**Project Title:** Preliminary Flood Risk Assessment  
Fluvial Flood Hazard Mapping-  
Normal Depth Method

**Client:** Office of Public Works

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Appendix A: Corine Land Use Survey Classifications (2000) and Assigned Manning’s ‘n’ Floodplain Roughness Values ..................................................................................................................35
Glossary

AEP  
Annual Exceedance Probability; this represents the probability of an event being exceeded in any one year and is an alternative method of defining flood probability to ‘return periods’. The 10%, 1% and 0.1% AEP events are equivalent to 10-year, 100-year and 1000-year return period events respectively.

Corine Land Cover Data  
The term ‘Corine’ is an acronym for ‘Co-ordination of Information on the Environment’ across the European Community. The land cover data has been used on this project to provide an estimate of the land cover and therefore the surface roughness at each of the ungauged nodes through the river network.

DSM  
Digital Surface Model; this is the digital surface from the topographic survey prior to filtering to remove vegetation and buildings for example.

DTM  
Digital Terrain Model; this is the digital topographic data following the filtering process to remove vegetation and buildings and should represent a model of the ground surface.

EPA  
The Environmental Protection Agency for the Republic of Ireland

FSU  
Flood Studies Update; this is the forthcoming update to the hydrological analysis methods from the Flood Studies Report (1975) and is currently being developed by the Office of Public Works.

GIS  
Geographical Information System.

IFSAR Data  
This topographic survey data was produced by Intermap Inc for Ireland and has a quoted level of vertical accuracy of +/- 0.7m. The survey is undertaken from aeroplanes and uses interferometric synthetic aperture radar, to collect data on the elevation of the ground surface and other features such as buildings. This forms the basis of the DSM.

Intermediate Nodes  
These GIS nodes are distributed along the watercourses at a finer resolution than the ungauged nodes, at a spacing of approximately 100m. These data points were used to improve the resolution of the flood hazard extents from this project.

\( Q_{fp} \)  
Calculated flow on the floodplain at each ungauged node.

\( Q_{fp10} \)  
Calculated flow on the floodplain for the 10% AEP event (equivalent to the 10-year return period event).
$Q_{fp100}$ Calculated flow on the floodplain for the 1% AEP event (equivalent to the 100-year return period event).

$Q_{fp1000}$ Calculated flow on the floodplain for the 0.1% AEP event (equivalent to the 1000-year return period event).

$Q_{fpmax}$ Maximum flow used in the derivation of water levels from the normal depth method at each of the ungauged nodes. This was determined as being equal to 1.3 times the $Q_{fp1000}$ flow and was designed to ensure additional water level and flow data for each node was captured in case of the requirement for climate change runs in the future.

$Q_{med}$ The median flow in a watercourse, equivalent to the 2-year return period or the 50% AEP event. For the normal depth method this was assumed to be equal to the inbank flow.

**OPW** The Office of Public Works.

**OSi** Ordnance Survey Ireland.

**Ungauged Nodes**

These GIS nodes were also developed for the Flood Studies Update project and are generally distributed at intervals of 500m along each watercourse (with specific rules governing their location at confluences and at the upstream and downstream extents of watercourses etc).
1. Introduction

1.1 Background to the Project

This Report describes the body of work undertaken to complete a high-level assessment of flood hazard areas for the watercourses in the Republic of Ireland based on the principle of a ‘normal depth’ hydraulic relationship between water depth and floodplain flow.

The key deliverable required within the Scope of Works (2019/RP/001/C) was a set of flood extent polygons showing an estimate of the areas at risk of flood inundation from rivers for the 10%, 1% and 0.1% annual exceedance probability (AEP) flood events\(^1\). The water depths on the floodplains have been approximated from the calculation of ‘normal depth’ for flood flows for each of these design events along each of the watercourses in the country.

The fluvial flood hazard areas form an important component of the Preliminary Flood Risk Assessment (PFRA) for the Republic of Ireland. The PFRA is the first stage of the EU Floods Directive (2007/60/EC) to identify ‘Areas of Potentially Significant Risk of Flooding’ across the country using available or readily derivable data. Detailed analysis of flooding from rivers has previously been completed for a range of studies for particular catchments and settlements across Ireland. However, it was necessary to undertake a national assessment of hazard from fluvial flooding to facilitate the country-wide predictive flood risk assessment required for the PFRA. Full details of this component of the PFRA are contained in a separate report (Preliminary Flood Risk Assessment – The Republic of Ireland, The Predictive Assessment of Potentially Significant Flood Risk, Mott MacDonald, June 2011).

This report focuses on the methods used for the national assessment of flood hazard from rivers to be used in the PFRA. It is important to note that the outputs from the project are hazard areas showing approximations to the flood extents from rivers and do not include any evaluation of ‘risk’ to any flood receptors within the hazard areas.

1.2 Summary of Work to Derive National Fluvial Hazard Areas

The project is wholly established within a GIS framework and is national in scope. It is based on a series of datasets developed under a previous project within the Flood Studies Update Programme (FSU 5-3 Preparation of Physical Catchment Descriptors, Compass Informatics, 2009) for the Office of Public Works.

The FSU project involved the construction of a meso-scale (1:50,000) GIS incorporating source data from Ordnance Survey of Ireland (OSi) and the Environmental Protection Agency (EPA) for the national river network. This GIS contained ‘ungauged’ node points at 500m intervals along the river courses (139,000 locations) for which a database of river network descriptors and spatial catchment descriptors were derived. A floodplain cross-section line was created at each node. In addition, ‘intermediate’ nodes with cross-section lines were placed at 100m intervals along the channels between the ungauged nodes to assist in the spatial definition of the output flood hazard polygons.

\(^1\) Annual exceedance probability represents the probability of an event being exceeded in any one year and is an alternative method of defining flood probability to ‘return periods’. The 10%, 1% and 0.1% AEP events are equivalent to 10-year, 100-year and 1000-year return period events respectively.
The flow estimates for the 10%, 1% and 0.1% AEP flood events at each of the ungauged nodes were developed by OPW based on parameters and methods arising from several of the preceding FSU Programme Work Packages. Estimates were made of the flood depth and therefore the flood extent at each ungauged node, using this flow data and the topography of the land surrounding each node as inputs to the ‘normal depth’ hydraulic equation.

The project utilised a relatively high resolution (5m) DTM developed by Intermap Technologies based on their IFSAR technology (a proprietary airborne Interferometric Synthetic Aperture Radar system). The DTM was used to assess elevation across the floodplain along cross-section lines and to determine the gradient along the channels and at ungauged node sites.

A GIS based workflow containing a series of technical method components was developed to derive the flood polygons for each design event. These steps are described in Section 2 of this document.

It is acknowledged that the principles of the normal depth equation only provide an approximation to the flood depth and flood extent at each node in the river network. However, given the scale of the river network across Ireland, detailed hydraulic modelling of all the river channels would have been impractical and inconsistent with the intentions of the Flood Directive for the use of ‘available and readily derivable data’ for the PFRA.

As this document explains, the method used for this project was taken through a series of development stages to try to minimise, wherever reasonably possible, any errors in the estimation of the flood hazard extents.

It should also be noted that this project only includes the definition of flood hazard areas from rivers. The derivation of hazard areas for other sources of flooding including tidal and groundwater sources is covered in the main PFRA report (Mott MacDonald, June 2011). In addition, for the PFRA the term flood hazard has been simplified to represent only the extent of flooding. Given the relatively simple method used, flood depth and velocity have been excluded from the outputs.

The project was developed in two stages. The preliminary stage comprised a pilot study on the Lee catchment (Hydrometric Area 19) together with checks on the outputs for other parts of the country such as the Shannon catchment in Hydrometric Areas 25 and 26. This stage served to provide a technical forum within the project team, including OPW, for the refinement of the methods based on an iterative review of draft outputs. The second stage allowed for the extension of the agreed methods to the national river and stream network. Some further refinements during the processing of the normal depth results for the national network were required to allow completion of the flood extent polygons in specific river catchments.

1.3 Structure of this Document
This report is organised in the following sections:

- Section 2: This section includes a summary of the key data and methods used to solve the normal depth calculations.
Central to this concept are the existing nodes along the river channels from the FSU programme and the use of hydrological data on the upstream catchments to estimate the flow rates at the nodes for each of the design events. A national topographic dataset then provides information at each of the nodes to enable the normal depth calculation to be solved, generating flood levels for each design event.

- Section 3: This section provides information on the conversion of the flood level results at each node into flood extent polygons along each watercourse. The method highlights how these automated extents have then been adjusted to remove obvious errors and artefacts from the standard approach.

- Section 4: This section provides further information on the checks that were made to ensure as far as possible, that the normal depth results could be validated using data from other studies.

1.4 Acknowledgements

The project has been developed and adapted from the original Scope of Works through the active participation of a Technical Steering group with input from OPW, Mott MacDonald and Compass Informatics. Acknowledgement is made of the contributions from all participants and in particular Anthony Badcock (Mott MacDonald Ltd) and Mark Adamson (OPW).
2. Derivation of Fluvial Design Water Levels using the Normal Depth Hydraulic Method

This section contains details of the different stages of the technical analysis to generate flood levels for three design events, using the relationship between water levels and flows under normal depth conditions. The section has been subdivided according to the following key aspects of the data requirements and hydraulic principals for this method:

- **Section 2.1:** Information regarding the GIS data taken from the FSU project including national datasets river centrelines, ‘ungauged’ nodes at approximately 500m intervals and cross-section lines for each of these nodes extending across the floodplain.

- **Section 2.2:** A summary of the national digital terrain model in GIS that was used to generate elevation values at the nodes and along the cross-section lines. Inclusion of quality checks to the nodal elevations to screen for inconsistencies along each watercourse.

- **Section 2.3:** Methods used to calculate the floodplain slope at each ungauged node in the national watercourse network using the node elevations over a 5km reach. This sub-section also covers rules that were developed to account for atypical nodes such as those found close to the watercourse extents, reservoirs and confluences.

- **Section 2.4:** The approach that has been taken to calculate floodplain flows for each of the design events at each node throughout the river network.

- **Section 2.5:** Use of the normal depth hydraulic flow equation to generate water levels on the floodplain for each design event.

- **Section 2.6:** Post-processing of the calculated normal depth water levels to account for backwater effects that may serve to increase design water levels above the calculated normal depth.

The transformation of these water levels into flood hazard extents is addressed in Section 3.
2.1 Data Components from FSU 5-3 Catchment Descriptors Project

The project “Preparation of Physical Catchment Descriptors” (FSU Work Package 5-3, Compass Informatics, 2009) had previously developed a series of national scale GIS datasets which serve as primary datasets for this project.

Detail on the preparation of these datasets is provided in the FSU project report. A synopsis of the key datasets utilised by this project is provided below.

2.1.1 Watercourses and Standing Waters

The definition of the river and stream network and associated standing waters was provided by the EPA from their national Water Framework Directive GIS system. These, in turn, are derived from OSi digital mapping as used in their 1:50,000 Discovery mapping programme. Additional work by EPA and other State Agencies has improved the geometry of the OSi source data and developed an accompanying series of descriptor attributes.

The dataset comprises approximately 74,000 km of river channel and 11,000 standing waters (lakes and reservoirs).

2.1.2 Ungauged Nodes

A series of ‘ungauged’ nodes had been placed along the river network in the GIS to facilitate the development of data relating to the analysis of the location specific hydrological networks and upstream catchment areas. These node locations are a series of systematic sampling points along the channels. The set of rules used to determine the locations of the nodes is summarised in the following points:

1. The nodes were placed at 500m intervals along each watercourse, where the upstream catchment area was above a minimum threshold of 1km².

2. An ‘initial’ node was placed at the upstream and downstream end of each GIS river segment (defined as a channel reach between confluence locations).

3. At the end of the river segments and in the immediate vicinity of channel confluence points, the distance between the penultimate and last node along each river segment is unlikely to be exactly 500m. Where this distance is less than 100m the notional ‘penultimate’ node was not used, and therefore the distance between the retained ‘penultimate’ node and the last node could be up to 600m.

4. These rules ensure that each confluence of two watercourses contains two inflow reach ‘end’ nodes and one outflow node at the start of the outflow reach. These three nodes are geographically coincident, despite being notionally located on different river segments of either the main river channel or the tributary.

5. Nodes were also placed at lake or reservoir inflow and outflow points.
6. At the downstream end of each river system a terminal node was placed at the marine boundary (indicated by the Mean High Water (tidal) boundary mapped by OSI).

These rules provided a total of approximately 139,000 ungauged nodes throughout the national river network.

In addition, a series of intermediate nodes were placed between the ungauged Nodes at an interval of 100m. These were used to improve the resolution of the outline of the GIS polygons showing the flood extents in this project and comprise a sub-dataset of 290,000 features.

2.1.3 Cross-Section Lines

Cross-section lines were located at each of the ungauged and intermediate nodes. These serve to facilitate floodplain analysis adjacent to the node. The orientation of each was approximately orthogonal to the direction of flow at the watercourse.

In addition, radial lines were located at 100m intervals around the boundary of standing waters to facilitate the analysis of flooding arising from increases in lake and reservoir water levels.

A marker point was recorded along each cross-section line to indicate the point at which the line crossed into the marine environment.
2.2 **Digital Terrain Model - Elevation Data**

At the outset of the project, topographic elevation data in the form of a 5m cell size Digital Terrain Model (DTM) were provided by OPW as a series of 10 x 10 km tiles. This topographic data was produced by Intermap Inc based on their IFSAR airborne technology platform (Intermap, 2009). The reported vertical accuracy of the data, in the form of RMSE (Root Mean Square Error), is approximately +/- 0.7m in unobstructed areas (Intermap's accuracy report on the data is held by OPW).

Post-processing of the original IFSAR data had already been performed to ensure consistent elevation values were present across individual standing waters (lakes and reservoirs). It is presumed that this process was facilitated by a dataset of waterbody polygons whose definition and origin has not been communicated to this project.

In the initial processing step, the topographic data for the 10 x 10km tiles were assembled into 37 larger area blocks to provide coverage of each Hydrometric Area.

Elevation values from the assembled DTM blocks were transferred into two of the project vector datasets:

- Ungauged nodes and intermediate node points – single elevation value;
- Cross-Section Lines – elevation values at 5m spaced intervals along the extents of the cross-section lines.

During the pilot stage of the project, it was observed that a local decrease in elevation of the nodes in the upstream direction was apparent along some of the channel reaches.

As a general trend, one might expect the elevations of the river banks to decrease in a downstream direction along the channel. However, due to differences variations in the elevations of the land surrounding the river banks, the generic limit in the accuracy of the data and possible residual defects from the filtering of the IFSAR data, this rule may not always be the case. The filtering process removes vegetation cover and other artificial raised features the data, generating a topographic representation of the ground surface of the floodplain in the form of the DTM.

To attempt to identify nodes where there was likely to be a significant error in the ground surface elevations, an automated screening process was setup in GIS.

This automated step was introduced to identify any instances where any nodes within 1km upstream of specified ‘target’ node had an elevation in the DTM of more than 1m below that of the target node. These target nodes were assumed to have incorrect elevation data and were termed ‘super-elevated’ nodes. An adaptive method was applied at these nodes in the final phase of the creation of the flood hazard polygons (see Section 3.2.3).
2.3 **Floodplain Slope**

To facilitate computation of the normal-depth equation, an estimate of the floodplain slope was required at each ungauged node. In the most common ‘default’ situation (as shown in Figure 1) the slope has been determined over a 5km river channel distance, using nodes 2.5km upstream and 2.5km downstream of the target node. This is achieved by automatically obtaining the elevation of the fifth node upstream and the fifth node downstream of the target node in GIS. However, the irregular distance between the penultimate and last nodes on a river segment (between 100 and 600m) required an adaptation of this procedure whereby the elevation at the first node encountered after a distance of 2.5km from the target node is used.

![Figure 1 Schematic showing Floodplain Slope Calculations – Default Scenario](image)

The river network is recorded as a dendritic geometric pattern in the GIS, with known principal flow directions on all of the watercourses. In this regard the identification and referencing of the fifth downstream node is unambiguous, whatever the location of the target node in relation to channel confluence points.

In the upstream direction, however, multiple potential flow paths can be followed, along either the main or tributary channels upstream of confluence points. A decision was taken for this project that the watercourse with the longest path to its headwater is classified as the ‘main’ river and provides the geometric path for floodplain slope analysis.

The channel distance along which floodplain slope is calculated can be affected in three further situations where:

1. the target node occurs within 2.5km of the upstream or downstream limit of the channel (as represented by the ungauged nodes), in which case the slope calculation has been terminated at the last available node (see Figure 2) and the distance data used in the calculation was adjusted accordingly;

2. a lake or reservoir with a traverse distance which exceeds 500m occurs in the reach, in which case the slope calculation reach has been terminated at the near side of the relevant waterbody. Conversely the slope calculation reach has been extended though water bodies where the traverse distance is less than 500m; and
3. the selected upstream or downstream node is deemed to have an erroneous elevation value (see Section 2.2), then the next node found which is not deemed to be ‘super-elevated’ is used (see Figure 3).

Figure 2  Schematic showing Floodplain Slope Calculations – Constrained Length of Reach Scenario

Figure 3  Schematic showing Floodplain Slope Calculations – Scenario for the Adaptation for ‘Super-elevated’ Nodes

Analysis of the floodplain slope values determined for the national set of ungauged nodes indicates instances where the computed slope is negative. Such instances occur primarily in flat terrain and are considered a manifestation of the reported level of accuracy of the DTM. In the subsequent normal-depth calculation (see Section 2.5), a minimum floodplain slope of 0.0001 (1/10000) is assumed for all ungauged nodes.
2.4 Calculation of Floodplain Flows at Ungauged Nodes for Design Events

2.4.1 Summary of Process for Flow Calculation

Estimates of floodplain flow values for the 10%, 1% and 0.1 AEP events at the ungauged nodes were provided by OPW. These have been derived through the FSU project component studies, including the analysis of GIS derived parameters (FSU 5-3 Physical Catchment Descriptors project), the Base Flow Index project (FSU 5-2) and other FSU work-packages.

The process followed by OPW to estimate floodplain flow was:

- Calculation of the median flow \( Q_{\text{med}} \) at each ungauged node, which is assumed to approximate the bankfull in-channel flow. The \( Q_{\text{med}} \) values were adjusted to account for the proportion of urban land cover upstream of the target node and had correction factors applied as determined from the FSU project.

- Calculation of the specific design event flows at each node, scaled from the \( Q_{\text{med}} \) flow using the statistical growth curve for Republic of Ireland and thereby generating the following total flow values for each node: \( Q_{10}, Q_{100}, Q_{1000} \).

- Calculation of the floodplain flow \( Q_{\text{fp}} \) for each event from the subtraction of the adjusted \( Q_{\text{med}} \) value from the design flow at each ungauged node.

- This process results in three sets of floodplain flows, \( Q_{\text{fp10}}, Q_{\text{fp100}}, Q_{\text{fp1000}} \) corresponding to the different design flood events.

- Calculation of a notional maximum flow at each ungauged node for the calculations, \( Q_{\text{fpMax}} \). This was determined by multiplying the \( Q_{\text{fp1000}} \) flows at each node by a factor of 1.3. This process provided some degree of future proofing for the water level and flow data at each node, considering any potential need in the future for the generation of flood polygons for climate change scenarios, for example.

The schematic in Figure 4 shows how these divisions between the floodplain and channel flow conditions have been applied for the example of 1% AEP flood event.

Figure 4 Schematic showing Components of the Cross-sections
2.4.2 Artificially Managed Rivers

During the development of the method to derive the overall and in-channel flows, some more unusual channel configurations were considered, particularly in relation to the assumption that the bankfull flow is equivalent to the \( Q_{\text{med}} \). For ‘managed’ watercourses where the channel banks are raised or the channel is artificially widened, it would be expected that the bankfull flow would be larger than the \( Q_{\text{med}} \). This would be the case for channels within arterial drainage schemes for example.

However, following checks with various regional engineers at OPW, it was decided that the level of protection for arterial drainage schemes would vary significantly both between different Hydrometric Areas and also probably within different parts of the same scheme. It was therefore agreed that trying to adjust the in-channel flow for nodes inside these schemes would not necessarily improve the accuracy of the results. A standard rule of the bankfull flow being equivalent to \( Q_{\text{med}} \) was agreed across the full national river network.

2.4.3 Problems Encountered in Generating Design Flow Estimates

Flow values were not available for some ungauged nodes, a situation primarily arising from the absence of one or more of the necessary catchment or hydrological network descriptors used in flow calculation. Example situations include the occurrence of an ungauged node at the very top of a mapped headwater channel (i.e. the upstream catchment is below the 1km\(^2\) threshold) or a node location at which it was not possible to derive a representative catchment polygon.

In such situations it was determined that flow estimates should be obtained from interpolation between, or extrapolation of, the calculated flows at adjacent nodes. Typically, flow estimates were missing for around 1-2% of the ungauged nodes for each Hydrometric Area.

Donor node(s) where flow estimates were available were identified to associate with those nodes lacking flow estimates. The primary search was to identify adjacent nodes along the same watercourse. This was achieved through an automated routine, except in the occasional instance where such a suitable donor node was not available and a manual examination of an adjacent watercourse was carried out.

Once a donor node(s) had been identified, flow estimates were transferred to the target node by employing the respective catchment areas or stream network length parameters as a scaling factor.

The necessary GIS based catchment and network hydrological descriptors were also absent from the FSU derived dataset in the cross-border catchments in Northern Ireland. These parameter values were calculated by amalgamating hydrological data from the FEH CD-ROM (Version 3, NERC - Centre for Ecology and Hydrology, 2009) for Northern Ireland with the available data sets for the FSU sub-catchment areas for the Republic of Ireland. This ensured that the methods for the design flow calculations for the cross-border catchments were as consistent as possible with the rest of the country.
2.5 **Normal Depth Estimation**

At each ungauged node, the $Q_{fp}$ estimate for each design event was converted into an estimate of water level on the floodplain using a version of the Manning’s normal depth equation:

$$Q_{fp} = \frac{1}{n} \frac{A^{5/3}}{P^{2/3}} S^{1/2}$$

Where:

- $Q_{fp}$ = Floodplain flow (m$^3$/s);
- $n$ = Manning’s ‘n’ roughness parameter;
- $A$ = Cross-sectional area of the floodplain (m$^2$);
- $P$ = Wetted perimeter of the floodplain (m);
- $S$ = Floodplain slope at the node (dimensionless).

### 2.5.1 Surface Roughness

The Manning’s ‘n’ roughness parameter at each node was based on the ‘land cover’ value in the Corine (Co-ordination of Information on the Environment) Landcover 2006 database (EPA, 2006, provided by OPW) that was coincident with the location of the ungauged node. The Corine data provides information on the spatial distribution of land cover types across the European Community. For the PFRA project this was the best available information on land cover and land use for Ireland, and provided a means for approximating surface roughness conditions for the flow calculations in the normal depth analysis. The GIS polygon version of the dataset was used as opposed to the gridded data as this had greater accuracy.

Most of the roughness values for the different land-use classes in the Corine database were derived from the land use categories and roughness values in the Conveyance Estimation System (CES, developed by HR Wallingford and JBA Consultancy). In some instances, where the Corine Landcover class was not directly represented in the CES, a close approximating class was selected. A copy of the table provided in the Scope of Works for the normal depth modelling, detailing the Corine classifications and the assigned Manning’s ‘n’ values is included in Appendix A of this document.

During the course of the normal depth modelling, it became apparent that other land use classes were present in the data set for Ireland and surface roughness values also needed to be approximated for these areas. These land use classes together with the roughness values assigned were as follows:

- **Corine class 331:** Beaches, sand and dunes, *Manning’s ‘n’ value* 0.02
- 324: Transitional woodland scrub, 0.06
- 421: Salt marshes, 0.04
- 423: Intertidal flats, 0.02
- 131: Mineral extraction sites, 0.1
- 132: Waste dumps, 0.1
- 511: Streams, 0.03
The percentage coverage of the different land use classes in the Republic of Ireland is included in the table in Appendix A. It is clearly evident that the majority of the land cover in Ireland has been classified as pasture (51.5%) with large amounts of peat bogs (16.1%), non-irrigated agricultural land (7.7%) and land occupied by a mixture of agriculture and natural vegetation (6.0%). The other relevant land use classes only cover relatively small proportions of the country.

The additional land use and Manning’s ‘n’ classifications listed above also cover very small parts of the country. It is clear that some of these land cover types are highly unlikely to be coincident with the rivers (such as mineral extraction sites and waste dumps), but Manning’s ‘n’ values were assigned for completeness to ensure the functionality of the programming in GIS.

The estimation of the roughness value for each node is limited by the resolution of the Corine land cover classes and is derived for the floodplain immediately surrounding the node on the watercourse. However, it is recognised that the CES provides a method of deriving a Manning’s ‘n’ value that is representative of the land cover across a specific cross-section on the floodplain. Given the high-level nature of the fluvial hazard analysis and the uncertainties in other aspects of the method, it was decided that it would not be appropriate to derive composite roughness values for the full extents of the floodplain cross-sections at all of the 139,000 nodes in the country.

2.5.2 Iterative Normal Depth Calculations

The computational process to derive the normal depth estimates for the floodplain flows for the 10%, 1% and 0.1% AEP events, together with the notional \( Q_{\text{fpMax}} \) flow, employs an iterative method, whereby the water depth is increased at the ungauged node in 0.1m increments until the \( Q_{\text{fpMax}} \) flow value is accommodated.

For each depth increment, the wetted perimeter and cross sectional area available on the floodplain were calculated by reference to the elevation information stored in the cross section lines, at 5m spaced points. The wetted perimeter for the floodplain excludes the length of the channel banks and river channel bed which is assumed to convey the \( Q_{\text{med}} \) flow (\( Q_{\text{med}} \) values are previously removed from the total flow to provide the floodplain flows, see Section 2.4.1) as illustrated in the schematic in Figure 5.
For each given 0.1m depth increment, the method evaluates the comparative topographic elevation at intervals of 5m moving away from the river centreline across both the left and right sides of the floodplain to identify the inundation extent.

For each increment, the normal-depth estimate of floodplain flow at the ungauged node is calculated based on the following parameters:

- the wetted perimeter for the iteration of the water depth;
- the cross section area for the iteration of the water depth;
- the known, and presumed invariant surface roughness factor at the node location; and
- the floodplain slope.

Water depth was increased at each node independently, until the wetted perimeter length and cross section area were sufficient for the calculated flow to equal or exceed the flow $Q_{fpMax}$, 1.3 times the $Q_{fp1000}$ flow. For each 0.1m increment of depth up to the target $Q_{fpMax}$ flow, the estimates of wetted perimeter, cross sectional area and flow were recorded to a database table.

At any particular depth increment the requirements for $Q_{fp10}$, $Q_{fp100}$ and $Q_{fp1000}$ may be met. It was determined that frequently a particular depth is adequate for more than one of the design event scenarios. Indeed, depending on the topographic profile across the floodplain, a single depth increment of 0.1m may be sufficient to accommodate all three design flow scenarios plus the $Q_{fpmax}$ flow.

The method does not identify potential flood conveyance through localised hollows beyond a higher area of land in the cross-section, despite this land being below the elevation of the water under consideration. This is illustrated in Figure 6. This rule recognises that across a single cross-section line, water will not spread laterally across the floodplain unless the water level is above the ground elevation, including obstructions such as natural or man-made embankments and flood defences. Whilst it is recognised that the extent of the inundation of the floodplain is only evaluated at cross-section lines rather than continuously across the floodplain surface, the use of additional cross-sections every 100m in addition to the main cross-section lines every 500m, means that this problem was reduced.
The decision to use depth increments of 0.1m in the determination of the normal depth calculation is based on practical computational limitations. It is also known that the vertical accuracy reported for the IFSAR DTM data, as used in the floodplain cross-section analysis, is some 0.7m RMSE which limits the benefit of implementing smaller depth increments in the normal-depth calculation.

Figure 6  
Schematic illustrating the Principles for the Floodplain Pockets from the Convective Flow Area at each Cross-section

The water depths above the node elevation required to convey the target flows were calculated at each node for each of the design events. However, these values were based on the 0.1m increments of water depth applied in the normal depth equation and are likely to generate a flow values in excess of the target design flows. This is illustrated in the schematic in Figure 7.

The schematic shows two depth increments of 0.1m and 0.2m that are calculated on the floodplain above the value of the bank elevation taken from the DTM. In this hypothetical example, a line has also been included between the 0.1m and 0.2m elevations to represent the water elevation for the 1% AEP (100-year return period) event. It is clear from the schematic that although the method only calculates the normal depth at 0.1m intervals, the target flow for a specific design event is likely to be accommodated between these intervals. This can cause an overestimation of the calculated water level for that event.

Figure 7  
Schematic illustrating the relationship between the calculated and target normal depth values on the floodplain
As a general rule, for relatively constrained floodplain topography the required depth to meet the same target flow is likely to be greater than for wider floodplains. In addition, it can be expected that the difference in flow estimates between two successive depth increments in narrow floodplain areas is likely to be less than for cross-sections in more open floodplains. These general patterns are predominantly a result of the increased cross-sectional area available for flow conveyance on wider floodplains rather than smaller, more restricted cross-sections, although clearly local variations in surface roughness for example will influence this pattern.

The potential flow variation between successive depth increments in a cross-section can be considerable. A step jump, rather than small increase, in the calculated flows is likely for situations where a particular locally high topographic feature in the cross-section is ‘overtopped’ and there is a sudden and large increase in the area of the floodplain that is inundated.

Thus, where a particular depth may be insufficient to accommodate a given flow, the next depth increment of 0.1 m may be capable of accommodating a large multiple of the same flow. This is more likely on unconstrained floodplains where the slopes across both sides of the floodplain in the cross-section are low. The presence of local topographic depressions encountered along specific cross-sections may serve to further accentuate this effect.

A comparison of the relationship between the normal-depth water level (based on 0.1m increments) required to process the estimated floodplain 1% AEP flow and the potential maximum flow through that flow depth is provided below to illustrate aspects of this issue. Information is presented for the ungauged nodes for two Hydrometric Areas, one with relatively steep topography (HA10) and the other with relatively flat topography (HA08).

Firstly, in the relatively flat HA08 a water depth of 0.1m is sufficient to accommodate the \( Q_{fp100} \) flow at 68% of the ungauged nodes. In the relatively steep terrain of HA10 this is reduced to 54%.

Secondly, in relatively flat areas one also expects a greater likelihood that the required calculated depth for the \( Q_{fp100} \) flow would also be able to accommodate a considerably greater flow. Table 1 classifies the maximum potential flow of the depth increment required for the \( Q_{fp100} \) flow. It indicates that in the flatter topographic situation there is a greater likelihood of a much larger potential flow through the cross section.

For example, in the flatter areas there is only a 35% likelihood that the potential flow is limited to 200% of the target \( Q_{fp100} \) flow; in the steeper situation this increases to 46%.
### Table 1  Hydrometric area comparison of estimated flow exceedance

<table>
<thead>
<tr>
<th>Maximum potential flow at the calculated 0.1m level increment vs. $Q_{fp100}$ flow</th>
<th>Hydrometric Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 (Generally steeper topography)</td>
</tr>
<tr>
<td>100-200%</td>
<td>46%</td>
</tr>
<tr>
<td>200-500%</td>
<td>16%</td>
</tr>
<tr>
<td>500-1000%</td>
<td>8%</td>
</tr>
<tr>
<td>&gt;1000%</td>
<td>30%</td>
</tr>
<tr>
<td>Likelihood that only the total depth required for all design events is 0.1m for instances where flow ratio is greater than 1000% (ten times the target flow)</td>
<td>96%</td>
</tr>
</tbody>
</table>

The minimum water depths required to route each of the four flow scenarios ($Q_{fp10}$, $Q_{fp100}$, $Q_{fp1000}$ and $Q_{fpMax}$) were recorded as attributes of the ungauged node. These normal-depth values were employed during the subsequent flood extent mapping process. In addition, as discussed above, the ratio of the maximum potential flow at the calculated water depth to the target flow was also recorded for each design event at each cross-section.
2.6 Post-Processing of Calculated Water Levels – Backwater Adjustment

In the first instance, the normal depth results were calculated for each ungauged node on an individual basis. Reference to the more general river context and the results at other cross-sections was limited to specific parts of the calculations such as the derivation of floodplain slope for the ungauged node as an average over 5km (see discussion in Section 2.3).

As a post-processing step, a method was employed to identify and mediate for any potential backwater effect that may serve to increase design water levels above the calculated normal depth.

At the downstream marine boundary of each watercourse the flood water level is defined from the normal depth equation analysis. At the downstream extent of each of the channels, the calculated flood water level for each design event was compared to the flood water level immediately upstream and the following rules applied:

- Where the flood water level at the target node was greater than the flood water level at the node immediately downstream, the flood water level at the target node would not be adjusted from the calculated value;
- Where the flood water level at the target node was less than the flood water level at the node immediately downstream, the water level at the target node was increased to equal the water level at the downstream node;
- However, where the flood water level at the target node was lower than the downstream node by more than 1m, the adjustment at the target water level was capped to the flood elevation at the target node plus 1m.

These rules for backwater adjustment were propagated in an upstream direction to the limit of the distribution of the ungauged nodes (1 km² catchment area limit) on each watercourse. Where an adjustment was made, both the pre- and post-adjusted levels were retained in the database for each node.
3. Flood Extent Polygons

3.1 Generation of Fluvial Flood Polygons

3.1.1 General Approach

A series of steps were undertaken to convert the calculated water depths into flood hazard polygons for each of the design events.

The initial polygon was created in GIS for the nodes associated with an individual river segment. In a later stage of the process, all of the constituent polygons along a watercourse were amalgamated into an integrated polygon.

In the first instance, the depth values recorded at the 500m spaced ungauged nodes from the flow calculations were used to infill depths at the 100m spaced, intermediate nodes. This process was based on an inverse distance weighted method, whereby the depth estimate at the intermediate node was biased towards that from the more proximal ungauged node. Once the constituent ungauged and intermediate nodes associated within a river segment had depth values determined for a specific design event, a flood hazard polygon was generated.

An automated GIS method traverses each cross section away from the channel, separately across the left and right sides of the floodplain, until the elevations of the normal-depth value at the node is found. Such elevation sampling occurs at 5m intervals along the cross section lines, which approximates the distance between cells in the DTM. The method is applied up to a maximum distance of 5km from the nodes on each bank. When the normal-depth level or the 5km limit is encountered, a flood event cross section end point is recorded in GIS. The series of end points associated with the nodes of a river segment are joined to form the flood outline polygon.

During the development of the method, there were discussions in the project team regarding the length of the FSU cross-section lines and the risk of unrealistic transfer of water levels between different catchments. This issue was resolved by the method employed to define the flood extent at each cross-section. This method applied automated procedures in GIS to define the cross-sectional area and wetted perimeter parameters moving away from the river centreline. In this way, elements of the floodplain cross-sections have therefore been only added to the flooded extent if the river water level is sufficiently high to allow flooding across the intervening ground. This is distinct from the alternative and more problematic method of ‘filling’ the cross-section vertically from the lowest elevation point in the full 10km width of the line which would clearly lead to incorrect results with the high chance of flooded areas being discontinuous from the channel.

The original cross-section lines associated with the nodes of a particular river segment are not necessarily parallel to each other. Instead the original cross section placement method recognised that the river path on the floodplain is likely to be longer than the distance down the floodplain and attempted to orient the cross section lines so that they are approximately orthogonal to the channel.
at the node (see FSU WP5-3 Report). As a consequence it was not unusual that cross section lines for the nodes along a river segment can cross. Where this occurs, spurious flood polygon parts arose and had to be removed as a post-processing step.

It should be noted that the definition of the flood polygons is wholly dependent on the analysis of terrain along the discrete cross-section lines. The method is inevitably a simplification of the reality of the flow and flood inundation process on the floodplain. More sophisticated hydraulic modelling packages could be used for smaller scale studies but were not possible to implement for such a high-level and national study and this decision was taken in accordance with the objectives of the PFRA to use ‘available and readily derivable’ data.

3.1.2 Lakes and Reservoirs

A normal-depth based flood polygon for each of the three design events was also drawn around standing waters. Where the standing water is considered to be a natural lake, i.e. without an impoundment or constructed outflow, the normal-depth estimate of the ungauged node at the lake outflow channel was taken as the depth to be mapped around the lake feature.

Where the standing water was considered to be a reservoir, the flood depth for the reservoir was taken from the normal depth results at the last node along the principal inflow river (based on the largest estimated flow). The classification of standing waters into lake and reservoir types was based on the best available information provided with Ordnance Survey Ireland digital mapping and may not be fully accurate or current.
3.2 Generation of Fluvial Flood Polygons

During the initial review stage of the project (Lee catchment pilot) a detailed examination was made of the draft flood polygons. Three particular outcomes were identified which were considered both undesirable and for which improvements could be made to the method. These issues are summarised in the following sections.

3.2.1 Tributary ‘Fan Effect’

A clear problem was identified at confluences between watercourses where there was an apparent overestimation of the flood polygons on the tributary channels between the penultimate node on the tributary and the confluence point. This issue arose from the relatively low water depth on more minor tributaries and high flood depths on the main river channels. On this basis the water depth interpolation method for the intervening 100m spaced intermediate nodes produced a ‘fan’ shape to the flood polygons which was likely to overestimate the flood extent on the tributary channels.

The remedy adopted was to apply the water depth at the penultimate ungauged node to all of the intervening intermediate nodes down to the confluence node rather than apply the standard inverse distance estimate of water depth which would incorporate the depth estimate of the confluence point. In this way the design flood depths on the tributary channel were derived from the nearest ungauged node on the tributary channel rather than being influenced by the flood depth on the main channel.

This method was restricted to tributary channels which were considered to be significantly smaller than the main channel. This was defined as a tributary flow which was less than 40% of the main channel flow into the confluence.

3.2.2 Lateral Wedge Effect

It was also noted that potentially spurious lateral artefacts were apparent along some of the flood polygons. These could be in the form of spikes (formed by a single point), a simple wedge (formed by 2 points) or complex wedges (formed by > 2 points) protruding laterally beyond the general width of the polygon. They were most likely to occur in locations where the limited accuracy of the DTM could have easily led to an overestimation of the width of a return period flood polygon. This was likely to occur in relatively flat terrain or on side tributary channels flowing onto low gradient terrain.

It was obviously possible that the wide flood polygons extents identified as spikes and wedges were a true representation of the flood extent. However, detailed visual analysis in several hydrometric areas indicated that the more extreme forms of this GIS phenomenon were likely to be inaccurate and were artefacts of the overall method to derive the flood polygons (which incorporates levels of inaccuracy or uncertainty from the original DTM and the consequent derived flood water levels).

A method was developed which led to simple wedge and spike reduction in the flood polygons in most cases. It was based on a comparison of flood extent widths for the sequence of nodes along a river segment and considered the left and right sides of the flood polygon separately. It incorporated the following features:
Short river segments comprising only 2 ungauged nodes (at the upstream and downstream ends) were not considered for this check;

A candidate ‘simple wedge’ point or ‘spike point’ must have a width from the river channel that is:
- Greater than 100m;
- Greater than or equal to five times the median width of the polygon; and,
- Be ranked as 1 of the 3 widest points along the polygon side.

A candidate ‘spike point’ was compared to the preceding and subsequent points along the side of the river segment. A candidate ‘wedge point’ is compared to the preceding and subsequent point along the side of the river segment, excluding the 2\textsuperscript{nd} point in the wedge pair.

The resultant width is:
- Reduced to that of the neighbouring point, where the neighbouring point is greater than or equal to twice the median width;
- Reduced to twice the median width where the width of the neighbouring point is less than twice the median width (to ensure that width reduction is not overly severe in cases where the comparator neighbouring point width is very narrow).

The purpose of the refinement was to reduce the width of the polygon at locations where the original width was likely to be unrealistically wide. The precursor conditions aim to restrict the modifications to instances of gross error. The effect of the refinement has been observed to provide a significant reduction in the occurrence of a spike or wedge artefact. However, it does not succeed in the removal of all such potential features.

Figure 7 shows an example of this polygon modification. The green area is the original polygon. The red outline shows the extent of the polygon after ‘spike’ and ‘wedge’ reduction.

A spike and wedge reduction method has not been implemented for the flood polygons around standing waters (lakes and reservoirs).
3.2.3 Adjustment for Super-Elevated Nodes

In Section 2.2, the potential occurrence of erroneously high elevations in the DTM at the locations of the river nodes was discussed. Through a comparative analysis, a screening process has been performed to identify possible errors in the elevations at the ungauged and intermediate nodes.

It was apparent that the addition of a particular normal-depth value onto an erroneous large node elevation could lead to a significant overestimation of the water level and consequent overestimation of the flood extent width at that location. This could occur at an ungauged node or through interpolation at a 100m intermediate node.

The effects arising from the interpolation of flooding at the intermediate nodes based on water level and water depth at the ungauged nodes were considered together with how this would vary when either the ungauged or intermediate nodes were identified as being super-elevated (see Figure 8).

Figure 8 Flood width variations - water depth & level interpolation methods

The occurrence of super-elevated nodes could be the result of features incorrectly retained in the DTM after the filtering process and could include earthworks, bridge decks, bridge parapets and buildings but most commonly areas of trees. For these nodes the normal depth equation was maybe solved for only one iteration of 0.1m above the node elevation, giving calculated flows hundreds or even thousands of times greater than the target design flows. Checks for the pilot work for Hydrometric Area 19 indicated that approximately 5% of the nodes were classed as super-elevated.

Where an intermediate node is 'super-elevated’ an interpolation between the nearest ungauged nodes based on water depth could lead to an overestimation of the flood extent. Conversely an interpolation based on water level could result in an artificial narrowing of the flood extent, represented by a minimum width
(10m) polygon at the node, the intermediate node effectively remaining above the water level.

In a similar manner it was determined that overestimation of the flood extent could occur at ungauged nodes which were super-elevated.

In summary, the following flood hazard extents were derived for the country. These were based on the following principles:

- No alteration of intermediate super-elevated nodes and the derivation of results at intermediate nodes based on water depth at the ungauged nodes. These polygons were termed ‘non-truncated’ and are illustrated by the purple flood extent outline shown in Figure 8.

- Results for super-elevated intermediate nodes calculated based on water level interpolation between the nearest ungauged nodes. These polygons were termed ‘truncated’ and are illustrated by the orange flood extent outline shown in Figure 8.

For both methods if an ungauged node was deemed to be super-elevated then the interpolation was based on the nearest valid ungauged nodes upstream and downstream of the target node.

**Following this analysis, it is important to emphasise that the final flood polygons used for the PFRA have been derived using results at the intermediate nodes taken from interpolating the water depths rather than water levels from the ungauged nodes.**

Various scenarios were assessed to determine the impact of locally elevated nodes from the DTM on the results at the intermediate nodes. It was agreed that interpolation based on water depth would be less likely to retain significant errors in the results, especially when combined with other checks and screening of the relative elevations of the nodes from the DTM.
3.3 **Flood Polygons in Estuaries**

The source river network dataset provided by EPA separates freshwater channels from brackish water sections in estuaries. The boundary between these water types was taken at the Mean High Water (MHW) limit on the rivers, as shown in the Ordnance Survey data. This limit was taken as the effective coastline, although it is noted that the impact of high tide levels it can extend for a considerable distance inland up river channels which would be considered (partially) fluvial for flood management.

The extent of the fluvial channel below this Mean High Water limit was not considered fully in the original work for the FSU WP5-3. Ungauged nodes and cross-section lines were placed along the GIS segments, although node catchment polygons and other metrics utilised in the estimation of the design event flows were not recorded.

It was noted that the lower river reaches below the Mean High Water limit often contain urbanised zones and other infrastructure prone to the effects of floods. It was deemed important to generate flood outlines in these regions, although adaptive approaches to the data management and normal depth calculations would be required.

The principal limitation was the unavailability of flow estimates for the three design events under consideration. However, flow estimates would be available for the main channel ungauged node at the Mean High Water limit upstream of these loci. In most situations, it was decided that flow arising from the additional side tributaries would not be substantial.

Normal depth estimates were calculated for the ungauged nodes on the channels below the Mean High Water limit based on the flow estimates at this limit. Sets of design event flood event polygons were developed based on water depth interpolation at the constituent intermediate nodes.

The exceptions to this rule were Dublin and Cork, where it was agreed with OPW that the channel capacity would be greater than the standard QMED assumption and the normal depth method would not be appropriate. In these cases, the results of the full hydraulic models that had been developed for OPW were used to supersede the normal depth results. Care was taken at the boundaries between the two different sets of results to ensure that the resultant polygons were consistent and did not contain any significant jumps in the flood extent width.
4. Validation of the Normal Depth Method

A validation process was required to assess the quality of the results of the flood extent mapping process described above. This validation was completed to assess the quality of the mapping outputs in relation to the sources of error from the DTM and the simplified nature of the normal depth analysis. Comparisons were undertaken between the normal depth results and the outputs from more detailed hydrodynamic modelling studies that have previously been completed for the watercourses in the hydrometric areas of the River Lee (HA19) and the River Shannon (HAs 25 and 26).

4.1 Validation of Flood Extent Width Results

As an initial comparison, the 1% AEP flood extent widths for a sample of 866 common nodes from the normal depth and hydraulic modelling processes in the Lee catchment are shown in Figure 9.

![Figure 9](image.png)

Figure 9 Comparison of the differences in 1% AEP flood extent widths between the normal depth and hydraulic model results for a sample of river nodes in the Lee catchment

Obviously, the ideal distribution for the validation process would be centred on a difference of zero metres between the flood extent widths from the two methods, with minimal distribution away from this central portion of the graph. The results of the analysis shown on the graph show a roughly symmetrical distribution centred approximately on a difference of 0-50m between the flood widths for the 1% AEP.

Figure 10 shows a similar graph comparing the residuals between the flood extent widths for the normal depth method and the hydraulic modelling for the 10-year return period event. The overall shape of the distribution of the residuals for the
10-year event flood extents is broadly similar to that of the comparison of the 100-year flood extents.

Figure 10  Comparison of the differences in 10-year return period flood extent widths between the normal depth and hydraulic model results for a sample of river nodes in the Lee catchment

A general pattern was observed in the similarity in the flood extent widths across the Lee catchment for the 10% and 1% AEP events from the normal depth method. To assess the sensitivity of the flood extent widths to the magnitude of the flood event, the widths for the 10% AEP normal depth results were compared to the widths from the hydraulic model for the 10%, 4%, 2% and the 1% AEP events. The results are shown in Table 2.

Table 2  Size of the flood extent width residuals when comparing the 10-year normal depth results with the 10-year to 100-year flood extent widths from the full hydraulic models.

<table>
<thead>
<tr>
<th>Design Event Results from Full Hydraulic Models (% AEP)</th>
<th>10%</th>
<th>4%</th>
<th>2%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>+/- 20m</td>
<td>22</td>
<td>24</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>+/- 50m</td>
<td>39</td>
<td>40</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>+/- 100m</td>
<td>60</td>
<td>61</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>+/- 200m</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td>83</td>
</tr>
</tbody>
</table>

These results suggest that for the assessed events between the 10% and 1% AEP levels, the flood extent widths from the normal depth results are relatively insensitive to changes in the magnitude of the river flow. This is the result of a large combination of factors but is thought to be principally due to errors in the DTM and in the derivation of elevations for the river nodes.

The comparison was also extended to the river reaches in the Shannon catchment. Table 3 shows a statistical comparison between the flood widths for the 1% AEP event for nodes in the catchments of both the River Lee and the
River Shannon. In the case of the River Shannon, the normal depth results have been compared to the available flood extent data from OPW for the recent flood event at the end of 2009. This event has been estimated to have been of a greater magnitude than the 1% AEP event. The comparison was only completed for Hydrometric Area 25, the more downstream and southern of the two areas that comprise the Shannon catchment.

Table 3

| Size of the flood extent width residuals comparing normal depth and full model results for samples of river nodes in the River Lee and Shannon catchments for the 1% AEP event |
|---------------------------------------------------------|-----------------|-----------------|
| River Lee Catchment | River Shannon Catchment |
| +/− 20m | 22% | +/− 20m | 13% |
| +/− 50m | 42% | +/− 100m | 62% |
| +/− 100m | 62% | +/− 100m | 43% |
| +/− 200m | 81% | +/− 200m | 57% |

It was noted that there were four locations in the sample for the River Lee Catchment where the difference between the flood extents was greater than +/−1000m. However it was identified that this was likely to be due to the orientation of the cross-sections across the surrounding topography. In these cases, on either channel bends or meanders, the cross-sectional profile across the floodplain, drawn close to or fully parallel to the direction of the valley, may not be providing realistic results.

For this reason, the comparison of flood extent widths between the normal depth results and the full hydrodynamic models may not always provide a like-for-like comparison. Although the nodes in the samples used in the comparisons above were specifically chosen due to their close proximity in both the FSU dataset for the normal depth analysis and the full hydrodynamic model there is no guarantee that the orientation of the cross-section will be the same. In addition, the full model of the Lee catchment used LiDAR aerial survey as a digital terrain model, whereas the best available nation-wide survey data set for the normal depth analysis was the generally less accurate IFSAR data.
4.2 Validation of Water Level Results and Discussion of Residual Sources of Error in the Normal Depth Results

In order to extend the analysis, comparisons have been made between the water levels derived from the normal depth process and the full hydrodynamic models in the Lee catchment. Figure 11 shows a map of part of Hydrometric Area 19 centred on Cork, with some of the key watercourses highlighted where detailed hydraulic modelling has previously been completed in other projects.

Figure 11 Map of Cork and surrounding area showing in red the extents of some of the fully modelled rivers for this catchment

The graphs in Figures 12 and 13 show comparisons between the water level results from the normal depth method and the CFRAM projects. The graphs show long-section plots for between 17km and 20km reaches of the Upper Sullane and the Owenboy rivers in HA19.

Figure 12 compares the two methods for the Upper Sullane watercourse from approximately Ballyvourney and Ballymakeery to Macroom. In general, there is a good correspondence between the results, although there is an evident trend is for the CFRAM results to be slightly higher.

Figure 13 shows the results of an equivalent comparison for a long reach of the River Owenboy. The graph shows that in this case the normal depth results are slightly higher than the full model results.

There are various potential reasons for these inconsistencies between two sets of data:

- **Errors in the DTM:** As explained in the preceding sections, automated screening checks were used to identify any unusually high, ‘super-elevated’ nodes along the river channels. Procedures were established to moderate the effect of these nodes on the final extents. However, it is possible that there are residual errors in the node elevations were still present as a result of the vertical accuracy of the data (0.7m RMSE, see
Section 2.2) and the potential for incorrect filtering of the DSM to produce the DTM. These issues could have generated errors in the elevations assigned as being representative of the bank level for each of the nodes.

In addition, no further checks could be made to the rest of the DTM, across the floodplain parts of the cross-sections. The base IFSAR DTM was used directly for this part of the process, but the same potential sources of error listed above could have generated localised inconsistencies in the derived cross-sections.

- **Impact of hydraulic structures:** There is no facility within the normal depth method to account for the impact of hydraulic structures on flood water levels. The water levels are calculated independently at each node along the channels based on the topographic data from the DTM.

  Although backwater analysis is included in the method (see Section 2.6) this is only generated from variations between the topography, and to a lesser extent the surface roughness and floodplain slope. Whilst the impact of some structures may be very localised, large barriers in the floodplain for example, such as embankments, may not have been represented in detail in the derived floodplain cross-sections due to the orientation of cross-section lines.

- **Assumption of bankfull flow being equal to QMED:** The method is dependent upon the central assumption that the inbank flow is equal to $Q_{med}$.

- **Errors in the estimated flows at the ungauged nodes:** The flows at the ungauged nodes were developed using the latest methods and equations from the FSU project. These techniques have been extensively trialled and tested as part of the FSU project and the approach for the hydrological analysis was deemed to be appropriate for the level of analysis required for the PFRA.

  It was noted that for some river reaches the maximum flows were not always associated with the most downstream node on that reach. The problem was identified as being a consequence of the calculation method for $Q_{med}$ which could generate step jumps or inconsistencies in the flow series along a watercourse depending on changes in the values of key parameters in the FSU equations. However, the inconsistencies in these flows are relatively minor and will have had low impact on the results considering the other assumptions and uncertainties in the data sets. It was agreed that there should be no change from the standard FSU equations for the calculation of $Q_{med}$.

Potential sources of errors in the normal depth method were identified where possible from checks to the final water level and flood extent results. These were addressed by amendments to the base method, systematically applied in GIS across the whole country. These changes included the identification and the adjustment of super-elevated nodes and wedges or spikes in the final flood extents.

With the exception of the incorporation of flood extent results that were available from the detailed hydraulic modelling in and around Dublin and Cork, there were no locally specific, manual adjustments made to the flood extents. If time had been available then an exercise could have been completed to assess all of the flood extents individually across the whole country with assistance from OPW.
engineering staff, who have local knowledge of particular Hydrometric Areas or watercourses.

However, apart from the extensive time and organisation required to achieve this level of checks, amending flood extents outside of a standard set of systematic and universal rules has the potential to introduce further inconsistencies and would make the final outputs difficult to audit. The preferred approach agreed with OPW for the high-level objectives for the PFRA was to use the results of the normal depth analysis directly in the flood risk analysis.
Figure 12  Graph comparing the results of the normal depth analysis with the hydraulic model results for the Lee CFRAM study.
Figure 13  Graph comparing the results of the normal depth analysis with the hydraulic model results for the River Owenboy
### Appendix A: Corine Land Use Survey Classifications (2000) and Assigned Manning’s ‘n’ Floodplain Roughness Values

<table>
<thead>
<tr>
<th>Artificial Surfaces</th>
<th>CORINE Land Use Classifications</th>
<th>Percentage of Coverage in Ireland (2000 dataset) *</th>
<th>Final Assigned Manning’s ‘n’ Value</th>
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<td>Level 1</td>
<td>Level 2</td>
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<td>1.1.2 Discontinuous Urban Fabric</td>
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<td>1.2.2 Road and Rail Networks and Associated Land</td>
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<td>1.2.3 Seaports</td>
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<td></td>
<td>1.2.4 Airports</td>
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<td>1.3.3 Construction Sites</td>
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Note: Categories marked in bold show land cover proportions for Ireland greater than 5% according to 2000 dataset.