Park Chesterfield, Smallfield

Flood modelling
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Approved

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MCM8267-RT003-R01-00
Summary

Development is proposed on a site known as Park Chesterfield in the village of Smallfield, Surrey. The Environment Agency has objected to the development on the grounds of flood risk. This report contains the results of hydraulic modelling that has been carried out to provide an independent check on the modelling that was used to determine the risk of flooding in the area.

Flooding at Smallfield is caused by overflow from the Weatherhill Stream that flows through the village in a culvert. Other sources of flooding have been reported including local surface water flooding (caused by direct runoff from rainfall) and groundwater flooding. However this report only covers flooding from Weatherhill Stream as this is the main source of floodwater at Park Chesterfield.

In July 2018 HR Wallingford undertook a high level review of the potential flood hazard at Park Chesterfield based on readily available information. Hydraulic modelling has been used by the Environment Agency to predict flood extents in the area. The model is referred to in this report as the ‘TUFLOW’ model because it was constructed using the TUFLOW hydraulic modelling software. It was identified in the review that the TUFLOW model may have overestimated the amount of flooding in Smallfield and a review of the modelling was undertaken.

The cause of the potential overestimate of flooding was that the upstream boundary of the TUFLOW model was close to the culvert inlet. Water flows out of Weatherhill Stream further upstream during floods and passes to the east of Smallfield. Floodwater that overflows from the stream would therefore not reach the culvert inlet. This loss of floodwater was not included in the TUFLOW modelling and therefore the flow at the culvert inlet could be overestimated, causing an overestimate of the amount of flooding predicted by the modelling.

The model review was completed in December 2018. It was confirmed that the upstream model boundary was close to the culvert and did not take account of the overflow further upstream which would reduce the flood flow near the culvert inlet. However two other factors were identified that could cause an underestimate of the amount of flooding predicted by the TUFLOW modelling. These factors were:

- The flood flows used in the modelling. The peak flood flows were lower than peak flood flows estimated in the high level review of July 2018. If the flows are too low the amount of flooding predicted by the modelling would be underestimated.
- The representation of the culvert that conveys the stream through Smallfield. The size of the culvert in the model was larger than the actual size, which could lead to an underestimate of the amount of flooding predicted by the modelling.

The purpose of the new hydraulic modelling was to test the impacts of these factors on the flood extents predicted by the TUFLOW model. The model used in this study is referred to as the ICM model because ICM is the name of the hydraulic modelling software used.

It was found that the effect of the upstream model boundary location in the TUFLOW model was offset by the fact that the design flows used in the TUFLOW model were much lower than those used in the ICM model. As a result, the flood flows just upstream of the culvert inlet were similar in both models. The ICM model did however predict flooding to the east of Smallfield caused by the overflow from Weatherhill Stream. This was not predicted by the TUFLOW model.
The culvert capacity was small compared with the flood flows in both models. This means that the impact of the culvert on flooding was small. As a result the amount of water that exceeded the capacity of the culvert and caused flooding in Smallfield was similar in both models.

The ICM and TUFLOW models predict very similar flood outlines at Park Chesterfield for the 100-year flood, indicating that the part of the site that would be in Flood Zone 3 based on model predictions is similar for both models. The modelled 100-year flood extents are also very similar to the area shown in Flood Zone 3 on the Environment Agency Flood Map for Planning.

The remainder of Park Chesterfield is shown as being in Flood Zone 2 on the Environment Agency Flood Map for Planning (flood frequency between 1 in 100-years and 1 in 1,000 years). The ICM and TUFLOW models predicts a much smaller flood extent at Park Chesterfield for the 1,000-year flood, indicating that the eastern part of the site should be in Flood Zone 1 and not Flood Zone 2.

The predicted depths of flooding in Park Chesterfield are small (less than 0.2 m) for all the flood events modelled. If development were to be permitted for the whole site, raising of building threshold levels to 0.2 m above ground level would prevent property flooding. In addition, the buildings could be accessed during flood events as the depth of flood water would be small.
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1. Introduction

1.1. Purpose

Development is proposed on a site known as Park Chesterfield in the village of Smallfield, Surrey. The Environment Agency has objected to the development on the grounds that the site is at risk of flooding. The Environment Agency objection is based on the results of hydraulic modelling used to predict the extent of flooding in Smallfield and elsewhere.

This report contains the results of independent hydraulic modelling that has been undertaken to check the modelling results used by the Environment Agency to determine flood extents for planning purposes in Smallfield.

1.2. The site

Smallfield is located to the east of Horley and the M23 in Surrey, about 5 km north-east of Gatwick Airport. The principal watercourse is Weatherhill Stream, which is a tributary of Burstow Stream. Weatherhill Stream enters Burstow Stream to the east of Horley. Weatherhill Stream rises to the east of Smallfield and is culverted through the village before draining westwards towards the M23.

Figure 1.1 shows the Park Chesterfield site in Smallfield. The figure also shows Weatherhill Stream including the culvert through Smallfield and the confluence with Burstow Stream.

![Figure 1.1: Site location](image-url)

Source: Based on OS Mapping
1.3. Previous work

An initial flood hazard assessment carried out by HR Wallingford identified that the hydraulic modelling undertaken on behalf of the Environment Agency may have overestimated the amount of flooding. This was because the upstream limit of the model was very close to the culvert inlet, and the modelling did not include overflow from the Weatherhill Stream upstream of the village. This overflow passes to the east of the village, thus reducing the amount of flood water passing through the centre of Smallfield. The amount of flooding would therefore be overpredicted by the modelling.

A review of the hydraulic model constructed on behalf of the Environment Agency was then carried out. It was confirmed that the upstream boundary of the model was close to the culvert inlet and the model did not include overflow to the east of the village.

However two other factors were also identified that could cause an underestimate of the amount of flooding predicted by the modelling. These factors were as follows:

1. The peak flood flows used in the modelling were lower than peak flood flows predicted by the initial flood hazard assessment (HR Wallingford 2018a). If the new flow estimates are used, the amount of flooding would be greater.

2. The size of the culvert that conveys the Weatherhill Stream through Smallfield was larger in the model than the actual size obtained from a field survey. This means that more water would flow through the culvert in the model than in reality and the amount of flooding would be underestimated.

Thus there are three factors that could affect the flooding predicted by the hydraulic modelling in Smallfield. Two of these factors could lead to an increase in the predicted amount of flooding and the third factor (identified in the initial flood hazard assessment) could reduce the predicted amount of flooding.

These factors have been taken into account in the new hydraulic model constructed for this study. The new modelling not only identifies the impacts of these factors, but also allows comparison with other elements of the Environment Agency modelling including the data used.

2. Hydraulic modelling

2.1. Introduction

An independent hydraulic model was constructed of Weatherhill Stream as it passes through Smallfield. The model includes the stream upstream of the village, the culvert through the village and the stream downstream of the village. The floodplain is also represented in the model.

Flows used for flood modelling were obtained from two sources: the modelling undertaken on behalf of the Environment Agency (referred to in the model review, HR Wallingford 2018b) and an independent hydrological assessment reported in the initial flood hazard assessment (HR Wallingford 2018a).

For the purposes of this study, the new model is referred to as the ICM model as it is constructed using the software InfoWorks ICM. The model used by the Environment Agency is referred to as the TUFLOW model as it is constructed using the software TUFLOW.
2.2. Software

The software used for the hydraulic modelling was InfoWorks ICM. This is an industry standard hydraulic modelling package. It has similar capabilities to the TUFLOW modelling software, used for the Environment Agency model.

The model was constructed as a fully 2-dimensional (2D) model including the channels. The TUFLOW model has a 1-dimensional (1D) representation of the stream and a 2D representation of the floodplains. TUFLOW has a square 2D grid for the floodplains whereas ICM has a triangular mesh which provides greater flexibility when fitting the mesh to ground features.

Flood outlines produced by both software reflect the grids used in the modelling. TUFLOW flood outlines have square edges whereas ICM flood outlines have triangular edges. The outlines can be smoothed in both cases by post-processing of the results.

For practical purposes there is little difference in the hydraulic calculations in both software and the results for the same data should be very similar.

2.3. Data

The main datasets used for the new modelling were:

- LiDAR topographic data for the floodplains;
- Ordnance Survey (OS) maps and data;
- A survey report for part of the culvert through Smallfield;
- Flood inflows from the TUFLOW model hydrology report and the independent hydrological assessment referred to above;
- Data that were not available from other sources were obtained from the existing hydraulic model.

The LiDAR data used for the study was downloaded from the Environment Agency online data store of freely available data. The data used was the 1m Digital Terrain Model (DTM). The data consisted of ground levels on a 1m x 1m square grid. The data have been processed so that buildings and vegetation have been removed to provide a ground model.

Ordnance Survey (OS) maps and data were obtained under HR Wallingford’s licence for using OS data for commercial purposes.

Details of the catchment and flood flows were found from the following documents provided by the Environment Agency:

- Burstow Stream Hydrology Report Final (Environment Agency 2012b);

In addition a detailed survey report of the first 380m of the Smallfield culvert was obtained (Halcrow 2010).
2.4. Model construction

2.4.1. The ground model

The model was constructed by delineating the limits of the model and then creating a model of the ground surface using the LiDAR data.

The inflow point to the model was further upstream on the Weatherhill Stream compared with the TUFLOW model. This was done because there are points upstream where flood flows overtop the channel on the left bank. This means that the flow reaching the culvert would be reduced compared with the calculated inflows from the hydrological analysis.

The model mesh consisted of triangular elements that varied in size between 5 m\(^2\) and 50 m\(^2\). A maximum height variation of 0.25 m was allowed in each model element. The roughness of the ground surface was represented by the Manning coefficient. A value of 0.04 was used for the channel and 0.08 for agricultural land.

In addition to the mesh, mesh level zones were used to adjust the DTM in order to represent features including the channel of the Weatherhill Stream and embankments. The mesh zones had a maximum element size of 1 m\(^2\) and a minimum element size of 0.5 m\(^2\). Smaller mesh sizes were used in areas where flow conditions changed rapidly, particularly at the culvert inlet.

2.4.2. The culvert

The culvert through Smallfield is the key hydraulic structure in the model. The length of the culvert in the TUFLOW model is 932.5 m with a diameter of 650 mm, an upstream invert level of 57.6 m Above Ordnance Datum (AOD) and a downstream invert level of 55.64 m AOD.

The survey report shows that the culvert diameter is 525 mm for a distance of 270 m from the inlet and 750 mm for a further 110 m to a location referred to as the outlet in the survey. The outlet invert level is 55.69 m AOD but the inlet invert level could not be taken because the inlet could not be accessed for the survey. The manhole described as the outlet is at the roundabout where Weatherhill, Redenhall and Chapel Roads meet and the culvert turns to the west and follows the main road through Smallfield. The drop in level of the culvert over the remaining 550 m is only 0.05 m. The culvert diameter for this section was assumed to be 750 mm. The culvert details used in the ICM model are therefore as shown in Table 2.1.

**Table 2.1: Culvert details**

<table>
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<th>Chainage (m)</th>
<th>Culvert diameter (mm)</th>
<th>Invert level (m AOD)</th>
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<tr>
<td>0</td>
<td>525</td>
<td>57.70</td>
</tr>
<tr>
<td>270</td>
<td>750</td>
<td>56.30</td>
</tr>
<tr>
<td>380</td>
<td>750</td>
<td>55.69</td>
</tr>
<tr>
<td>932</td>
<td></td>
<td>55.64</td>
</tr>
</tbody>
</table>
The Manning’s roughness value for the culvert was 0.02. A longitudinal section of the culvert is shown in Figure 2.1, which emphasises the change in slope that occurs at the roundabout where Weatherhill, Redenhall and Chapel Roads meet.

![Culvert longitudinal section](image)

Figure 2.1: Culvert longitudinal section

3. Main differences from the earlier modelling

3.1. Introduction

In the model review, three main differences were identified in the new modelling compared with the earlier modelling. These were:

- Flood flows;
- Upstream model boundary;
- Representation of the culvert.

3.2. Flood flows

The flood flows that were used in the TUFLOW modelling and the flood flows that were used in the ICM model are shown in Table 3.1. The flood flows derived for this study and used for the ICM model are based on the Flood Estimation Handbook (FEH) which is the standard method in the UK for estimating flood flows. Two methods are used, a method based on flow statistics and a method based on rainfall (the ‘rainfall-runoff’ method).

Flow estimates are normally compared with observed flood flows where suitable flow data exists. This is the process of calibration, to ensure that the flood flows used in the modelling take account of actual data.
However in this case there are no suitable data. Under these circumstances it is standard practice to average the flows obtained from the two methods. Thus an average flow is shown in Table 3.1 which is compared to the flows used in the TUFLOW modelling.

**Table 3.1: Estimated peak flood flows**

<table>
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<tr>
<th>Flood return period (years)</th>
<th>Peak flood flow: ICM model (m$^3$/s)</th>
<th>Peak flood flow TUFLOW model (m$^3$/s)</th>
<th>Ratio</th>
</tr>
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<td>Statistical method</td>
<td>Rainfall-runoff method (ReFH2)</td>
<td>Average</td>
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<td>0.82</td>
<td>1.24</td>
<td>1.03</td>
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<tr>
<td>50</td>
<td>1.43</td>
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<td>1.77</td>
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<td>200</td>
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<tr>
<td>1000</td>
<td>2.76</td>
<td>4.00</td>
<td>3.38</td>
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</table>

The flows in the TUFLOW modelling are much lower than those derived for this study. The reason for this appears to be that the flows in the TUFLOW model are intended to provide the worst conditions at a point further downstream. The maximum amount of flooding at each location in a river catchment depends on the duration of the rainfall. For locations in the upper part of a catchment, the maximum amount of flooding is usually caused by intense, short duration rainfall events. Further down the catchment, the critical conditions are often caused by longer duration rainfall events with a lower maximum rainfall intensity.

In this case the TUFLOW modelling uses relatively long duration rainfall events with a relatively low rainfall intensity, in order to provide the worst conditions for flooding at a point further downstream in the catchment. The flow estimates for the ICM model are intended to provide the worst flood conditions in Smallfield.

The impacts of these differences are shown in Figure 3.1, which shows the flow in Weatherhill Stream against time for the estimated 100-year flood flows from the ICM and TUFLOW modelling. It is apparent that the estimated flood flow for the ICM model has a shorter duration but a much higher peak flood flow.

Flooding at the Park Chesterfield site is directly affected by the magnitude of the peak flood flow because it is adjacent to the flow path of water that exceeds the capacity of the culvert. The flood flows in the TUFLOW model are likely to be underestimates of the actual flows that could occur, and therefore the flood extents predicted by the TUFLOW model are also likely to be underestimated.

This effect is however counteracted by the location of the upstream model boundary, as the additional flow in the ICM model overflows onto the floodplain upstream of Smallfield and does not reach the culvert. This is discussed in Section 3.3.
3.3. Upstream boundary

The model boundary in the TUFLOW model is about 260 m upstream of the culvert inlet. It is however downstream of a section of Weatherhill Stream where water overflows on the left bank and flows to the east of Smallfield, thus reducing the flow in the stream at the culvert inlet. The upstream model boundary in the ICM model was moved to a location that is upstream of the section of the watercourse where water overflows. The new location is shown in Figure 3.2.

The effect of the overflow on the 100-year flood hydrograph in the ICM model is shown on Figure 3.3. The peak flow at the upstream limit of the model is 2.04 m$^3$/s. However the effect of the overflow is to reduce the peak flow at the culvert inlet to 1.1 m$^3$/s. This is very similar to the 100-year flow used in the TUFLOW model of 1.09 m$^3$/s. Figure 3.3 also shows the volume of overflow that passes to the east of Smallfield.

Figure 3.4 shows a comparison of the flood flow hydrographs for the ICM and TUFLOW models just upstream of the culvert inlet. It is apparent that the peak flows are very similar but the shapes and the timing of the hydrographs are different.

By coincidence, the two peak flows are very similar. This is however not the case for other floods. For example, the 1,000-year flow in the TUFLOW model at the culvert is 2.15 m$^3$/s, considerably more that the flow in the ICM model of 1.35 m$^3$/s. The inflow at the upstream boundary in the ICM model is 3.38 m$^3$/s, upstream of the point where overflow occurs.

The effect of changing the location of the upstream model boundary is to reduce the flood flow at the culvert inlet because of the overflow. Thus the higher inflows used in the ICM modelling discussed in Section 3.2 are reduced by the overflow and the peak flood flows upstream of the culvert inlet are similar in both models.
Figure 3.2: Location of the upstream model limits
Source: Based on Environment Agency surface water flood map

Figure 3.3: 100-year flood flow hydrographs in the upstream section of the ICM model
3.4. Representation of the culvert

The culvert is represented in the TUFLOW model as a 650 mm pipe culvert from the inlet to the outlet. The culvert is represented in the ICM model using the data in Table 2.1 including the section of 525 mm diameter culvert downstream of the inlet.

The results show that the capacities of the culvert in the two models are as follows:
- ICM model: 0.17 m$^3$/s
- TUFLOW model: 0.25 m$^3$/s

Whilst these flow values are different, they are both small compared with the flood flows at the culvert inlet. The effect on the proportion of the 100-year flood flow that exceeds the culvert capacity is as follows:
- ICM model: 1.10 - 0.17 = 0.93 m$^3$/s
- TUFLOW model: 1.09 - 0.25 = 0.84 m$^3$/s

Thus the flows that cause flooding in the two models are similar.

4. Model runs

The model runs carried out with the ICM model for this study are listed below. All of the runs were carried out using the flows derived for this study except where stated. The allowance for climate change in the TUFLOW modelling was a 20% increase in inflows.
- 30-year flood;
- 30-year plus climate change flood (20% increase in flood flows);
- 100-year flood;
- 100-year plus climate change flood (40% increase in flood flows);
1,000-year flood.

In addition, the ICM model was used with inflows from the TUFLOW model for the following events:
- 100-year flood;
- 100-year plus climate change flood (20% increase in flood flows).

The results were compared with results from the TUFLOW modelling, particularly the 100-year flood which forms the limit of Flood Zone 3.

4.1. Results: flood extents

Figure 4.1 and Figure 4.2 show a comparison of ICM and TUFLOW flood extents for the 100-year flood. It is apparent that the flood extents are very similar, particularly at the Park Chesterfield site. The TUFLOW flood extent is greater to the north-west of the site but does not include any of the flooding in the eastern part of Smallfield, caused by the overflow from Weatherhill Stream upstream of the culvert. The overflow to the east of Smallfield is caused by the additional inflow in the ICM model that overflows onto the floodplain upstream of the culvert.

Figure 4.1: 100-year flood: comparison of ICM and TUFLOW model results
Figure 4.2: 100-year flood: comparison of ICM and TUFLOW model results: detail

Figure 4.3 shows the 100-year flood extents with climate change. The effect on flooding at Park Chesterfield is small. Flooding to the east of Smallfield in the ICM modelling has increased because most of the additional flow overflows upstream of the culvert and passes to the east of the village.

Figure 4.3: 100-year flood plus climate change: comparison of ICM and TUFLOW model results
Figure 4.4 shows the flood extent for the 1,000-year flood predicted by the ICM model. The 1,000-year flood extent predicted by the TUFLOW model is similar. Comparison with Figure 4.2 shows that there is very little difference compared with the 100-year flood outline at the Park Chesterfield site. The main difference is to the east of Smallfield where the overflow from Weatherhill Stream has increased.

This effect is also shown on the 100-year plus climate change result (Figure 4.3). In this case the peak flood flow is 2.86 m³/s which is about 15% lower than the 1,000-year flow of 3.38 m³/s.

Figure 4.5 shows the flood extent for the 30-year flood. Comparison with Figure 4.2 shows that the flood extent at Park Chesterfield is slightly less than for the 100-year flood.
A second culvert was identified during the site visit at the culvert inlet. It is understood that this was an overflow culvert that is not used. The culvert survey undertaken on behalf of the Environment Agency in 2010 identified the first sections of this culvert including the first three manholes. However the end of the culvert was not located and it was assumed that the culvert is no longer functioning.

If however this culvert was functional, it provides an opportunity to increase the flow into the culvert and reduce the amount of flooding. The culvert is a 525 mm diameter pipe, the same size as the upper section of the culvert through Smallfield.

A separate model run was carried out assuming that this culvert could discharge into low ground in Smallfield. The result showed very little change in the flood extents. It was estimated that the flow in the culvert would be of the order of 0.1 m$^3$/s which is a small proportion of the total flood flow. This is less than the flow in the main culvert through Smallfield because the gradient is less steep.

4.2. Results: flood depths

Flood depth results have been produced from the ICM model at the car park, office and yard locations within the Park Chesterfield site shown in Figure 4.6. In addition, flood depth results from TUFLOW at points A and B in Figure 4.6 have also been abstracted from the TUFLOW model.
Figure 4.6: Locations where flood depth results are provided

The results are listed in Table 4.1. The corresponding results from the TUFLOW modelling are shown in red.

Table 4.1: Flood depth results at Park Chesterfield

<table>
<thead>
<tr>
<th>Flood event</th>
<th>Peak flow (m³/s)</th>
<th>Flood depths (m)</th>
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<tr>
<td></td>
<td>Yard</td>
<td>Office</td>
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<tr>
<td>30-year</td>
<td>1.89</td>
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<tr>
<td>30-year + CC (20%)</td>
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<tr>
<td>100-year</td>
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<td>100-year + CC (40%)</td>
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<td>1,000-year</td>
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<td>100-year: ICM model; TUFLOW flows</td>
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<tr>
<td>100-year + CC (20%): ICM model; TUFLOW flows</td>
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</table>

The eastern part of the site does not flood in any of the events that have been modelled including the 1,000-year event, which defines the boundary between Flood Zone 2 and Flood Zone 1. There is very little variation in flood depths elsewhere on the site. The flood depths in the car park range from 0.13 m to 0.17 m for the 30-year and 1,000-year floods respectively.

5. Discussion of results

The model results show very little difference between the ICM and TUFLOW model runs. The main differences in the modelling are the higher flows in the ICM model and the overflow to the east of Smallfield that is not included in the TUFLOW model.

The flood extents and depths are similar for all of the events modelled. The main reason for this appears to be the fact that the maximum flow that can reach the culvert is similar for all of the floods modelled because flows above about 1.1 m³/s overtop the left bank of Weatherhill Stream and flow to the east of Smallfield.
Table 5.1 shows a comparison of flows from the ICM model and the TUFLOW model. Whilst the inflow in the ICM model is much higher than the TUFLOW model, the flows at the culvert are very similar. The capacity of the culvert is different between the models but is small in both cases, which means that the flow that cannot enter the culvert and causes flooding in Smallfield is similar in both models (0.93 m$^3$/s in the ICM model and 0.84 m$^3$/s in the TUFLOW model).

Table 5.1: Comparison of flows for the 100-year flood event (m$^3$/s)

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow (ICM)</th>
<th>Flow (TUFLOW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Upstream boundary</td>
<td>2.04</td>
<td>1.09</td>
</tr>
<tr>
<td>B. Culvert inlet</td>
<td>1.10</td>
<td>1.09</td>
</tr>
<tr>
<td>C. Culvert flow</td>
<td>0.17</td>
<td>0.25</td>
</tr>
<tr>
<td>D. Overflow at culvert (B – C)</td>
<td>0.93</td>
<td>0.84</td>
</tr>
</tbody>
</table>

The Flood Zones used for land use planning are as follows:

- **Flood Zone 1:** Less than 0.1% (or 1 in 1,000) chance of flooding in any year. There are very few restrictions to development in Flood Zone 1;
- **Flood Zone 2:** Between 0.1% and 1% (or 1 in 1,000 to 1 in 100) chance of flooding from rivers in any year;
- **Flood Zone 3:** Greater than 1% (or 1 in 100) chance of flooding in any year.

Figure 5.1 shows the Environment Agency Flood Map for Planning for the Park Chesterfield site, showing flood outlines for the 100-year and 1000-year flood events predicted by the ICM model. Both the ICM and TUFLOW model results show that the 100-year flood outline in the Park Chesterfield site is very similar to the boundary of Flood Zone 3 on the Flood Map. The modelling therefore confirms that the boundary of Flood Zone 3 on the Environment Agency Flood Map for Planning is correct.

However the 1,000-year flood extent predicted by the ICM and TUFLOW models is much less that the extent of Flood Zone 2 on the Flood Map within Park Chesterfield. The modelling shows that the east part of the site should be in Flood Zone 1 and not Flood Zone 2. Whilst the model results are based on flows from Weatherhill Stream only, there do not appear to be other sources of flooding that could lead to flooding of this part of the site.

The depths of flooding in the Park Chesterfield site are small (less than 0.2 m) for all the flood events modelled. If development were to be permitted for the whole site, raising of building threshold levels to 0.2 m above ground level would prevent property flooding. In addition, the buildings could be accessed during flood events.
6. Conclusions

1. The Weatherhill Stream passes through Smallfield in a culvert. The capacity of the culvert is small and water that cannot pass through the culvert during flood events overflows and causes flooding in Smallfield.

2. Flooding in Smallfield has been modelled using a new model, referred to as the ICM model, and the results have been compared with results from an existing model, referred to as the TUFLOW model. The TUFLOW and ICM models differ in two important respects:
   a. The flood inflows used in the TUFLOW model are much less than those used for the ICM model;
   b. The upstream boundary of the TUFLOW model is close to the culvert inlet and does not include a section of the stream where flood water overflows the banks and flows to the east of Smallfield.

3. These two differences counteract each other with the result that flood flows at the culvert inlet are similar for both models.

4. The modelling of the culvert through Smallfield differs between the two models and the TUFLOW model has slightly higher flows within the culvert. However the culvert flow is a small proportion of the total flood flow. The amount of water that exceeds the capacity of the culvert inlet is therefore similar for both models and the amount of flooding is also similar.

5. The 100-year flood outline predicted by the ICM model at Park Chesterfield is very similar to the boundary of Flood Zone 3 on the Environment Agency Flood Map for Planning, indicating that model results agree with the boundary of Flood Zone 3 on the Flood Map.
6. The ICM model predicts a much smaller flood extent at Park Chesterfield for the 1,000-year flood compared with the Environment Agency Flood Map for Planning, indicating that the eastern part of the site should be in Flood Zone 1 and not Flood Zone 2.

7. The predicted depths of flooding in the Park Chesterfield site are small (less than 0.2 m) for all the flood events modelled. If development were to be permitted for the whole site, raising of building threshold levels to 0.2 m above ground level would prevent property flooding. In addition, the buildings could be accessed during flood events.

7. References


HR Wallingford is an independent engineering and environmental hydraulics organisation. We deliver practical solutions to the complex water-related challenges faced by our international clients. A dynamic research programme underpins all that we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.