in the overland links. This reason is another contributory factor in the depth differences observed. Additional simulations were undertaken replacing the overland flow paths with weirs, in order to remove the storage potential in the links, and results were compared. This did result in a slight improvement in the results.

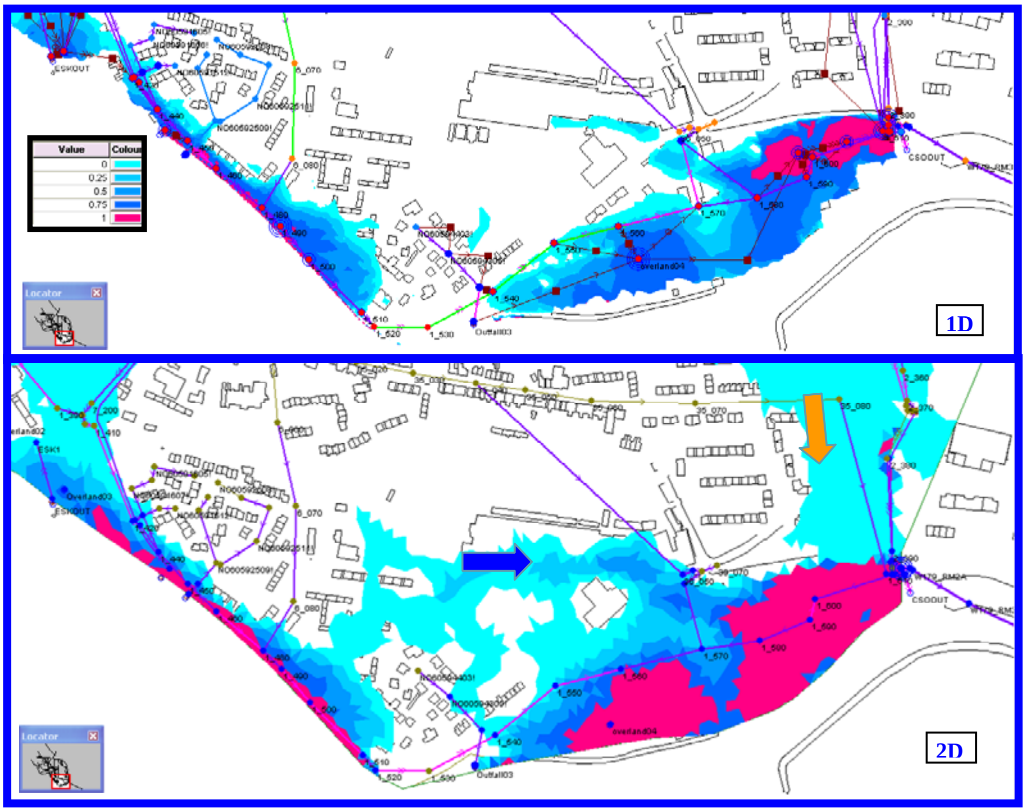

Figure 7. 1D-2D comparison shows a higher depth with the 2D results

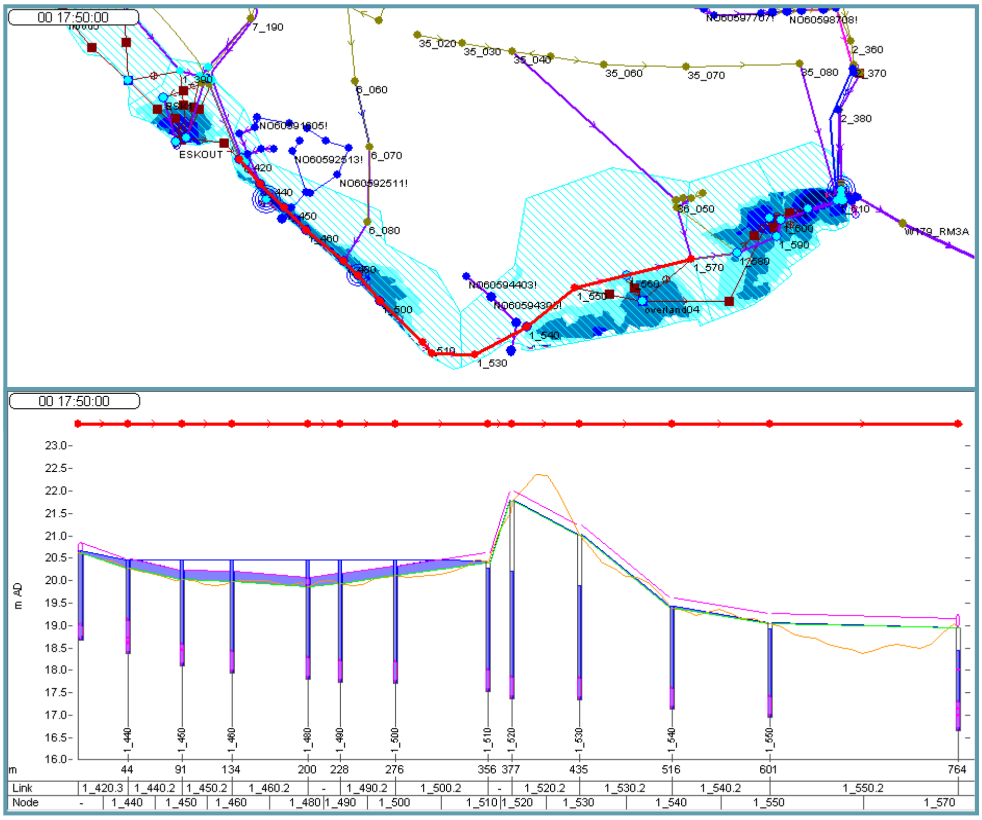

Figure 8. 1D-2D Comparison: Storage in overland flow links

Figure 9 shows two very different flow routes at a junction when comparing 1D and 2D methods. For the 1D model the overland flow path was assumed to follow the road, (Figure 10) however the results from the 2D model show that the flow disperses. The cause of this is shown in Figure 11 where it is evident that there is a high point in the ground model and therefore this would not realistically form a flow path. An assumption used by the 1D model is that the flow path has a uniform gradient between manholes. Figure 11 shows that this provides an erroneous path. This problem highlights the need for a good DTM supplemented by local knowledge, to form a full understanding of the flood processes.

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Figure 9. 2D results

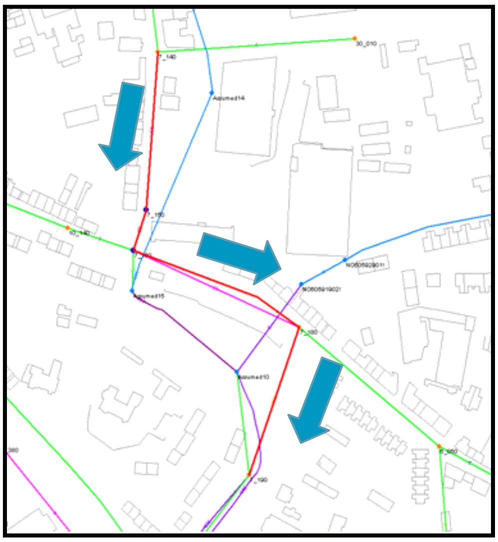

Figure 10. 1D defined

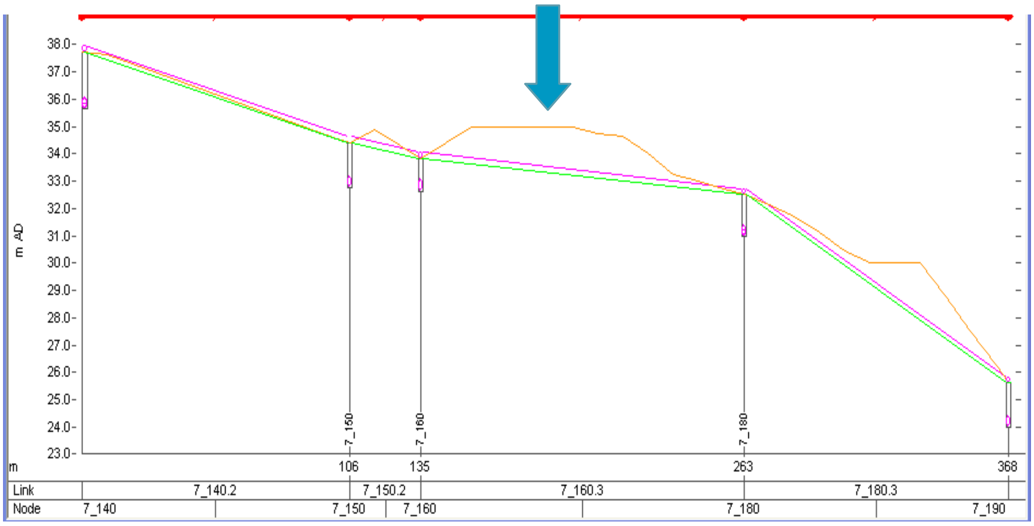

Figure 11. Cross section view

CONCLUSIONS

The 1D model gave a good approximation of the flooding process and locations, although the model set up and construction was tedious and was based on a number of simplifying assumptions. Flood cones and links do not always accurately represent the storage on the catchment surface. For example the definitionof the flood cone shape is never satisfactory in representing flood depth–extent relationships and trying to get these as accurate as possible requires a great deal of effort. The use of 1D overland links in ponding areas also generates additional storage that can reduce the predicted flood extent.

The 1D model is computationally faster than the 2D model. Increased computer capabilities and a good understanding of 2D modelling techniques have reduced the magnitude of this problem.

There was a slightly higher prediction of average flood depth and extent with the 2D model. This can be explained by the fact that the 2D model facility is a much more flexible, dynamic and reliable flood mapping approach, although the requirement of additional data such as walls, buildings and detailed ground models is significant.

It is extremely important to have a detailed terrain model that represents accurately the surface of the catchment. For our research study, the simplified ground model available was good enough, as it was only a comparison exercise of two different flood-mapping techniques. However, for the second phase of the Brechin study it was essential to have a more detailed ground model, especially considering that the proposed solution was so sensitive to surface flow paths.

After careful consideration of the options available for obtaining a more detailed ground model, Angus Council decided to undertake a LiDAR survey of the catchment. This has the added bonus of including the outlying rural areas enabling an improved understanding of the full catchment extent. At the time of writing this paper, the second phase of the study is still ongoing. Additional results will be provided in the presentation to accompany this paper.

In conclusion, surface modelling will always have a higher degree of uncertainty than below ground modelling where it is possible to calibrate model prediction with observed results. InfoWorksCS 2D is a user friendly software package, which is very quick to build and fully integrated with the below ground system. It gives a greater degree of confidence in the definition and identification of the overland flow paths than the 1D approach and provides a more reliable mapping of the flood extent.

For additional information about the robustness and technical characteristics of both modelling components (1D and 2D) see InfoWorks CS Help Files and Gutierrez (2008).

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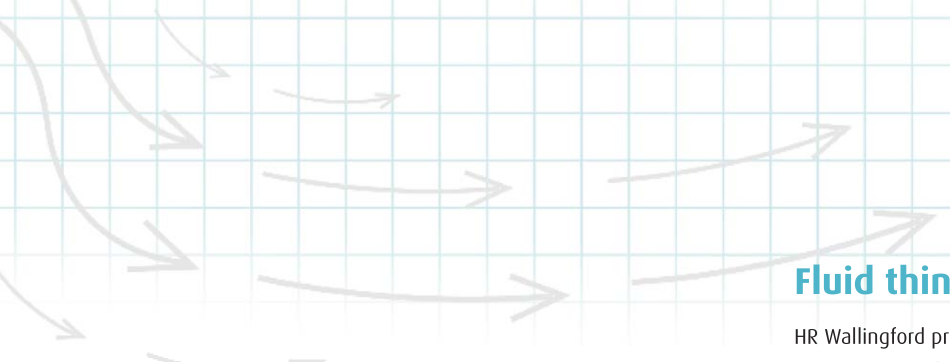

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