# NOTE TO FILE

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## 1 Introduction

This document is designed to give an overview of the 2D modelling approach for the strategic modelling used to assess fluvial flood risk to site allocations in the Tewkesbury Borough Level 2 SFRA, where no detailed Environment Agency models were available.

## 2 Modelling Approach

### 2.1 Introduction to hydraulic modelling

Hydraulic modelling allows simplification of very complex processes, which can enable us to predict flooding caused by events of different return periods. Hydraulic models can be classified according to the number of dimensions in which they represent the spatial domain and flow processes.

One-dimensional models can be useful for studying flood levels and discharges in river systems, and have been applied to flood routing problems at the reach scale. They allow for rapid evaluation of water levels and are best suited for describing flow within channels and through hydraulic structures. They are computationally very efficient but can be potentially expensive in terms of time and data required. The areas between cross-sections are not explicitly represented and a secondary processing step is required in order to map flood inundation.

Two-dimensional models are capable of accurately simulating flow patterns during partial inundation and drainage of the floodplain in order to predict flood risk in these regions. They are therefore best suited for describing the lateral diffusion of shallow water flows over low-lying areas. With two-dimensional models the topography and roughness is described as a continua and they facilitate direct mapping of flood inundation. However, when compared to 1D models, 2D models can be relatively computationally expensive and poor at describing flow through hydraulic structures.

Coupled 1D-2D models can therefore be used to combine the best attributes of each model class to achieve acceptable, computationally affordable predictions of flood extent when compared to typically available verification data.

### 2.2 2D modelling using JFlow

JFlow® is JBA's proprietary 2D hydraulic model. The model solves the full Shallow Water Equations on a regular square cell grid, and utilises GPU technology to provide parallelised calculations which allows large regions to be modelled efficiently, whilst capturing a wide range of flood hydraulic processes.

The Shallow Water Equations are comprised of two components. The first part is the continuity equation which describes the amount of water that moves in a given amount of time (the given amount of time is known as the timestep). The second component is the momentum equation which describes the rate at which water will move between cells. By solving both of these components at a point in time, the velocity and depth of water at a location can be determined, and by solving these sequentially through time, the passage of a flood wave over an area can be determined.

The inputs to JFlow® are a topographical domain model, which is represented as a grid where each cell of the grid represents a coordinate position with elevation data. Water is then added to the grid as either a hydrograph (river discharge vs time) or as a hyetograph (rainfall depth vs time). A number of additional parameters to the Shallow Water Equations are also input, such as Manning's n, which is a friction coefficient that accounts for losses in momentum caused by water travelling over a surface.

JFlow® determines for each cell, for each timestep in a simulation, a water depth, and a velocity. This is done in three steps. Assuming that for a cell, the water depth and the velocity of the adjacent cell is known, the first step involves determining the volume of water in the cell and the adjacent cell, and calculating the amount of water that can move between those cells (Figure 1). The second step, the inter-cell flux, determines the rate at which the amount of water calculated in step 1 can move, using the velocity of water from the previous cell and the momentum component of the shallow water equations. These two steps then allow the water depth and velocity in the cell to be calculated. Step 3 then repeats this calculation for all adjacent cells, to determine the direction, speed and volume of flow (Figure 2). This leads to a vector calculation from the cell, in the direction of the greatest hydraulic slope calculated from each of the intercell fluxes.

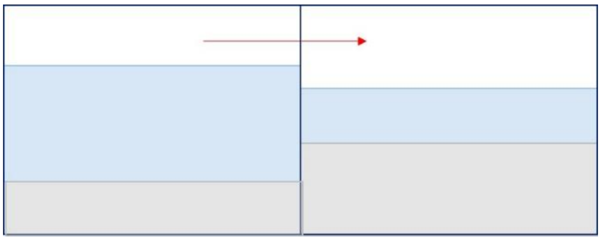


Figure 1: (Step 1 & 2) The Intercell Flux is calculated between two cells. The depth of water in each cell and the height of the terrain determines the volume of water to move. This figure will lead to a movement of water from the left side cell to the right side cell as represented by the red arrow.

The process is performed for all model cells in the domain for an interval of time (the time step), before the time interval is evolved and a new set of water depths in the grid are calculated based on the previous time interval. These steps are then repeated for the duration of the modelled flood event to determine the movement of the flood wave over the model domain.

In order to determine the greatest hazard from flooding, the maximum calculated flood depth for each cell across the time duration is calculated. The final hazard output represents a composition of the highest water depths for each cell, during the flood event. A series of model domains are used to model river reaches, before being amalgamated into a final flood hazard map.

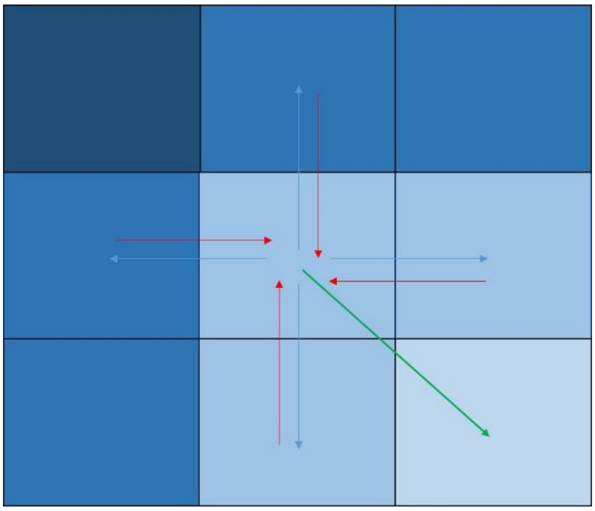


Figure 2: (Step 3) Calculating the intercell flux for all cells and solving to determine the new depth values. After step 1 and 2 are completed (red arrows), all intercell fluxes are calculated for adjacent cells and new values of depth are based on the net values of the intercell fluxes. The resulting sum in this example would see the overall flood wave propagating in the direction of the green arrow in the direction of greatest water slope

### 2.2.1 Hydrology

In order to run Jflow, hydrological estimates need to be generated for each inflow point. These estimates are based on catchment descriptors extracted from the FEH CD-ROM. Typically, there was an inflow point upstream of each of the site allocations requiring Jflow; however, on longer stretches of watercourse multiple points were used at 100m spacing intervals. The key information within the catchment descriptors which was used to determine hydrological flows is listed in Table 1. In some cases, the catchment descriptors associated with an inflow point can be extracted from a nearby river or stream, which may cause jumps or falls in the hydrograph values compared with the rest of the reach. In these instances, donor catchments of nearby inflow points were used with adjustments made to the catchment descriptors to represent the new characteristics.

Table 1: Example catchment descriptors

| Catchment Descriptor | Explanation |
|---|---|
| Area | Drainage area km$^2$ |
| DPLBAR | Mean drainage path length (km) |
| DPSBAR | Mean slope between nodes (m/km) |
| FARL | Flood attenuation due to reservoirs and lakes (1.0 for no attenuation) |
| SAAR | Standard annual average rainfall 1961-1990 (mm) |
| BFIHOST | Baseflow index from hydrology of soil types |
| SPRHOST | Standard percentage runoff from soil types |
| PROPWET | Proportion of time catchment is wet (Soil moisture deficit < 6mm) |
| URBEXT1990 | Urban extent in 1990 |

Once catchment descriptors had been extracted for each inflow point a JBA tool was used to generate hydrographs for various return periods. Flood Estimation Software (JFes) provides flood estimation for catchments in UK and Ireland. JFes has the capacity to create hydrographs suitable for use in JFlow to produce river hazard maps using catchment descriptors obtained from the FEH CD-ROM as described in the previous section. JFes uses information from the HiFlows-UK dataset to search for donor sites. HiFlows-UK provides flood peak data and station information, for approximately 1,000 gauging stations in the UK. Each point extracted from FEH CD-ROM has a unique ID. The output from the bulk extraction section of JFes produces a file for each requested return period comprising hydrographs for each point with and information about peak flows. The hydrograph is suitable for use in Jflow modelling and requires minimal data manipulation.

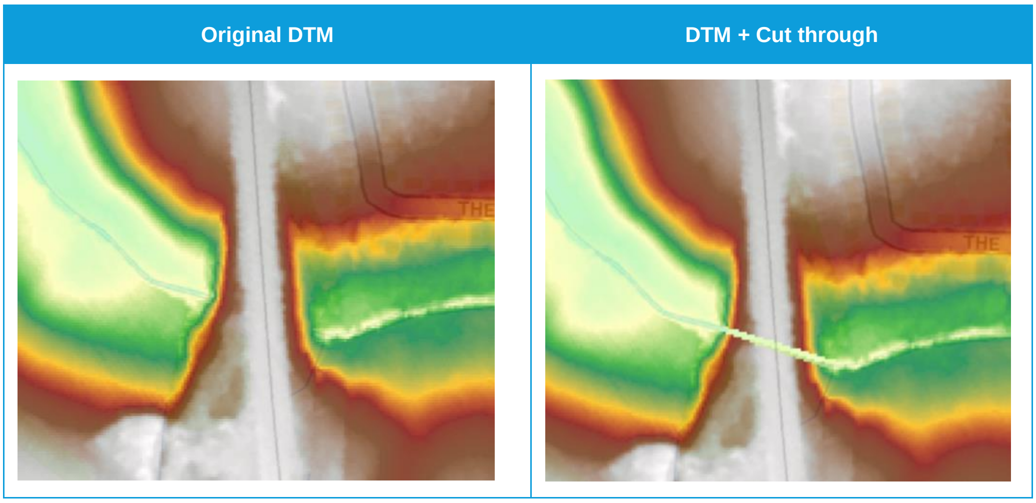
For the purpose of the SFRA the following return periods were modelled.

- 20-year (to inform Flood Zone 3b)
- 100-year (to inform Flood Zone 3a)
- 100-year + Climate Change (+35% and +70% to account for 2080s allowances)
- 1,000-year (to inform Flood Zone 2)

### 2.2.2 Digital Terrain Model

The Digital Terrain Model (DTM) was created from open LIDAR downloaded from the open.gov.uk website (supplied from Environment Agency). The DTM is a bare earth model but still contains some features such as bridges, subways and embankments which appear as high ground and act as obstacles to flow during the modelling process. This can result in flow accumulating behind which can cause unrealistically high depths and wide extents. In reality, water would flow underneath or around these structures. Where unusual flood extents and depths were observed, the presence or absence of a man-made structure was confirmed by inspecting aerial imagery and the terrain model. If a structure was identified, the high elevations due to man-made obstacles were 'cut through' enabling more natural flow (See Figure 3).

Figure 3: DTM cut through example



Original DTM

DTM + Cut through

### 2.2.3 Hydraulic Modelling Assumptions

A number of assumptions were made during the hydraulic modelling process:

- Channel capacity - This was assumed to equal QMED (2-year return period) for all rivers. Particularly in urban areas where channel improvements may have been carried out, this assumption can result in an underestimation of the channel capacity and hence an overestimation of the flood extent. However, studies have shown that unmodified river channel capacities frequently compare well with QMED and so this is deemed an appropriate assumption.
- Manning's *n* - A value of 0.1 was used throughout the study area. This represents a relatively conservative estimate but has been shown to provide acceptable model output in previous studies.
- Structures - Such as bridges and weirs were not explicitly modelled.
- Culverts - These were not explicitly modelled although smaller culverts through large structures such as railway embankments have been crudely cut into the DTM.
- Blockages - Where culvert blockages have been modelled, culvert capacity has been assumed as QMED and the 75% blockage applied to this value.
- Undefended - All river modelling is undertaken as undefended.
- Climate change hydrology – It has been assumed that hydrology for the 100-year + Climate Change 35% and 70% is a straight upscale of the 100-year hydrograph.

### 2.2.4 Outputs

Upon running Jflow, the following outputs were produced for each inflow point:

- Maximum depth
- Maximum velocity
- Maximum hazard

Following completion of the modelling, all outputs from each inflow point were mosaicked into one dataset per return period.

### 2.2.5 Quality Control

Once the hydraulic model was run for each return period, the resulting depth grid outputs were visually checked and adjustments to the modelling inputs were made where required. The adjustments and checks made include (but are not limited to):

- **Straight edges** – In some cases, straight edges can occur in the flood outlines where the flow is artificially restricted by the modelling domain size. The domain was extended to allow flow to run out naturally where possible.
- **Disconnected flooding** – Flood outlines can be disconnected as a result of a high point in the DTM that restricts the flow. This can be improved by moving an inflow point to the high point in an attempt to fill the break in the flood outline. In some cases, where the channel is not well represented, manual editing of the channel can occur. In all cases the channel was considered with reference to aerial imagery.
- **Cross section edges** - Due to the modelling methods used, straight edges of relatively deeper depths can occur where inflow points are located across the flood outline. This is especially prominent where flow can become constricted behind a road or railway line. To mitigate this, the inflow point was moved upstream further away from the restriction or the cross sections re-angled appropriately.
- **Alignment of points** – Due to the nature of the watercourses and the resolution of the LIDAR creation of inflow points, in some cases these were located outside of the river channel causing unrealistic flood outlines. These points were moved onto the lowest part of the river channel to correct this problem.
- **Restriction of flow due to structures** – The flood depths can be artificially increased by the presence of blockages in the DTM, these can be mitigated by DTM editing (as explained in section 2.1.2)
- **Increase in depth/extent per return** – both visual and automatic checks are undertaken to ensure that flood depths and flood extents increase with return period.
- **Unrealistic output** – in certain circumstances, JFlow can produce erroneous output where flood depths and extents are unrealistically produce. These errors were spotted both visually and through automatic checks.