**Northern Ireland Undefended Floodplain Mapping**

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## 1.0 Introduction

Mapping the undefended floodplains in Northern Ireland is being undertaken as a direct response to proposals set out in the EU Floods Directive. It is the first in a series of maps and tools, as described in the National Flood Risk Assessment for Northern Ireland Flood Mapping Strategy (Sayers and Calvert 2007), to be developed to fulfill the requirements set out in the Directive.

RPS Consulting Engineers were commissioned to produce flooded area maps using methodologies developed by HR Wallingford for all river catchments in Northern Ireland with an area greater than $3km^2$ for floods at a 1% and 0.1% annual probability (100 year and 1000 year return period floods). A semi-automated approach, using available national datasets, was applied in the fluvial mapping for ease of application across the whole of Northern Ireland. In addition to this the coastal floodplain for the combined 0.5% and 0.1% annual probability water levels was mapped. This paper covers the approach and methodology applied to the delivery of the fluvial mapping.

## 2.0 Datasets

Four base datasets were essential for the completion of the Northern Ireland Undefended Floodplain Mapping, these datasets consisted of:

1) Digital Terrain Model (DTM),
2) Gridded Point Flow Dataset ($Q_t$ Grid),
3) Directional River Network (DRN),
4) Land Cover Dataset.

To ensure the best datasets available at the time were used a pilot data scoping study was undertaken to compare available sources based on four main criteria:

1) Availability of data in relation to the project timeframe,
2) Quality of the data and the likelihood of data updates / improvements within the project timeframe,
3) Consistency and transparency of the data origin,
4) Storage requirements (in-particular, for managing and handling the national scale DTM)

### Digital Terrain Model (DTM)

At the start of the Project, Ordnance Survey of Northern Ireland (OSNI) had already begun an ortho-photography project. As a by-product of this they were also creating a DTM. However the progression and completion of the DTM was dependant on flying time available to the survey company which as a rule for surveys of this type is very much reliant on weather conditions. The Ortho-DTM produced has a 10m grid resolution with a +/-2.5m RMS horizontal accuracy and +/- 1.5m RMS vertical accuracy. Although other options were available to produce a DTM they were considered less suitable and of inferior quality to the Ortho-DTM. They were however kept in mind in case of excessive delays or failure in the production of the Ortho-DTM.

### Gridded Point Flow Dataset ($Q_t$)

The $Q_t$ dataset, produced by the Centre for Ecology and Hydrology (CEH), consists of a point every 50m along a river reach. Each point within the dataset contains flow and catchment characteristic information relating to that location on the river. This dataset was commissioned for Northern Ireland at the inception of the Flood Mapping Project. No alternate datasets were available to provide the information contained in the CEH $Q_t$ dataset.

### Directional River Network

Two river centreline datasets were available:

1) Rivers Agency designated waterways dataset containing the centreline network of all Designated Waterways. This dataset does not contain all rivers which needed to be mapped and so was disregarded for use within the project.

2) OSNI 1:50,000 river centreline dataset is a digitised dataset taken form the OSNI 1:50,000 raster mapping. This dataset was deemed as being the best dataset available at the time for use during the project as it contained all rivers of interest.

**Land Cover**

A land cover dataset is required to allow assessment and assignment of roughness coefficients at river cross sections. Two nationally available datasets were available to fulfil the requirements:

1. The Corine Land Cover Map for 2000 (CLC2000) is produced jointly by the European Commission and the Member States and is an update of a similar map produced for 1990. CLC2000 is designed to be used at a scale of 1:100,000 and has a minimum mapable unit of 25ha. It records 44 land cover and land use classes which represent the major surface types across Europe (www.ceh.ac.uk).
2. The Land Cover Map 2000 (LCM2000) is a CEH product which provides a census of UK Habitats and land cover as digital maps and databases. It is constructed by analysis of data from Earth observation satellites. The satellites sensors record spectral reflectance from the Earth's surface, on a grid of approximately 25m x 25m cells (Fuller *et. al.* 2001). The database contains 72 variants, split into 26 subclasses and grouped into 20 Broad Habitats (BH) (www.ceh.ac.uk). The LCM2000 dataset was chosen as the more suitable due to its more detailed resolution.

**3.0 Methodology**

The methodology and tools used to produce the river models and ultimately the flood mapping outlines was developed by HR Wallingford. This system, originally applied in Scotland to produce the "Second Generation Flood Map for Scotland" was altered to accommodate Northern Ireland's datasets. The methodology is broadly divided into six work packages:

**WP 1.** **Raw data processing**: this initial phase involves preparation of the data into a format suitable for use in the one-dimensional hydraulic modelling package, InfoWorks RS. For this, the various datasets are processed, integrated, referenced and reviewed for any inconsistencies. A key element of this phase is the stream ordering, whereby the river system is divided into tributary based orders, which will be modelled independently. WP1 is split into five major steps, each of which is split into sub-steps to allow the data to be checked as the processing is progressed.

**Step 1** The processing in step one is carried out in three sub-steps:

1) The DRN is cleaned and provided with the "to" and "from" direction information for each reach. Elevations are also extracted from the DTM for the upstream and downstream ends of the reach to calculate the DRN slope for each reach.
2) The CEH flow points are snapped to the DRN using a simple distance rule. During this step some flow points may be snapped to multiple reaches.
3) A number of logical rules are applied and duplicate flow points are removed along with any DRN reaches which have no associated flow points. Stream ordering is also carried out within this step, with the main outlet channel having an order of 1 and its tributaries an order of 2 and so on.

**Step 2** The processing in step two is carried out in four sub-steps:

1) The river centreline is smoothed based on a curve fitting approach, which uses a rolling Bezier method based on input lines, creating virtual nodes and a smoothing factor. The degree of smoothing is linked to the longitudinal bed slope derived in sub-step1.1. The smoothing is carried out because the channel cross sections need to be generated perpendicular to the river centreline with as few intersecting cross sections as possible. Figure 1 illustrates a smoothed centreline in relation to the original DRN.
2) The $Q_t$ flow points from sub-step1.3 are snapped to the smoothed centreline.
3) Initial elevation values are assigned to each of the $Q_t$ flow points.
4) The DRN is dissolved based or the stream order values and each reach is assigned a unique identifying number i.e. stream order 2 reaches would be renamed 2.1, 2.2, … 2.n.

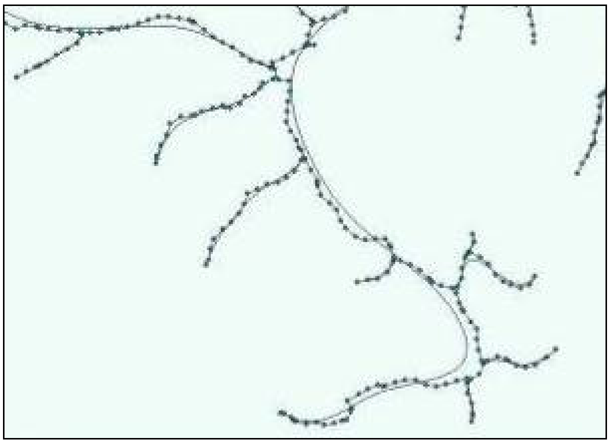


**Figure 1 Smoothed Valley Centerline**

**Step 3** The processing in step three is carried out in three sub-steps:

1) The $Q_t$ flow points are snapped to the dissolved DRN from sub-step 2.4.
2) Each $Q_t$ flow point is assigned an unique identifying number based on the Hydrometric sub-area number, the stream order of that reach and the point number along that reach, numbered from upstream to downstream.
3) A transect is drawn for each of the $Q_t$ flow points and the DTM is then interrogated at predetermined intervals for the cross section elevations. The transect extents are dependant on limiting parameters entered prior to processing starting, these include cross section height above the channel bed and distance from the DRN.

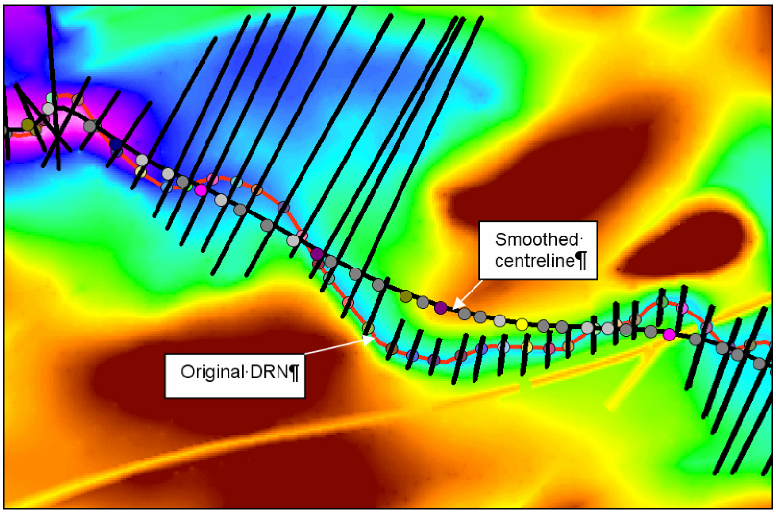



**Figure 2 Transects generated perpendicular to smoothed centreline along original DRN**

**Step 4** The processing in step four is carried out in three sub-steps:

1) Transects are trimmed if they intersect more than one DRN reach. They are trimmed back to the highest point between the two reaches.
2) Transects are sorted into separate shapefiles for each stream order.
3) Overlapping transects are removed within each stream order, based on a set of logical rules related to the number of intersects for a particular transect.

**Step 5** The processing in step five is carried out in a single step.
The number of elevation points used to describe each cross section is reduced; this in turn reduces the computational expenditure when the models are incorporated into InfoWorks RS, which has a 400-point upper limit. The approach is based on removing cross-section points where there is a small change in lateral slope for example, an approximately horizontal section of the valley bed. Here, the channel roughness is also taken into consideration. Channel points are only removed where the roughness is not varying laterally at that point, to ensure the true channel cover is represented. Figure 3 illustrates this for different lateral slope tolerances.

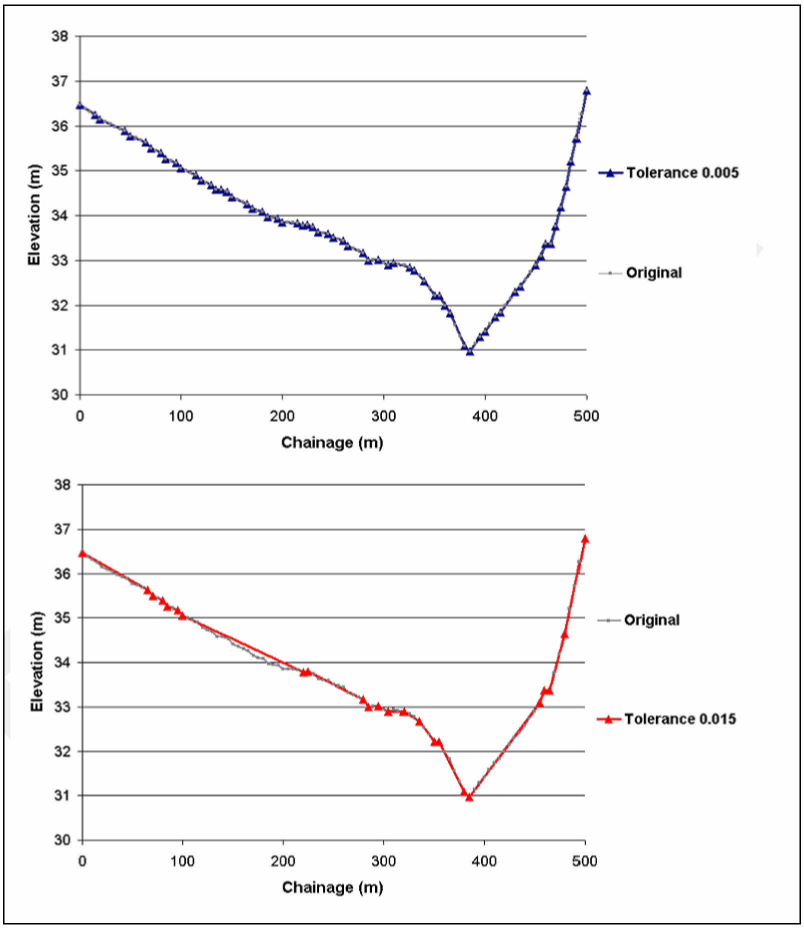



**Figure 3 A Reduction From 100 Points to (a) 62 points and (b) 23 points based on a lateral slope tolerance of 0.005 and 0.015 respectively**

The LCM2000 is then interrogated to assign roughness values along the cross sections and pre-processed data is exported to a series of node and cross section text files for each stream order. (McGahey and Benwell 2006)

**WP 2. InfoWorks RS data processing & import**: this stage involves importing the processed data sets into InfoWorks RS and developing them within the InfoWorks RS environment to create a complete hydraulic model with channel cross-sections, roughness allocations, inflow boundary conditions and additional information such as bed and panel markers. Prior to importing the data into InfoWorks RS, the cross-section and roughness information is imported into the Conveyance Estimation System software to generate rating curves for each cross-section. These curves are then used in the InfoWorks RS hydraulic calculation. WP2 is also split into a series of steps which are carried out using various DOS scripts and the CES software.

1) The output data from WP1 was initially sorted and processed into .csv files which are suitable for import into InfoWorks RS using a DOS script.
2) Another DOS script then created the Conveyance Estimation System .rad and .gen files which were used to produce conveyance curves within the CES software (Figure 4). The conveyance curves were then exported as .csv files ready for import to the InfoWorks RS model.

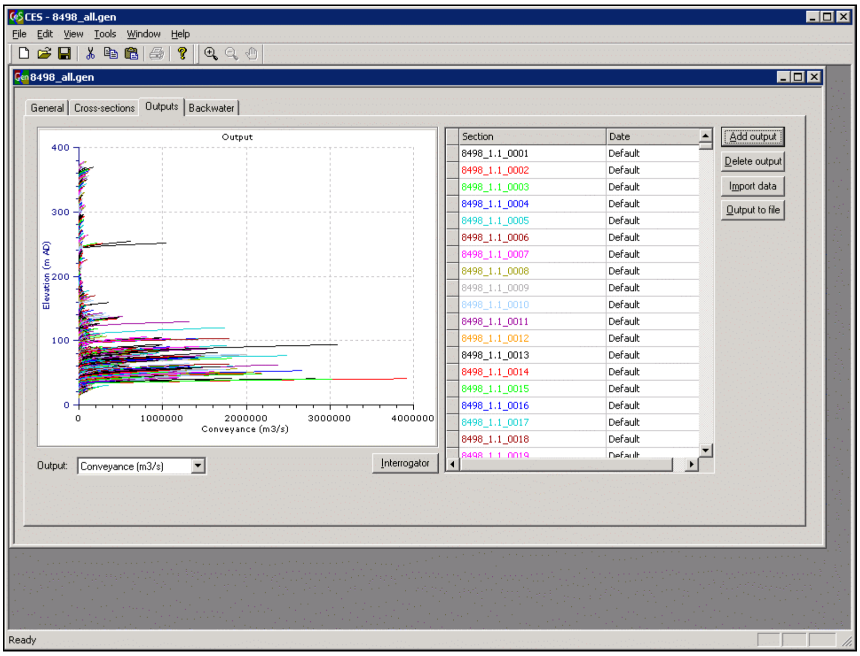



**Figure 4 Rating Curves in CES Prior to Export**

3) Two further DOS scripts were then utilised to automatically build the InfoWorks RS models. The first script created the base models using the standard normal depth rating curves. These models tended to produce irregular water levels with some downstream water levels exceeding upstream water levels. The second script built corrected models with updated rating curves based on the downstream cross sections with greater water levels. (Ratzko and McGahey 2005)

**WP 3. Normal depth model simulation**: this involves running hydraulic model simulations for the Qmed, Q10, Q100, Q200, Q1000 and Q10000 year food events (the Q10000 was simply extrapolated using the other extreme events and should only be taken as a very low probability event and not the actual 1:10000 year return period event), using the Muskingum-Cunge flood routing method. At this stage, the results are reviewed and any inconsistencies are flagged. A normal depth correction is applied and the final flood outlines are generated.

**WP 4. Aggregation of results**: this final post-processing phase which entails merging the flood outline results for the different stream orders, and ensuring smooth transitions at channel confluence .was undertaken in two steps:

1. The required input datasets for this step of the post-processing are the DRN from sub-step 1.3, the CEH flow points from sub-step 3.2, the transects from sub-step 4.1 and the exported InfoWorks RS flood outline shapefiles for each stream order and event from the hydraulic modeling. A new river centerline was generated by linking the lowest points in the cross sections within a given distance of the DRN.
2. The new river centerline was used together with the flood outlines to remove any outlines which were remote from the DRN i.e. had no flood route for the water to get to this point, this is illustrated in Figure 5. The outlines for each stream order were then cleaned, merged and dissolved to leave one shapefile. The lakes shores dataset was also included and any lake outlines along a river reach were included in the final merged output.

Before After

**Figure 5 Removal of Remote Flood Outlines**

**WP 5.** **Backwater simulations**: this was an additional step for all rivers feeding into the coast or lough (typically stream order one reaches). The Muskingum-Cunge flood routing model is converted to a river model and a downstream boundary condition is specified based on the coastal or lough water levels. The model is then run to ascertain the upstream influence of the backwater.

**WP 6.** **Review and attribution of uncertainty**: this involved assessing the degree of uncertainty associated with the result and hence provision of an uncertainty ‘flag’ for each modelled reach. (McGahey and Sloan 2007)

**4.0 Application to a Pilot Catchment**

The methodology was tested on a pilot catchment prior to application of the national datasets. The pilot catchment selected was the Bush River in County Antrim. The primary driver for selecting this catchment for the Pilot Study was data availability. Coverage of both the DTM and $Q_t$ grid was limited to the North East of Northern Ireland (Figure 6).

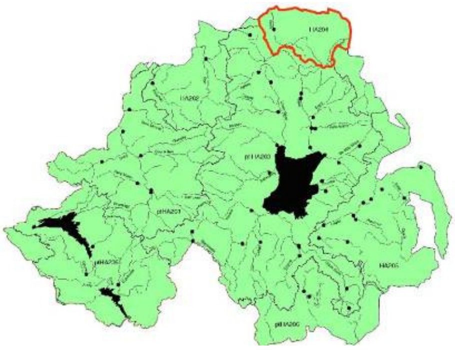


**Figure 6 Pilot Study Area**

During the pre-processing undertaken in WP1 there were 7 parameters that could be varied which would potentially have influenced the shape of the flood outline produced. The purpose of applying the methodology to a pilot catchment was to assess the most appropriate values for these parameters. The parameters are listed below with a brief description of each;

1) **Height** (Vertical Total Positive) controls the height above the channel bed level a transect can be generated to.
2) **Drop** (Vertical Total Negative) limits how far below the channel bed level a transect can be generated to.
3) **Maximum Width** specifies the maximum distance a transect can span away from the bed marker.
4) **Resolution** governs the sampling spacing during the extrapolation of the transect levels from the DTM.
5) **Land Cover Roughness Values** assigned to each Land Cover Map 2000 category. They are used to define energy losses due to friction between the water and the land surface. For the pilot study 3 sets of roughness values were created, a maximum, minimum and mean.
6) **Flow** needed to be investigated in the pilot study as it is difficult to assess whether the bed is being represented in the DTM or the surface of the water in the river.

7) **DRN** smoothing is the degree to which the centreline of the river is straightened/smoothed to reduce the number of transects being removed as a result of intersections.

Parameters 1 – 4 could be altered within the GTI Floodplain GUI (GTI Floodplain is a bespoke GIS-based tool comprising detailed data manipulation routines). Parameter 5 was changed via two separate sets of model build scripts each with a different group of predetermined roughness values. Parameter 6 was altered prior to the pre-processing stage using the attribute table of the $Q_t$ dataset in ArcGIS. Parameter 7 required recoding of the GTI Floodplain tool to achieve different degrees of smoothing based on the longitudinal slope and the Bezier function.

To allow a constructive investigation into how the alteration of the parameters affects the outcome of the modelling, a control run was created. The control used the default values for each parameter within GTI Floodplain and InfoWorks RS Scripts, which were adopted from a previously undertaken flood mapping project in Scotland. Table 1 presents the values used during the pilot study for each of the scenarios and the control.

**Table 1 Pilot Study Parameter Scenarios**

| Scenario | Height (m) (Vertical Total Positive) | Drop (m) (Vertical Total Negative) | Maximum Width (m) | Resolution (m) | LCM | Flow Return Period |
|---|---|---|---|---|---|---|
| (Control) | 6 | 5 | 1000 | 5 | Mean | 100 |
| 1 | 10 | 5 | 1000 | 5 | Mean | 100 |
| 2 | 6 | 2.5 | 1000 | 5 | Mean | 100 |
| 3 | 6 | 5 | 500 | 5 | Mean | 100 |
| 4 | 6 | 5 | 1000 | 10 | Mean | 100 |
| 5 | 6 | 5 | 1000 | 5 | min | 100 |
| 6 | 6 | 5 | 1000 | 5 | max | 100 |
| 7 | 6 | 5 | 1000 | 5 | mean | 100-Qmed |

The scenarios presented in Table 1 can be categorised into three groups with each group targeting a different way the model input data can be manipulated to provide more realistic outputs. Group one contains scenarios 1-4 which were aimed at analysing how cross section shape affected the performance of the model both in terms of computational time but also in choosing cross section representations that capture the actual channel itself and the likely valley / floodplain areas without picking up neighbouring valleys or missing the actual channel. Group two contains scenarios 5 and 6 aimed at investigating the sensitivity of the model to change in roughness coefficient. Group three contains scenario 7 which was designed to examine how the effects of the presence of the water surface in the DTM and subsequently in the cross sections derived from it can be countered or reduced.

Quantitative and qualitative analysis was carried out on the results to assess the impact each parameter had on the model results and ultimately inform the decision to which values should be used during the national application.

*Qualitative Analysis*

- Comparison of water levels and bed levels with those extracted from Hec-RAS.
- Comparison of the predicted $Q_{100}$ flood outline with the Northern Ireland IH130 outlines.
- Comparison of Observed outlines (known and unknown return periods) with cross section extents and predicted flood outlines.
- Comparison of CEH flows with gauged flows.

*Quantitative Analysis*

- Comparison of cross section shapes created by varying the pre-processing parameters.
- Analysis of sampling frequency for cross section generation.
- Analysis of model sensitivity to roughness values.
- Analysis of DRN smoothing effects on transect generation.
- Sensitivity analysis of water levels to percentage of $Q_{100}$ flow input to the model.

## 5.0 Uncertainty

The attribution of uncertainty to the outlines produced was seen as a fundamental deliverable of the project. The uncertainty should represent the reliability of the input data, any discrepancies due to features of the methodology and a general assessment of the final maps compared to local knowledge, previous observations and/or detailed model predictions (McGahey and Sloan 2006). The uncertainty was represented using uncertainty flags as a theme on the DRN which can be viewed as an overlay on the flood outlines. The uncertainty flag was based on the input data sets and the method, each initially given a default score as national datasets were used (the values given in brackets are the initial uncertainty scores);

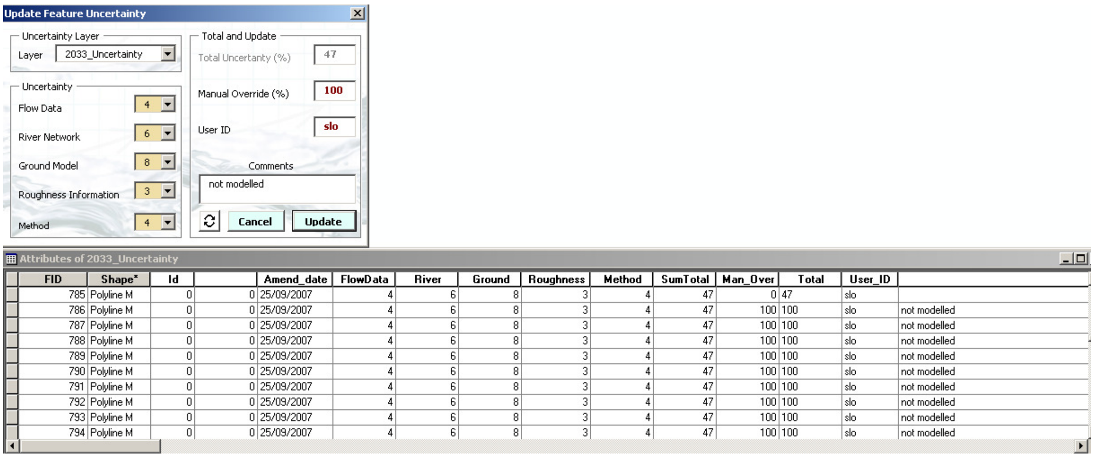
1. River Network (4): The CEH flow path data was considered a reasonable representation of the true drainage network.
2. Flow Data (6): The flow calculation is based on the FEH statistical methods and there is a large uncertainty associated with these.
3. Ground model (8): this was derived from the national orthophoto DTM, on a 10m grid resolution, and is considered the largest source of data uncertainty.
4. Roughness information (3): The analysis undertaken in the pilot study showed negligible affect on results by changing the roughness values. There is however scope for improvement as more detailed roughness information becomes available.
5. Method (4): The broad-scale indicative flood mapping method and parameters have been tested and fine tuned to best simulate the Northern Ireland fluvial system.

If better data was available for a certain area e.g. LiDAR coverage was available for all of Belfast, this was reflected in the uncertainty score by lowering the assigned value.

The total uncertainty score was obtained by the root sum of the squares of the 5 values described above and expressing them as a percentage of the maximum allowable score, 22.4 as follows:

$$SumTotal = \sqrt{U_{river}^2 + U_{flow}^2 + U_{ground}^2 + U_{roughness}^2 + U_{method}^2}$$

The uncertainty was applied using an uncertainty tool developed by HR Wallingford which initially assigned default values to each individual river reach. The tool was used to update the uncertainty values as necessary through a user interface as shown in Figure 7. A simple thematic scheme was also applied to the uncertainty layer to allow users to quickly assess the quality of the flood outlines. This consisted of colour coding the layer based on four interval ranges from the SumTotal; 0 – 33% represented by dark green, 33 – 66% represented by light green, 66 – 99.9% represented by orange and 100%, which was only applied to unmodelled reaches, represented by red.




| FID | Shape* | Id | | Amend_date | FlowData | River | Ground | Roughness | Method | SumTotal | Man_Over | Total | User_ID | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 785 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 0 | 47 | slo | |
| 786 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 787 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 788 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 789 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 790 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 791 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 792 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 793 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |
| 794 | Polyline M | 0 | 0 | 25/09/2007 | 4 | 6 | 8 | 3 | 4 | 47 | 100 | 100 | slo | not modelled |

**Figure 7 Uncertainty Tool User Interface and Uncertainty Layer Attribute Table.**

## 6.0 National Application

The national application of the methodology was initiated when approval of the finalised methodology and pre-processing parameters was given. There are seven hydrometric areas in Northern Ireland which allowed an easily definable structured approach to be undertaken, with each hydrometric area being modelled in turn. Due to dataset file size and required processing time each hydrometric area was further split into smaller sub-areas as defined in Figure 8. These sub-areas were based on major river catchments or the combination of a number of smaller river catchments. This approach made data handling and processing much more manageable. Error detection and correction was also made less onerous when carried out on smaller areas.

Once post processed the model output was verified against available local study (i.e. detailed predictive mapping) and historical flood outlines, with major inconsistencies being flagged within the uncertainty layer. The outlines are currently being supplied to DARD Rivers Agency (RA) as ArcGIS shapefiles. Subject to IPR constraints, these shapefiles may eventually be passed to other interested stakeholders and third parties e.g. DOE Planning Service and it is the intention that the flood maps will be published on the internet with a 1:50,000 scale mapping background (Figure 9).

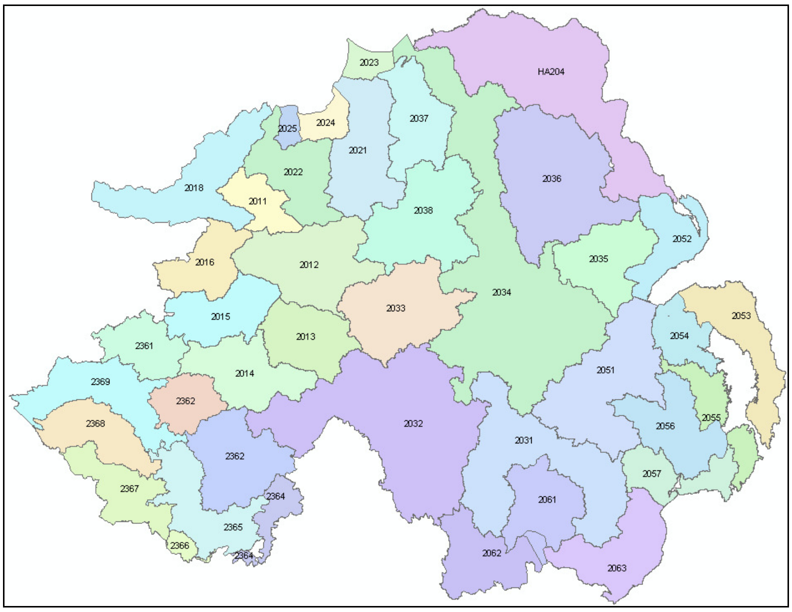



**Figure 8** **Hydrometric Sub-Areas**

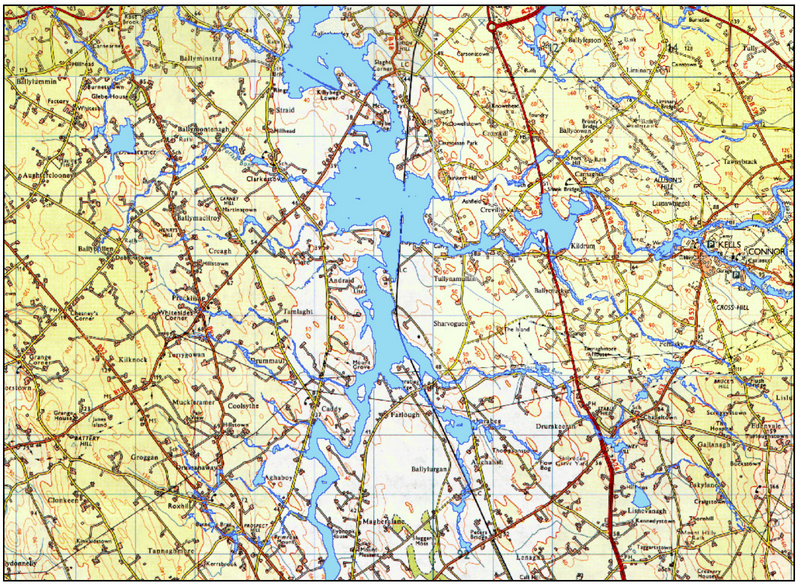


**Figure 9** **Example Flood Mapping Outline**

## 7.0 References

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